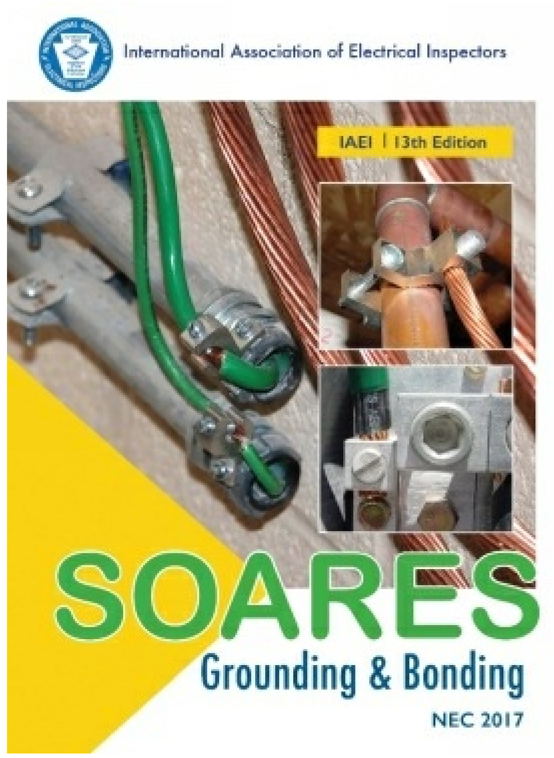
International Association of Electrical Inspectors

IAEI | 13th Edition

SOARES

Grounding & Bonding

NEC 2017



Soares Grounding and Bonding

Thirteenth edition

International Association of Electrical Inspectors
Richardson, Texas

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Contents

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National Fire Protection Association, NFPA 780-2017, "Standard for the Installation of Lightning Protection Systems," (Quincy, MA: National Fire Protection Association, 15 August 2010).

Preface

This book is dedicated to the memory of Eustace C. Soares, P.E., one of the most renowned experts in the history of the *National Electrical Code®* in the area of grounding electrical systems. A wonderful teacher and man of great vision, Eustace foresaw the need for better definitions to clear up to the great mystery of grounding of electrical systems.

Eustace Soares' book, *Grounding Electrical Distribution Systems for Safety* was originally published in 1966 and was based upon the 1965 edition of the *National Electrical Code*. Over the years, this book has become a classic.

A great majority of the recommendations contained in the original edition of his book have been accepted as part of Article 250 as well as many other sections of the *National Electrical Code®*. The grounding philosophies represented in the original edition are just as relevant today as they were then. To say that Eustace contributed more than any other man to solving some of the mysteries of grounding of electrical systems would not be an overstatement of fact. Previous editions have been extensively revised both in format and in information. An effort has been made to bring this work into harmony with the 2017 edition of the *National Electrical Code®* and to retain the integrity of the technical information for which this work has been well known, at the same time adding additional information which may be more recent on the subject of grounding and bonding. The 13th edition was again revised to provide a better flow of the information closer to what designers and installers will experience in an actual project.

IAEI acquired the copyright to Soares' book in 1981 and published the second edition under the title *Soares Grounding Electrical Distribution Systems for Safety*. IAEI acknowledges the contributions of Wilford I. Summers to editions two and three, and J. Philip Simmons as the principal contributor in the revision of the fourth through seventh editions. IAEI acknowledges Michael J. Johnston as the principal contributor in the revision of the eighth, ninth, and tenth editions. The principal contributors to the revision of the eleventh, twelfth, and thirteenth editions were Charles F. Mello and L. Keith Lofland.

IAEI intends to revise this work to complement each new edition of the *National Electrical Code®* so this will be an on-going project. Any suggestions for additional pertinent material or comments about how this work could be improved upon would be most welcome.

⏚ Chapter 1
General Fundamentals

Objectives to understand

- Fundamentals and purpose of grounding of electrical systems
- Definitions relative to grounding equipment from grounded and ungrounded systems
- Effects of electric shock hazards
- Purpose of grounding and bonding
- Short circuit vs. ground faults in electrical systems
- Circuit impedance and other characteristics
- Basic electrical circuit operation
- Ohm's Law

From the beginning, the use of electricity has presented many challenges ranging from how to install a safe electrical system to how to develop minimum *Code* requirements for safe electrical installations.

These installations depend on several minimum requirements, many of which are covered in NFPA 70, *National Electrical Code*, Chapter 2, Wiring and Protection. Understanding the protection fundamentals and performance requirements in Chapter 2 is essential for electrical installation, design, and inspection. To truly understand how and why things work as they do, one must always start with the basics. The first part of basics is understanding and properly using the terminology for grounding and bonding. Unless the terms used are clearly understood, misunderstandings and confusion will prevail. It is important that basic electrical circuits be understood because grounding and bonding constitute an essential part to a safe electrical circuit. The process of grounding and bonding creates safety circuits that work together and are associated with the electrical circuits and systems that control and supply electricity to equipment.

The material in this book analyzes the how and why of these two functions of grounding and bonding and expresses their purpose in clear and concise language. It also examines grounding and bonding in virtually every article of the *Code* in addition to the major requirements of Article 250. Further, it provides information on grounding and bonding enhanced installations that exceed the minimum *NEC* requirements, such as for data processing facilities and sensitive electronic equipment installations. Chapter eighteen expands the information about those types of installations that are designed to exceed the *Code* requirements. It covers establishing an enhanced grounding electrode system or earthing system and installing feeders and branch circuits in a fashion that helps reduce the levels of electrical or electromagnetic interference (EMI) noise on the grounding circuits. This is accomplished though insulation and isolation of the grounding circuit as it is routed to the original grounding point at the source of supply (service or source of separately derived system).

Some definitions of electrical terms that should be understood as they relate to the performance of grounding and bonding circuits are also included in this first chapter. This book emphasizes the proper and consistent use of the defined terms in both the electrical field and the *NEC* in order to develop a common language of communication.

Taking the Mystery Out of Grounding

For many years the subjects of grounding and bonding have been considered the most controversial and misunderstood concepts in the *National Electrical Code*. Yet there is no real reason why these subjects should be treated as mysteries and given so many different interpretations. Probably the single most effective method for clearing up the confusion is for one to review and clearly understand the definitions of the various elements of the grounding system. In addition, these terms should be used correctly during all discussions and instruction on the subject so that everyone will have a common understanding. For example, using the term ground wire to mean an equipment grounding conductor does no more to help a person understand what specific conductor is being referenced than does the use of the term vehicle when one specifically means a truck.

It is recommended that the reader carefully review the terms defined at the beginning of each chapter in order to develop or reinforce a clear understanding of how those terms are used in regard to that particular aspect of the subject. Also, many of the terms associated with the overall grounding system are illustrated to give the reader a graphic or pictorial understanding of their meaning. It should be noted that the graphics in this text are designed to illustrate a specific point and that not all conductors or details required for a fully compliant installation are necessarily shown.

This book is intended to assist the reader in establishing a strong understanding of the fundamentals of and reasons for the requirements of grounding and bonding to attain the highest level of electrical safety for persons and property. Appendix A provides information on the origin of concrete-encased electrodes. Appendix B provides a short history of the National Electrical Grounding Research Project. IAEI is committed to providing the highest quality information on grounding and bonding to the electrical industry and hopes that the reader benefits immensely from this volume.

Definitions of Basic Electrical Terms

The following terms are not in alphabetical order; instead, they are sequenced on how the concepts are taught in logic starting with what pushes current, what current is, and then what impedes that current flow from dc then ac circuits.

Voltage (Electromotive Force). A volt is the unit of measure of electromotive force (EMF). It is the unit of measure of the force required to establish and maintain electric currents that can be measured. By international agreement 1 volt is the amount of EMF that will establish a current of 1 amp through a resistance of 1 ohm.

Current (Amperes). Current, measured in amperes, consists of the movement or flow of electricity. In most cases, the current of a circuit consists of the motion of electrons, negatively charged particles of electricity.

Resistance (Ohms). Resistance is the name given to the opposition to current offered by the internal structure of the particular conductive material to the movement of electricity through it, i.e., to the maintenance of current in them. This opposition results in the conversion of electrical energy into heat.

Impedance (Ohms). The term resistance is often used to define the opposition to current in both ac and dc systems. The correct term for opposition to current in ac systems is impedance. Resistance, inductive reactance, and capacitive reactance all offer opposition to current in alternating-current circuits. The three elements are added together vectorially (phasorially), not directly. This results in the total impedance or opposition to current of an AC circuit. Impedance is measured in ohms

Capacitance. A capacitor basically consists of two conductors that are separated by an insulator. A capacitor stores electrical stress. Capacitive reactance is the opposition to current due to capacitance of the circuit. The Institute of Electrical and Electronics Engineers (IEEE) defines capacitance as, “The property of systems of conductors and dielectrics which permits the storage of electricity when potential difference exists between the conductors.”

Inductance. Inductance is the ability to store magnetic energy. Inductance is caused by the magnetic field of an alternating-current circuit as a result of the alternating current changing directions. This causes the magnetic lines of force that surround the conductor to rise and fall. Induction is measured as inductive reactance. As the magnetic lines of force rise and fall, they work to oppose the conductor and induce a voltage directly opposite the applied voltage. This induced voltage is called counter-electromotive force or counter EMF. Induction is the current effect of an ac circuit. Where there is an alternating magnetic field there will be induction. This induction will result in inductive reactance, which opposes the current.

The Foundation of Grounding

The first and most vital element of a sound, safe structure is a solid footing or foundation on which to build the building. This foundation, usually consisting of concrete and reinforcing bars, must be adequate to support the weight of the building and provide a solid structural connection to the earth on which it sits. If the building or structure does not sit on a solid foundation, there can be continuous structural problems that might lead to unsafe conditions. Likewise, the electrical grounding system serves as the foundation for an electrical service or distribution system supplying electrical energy to the structure. Often the grounding of a system or metal objects is referred to as earthing, being connected to the earth. When solidly grounded, the electrical system must be connected to a dependable grounding electrode or grounding electrode system without adding any intentional impedance. The grounding electrode(s) supports the entire grounding system and makes the earth connection. It must be effective and all grounding paths must be connected to it. This serves as the foundation of the electrical system. Chapter six covers the grounding electrodes, their functions, and their installations.

Electrical Circuitry Basics

Anyone who has been involved in the electrical field for any length of time has heard the phrase, “Electricity takes the path of least resistance.” From grade school science class to the first-year apprentice to the seasoned veteran of the industry, the phrase is used to describe the path electrical current will take. The phrase is stated with pride, “Electricity takes the path of least resistance” or “Current takes the path of least resistance,” and usually not much thought is given as to what is really going on. In reality, current will take all paths or circuits that are available. Where more than one path exists, current will divide among the paths (see figure 1.1). As we will review later, current will divide in opposite proportion to the impedance. The lower impedance path or circuit will carry more current than the higher impedance path(s). The study of grounding and bonding is vital to applying basic rules relative to this important safety element of the electrical circuit. It is important to review some basic principles and the fundamental elements of electricity and how current relates to electrical safety.

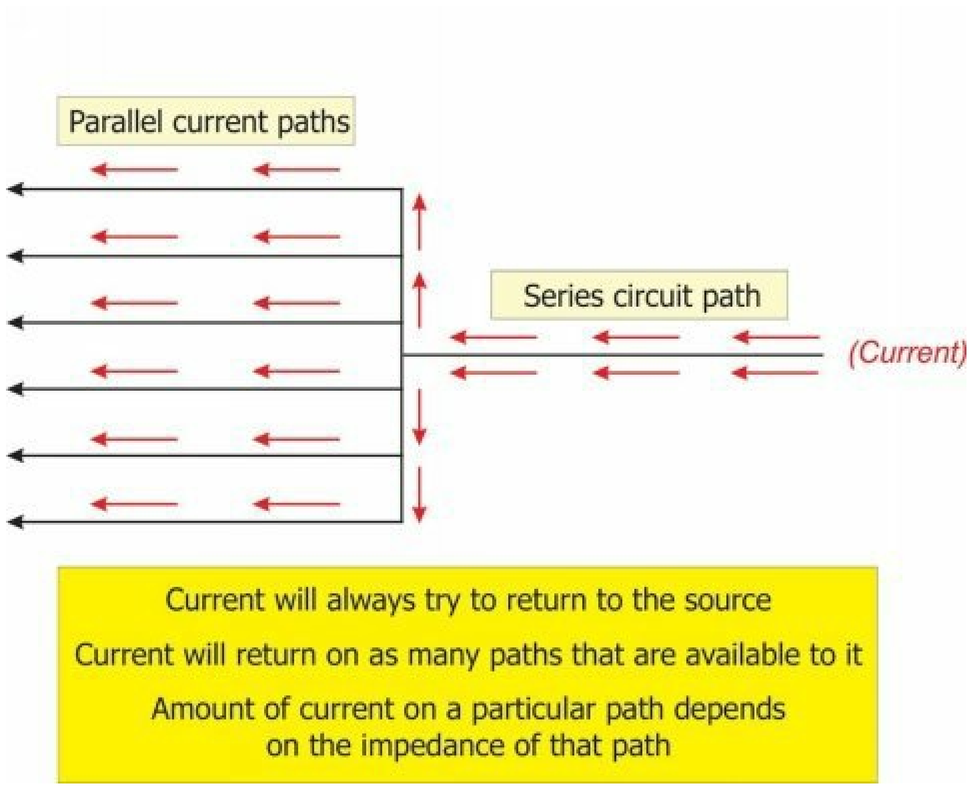


FIGURE 1.1 Series and parallel paths for current

Ohm's Law in Review

Before we can have current flowing, there needs to be a complete circuit (see the circuit diagram in figure 1.2). The amount of current in an electrical circuit depends on the characteristics of the circuit. Voltage or electromotive force (E) will cause (push) current or intensity (I) through a resistance (R). These are the basic components of Ohm's law (see Ohm's law and its derivatives in Watt's wheel in figure 1.2). Electrical current can be compared with water flowing through a water pipe. With the pressure being the same, the bigger the pipe, the less the resistance is to the flow of water through the pipe. The smaller the pipe, the greater the resistance is to the flow of water through it. The same holds true for electrical current. Larger electrical conductors (paths) offer lower resistance to current. Smaller electrical conductors (paths) offer greater resistance to current. There must be a complete circuit or path and a voltage (difference of potential) or there will be no current. This is true of both normal current and fault current.

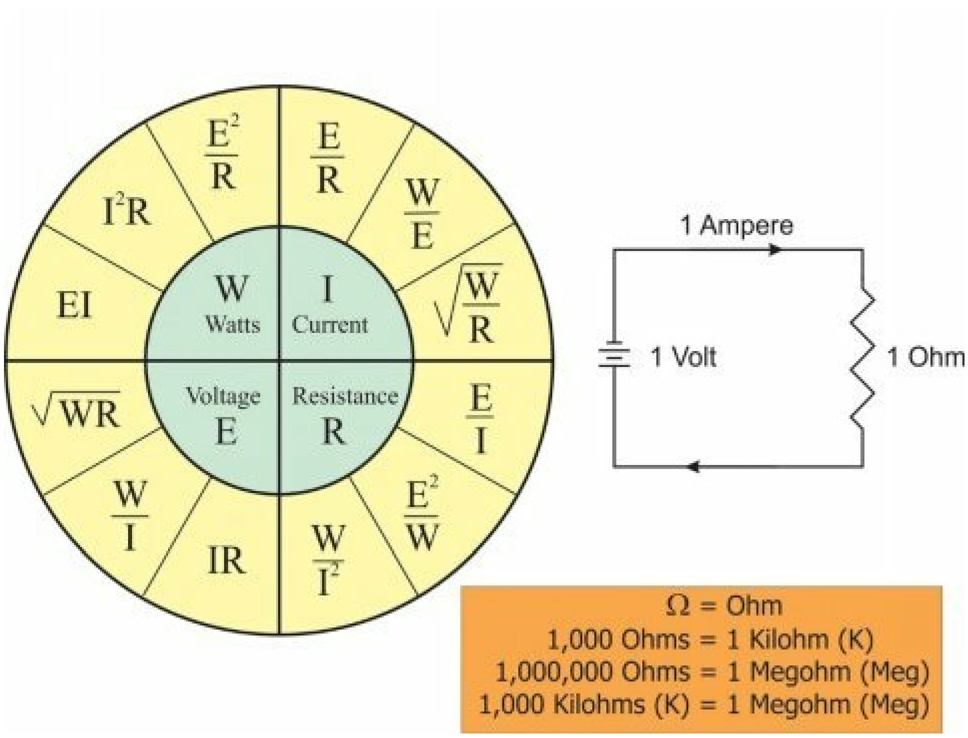


FIGURE 1.2 Watt's wheel—current in a circuit

Resistance as Compared to Impedance

Understanding the differences between the pure resistance of an electric circuit and the impedance of a circuit is important in gaining a thorough understanding of the grounding or safety circuit. In Ohm's law, resistance is the total opposition to current in a dc circuit. In an alternating-current circuit, the total opposition to current is the total impedance comprised of three components. The impedance (Z) of an ac circuit is the inductive reactance, capacitive reactance, and the resistance added together vectorially (phasorially) [see formula in figure 1.3]. In a 60-Hertz ac circuit, alternating current changes amplitude and direction 120 times per second and develops a magnetic field that results from the inductive reactance of the circuit. In addition, any circuit with insulated conductors at different instantaneous potentials and a potential from ground will have capacitance and capacitive reactance. Therefore, minimizing the amount of the overall opposition (impedance) to current in the grounding and bonding circuits of electrical systems is very important. These circuits can be looked upon as silent servants, just waiting to perform the important function of carrying enough current so overcurrent protective devices can operate to clear a fault. This is one reason the *Code* requires all conductors of a circuit to be closely installed together, *NEC* 300.3, to minimize the overall impedance.

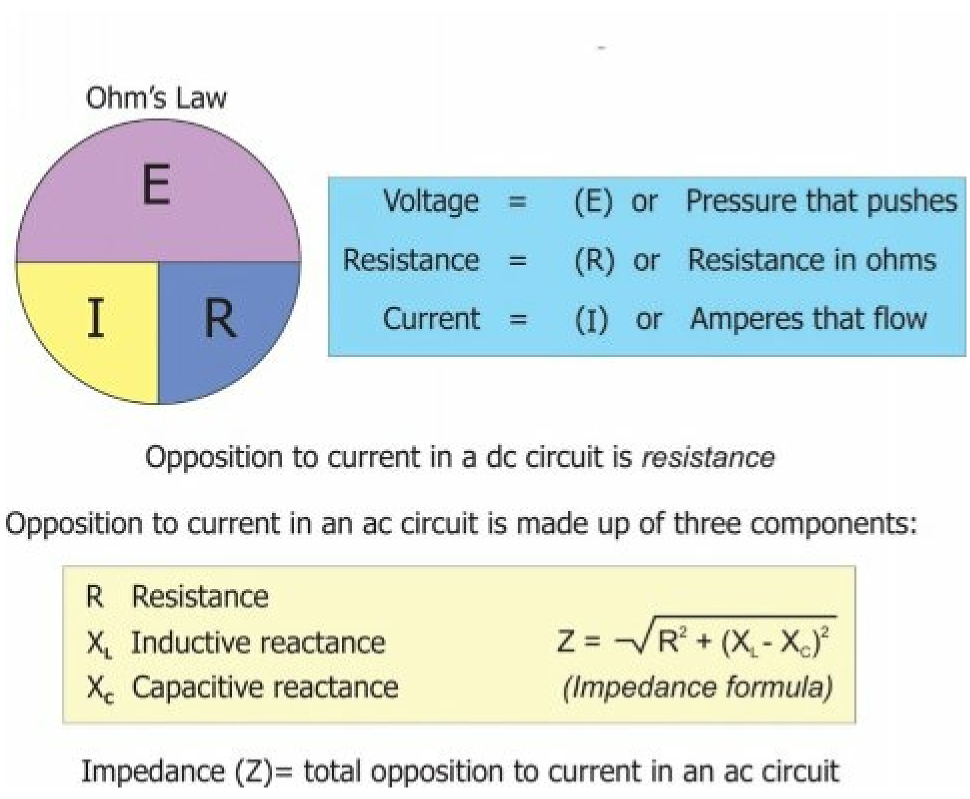


FIGURE 1.3 Basic electrical theory terms and formulas, including basic formulas for ac circuit resistance and impedance

Current in a Circuit

In any complete circuit or path that is available, current—be it normal current or fault current—will always try to return to its source. The statement on taking the path of least resistance is partially correct. Electrical current will take any and all available paths to return to its source (see figures 1.1 and 1.5). If several paths are available, current will divide and the resistance or the impedance of each path will determine how much current is on that particular path. It can be concluded from the above that if there is no complete circuit, then there is no current. Care is given to the installation of ungrounded (phase or hot) conductors so that the circuit will be complete to provide a suitable path for current during normal operation. The same principles and fundamentals apply to the installation of grounding and bonding conductors that make up the safety circuits. The equipment grounding (safety) circuit must be complete and must meet three important criteria: (1) the path for ground-fault current must be electrically continuous; (2) it must have adequate capacity to conduct safely any ground-fault current likely to be imposed on it; and (3) it must be of low impedance (see figure 1.26 and chapter eleven for more specific information relative to clearing ground faults and short circuits).

Article 250 mentions the term low-impedance path several times. As a quick overview, the opposition to current in a dc circuit is resistance. The total opposition to current in an ac circuit is impedance. When the phrase "low-impedance path" is used in the *Code*, it is referring to a path that offers little opposition to current whether it is normal current or fault current. The key element is ensuring there is low opposition or impedance to the flow of the current.

E = Voltage **R = Ohms** **I = Amperes**

Voltage	=	*Resistance	x	**Current
120	=	60	x	2
120	=	40	x	3
120	=	20	x	6
120	=	10	x	12
120	=	5	x	24

* As the resistance or opposition to current increases, the current in the circuit decreases

** As the resistance or opposition to current decreases, the current in the circuit increases

FIGURE 1.4 Proper grounding and bonding facilitates the operation of overcurrent devices.

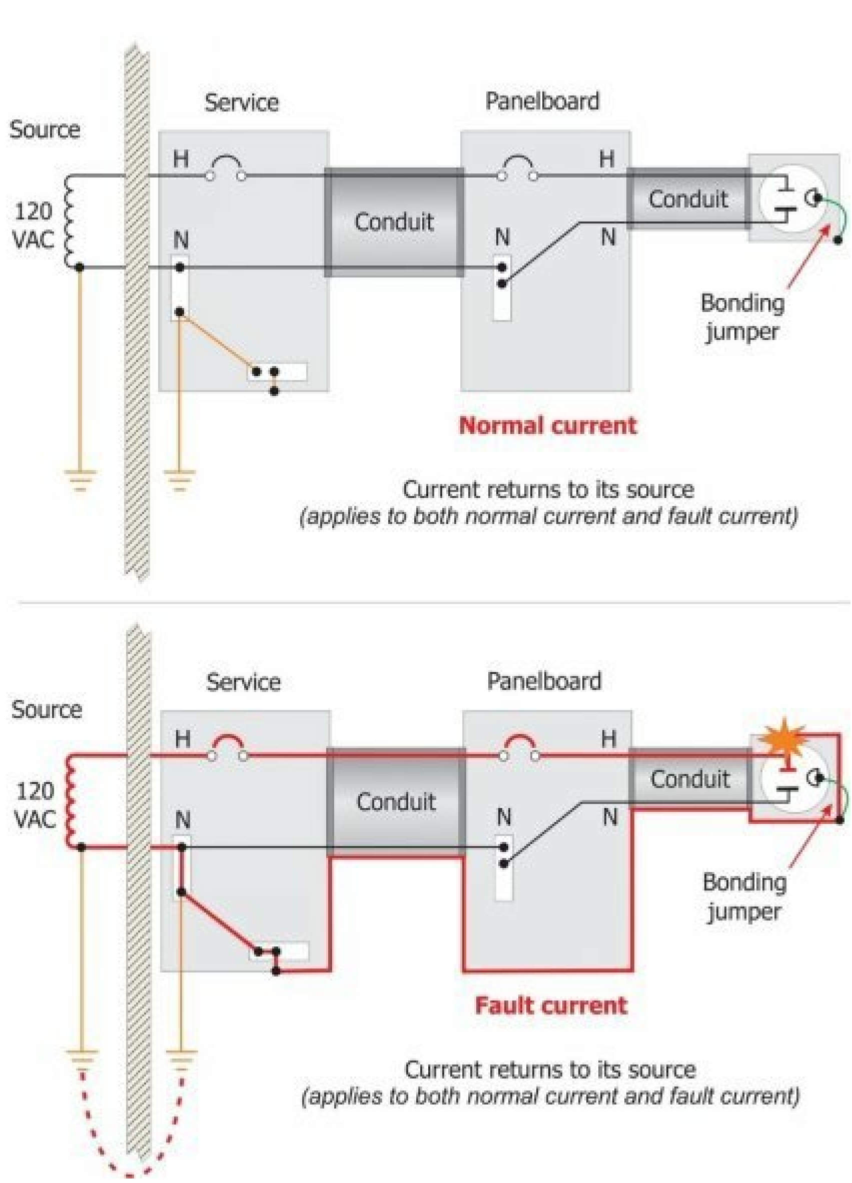


FIGURE 1.5 Current will try to return to its source (normal and fault current work the same way)

Overcurrent Device Operation

Overcurrent devices operate because of more current (amps) flowing than the device is rated to carry. Generally speaking, the more current through overcurrent devices above their rating the faster they open or operate; this is because they are designed to operate in inverse time. Relative to the discussion about impedance, the higher the impedance of the path, the lower the current through the overcurrent device and therefore longer time to open. The lower the impedance of the path, the greater is the current through the overcurrent device and faster opening time. Understanding these basic elements of electrical circuits helps one apply some important rules in Article 250. The following examples clearly demonstrate that amps operate overcurrent devices (see figures 1.6 and 1.7).

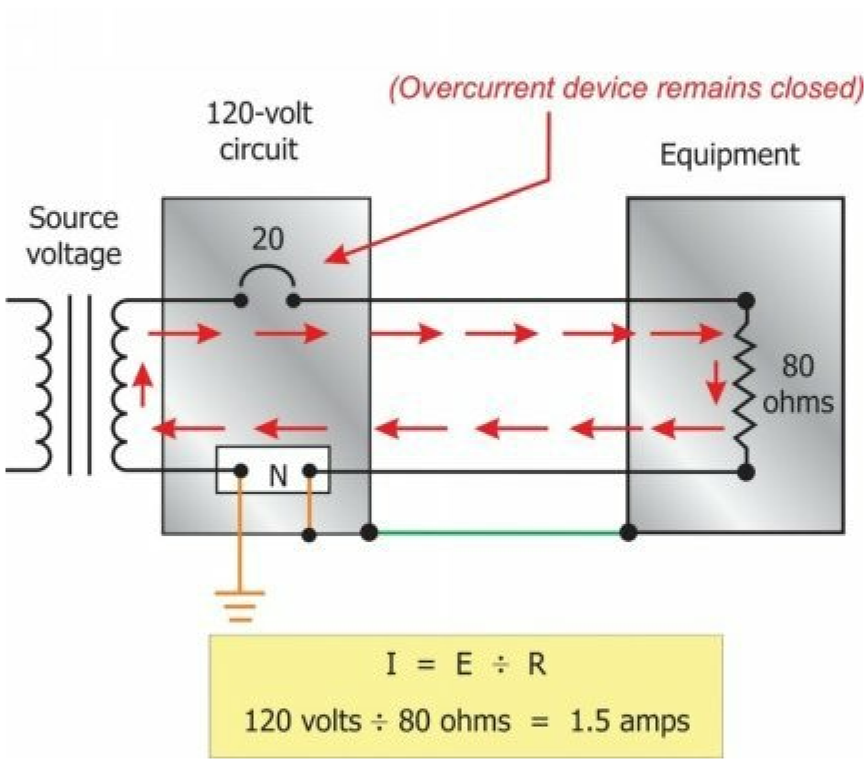


FIGURE 1.6 Normal electrical circuit (normal current in circuit)

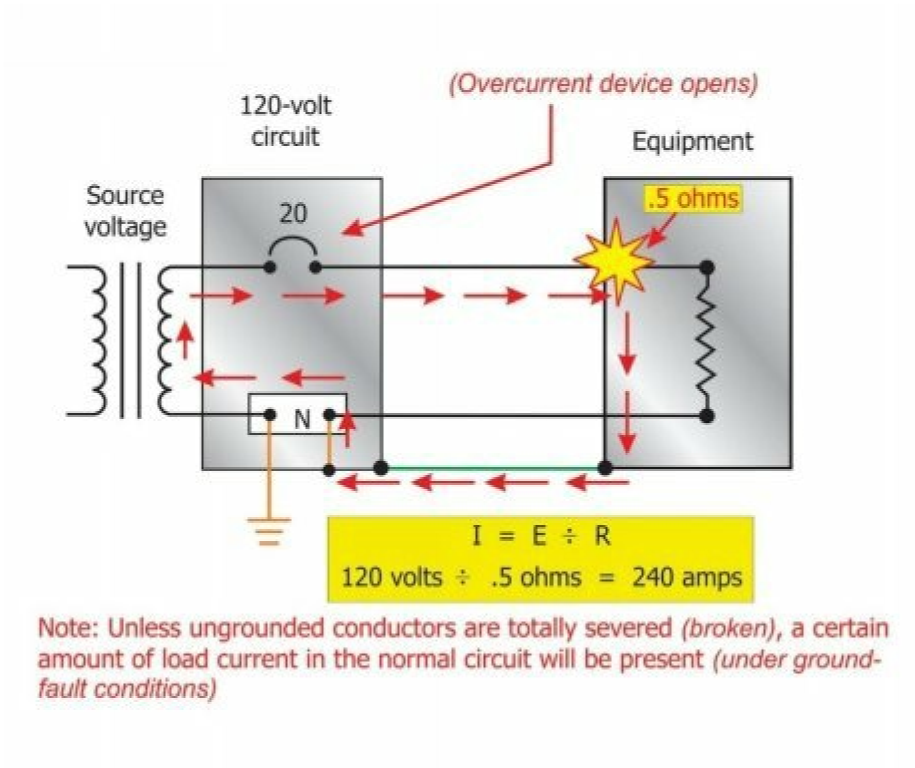


FIGURE 1.7 Electrical circuit with ground fault to enclosure

As with the electrical circuit installed for normal current, the equipment grounding (safety) circuit must also be installed for abnormal current to ensure overcurrent device operation in ground-fault conditions. The equipment grounding or safety circuit must be complete and constructed with as little impedance as practicable for quick, sure overcurrent device operation. Care must be taken when installing electrical systems and circuits, including the equipment grounding and bonding circuits of the system. Where the human body gets involved in the circuit it can, or often, results in an electrical shock or even electrocution in some cases. The human body introduces a relatively high level of impedance that impacts the overcurrent device operation. Ground-fault circuit interrupters provide a degree of protection from electrical shock, but standard overcurrent devices do not. Later in this chapter is a discussion about shock hazards and effects on the human body, and chapter fourteen provides more information about ground-fault circuit interrupters.

Proper Language of Communication

A common language of communication has been established to enable one to understand the requirements of the *NEC*, in general, and of grounding and bonding, in particular. A common set of terms, defining and explaining the function of the terms as used in the *Code*, is included in Article 100 and in sections xxx.2 of other articles. Two specific conductors of the electrical circuit should be mentioned and a brief story told about each: the grounded conductor and the equipment grounding conductor.

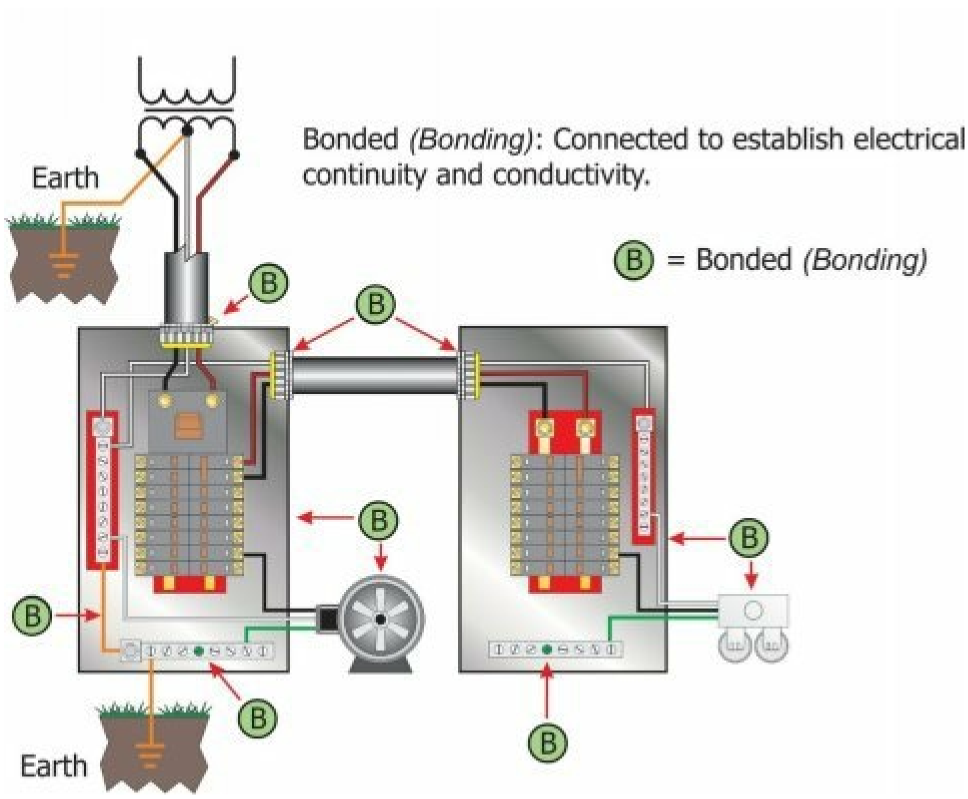


FIGURE 1.8 Grounding connects equipment and systems to ground (the earth).

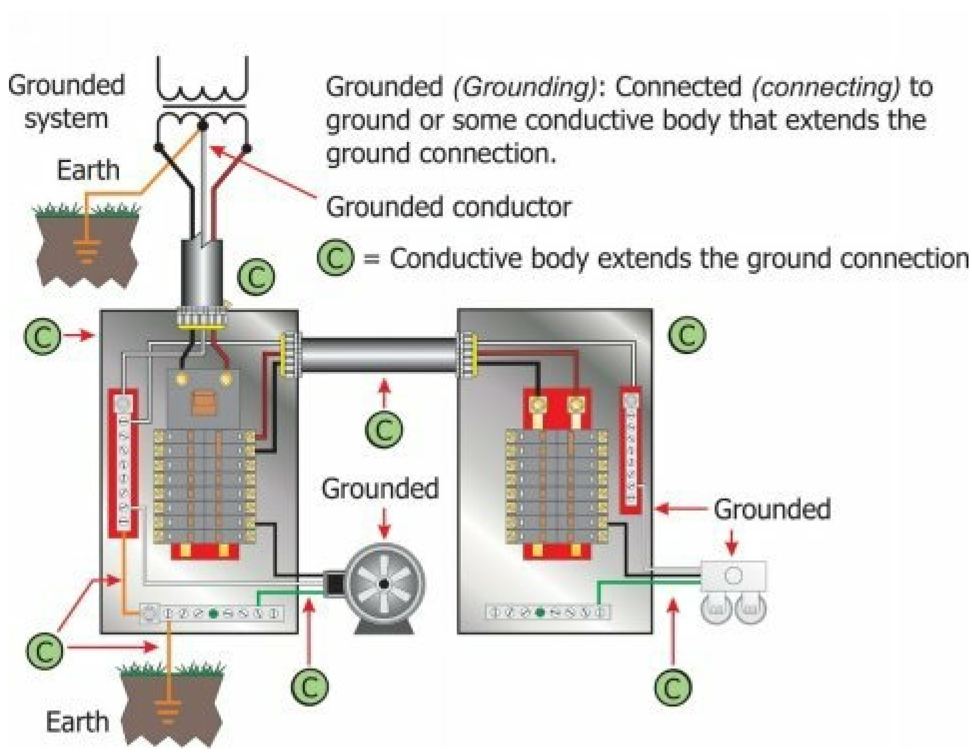


FIGURE 1.9 Bonding (bonded) establishes electrical continuity and conductivity.

Grounded and the Grounded Conductor

The grounded conductor (usually a neutral) is generally a system conductor intended to carry current during normal operation of the circuit. The connection to ground (earth) of the system grounded (often a neutral) conductor is accomplished by a connection through a grounding electrode conductor either at the service or at a separately derived system. Generally, it should be understood that the grounded conductor should not be used for grounding of equipment on the load side of the system grounding connection at the service or source of separately derived systems. This separation between grounded conductors and equipment grounding conductors keeps the normal return current on the neutral (grounded) conductor of the system, where it belongs, when returning to its source. These principles are reinforced by requirements in 110.7, 250.24(A)(5) and 250.30(A). *Code* rules and requirements for the grounded conductors are covered in depth in chapter fourteen of this text.

Grounding and Equipment Grounding Conductor

As used in Article 250 and other articles, grounding is a process that is ongoing. The conductor to look at is the equipment grounding conductor. The action is ongoing through every electrical enclosure it is connected to all the way to the last outlet on the branch circuit. The equipment grounding conductor provides a low-impedance path for fault-current if a ground fault should occur in the system and also connects all metal enclosures to the grounding point of the service or system.

So it is important that the equipment grounding conductor make a complete and reliable circuit back to the source. At the service is where the grounded (neutral) conductor and the equipment grounding conductor(s) are required to be connected together through a main bonding jumper. In a separately derived system, this connection is made with a system bonding jumper installed between the grounded conductor and the equipment grounding conductor(s). The main bonding jumper and the system bonding jumper complete the ground fault-current circuit back to the source. The rules and requirements for equipment grounding conductors are covered in depth in chapter nine.

Grounding as Compared to Bonding

Defined in Article 100, both of these functions are essential for the complete safety anticipated by the rules in Article 250 (see figure 1.10).

Ground. "The earth."

Grounded (Grounding). "Connected (connecting) to ground or to a conductive body that extends the ground connection" (see figure 1.8).

Bonded (Bonding). "Connected to establish electrical continuity and conductivity" (see figure 1.9).

These are two separate functions with two different purposes. It is important to establish a clear understanding of the grounding (earthing) circuit and its purpose as compared to the equipment grounding conductors and bonding jumpers or connections.

Section 250.4 has been broken down into grounded systems and ungrounded systems. Requirements in this section include descriptive performance requirements and establish the purposes served by each of these actions. The title of Article 250 is "Grounding and Bonding." The article contains an equally strong emphasis on bonding requirements. Chapter eight presents detailed information on these bonding requirements (see sidebar for important information about grounding and bonding terminology revisions started with the 2008 *NEC* and with additional revisions in the 2011 and 2014 *NEC*).

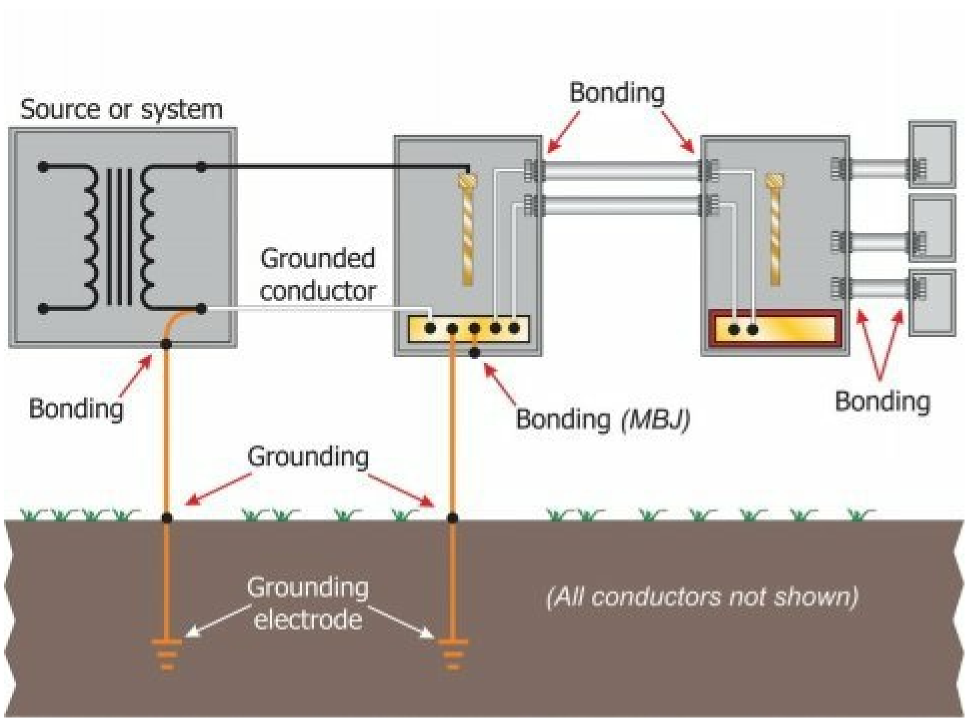


FIGURE 1.10 Grounding compared to bonding showing the connection to earth at the source (utility) and service and everything bonded to that point of grounding

The *National Electrical Code* Trend

The *NEC* in recent cycles has been revised to reduce the allowance of using the grounded conductor for grounding equipment downstream from the main bonding jumper in a service, or downstream from the system bonding jumper at a separately derived system. As stated earlier, the reasons are elementary. Current, be it normal current or fault current, will take all the paths available to it to try to return to its source. If the grounded conductor (neutral) and equipment grounding conductors are connected at points downstream of the service or separately derived system, such as at sub-panels, multiple paths will be available on which the current will try to return to the source. This can lead to normal neutral current on water piping systems, conduit, wire-type equipment grounding conductors, and any other electrically conductive paths, and all these extra paths can compromise electrical safety and even proper overcurrent device operation in ground-fault conditions.

In recent editions of the *NEC* (1996), electric range and dryer circuits were required to include an equipment grounding conductor in addition to an insulated grounded conductor. Existing range and dryer circuits are allowed to continue the use of the grounded conductor, or neutral, to ground the boxes at the outlet and the frames of the equipment. New installations, however, are required to maintain isolation (insulation) between the grounded conductor and the equipment grounding conductor.

The rules covering the use of the grounded conductor for equipment grounding purposes at a second building or structure are provided in Section 250.32. Section 250.32(B) requires an equipment grounding conductor to be installed with the feeder supplying the second building or structure; separation between the grounded (neutral) conductors is to be maintained. There is an allowance in 250.32(B) Exception, for existing installations only, to utilize the grounded conductor of the feeder for grounding equipment under three specific and very restrictive conditions. First, an equipment grounding conductor is not included with any feeders and/or branch circuits supplying the building or structure. Second, there are no continuous metallic paths bonded to the grounding system in both buildings. Third, there is no ground-fault protection of equipment installed at the service or the feeder system supplying the building or structure. If all of these conditions are met at existing installations only, the grounded conductor may continue to be used for equipment grounding and must be connected to the building or structure disconnecting means enclosure.

In these cases, the grounded conductor is also required to be connected to a grounding electrode at the building or structure and installed in accordance with Part III of Article 250. This will serve as the grounding means and as the path for both normal current and fault current to clear overcurrent devices. Using the exception to 250.32(B) requires that there be no continuous metallic paths bonded to the grounding system in each structure. This requirement encompasses all paths, not just wires or conduits. These paths could include items such as metal water pipes, other metal piping, steel members, and paths such as the shielding on a communications cable or a coaxial cable installed between the structures. If this connection was made and the service was equipped with ground-fault protection (GFP) in accordance with 230.95, these connections could desensitize the GFP device, possibly preventing it from operating properly when a ground-fault condition occurred because of multiple paths for current.

Current on the Proper Path

It is important that the basic elements of current be understood and carefully considered while applying the rules of the *NEC*. Section 250.24(A)(5) states that a grounding connection to any grounded circuit conductor on the load side of the service disconnecting means shall not be made, unless otherwise permitted in the article (see figure 1.11). The Informational Note refers to three situations where this is acceptable but also restrictive: for separately derived systems in 250.30; for separate buildings or structures in 250.32; and for grounding equipment under the limitations of 250.142.

Installers and inspectors should be watchful to ensure there are no neutral-to-ground connections on the load side of the grounding connections at either a service disconnecting means or source of a separately derived system. In other words, isolate (insulate) the neutral conductors and equipment grounding conductor connections (see figures 1.11 and 1.12). Give current, be it fault current or normal current, the low-impedance path anticipated by the requirements of the *NEC*.

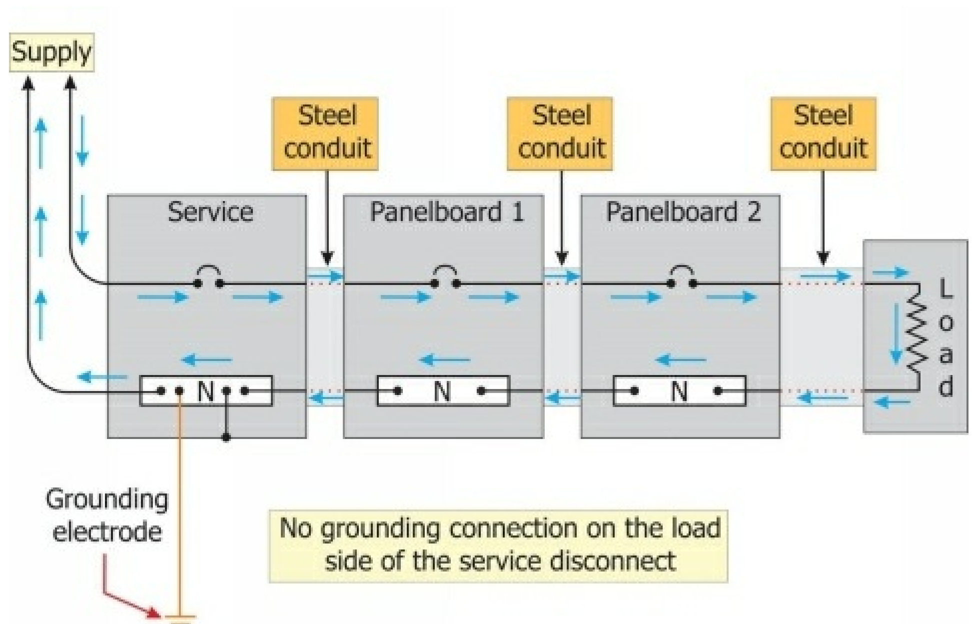


FIGURE 1.11 Proper path for current over grounded conductor returning to the source (correct)

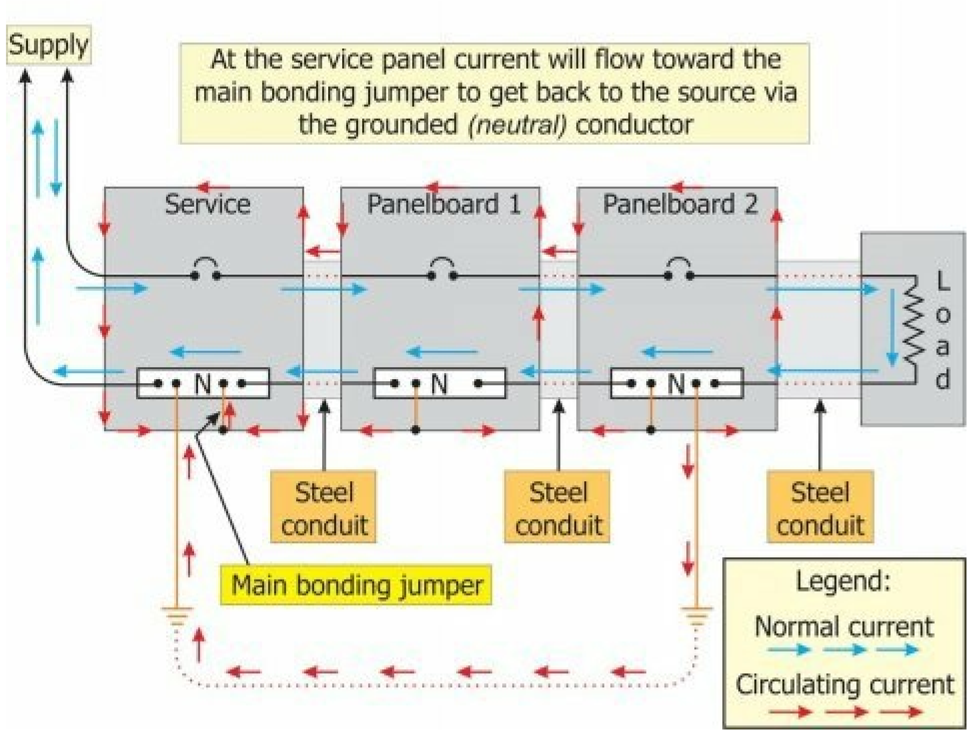


FIGURE 1.12 Current taking multiple paths trying to return to the source (incorrect)

Grounding and bonding must be effective and include the following vital characteristics:

- Be a continuous path
- Have adequate capacity for the maximum faultcurrent likely to be imposed
- Provide a fault-current path of low impedance

The definitions of 250.2 and Article 100 describe three important terms used in Article 250. These three terms are:

Effective Ground-Fault Current Path. "An intentionally constructed, low-impedance electrically conductive path designed and intended to carry current under ground-fault conditions from the point of a ground fault on a wiring system to the electrical supply source and that facilitates the operation of the overcurrent device or ground fault detectors" (see figure 1.13).

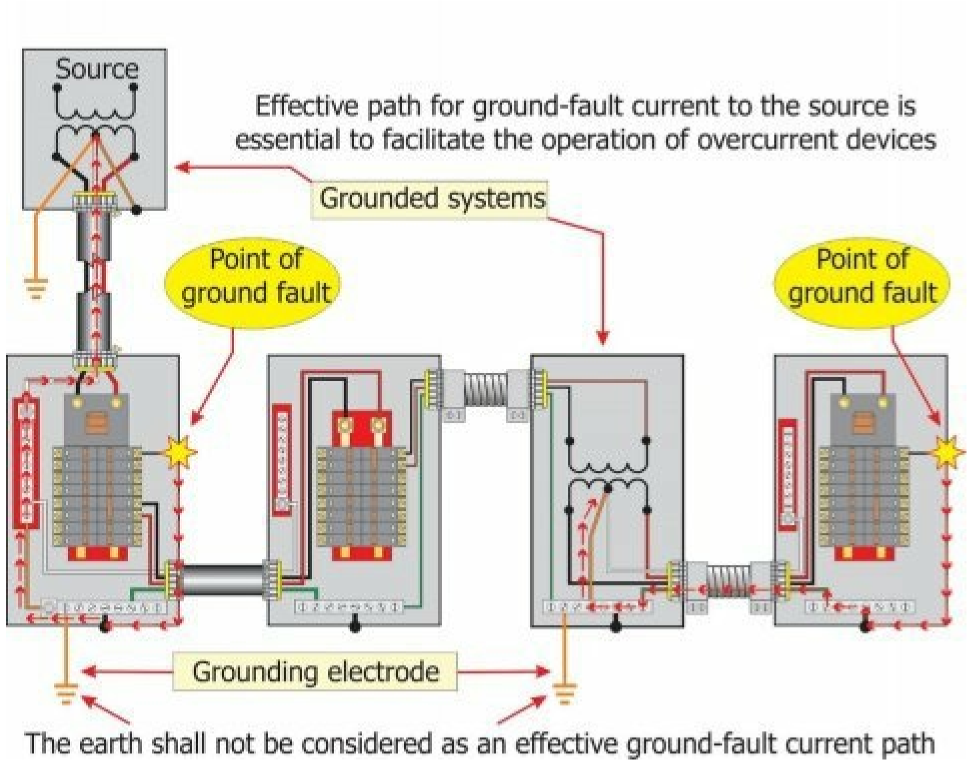


FIGURE 1.13 Effective ground-fault current path

Ground Fault. “An unintentional, electrically conductive connection between an ungrounded conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth.”

Ground-Fault Current Path. “An electrically conductive path from the point of a ground fault on a wiring system through normally non-current-carrying conductors, equipment, or the earth to the electrical supply source.”

A new Informational Note in the 2014 *NEC* to this definition now in Article 100 provides some examples of ground-fault current paths.

“Informational Note: Examples of ground-fault current paths are any combination of equipment grounding conductors, metallic raceways, metallic cable sheaths, electrical equipment, and any other electrically conductive material such as metal, water, and gas piping; steel framing members; stucco mesh; metal ducting; reinforcing steel; shields of communications cables; and the earth itself.”

Overview of NFPA 70 Article 250

Proper grounding and bonding provide protection from electric shock hazards and facilitate operation of overcurrent devices to clear circuits under ground-fault conditions. Fast and effective operation of overcurrent devices, covered in Article 240 during a ground fault, depends on the proper bonding and effective ground fault-current paths required by Article 250. Article 250 is located in Chapter 2, Wiring and Protection, of the *NEC* and is made up of ten parts. Part I includes general requirements and some important performance requirements vital to the understanding and proper application of prescriptive requirements found in latter parts of the article.

The parts of Article 250 are very much interlocking; that is, they must be used together in many instances to properly apply the rules. Figure 250.1 (reproduced in figure 1.14) is a built-in map for Article 250, which serves to enhance the usability issues in the *Code*. Figure 1.14 assists the reader in understanding the arrangement of the article at a glance.

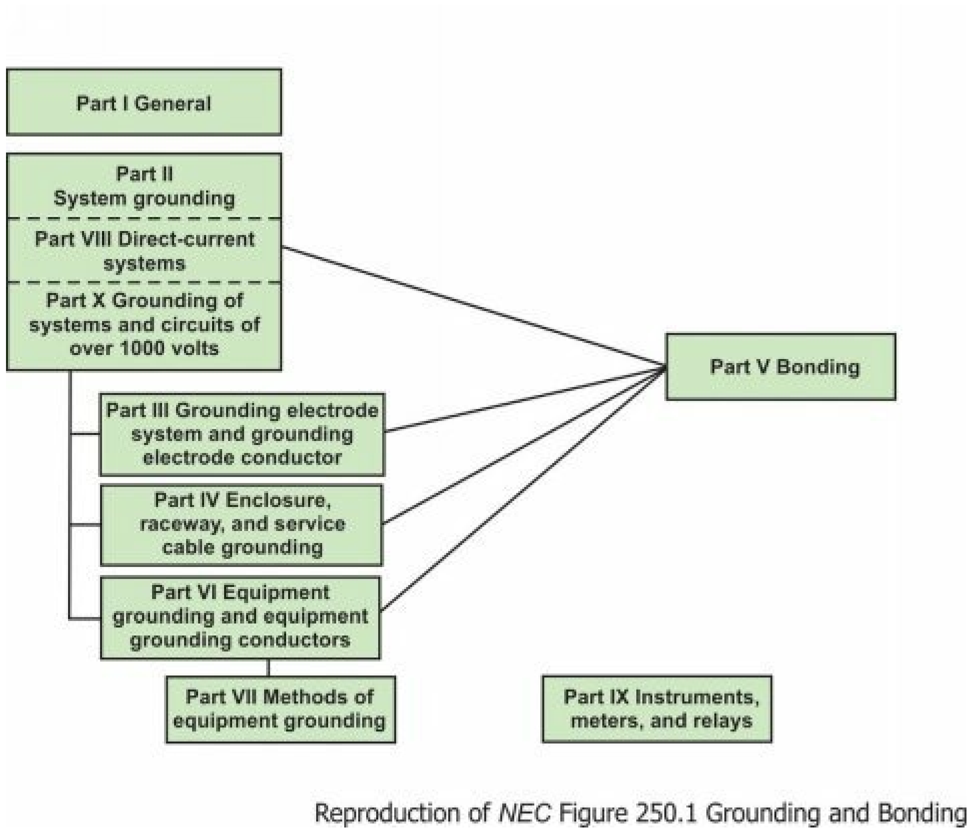


FIGURE 1.14 A reproduction of Figure 250.1 in the NEC

Section 250.1 sets the scope for the article including general requirements for grounding and bonding of electrical installations, and identifies six ”specific requirements.

- Systems, circuits, and equipment required, permitted, or not permitted to be grounded
- Circuit conductor to be grounded on grounded systems
- Location of grounding connections
- Types and sizes of grounding and bonding conductors and electrodes
- Methods of grounding and bonding
- Conditions under which guards, isolation, or insulation may be substituted for

grounding.”

Alternatives to Grounding

Item six in 250.1 indicates that three conditions—guards, isolation, or insulation—may be substituted for grounding under certain conditions. Definitions of these terms, two of which are found in Article 100, help clarify the intent of the alternatives.

Guarded. "Covered, shielded, fenced, enclosed, or otherwise protected by means of suitable covers, casings, barriers, rails, screens, mats, or platforms to remove the likelihood of approach or contact by persons or objects to a point of danger."

Isolated (as applied to location). "Not readily accessible to persons unless special means for access are used."

Insulated. "Equipment or materials that are covered with an insulating material."

The insulation must have sufficient dielectric strength to provide protection against electrically conductive parts. Power tools are an example of a product where a metallic case is likely to become energized and present shock hazards to personnel. The supply cord for these products is required to have an equipment grounding conductor and an appropriate grounding type cord cap. Where the tool is built with a system of double insulation, this type construction is permitted to be used as a substitute for the equipment grounding.

Grounding of Electrical Systems

Some features of electrical safety are so fundamental they have appeared in some form in every edition of the *National Electrical Code*. These include requirements for suitable insulation for conductors; overcurrent protection for circuits; and grounding of electrical systems and equipment for safety. The grounding of equipment and conductor enclosures, as well as the grounding of one conductor of an electric power and light system, has been practiced in some areas since the use of electricity began.

At first, there was no uniform standard for grounding. However, it was not long before it became universal to ground one conductor on all 120-volt lighting circuits. Early editions of the *Code* firmly established the practice of grounding by making it mandatory to ground all such systems where the system can be grounded so that the voltage to ground does not exceed 150 volts. These editions also recommended that alternating-current systems be grounded where the system voltage to ground did not exceed 300 volts, while at the same time stating that higher voltage systems were permitted to be ungrounded. The 1971 *Code* made it mandatory to ground any system having a nominal voltage to ground of not more than 300 volts if the grounded service conductor (usually a neutral) was not insulated.

Grounded (Grounding)

Grounded (grounding) is defined in Article 100 as, "Connected (connecting) to ground or to a conductive body that extends the ground connection" (see figure 1.15). Conductive bodies that extend the ground connection include conduits, boxes, enclosures, equipment grounding conductors and wiring devices and may now include structural metal members and metallic water piping. These are, in fact, an extension of the ground (earth) by being electrically connected to the earth by reliable electrical and mechanical means. Metal frames of buildings that have an established connection to earth are acceptable as an extension of the earth and are a "common grounding electrode conductor," but are not permitted to be used as an equipment grounding conductor.

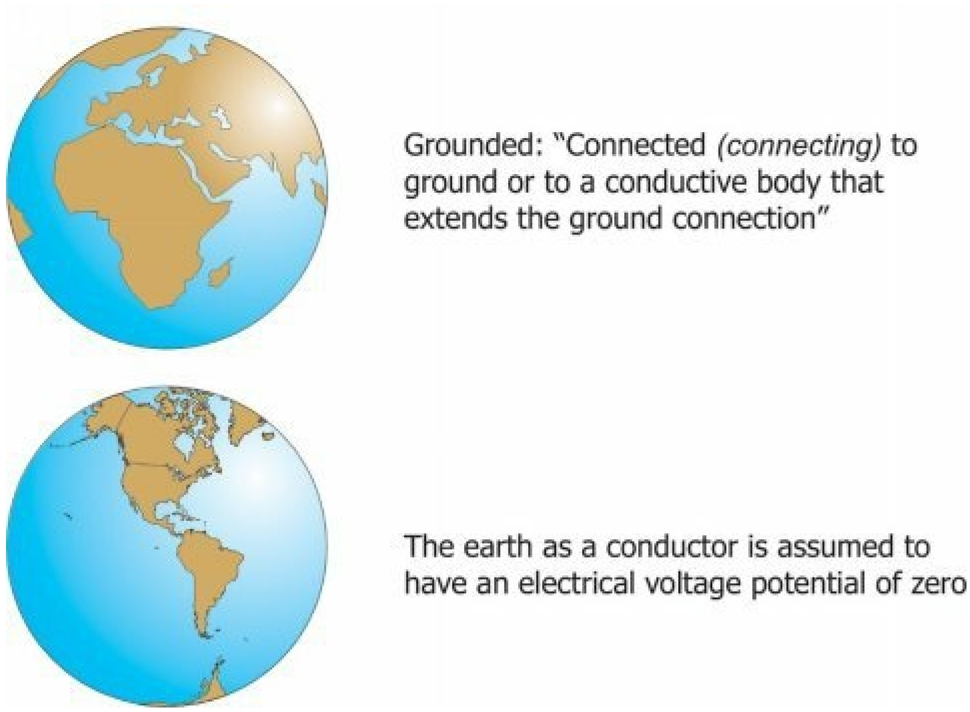


FIGURE 1.15 Grounded means "connected to ground (earth)."

The earth as a whole is properly classed as a conductor. For convenience, its electric potential is assumed to be zero. Based upon the composition of the soil or earth, the resistance of segments of the earth can vary widely from one area to another. The earth is composed of many different materials, some of which, especially when dry, are very poor conductors of electricity. Soil temperature, moisture content and chemical composition are factors that have a great influence on soil resistance. As a result of these factors, the capability of the earth to carry electrical current also varies widely (see chapter six for more information on composition of the earth and effectiveness of grounding electrodes).

A metal object, such as a box or other equipment enclosure, that is grounded by connecting (bonding) it to the ground (earth) by means of a grounding electrode, grounding electrode conductor, and/or equipment grounding conductor is thereby forced theoretically to take the same zero potential as the earth (see figures 1.16, 1.17, and 1.18). Slight differences in potential can exist due to differences in impedance of the materials or connections. Any attempt to raise or lower the potential of the grounded object results in current passing through the grounding path until the potential (voltage) of the object and the potential (voltage) of the earth (zero) are equalized. Usually, this potential above ground is caused by a line-to-ground fault. Hence, grounding is a means for ensuring that the grounded object cannot take on a potential differing enough from earth potential to be hazardous. When the equipment grounding conductor or grounding electrode conductor is broken, is inadequate in size, or has a poor connection, a hazardous, aboveground potential can be present from an abnormal condition.

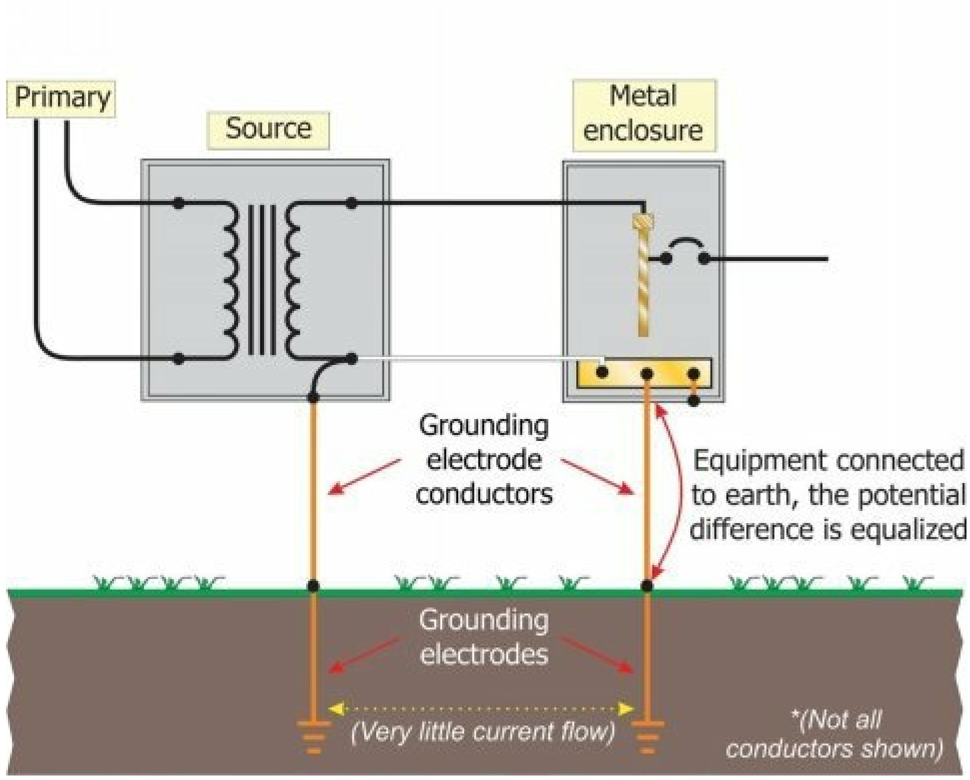


FIGURE 1.16 Grounding fundamentals showing proper grounding and bonding

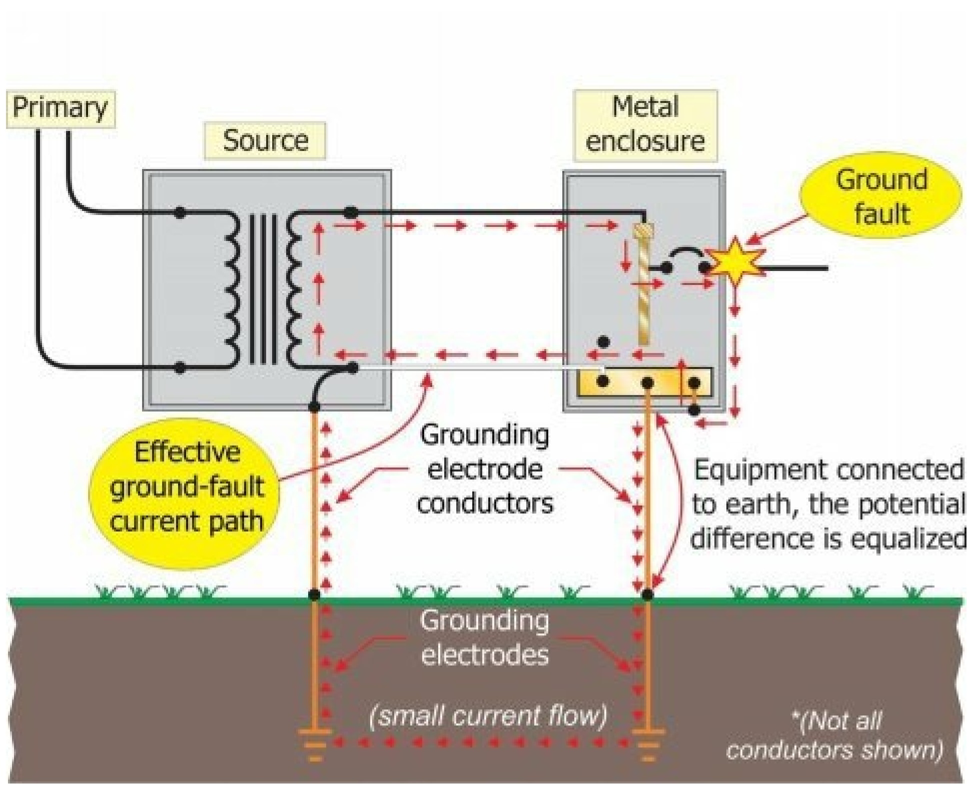


FIGURE 1.17 Grounding fundamentals and current paths

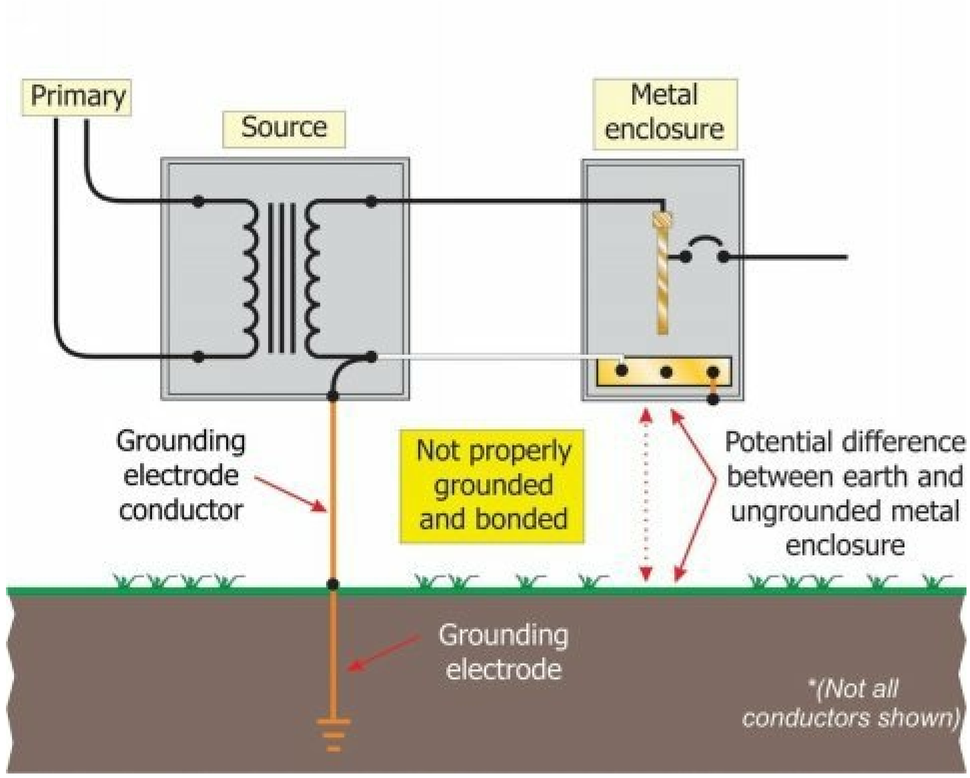


FIGURE 1.18 Potential hazard is present when systems and equipment are not properly grounded.

Resistance and Impedance

Though a comprehensive discussion of the subject is beyond the scope of this text, a brief explanation of the terms resistance and impedance is offered.

For direct current (dc) systems and circuits, resistance (R) is properly used to describe the opposition to current. We are accustomed to using the term ohms to relate to the resistance of the circuit, such as 35 ohms. Ohm's law can be summarized as follows: in a dc circuit, the current is directly proportional to the voltage and inversely proportional to the resistance (I = E/R). This means, as the voltage is increased, the current will increase through a fixed resistance. As the resistance is reduced, the current will increase if the voltage stays the same. A pressure (voltage) of one volt will cause one ampere of current through a resistance of one ohm.

For alternating-current (ac) systems and circuits, impedance (Z) is the proper term to describe the total opposition to current. Impedance consists of three components: inductive reactance, capacitive reactance and resistance. Impedance, rather than resistance, is used most often throughout this text since, for the most part, ac electrical systems and circuits are being considered. See chapter two for a detailed discussion of the importance of keeping all conductors of the circuit, including the equipment grounding conductor, close together to keep the impedance as low as possible. Also, many excellent books on electrical theory cover the subject of impedance, inductive reactance, capacitive reactance and resistance in detail.

Equipment Supplied from a Grounded System

Where the electrical system is grounded, it is critical to provide a low-impedance ground-fault return path with adequate capacity from all the equipment supplied by the system back to the source of the system: (1) to maintain the metal equipment enclosures as close to earth potential as possible to reduce a shock hazard; and (2) to ensure the overcurrent protection will operate in the event of a line-to-ground fault. This is required by 250.4 and is emphasized in several portions of this text.

Electrical equipment that is supplied by a grounded system but is left ungrounded/unbonded or that has a poorly connected equipment grounding path becomes a silent and often lethal source of electrical shock when a ground fault occurs. Another hazard of equal significance can occur where two separate pieces of electrical equipment are supplied from a grounded system and both are within reach of a person. If one piece is not properly connected or has a poorly connected equipment grounding path and becomes energized through a failure of the insulation system (ground fault), the person making contact with the two (or more) pieces of equipment becomes the circuit (path) for fault current to pass through as it tries to find its way back to its source. In some cases, the person will receive a mild shock. In other cases, the shock can be fatal. Even though the impedance of the human body can be relatively high, approximately 200 milliamp (mA) of current through it can be lethal. A milliamp is equal to one thousandth of an ampere (see figure 1.20).

Equipment Supplied from an Ungrounded System

Section 250.21 permits some electrical systems to be operated ungrounded. In this case, the electrical enclosures for the service, feeders, circuits and other equipment are connected to ground (earth) but the system itself is not grounded. In many parts of North America, the serving utility will provide only a grounded electrical system. From a practical standpoint, an ungrounded system exists only in theory or at the distribution transformers hanging on nonmetallic poles before the system is connected to the plant electrical system. Where the ungrounded system conductors are installed in grounded metal raceways or enclosures or connected to motors, the frame of which are grounded, the ungrounded system becomes capacitively coupled to ground (see chapter two for a more detailed discussion of this subject).

An ungrounded electrical system will become accidentally grounded when a line-to-ground fault occurs. This essentially creates a poorly grounded system and that poor ground connection is at an unknown location. The other phases of the system then rise to a potential to ground equal to the system voltage. For example, in a 480-volt, ungrounded system, if one of the phases becomes grounded anywhere on the system, the other phases will then have a voltage to ground of approximately 480 volts. Obviously, this becomes a greater shock hazard to personnel who may be servicing the installation and adds greater stress on the conductor insulation, including transformer and motor windings.

Effect of Electricity on Humans

Like the bird on an electric wire, the human body is immune to electric shock as long as it is not part of the electric circuit. The easiest way to avoid danger from electric shock is to keep one's body from becoming a part of the electric circuit. Due to the common use of electric tools, equipment and appliances, the risk of being exposed to electric shock is multiplied by the numbers of these items the person is exposed to.

When a person becomes a path for electricity, he or she will experience an electrical shock. The intensity and damage done to the body by the shock will be determined by the current level (the amount through the person), how long the current exists (the duration), the person's size, the pathway the current takes through the body, and the circuit frequency (see figure 1.19). Speaking in electrical terms, the person can be thought of as a resistor or impedance in the circuit. The skin of the human body can be thought of as insulation; however, its resistance is rather low and varies depending on moisture. The inside of the human body is a relatively good conductor as it is composed primarily of fluids and salt. Once electrical current has entered the body through the skin, the resistance is very low, and severe injury or death is likely.

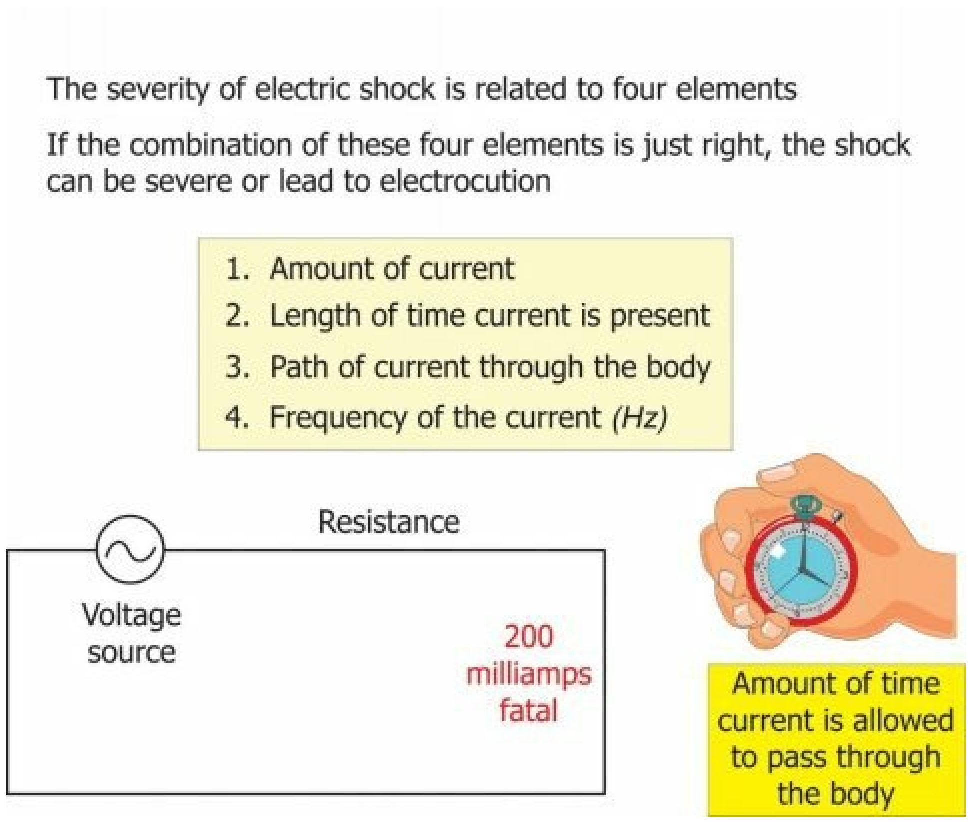


FIGURE 1.19 Severity of electric shock is related to four elements.

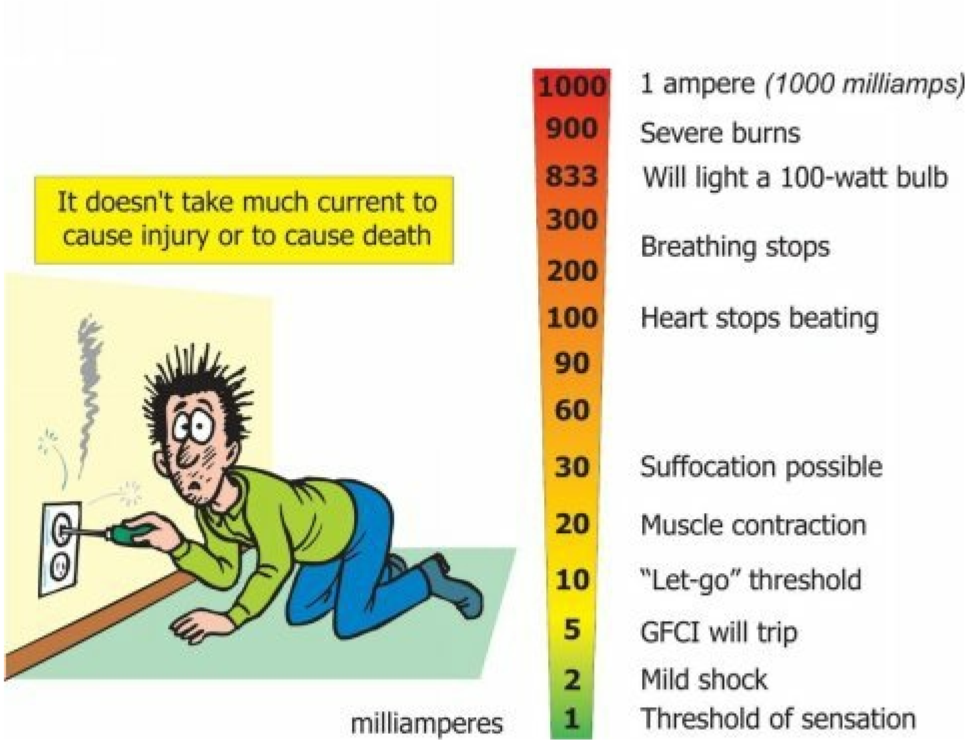


FIGURE 1.20 Level (in milliamperes) of current through the body

A person can become a pathway to ground or between conductors in one of two ways: in a series or a parallel circuit. In a series circuit, the person is the only path through which the current will attempt to return to its source. An example of this is when a person comes into contact with an ungrounded electrical appliance that is energized through a line-to-ground fault and at the same time touches another grounded appliance like an electric range or a grounded kitchen sink (see figure 1.21). In general terms, the amount of current that passes through the person's body is determined by Ohm's law using the relationship of the voltage of the circuit and the impedance offered by the person's body (see chapter fourteen for a greater discussion of current and the human body.)

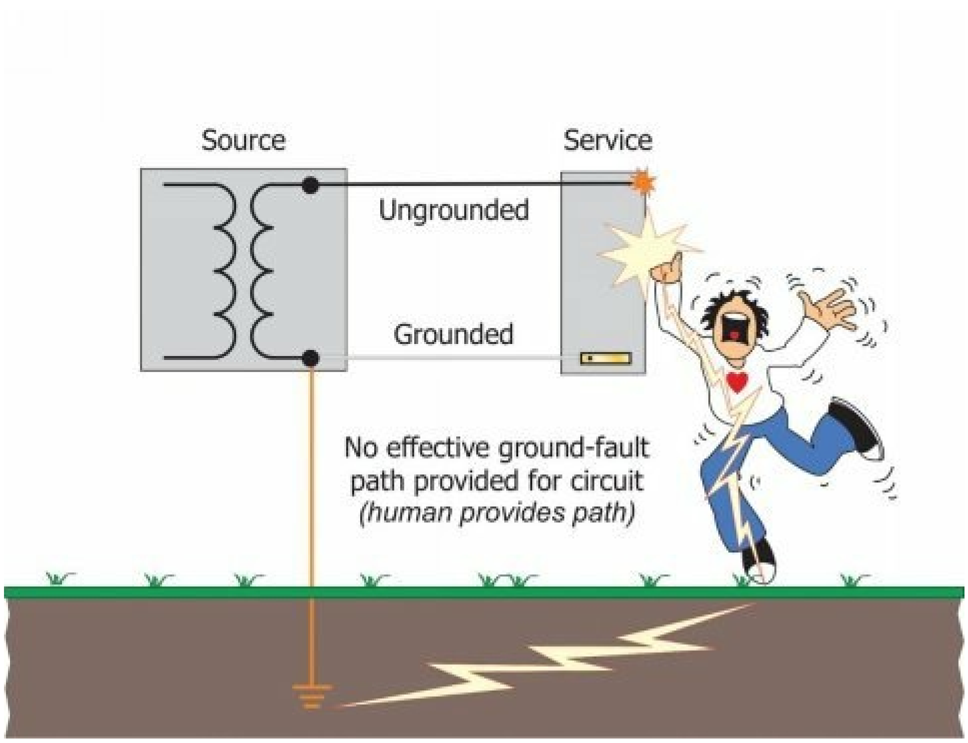


FIGURE 1.21 Human completing the path for current through the earth

In a parallel circuit, the human body and another path such as an equipment grounding conductor each provide a path for current at the same time. The current will divide among the paths based on the impedance of those individual paths. The greater the impedance of the path, the less current is in that path (see figure 1.22). With a high impedance for the human that will result in lower current, but as stated before it only takes a very small current going through the body to cause serious injury or even death.

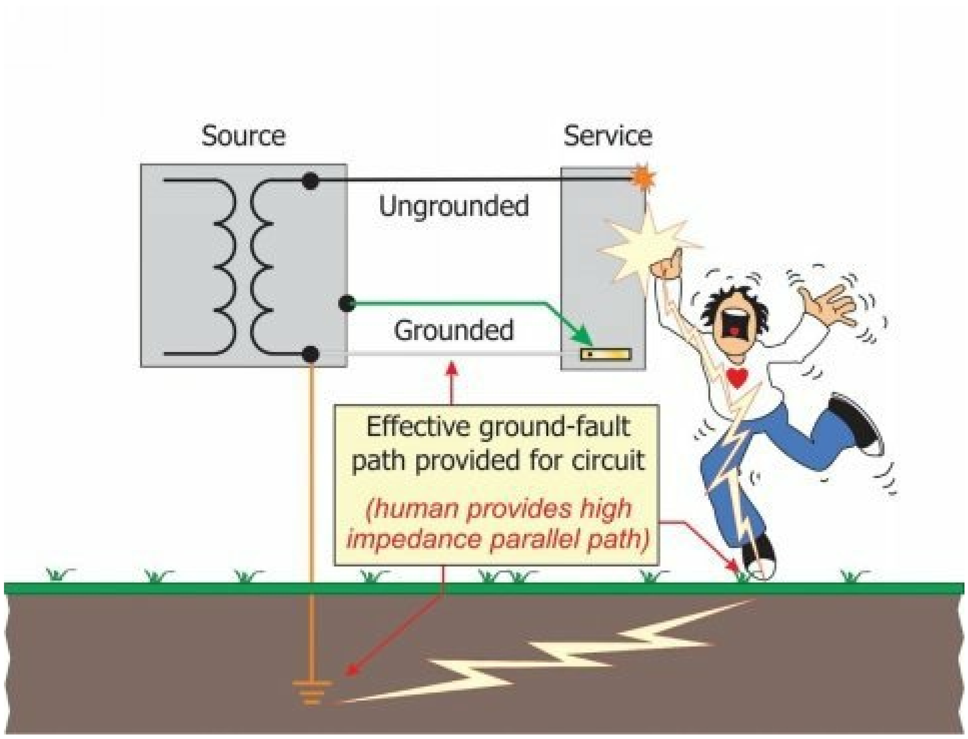


FIGURE 1.22 Human in parallel with equipment grounding conductor during ground fault

The smallest risk of shock hazard occurs where the circuit protective device, usually a fuse or circuit breaker, opens the faulted circuit immediately. A factor is the time it takes for the overcurrent device to clear the fault from the circuit. During this time, the equipment subject to the ground-fault condition will have a potential above ground depending upon the voltage drop of the equipment grounding circuit.

In some installations, the equipment may be grounded but through a high impedance. This can be the result of an equipment grounding conductor that is too small or too long for its size; the connection has become loose; or it is routed improperly. In this situation, there is usually not enough current through the equipment grounding conductor to cause the overcurrent protective device to operate and clear the faulted equipment. Part of the fault current will then be through the person in contact with the energized equipment and part through the equipment grounding conductor path. The current will divide in opposite proportions to the resistance or impedance of the paths. The greatest amount of current will be through the path providing the lowest resistance or impedance. Even though the human body can have impedance that is much greater than the other path(s), it only takes a small amount of current to cause serious injury or death (see figures 1.20 and 1.22).

The primary emphasis is to provide a path for ground-fault current that is permanent and continuous, is adequately sized and of low-impedance from all electrical equipment back to the source to facilitate the operation of the overcurrent device in a reasonable time. Protection of persons from lethal levels of electric shock is the reason ground-fault circuit-interrupter devices (GFCIs) have become so popular over the recent years.

Burns and Other Injuries

The most common shock-related injury is a burn. Burns suffered in electrical accidents can be of three types: electrical burns, arc burns, and thermal contact burns.

Electrical burns are the result of the current through tissues, blood vessels, or bone. Tissue damage is caused by heat generated by the current through the body and is often immediately classified as a third degree burn. In many cases, the damage caused to the tissues becomes more apparent in the days or even months following the incident. Severe permanent damage can be caused to internal tissues or organs with little external indication until sometime after the electric shock happens. Burns from electric shock are one of the most serious injuries that can be experienced and should be given immediate medical attention.

Arc or flash burns, on the other hand, are the result of high temperatures produced by an electric arc or explosion near the body. These burns can be of the more minor first-degree type, more severe second-degree or most severe third-degree burns. They should also be attended to promptly and properly.

Finally, thermal contact burns are those normally experienced when the skin comes into contact with hot surfaces of overheated electric conductors, conduits, or other equipment. Additionally, clothing can be ignited in an electrical arc or explosion and a thermal burn will result. All three types of burns can be produced simultaneously.

The proper use of work procedures and personal protective equipment can minimize these injuries. [See NFPA 70E-2015 Standard for Electrical Safety in the Workplace for information about electrical safety requirements and safe working practice and procedures for employees in workplaces.]

Electric shock can also cause injuries of an indirect or secondary nature in which involuntary muscle reaction from the electric shock can cause bruises, bone fractures, and even death resulting from collisions or falls. In some cases, injuries caused by electric shock can contribute to delayed fatalities.

In addition to shock and burn hazards, electricity poses other dangers. For example, when an arcing type short circuit or ground fault occurs, hazards can be created from the resulting arcs. If high current is involved, these arcs can cause injury to personnel or start a fire. Extremely high-energy arcs can damage equipment, causing fragmented metal to fly in all directions, or melt steel, copper or aluminum. Even low-energy sparks can cause violent explosions in atmospheres that contain flammable gases, vapors, or combustible dusts.

Effect of Electricity on Animals

Some animals are especially sensitive to electricity. For example, past studies claimed that dairy cattle are so sensitive to electricity that a potential of as little as two volts between conductive portions of floors, walls, piping and stanchions has caused behavior problems that resulted in loss of production. More recent studies claim the voltage difference to be about four volts. In other cases, severe health problems are attributed to the effects of electricity, which, if not corrected and treated can lead to death of the animal. (See chapter fifteen for methods of preventing and minimizing these problems in agricultural structures.)

Purpose of Grounding and Bonding

The general requirements for grounding and bonding are contained in 250.4. The requirements include the grounding and bonding performance requirements for grounded systems and ungrounded systems as follows:

(A) Grounded System

(1) Electrical System Grounding

(2) Grounding of Electrical Equipment

(3) Bonding of Electrical Equipment

(4) Bonding of Electrically Conductive Materials and Other Equipment

(5) Effective Ground-Fault Current Path

(B) Ungrounded Systems

(1) Grounding of Electrical Equipment

(2) Bonding of Electrical Equipment

(3) Bonding of Electrically Conductive Materials and Other Equipment

(4) Path for Fault Current

The requirements for grounded systems and ungrounded systems and the differences between them are covered in detail in chapter three of this text.

Grounding of Electrical Systems [250.4(A)(1)]

Systems are solidly grounded to limit the voltage to ground during normal operation and to prevent excessive voltages due to lightning, line surges or unintentional contact with higher-voltage lines and to stabilize the voltage to ground during normal operation. Several methods of grounding electrical systems are used depending on *National Electrical Code* requirements and system design and function. These methods of grounding electrical systems are covered in detail in chapter six.

Grounding of Electrical Equipment [250.4(A)(2), 250.4(B)(1)]

Conductive materials enclosing electrical conductors or equipment or that are part of the equipment are grounded to limit the voltage to ground on these materials and bonded to facilitate the operation of overcurrent devices under ground-fault conditions [see figures 1.23 and 1.24]. Where the electrical system is grounded, the equipment grounding conductor is connected to the grounded system conductor (often a neutral) at the service or the source of a separately derived system. Where the electrical system is not grounded, the electrical equipment is connected to earth at the service or source of separately derived system to maintain the equipment at or near earth potential and the equipment is bonded together to provide a path for fault current. This occurs where a second ground fault occurs before the first one is cleared.

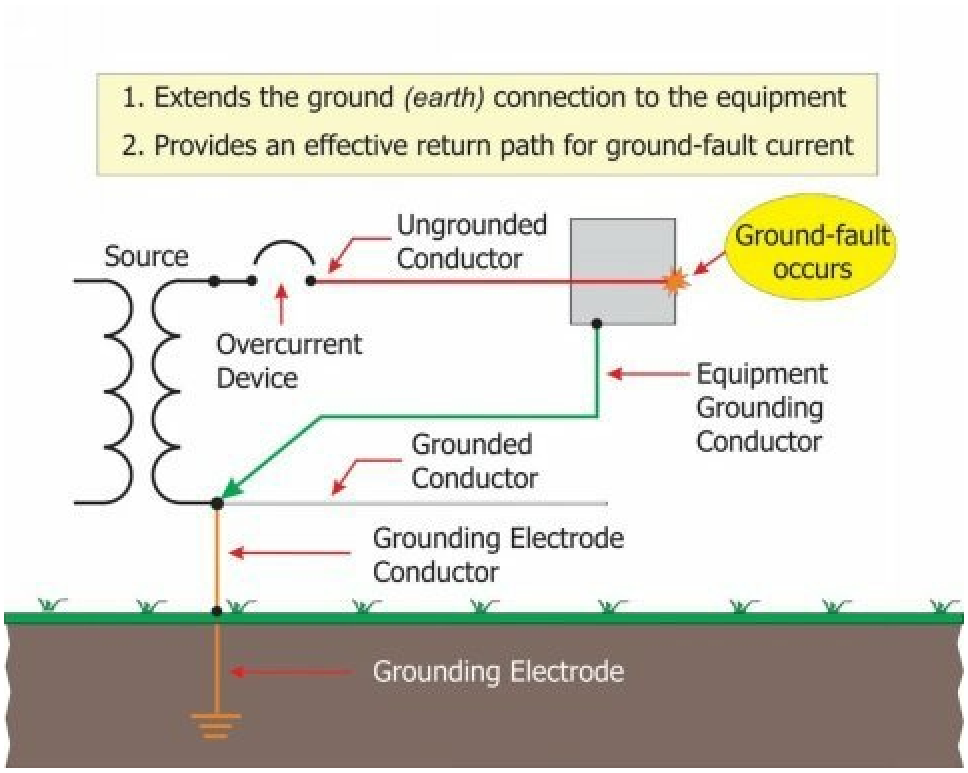


FIGURE 1.23 Purpose of the equipment grounding conductor

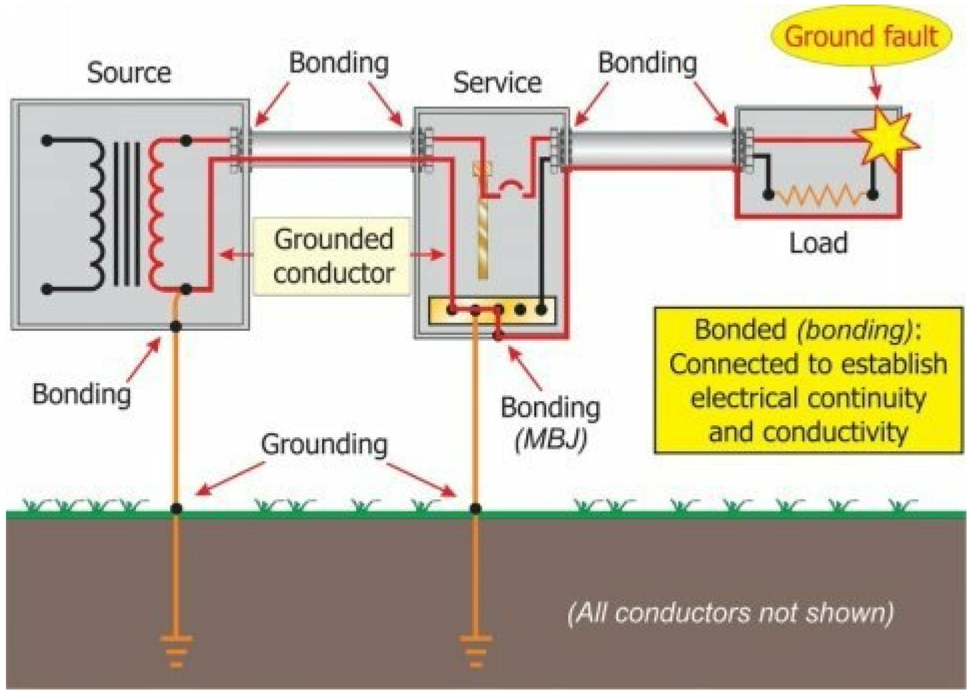


FIGURE 1.24 Purpose of bonding equipment and enclosures

Bonding of Electrical Equipment [250.4(A)(3), 250.4(B)(2)]

The normally non-current carrying metallic enclosures, raceways and other parts of the electrical system need to be bonded together by direct connection or bonding jumpers so a low impedance path is formed to carry ground-fault current when a ground fault occurs. For grounded systems these parts are to be connected together and to the supply source in such a manner so as to form an effective ground-fault current path. For ungrounded systems these parts are connected together and to the supply source grounded equipment in such a manner that a low-impedance ground-fault current path is created, and this path is capable of carrying the maximum fault current likely to be imposed on the equipment. Remember for ungrounded systems, this fault current can be essentially a line-to-line fault passing through the equipment grounding system from the first fault point to the second (see figure 1.25).

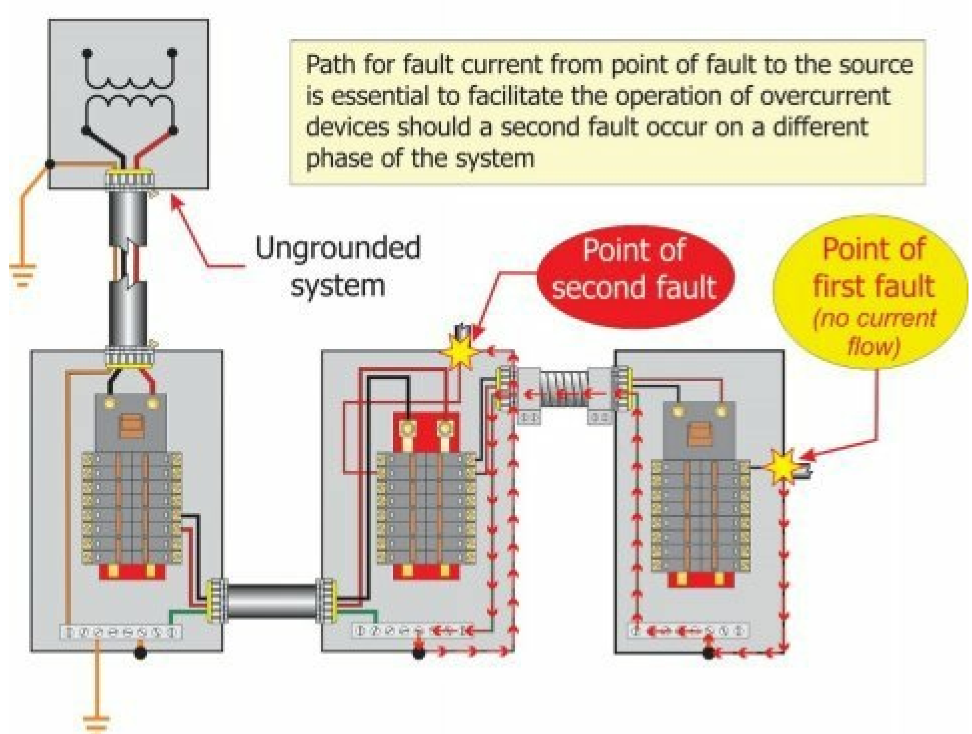


FIGURE 1.25. Effective ground-fault current path on an ungrounded system

Bonding of Electrically Conductive Materials and Other Equipment [250.4(A)(4), 250.4(B)(3)]

Electrically conductive materials, such as metal water piping, metal gas piping and structural steel members that are likely to become energized are bonded to provide a low-impedance path for clearing ground faults that otherwise would energize the equipment at a level above earth potential. For systems that are grounded, the equipment is ultimately bonded to the grounded system conductor (often a neutral) and the grounding electrode conductor at the service or source of a separately derived system. Where the electrical system is not grounded, the electrical equipment is connected to earth at the service or source of separately derived system to maintain the equipment at or near earth potential and the equipment is bonded together to provide a path for fault current. This fault current occurs where a second ground fault occurs before the first one is cleared [see 250.4(B)(4)]. Chapter eleven provides more detail about ungrounded electrical systems.

Effective Ground-Fault Current Path [250.4(A)(5), 250.4(B)(4)]

Sections 250.4(A)(5), Effective Ground-Fault Current Path, and 250.4(B)(4), Path for Fault Current, provide requirements relative to one of the most critical elements of the grounding and bonding safety system. These sections require that the fault-current path: (1) be electrically continuous; (2) be capable of safely carrying the maximum fault current likely to be imposed on it; and (3) have sufficiently low impedance to facilitate the operation of the overcurrent devices under fault conditions.

Each of these points is important and worthy of discussion.

First, a permanent, reliable and electrically continuous grounding and bonding system is vital to the overall safety of the electrical system. This includes a stable voltage reference and provides an effective path for fault current due to abnormal conditions. Intermittent connections are like an unpredictable earthquake, waiting to wreak havoc on the unsuspecting. The grounding and bonding system, including all connections, whether a wire, conduit, equipment enclosure, or other element of the path, must be electrically continuous, and have all connections made up tightly and in a workmanlike manner (see figure 1.26). In describing an effective ground-fault current path, the word "permanent" was removed at 250.4(A)(5) in the 2008 edition of the *NEC*. However, the fact remains that this path must be a stable, reliable path back to the source to facilitate the opening of the overcurrent device.

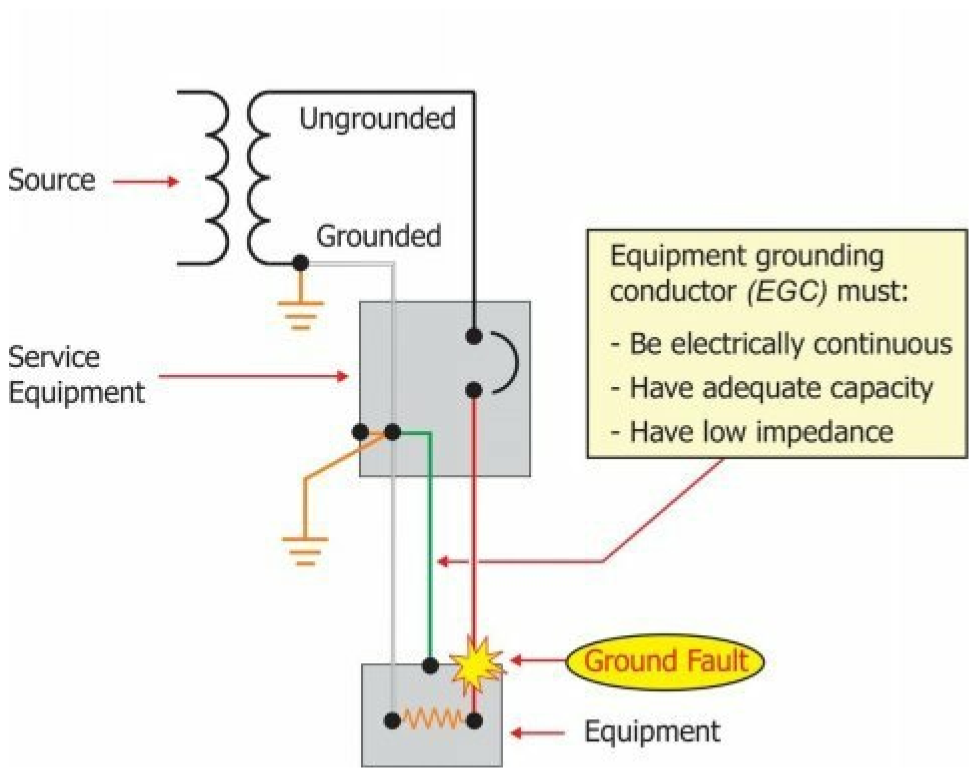


FIGURE 1.26 Effective ground-fault current path

In the event the insulation system of other conductors of the system, like ungrounded (hot) or grounded circuit conductors, fail, it usually is obvious when a piece of equipment or an appliance stops functioning. This is not true of the equipment grounding path. Usually, a failure of the ground-fault path is not known until someone receives an electric shock. Also, the conductors comprising the equipment grounding conductor system normally only carry current in a fault situation. At this time, the equipment grounding conductor path will usually carry far more current than the ungrounded (hot) or grounded conductor (often a neutral) typically carries during normal conditions.

Second, providing adequate capacity for the fault current is also of paramount importance. The minimum size of the grounded conductor, bonding conductor(s) and equipment grounding conductor(s) are given in several locations, many of them in Article 250. Obviously, an equipment grounding conductor or bonding jumper that burns apart (fuses) due to excessive current while it is carrying out its intended purpose is of little value in the safety system. The sizes of equipment grounding conductors given in Table 250.122 are the minimum. There are cases where the withstand rating of conductors is exceeded by the available fault current and larger conductors are necessary (see chapter eleven for additional information on the subject).

Third, the ground-fault path that is effectively connected and is of adequate capacity is of little value if it does not have low impedance (measured in ohms). A high-impedance path provides higher opposition to current flow in the circuit, thus limiting the amount of current. This allows a voltage above ground to be present on faulted equipment that can then present a shock hazard (E = I x R). The *NEC* stops short of specifying the maximum impedance acceptable for the ground-fault path, except to say that the path must have impedance that is low enough to facilitate the operation of the overcurrent protective device. Every circuit has different characteristics associated with it that contribute to the impedance of the particular circuit and, thus, the impedance value of the equipment grounding circuit will vary, but must be kept as low as possible in all equipment grounding circuits (see chapter eleven for additional information on the subject).

The goal of good design of the ground-fault path is to provide a permanent and adequate path of low impedance so there will be enough current in the circuit to cause a circuit breaker to trip or a fuse to open. If the opening of the breaker or fuse on the line side of the faulted circuit does not take place rapidly, thus taking the faulted equipment off the line, the grounding and bonding system will have failed to perform its critically important function. This failure can result in greater equipment damage, possibly fires or injury to personnel.

Electrical System Design for Fault Protection

One key goal of good electrical system design is to prevent all faults, including ground faults, from occurring. This is accomplished by proper design, installation, operation and maintenance of electrical equipment and systems. System conductors that are ungrounded are separated from grounded conductors and grounded equipment by insulation. This insulation can be in the form of thermoplastic, thermosetting or other similar insulating material applied to wires or busbars or by separating conductors having a potential (voltage) between them. This separation is usually accomplished by mounting uninsulated conductors such as busbars on insulators. The air then becomes the insulation between phases and a grounded enclosure. However, it is possible to have a failure or breakdown in the insulation system in any electrical installation. Therefore, overcurrent protection and an effective ground-fault current path must be provided to safely clear line-to-ground faults that can occur. The phrase "likely to become energized" is included in Annex B of the *NEC* Style Manual as a standard term, meaning "failure of insulation on."

Section 110.7 requires that electrical wiring installations shall be free from short circuits, ground faults, or any connections to ground other than as required or permitted in the *NEC*. Though not always practiced, it is wise to test the insulation integrity of all installations to be certain they are free from unintended short circuits and ground faults before the wiring is energized. This can be done with some means of continuity testing, which can be a battery and a bell and leads (the origin of the term ring-out). An ohmmeter or megohm-meter (megger) can also be used. This is more than a simple continuity test. A voltage is applied to the conductor under test and the amount of leakage current through the insulation is measured. Testing the insulation integrity of the system before it is energized is often required in project specifications prepared by architects or engineers for commercial and industrial jobs.

Also, the impedance (rather than the resistance) of the equipment ground-fault return path can be verified by testing instruments. This is especially true for branch circuits where plug-in type testers are available and greatly simplify the testing process.

Designing Electrical Systems for Safety

Electrical systems need to be designed to be certain they are adequate for the loads to be served by them. The *NEC* requires that electrical systems are to be adequate for the calculated load in accordance with Article 220 [see 230.42(A)]. Methods for calculating the minimum capacity for electrical services and separately derived systems are found in Article 220 rather than in Article 230. The calculation method for determining the minimum size of the system grounded conductor (often a neutral) is found in 220.61. Section 250.24(C) specifies the minimum sizes for grounded service conductors and 250.30(A)(3) specifies the minimum sizing requirement for the grounded conductor of a separately derived system.

The *Code* does not require that electrical systems be designed with any additional capacity for future load expansion [see 90.1(B)]. From a practical standpoint, some additional capacity should be provided for when the system is first installed. Some designers typically plan the electrical system for at least 25 percent spare capacity.

Electrical Systems Abused

Electrical systems are intended to provide reliable service for many years. That is generally the case, provided the system is designed for the load to be carried, and the system is installed in a proper manner. Overloading the system is one of the major abuses that occurs and can lead to faults occurring. With the expanded use of new or more modern electrical appliances, larger electrical distribution systems are often required. It is not uncommon to find relocatable power taps, extra conductors placed under circuit breaker terminals, or splices being improperly made in attics or in crawl spaces to add extra electrical equipment to the electrical system. Often, extra fuse or circuit breaker panelboards are added to existing systems without taking proper steps to ensure that the supply conductors and equipment supplying the loads are adequate.

In industrial or commercial installations, additional equipment is often added to existing electrical systems. At times, this is done without consideration for whether the existing system is adequate for the additional load.

In addition, electrical systems can be exposed to overvoltage from lightning or power-line crosses, insulation failure in high-to-low voltage transformers, and to short circuits and ground faults. In some cases, electrical systems are abused until they fail. The opening of a fuse or tripping of a circuit breaker often is the first indication of a failure in the electrical system. These events should not be treated as a nuisance tripping situation.

Major Problems in Electrical Systems

The major cause of trouble in an electrical distribution system is insulation failure. The insulation can be air, such as in busways, switchboards and motor control centers, where clearance between uninsulated busbars and grounded metallic electrical equipment is maintained by air space. The clearance is maintained by insulators in the form of rubber, ceramic or thermoplastic, or insulation that is applied directly to the conductors. Insulation for wire or busbars is usually rubber, thermoplastic or thermosetting material.

Insulation failure can result in two kinds of faults: line-to-line or line-to-ground. The least likely failure is line-to-line or between any two conductors of the system, that is, from one phase conductor to another or from one phase conductor to the neutral or grounded conductor. Experience has shown that most insulation failures (as high as 80 percent or more) are line-to-ground faults or from one phase conductor to the conductor enclosure or equipment.

While the entire *National Electrical Code* and other safety electrical codes, like the Canadian Electrical *Code*, are developed and updated to provide protection against electrical fires and shocks, they are not design specifications. But an electrical design cannot be complete without using the applicable electrical code and adding specific details for the particular application. By following the rules of these codes, one will have an installation that is essentially free from hazard, but not necessarily efficient, convenient, or adequate for good service or future expansion (see 90.1).

Insulation Resistance

Previous editions of the *Code* (e.g., up to the 1965 *NEC*) contained recommended values or results for testing insulation resistance. It was found that the resistance values were incomplete and not sufficiently accurate for use in modern installations, and the recommendation was to delete them from the *Code*. However, basic knowledge of and the need for insulation-resistance testing are important.

Measurements of insulation resistance can best be made with a megohm-meter insulation tester, commonly called a megger. These instruments are available from several manufacturers and vary in cost and features. As measured with such an instrument, insulation resistance is the resistance to direct current (usually at 500, 1000, or 1500 volts for systems of 1000 volts or less) through or over the surface of the insulation in electrical equipment. Energizing the conductor, wire or busbar with the potential and measuring the current that leaks through the insulation accomplishes the test. By Ohm's law, the insulation resistance is $R = E \div I$. The results are displayed in ohms or megohms, but acceptable insulation resistance readings will be in the megohm range.

The insulation-resistance test is nondestructive, quite different from a high-voltage dielectric insulation or breakdown test, often called a hi-pot test (see photo 1.1). It is made with direct current rather than alternating current and is not a measure of dielectric strength as such. However, insulation-resistance tests assist greatly in determining when and where not to apply high voltage.

PHOTO 1.1 Insulation-resistance (hi-potential) testing in progress. Courtesy of Electro-Test, Inc.

In general, overall insulation resistance decreases with increased size of a machine or length of cable. This occurs because there is more insulating material in contact with the conductors and the frame, ground, or sheath. The greater volume of insulating material allows more total leakage and, therefore, lowers the overall insulation-resistance reading.

Insulation resistance usually increases with higher voltage rating of apparatus because of increased thickness of insulating material. Also different types of insulation, for example, air versus thermoplastic, will have different levels of insulation resistance.

Insulation-resistance readings are not only quantitative, but are relative or comparative as well, and since they are influenced by moisture, dirt, and deterioration of the insulation, they are reliable indicators of the presence of those conditions. Cable and conductor installations present a wide variation of conditions from the point of view of the resistance of the insulation. These conditions result from the many kinds of insulating materials used, the voltage rating or insulation thickness, and the length of the circuit involved in the measurement. Furthermore, such circuits usually extend over great distances and can be subject to wide variations in temperature, which will affect the insulation-resistance values obtained. The terminals of cables and conductors will also affect the test values unless they are clean and dry, or guarded.

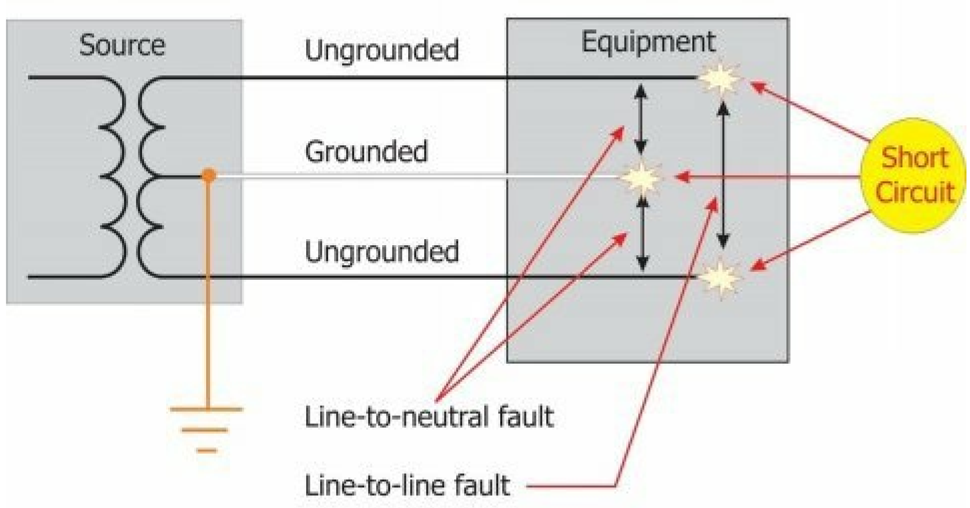
Records of insulation resistance should be maintained so failures of conductors or equipment can be predicted. To make valid comparisons or to indicate trends, the recorded values must be corrected to a standard temperature, typically 20°C, and differences in the relative humidity must be accounted for. Equipment or conductors can then be scheduled for repair or replacement to reduce plant downtime, which often happens at inconvenient times causing expensive loss of production.

Differentiate Between a Short Circuit and a Ground Fault

It is common practice to call all faults or failures in the electrical system insulation shorts or short circuits. That can lead to misunderstanding, and has done so, because the terms are not used properly. A short circuit and a ground fault are different, although they both stem from insulation failure. To end this confusion, the definitions of the two terms follow:

Short circuit. A conducting connection, whether intentional or accidental, between any of the conductors of an electrical system whether it is from line-to-line or from line to the grounded conductor (see figure 1.27). The grounded conductor often is also the system or circuit neutral. The short circuit can be a solid or bolted connection, or it can be an arcing fault completing the path through a short air space.

In the case of a short circuit, the failure can be from one phase conductor to another phase conductor or from one phase conductor to the grounded conductor or neutral. For either condition, the maximum value of fault current is dependent on the available capacity the system can deliver to the point of the fault and the impedance path of the two faulted conductors. Similarly, the maximum value of short-circuit current from line-to-neutral will vary depending upon the single-phase source impedance and the distance from the source to the fault and the impedance of the path. The available short-circuit current is further limited by the dynamic impedance of the arc, where one is established, plus the impedance of the conductors to the point of short circuit (see figure 1.27).



Short circuit. A conducting connection, whether intentional or accidental, between any of the conductors of an electrical system whether it is from line-to-line or from line to the grounded conductor.

FIGURE 1.27 Basic diagram of a short-circuit condition

Ground Fault. An unintentional, electrically conductive connection between an ungrounded conductor of an electrical circuit and the normally non–current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth [see *NEC* Article 100 and figure 1.28].

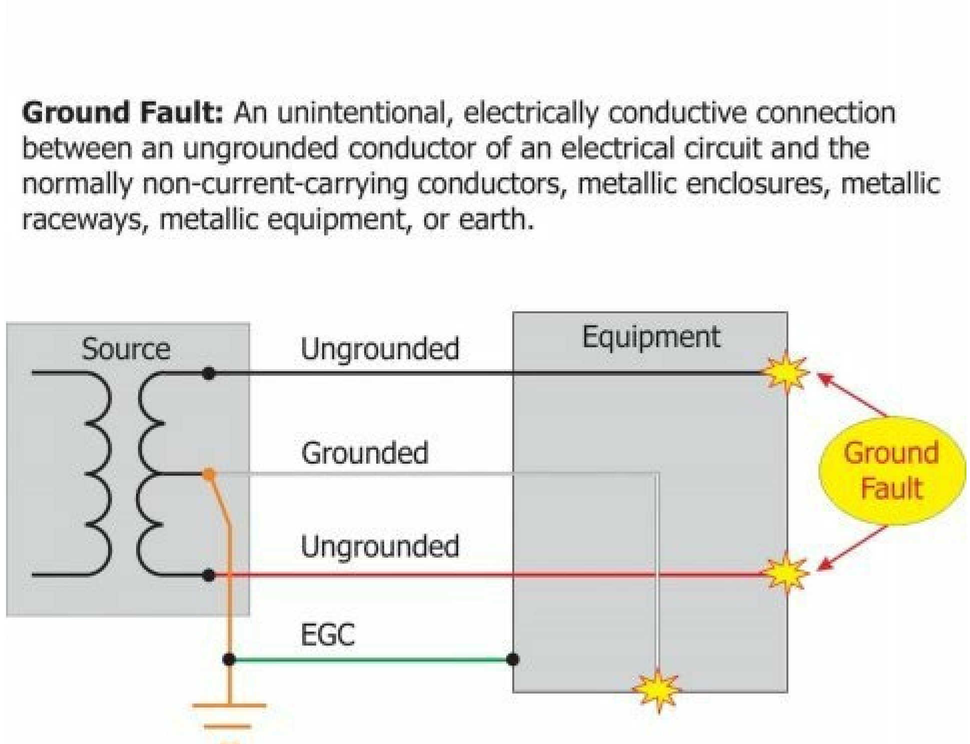


FIGURE 1.28 Basic diagram of a ground-fault condition

In the case of a ground fault, there is unintentional contact between an ungrounded phase (hot) conductor and the conductor enclosure or from the grounded phase conductor to the conductor enclosure (wire-to-conduit, wire-to-motor frame, and so forth). It is not common practice to refer to a conductor that is intentionally grounded, such as a grounded phase conductor or system grounded (neutral) conductor as being in a ground-fault condition. However, a grounded system conductor, such as a neutral conductor, that is not generally permitted to be grounded again past the service disconnecting means can be considered a ground fault. This condition is particularly important with equipment ground-fault protection systems and GFCI devices where grounding the system grounded conductor downstream from the point of protection will desensitize the protection system or potentially cause nuisance tripping.

It is often the case that a fault can easily involve both conditions: short circuit and ground fault. The fault can start as a ground fault or line-to-ground fault and escalate into a short circuit or phase-to-phase fault. A fault can also start as a short circuit and expand to a ground fault. For electrical systems of 120-volts-to-ground, the circuit protective devices will usually, but not always, clear the fault or it will be extinguished when the alternating voltage passes through a voltage zero in the cycle. For 277-volts-to-ground systems, destructive arcing faults can be more easily sustained by the higher system voltage. Equipment ground-fault protection systems have been designed to address this problem. In some cases, the use of this equipment is required by the *NEC* such as in 230.95 (services) 215.10 (feeders) and 210.13 (branch circuits) (see chapter fourteen for additional information on this subject).

NEC Requirements

Article 250 covers the subject of grounding and bonding. Grounding and bonding are practiced for the protection of electrical installations, which in turn protects the buildings or structures in which the electrical systems are installed. Persons and animals that can come into contact with the electrical system or that are in these buildings or structures are also protected if the grounding system is installed and maintained properly. The *NEC* does not imply here that grounding is the only method that can be used for the protection of electrical installations, people or animals. Insulation, isolation and guarding are suitable alternatives under certain conditions.

Grounding of specific equipment is covered in several other *Code* articles. For example, health care facilities as covered in Article 517 and swimming pools in Article 680. Refer to the indices of this text, the *National Electrical Code*, or Ferm's Fast Finder Index for specific sections of the *Code* that apply to the equipment in question.

Circuit Impedance and Other Characteristics

Electrical equipment intended to interrupt current at fault levels must be designed and installed so it has an interrupting rating at nominal circuit voltage sufficient for the current that is available at its line terminals [see 110.9 and figure 1.29]. Failure to comply with this important requirement can result in disastrous consequences. This includes the destruction of electrical equipment, such as circuit breakers or fuses that are themselves designed to protect the system.

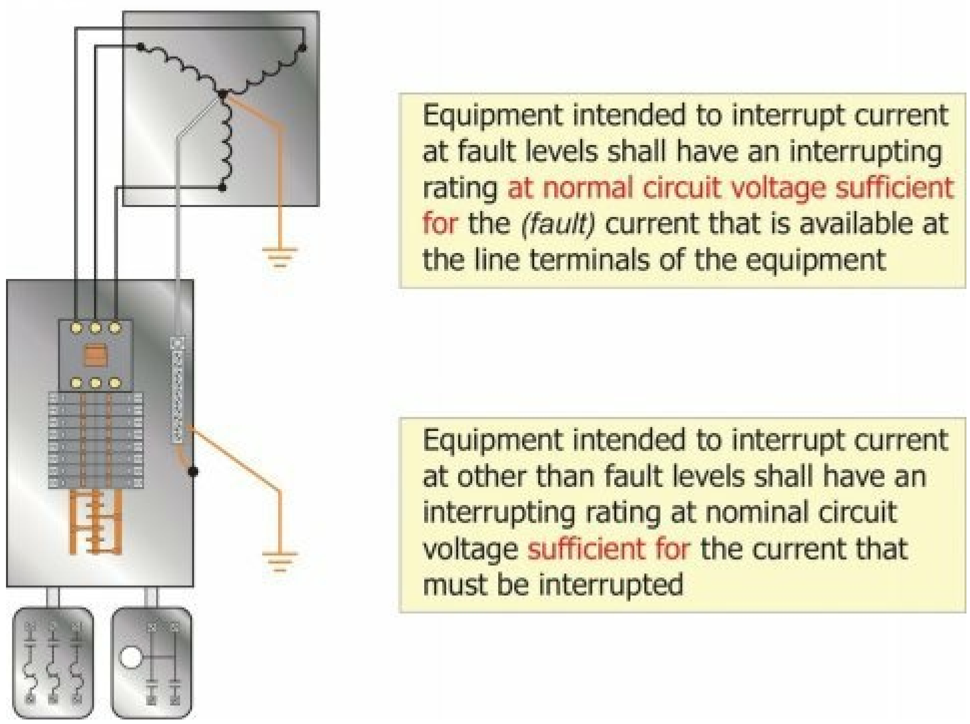


FIGURE 1.29 Interrupting ratings of equipment

Equipment such as time clocks, motor controllers, lighting contactors, and so forth that are intended to interrupt current at only rated load must be suitable for the nominal circuit voltage and current that must be interrupted. These devices must also be able to withstand the higher fault current levels until an upstream protective device, such as a fuse or circuit breaker, opens.

In addition, 110.10 requires that, "The overcurrent protective devices, the total impedance, the equipment short-circuit current ratings, and other characteristics of the circuit to be protected shall be selected and coordinated to permit the circuit protective devices used to clear a fault to do so without extensive damage to the electrical equipment of the circuit (see figure 1.30). This fault shall be assumed to be either between two or more of the circuit conductors, or between any circuit conductor and the equipment grounding conductor or enclosing metal raceway. Listed products applied in accordance with their listing shall be considered to meet the requirements of this section."

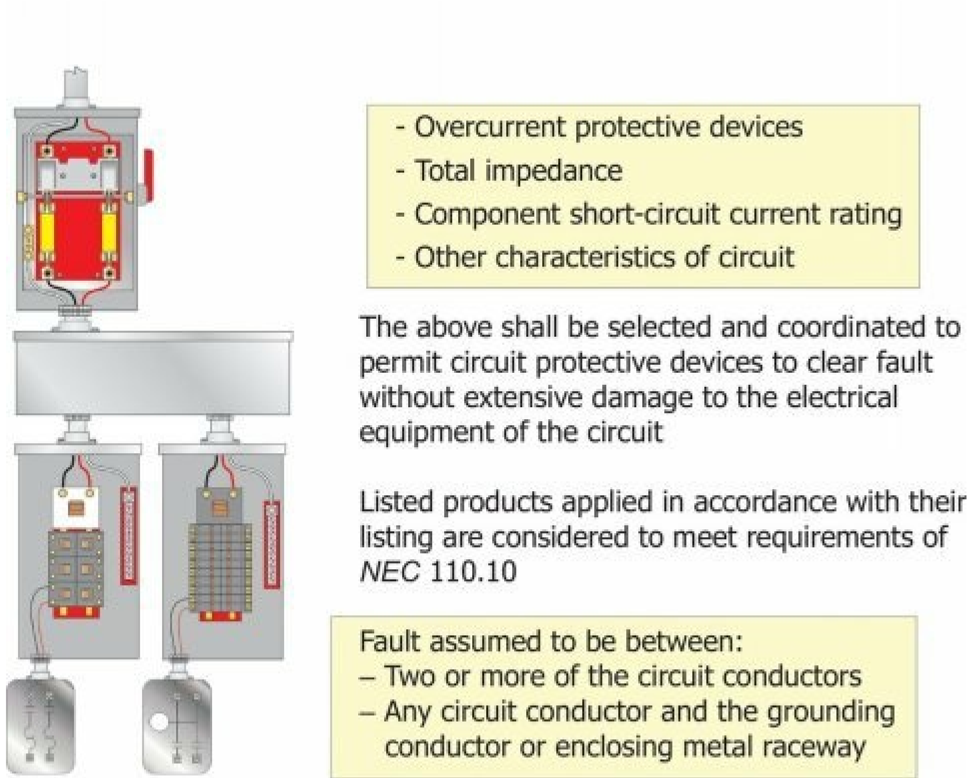


FIGURE 1.30 Electrical components and equipment are required to be protected.

Listed equipment such as fuses, including the associated switch, and circuit breakers has nominal voltage and short-circuit current ratings. This is the maximum voltage and current for which the equipment is designed. In addition, other equipment such as busways may be marked with the short-circuit current rating. For example, the requirement for busways states, "Busways and associated fittings marked 'Short Circuit Current Rating(s) Maximum RMS Symmetrical Amperes _____ Volts ______' have been investigated for the rating indicated."[1] Electrical system components such as metering equipment, switchboards, panelboards, and motor control centers have short-circuit ratings that must not be exceeded.

Overcurrent protective devices such as circuit breakers and fuses should be selected and installed to ensure that the short-circuit current rating of components of the system being protected will not be exceeded should a short circuit or ground fault occur. The overcurrent device that is selected must not only safely interrupt the fault current that is available at its line terminals, it also must limit the amount of energy that is let through to downstream equipment so as not to exceed that equipment's short-circuit current rating.

Electric utilities usually provide information on the short-circuit current (often referred to as the available fault current) that is available at the secondary terminals of the transformer or at the service equipment. The short-circuit current must then be calculated to the point on the electrical system under consideration. Methods for calculating the available fault current at any point on the electrical system can be found in literature from many circuit breaker or fuse manufacturers. See also the Institute of Electrical and Electronic Engineers (IEEE) "Buff Book" (IEEE 242) IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems,[2] Underwriters Laboratories product safety standards and "guide card information" for the equipment under consideration,[3] and Ferm's Formulas, Charts & Information[4] where, in addition to the point-to-point method, many pages of calculations are presented in an easy-to-use table form.

Other components of the electrical system, such as wire and cable, have published withstand ratings, in addition to allowable ampacity ratings, that must be considered for safety. Withstand ratings are not marked on the wire or cable but can be determined from the manufacturer's data, IEEE Standards, or calculated as described in chapter eleven.

As can be seen upon review of this literature, a conductor can safely carry much more current than allowed in the allowable ampacity table if the time the current exists is reduced. For insulated conductors, the ampacity of the conductor can be thought of as the conductor's longtime or continuous rating and the withstand-rating as the conductor's short-time rating. This is most important when considering the proper size of equipment grounding conductors to use, as they must carry the ground-fault current without damage until an overcurrent device opens (see chapter nine for additional information on this subject).

Bonding and Grounding Terminology

IAEI's *Soares Book on Grounding and Bonding* places a huge emphasis on definitions of words and terms used for proper application of *Code* rules relating to the subject of grounding and bonding. Using a common language of communication is imperative to understanding this subject, and applying the *Code* to installations and systems in the field as clearly indicated in chapter one of this book. It is important that words and terms related to this subject mean what they imply by definition for all code users.

NEC Grounding and Bonding Revisions

In recent editions of the *Code*, there have been numerous revisions to many of the grounding and bonding terms used in the *NEC*. These revisions were the result of significant efforts of a special task group assigned by the *NEC* Technical Correlating Committee. The primary objective of this task group was to ensure accuracy of defined terms related to *grounding* and *bonding*, differentiate between the two concepts, and verify the use of these terms is uniform and consistent throughout the *NEC*. The work of this task group resulted in simply changing the meaning of defined grounding and bonding terms to improve clarity and usability within the *NEC* requirements where they are used. *Code* rules that use defined grounding and bonding terms were revised as needed to clarify the meaning of the rule and to ensure that these terms are used consistently with how they are defined in Article 100 and at 250.2. In many instances, rules were revised to become more prescriptive for code users to provide clear direction on what is intended to be accomplished from a performance standpoint. As an example, many rules throughout the *Code* used the phrase "shall be grounded," which was replaced with the phrase "shall be connected to an equipment grounding conductor." This simple revision will relay to the code user that a certain object not only needs to be grounded, but more importantly, "how" the object is to be grounded.

[1]General Information for Electrical Equipment Directory, "Busways and Associated Fittings (CWFT)," (Underwriters Laboratories Inc., Northbrook, IL, 2007), p. 39.

[2]Available from IEEE Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, (800) 678-4333

[3]Available from Publications Stock, Underwriters Laboratories, 333 Pfingsten Road, Northbrook, IL 60062-2096, (847) 272-8800 Ext. 42612 or 42622.

[4]Available from International Association of Electrical Inspectors, P. O. Box 830848, Richardson, TX 75083-0848, (800) 786-4234, Fax (972) 235-6858.

Review Questions

1. A grounded electrically conductive object is forced to take the same potential as the ____.

   1. electrode
   2. metal raceway
   3. ground (the earth)
   4. system

2. Electrical systems that are grounded are required to be connected to the earth to limit the voltage to ground during normal operation and to prevent excessive voltages because of ____, line surges or unintentional contact with higher voltage lines.

   1. low voltage
   2. overloads
   3. loose connections
   4. lightning

3. The effective ground-fault current path must be installed in a manner that creates a path that is ____.

   1. electrically continuous
   2. has the capacity to conduct safely the maximum ground-fault current likely to be imposed on it
   3. has sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit
   4. all of the above

4. Insulation is considered to be air where conductors are mounted on insulators such as on poles, in busways or in equipment, or on rubber or ____ material or thermosetting material.

   1. listed
   2. approved
   3. thermoplastic
   4. acceptable

5. Measurements of insulation resistance can best be made with a ____ insulation tester.

   1. voltage
   2. megohm-meter
   3. low voltage

4. high voltage

6. Insulation resistance is the resistance to direct current (usually at ____ or ____ volts for systems of 600 volts or less) through or over the surface of the insulation in electrical equipment.

1. 500 or 1000
2. 600 or 1500
3. 800 or 1800
4. 900 or 2000

7. An insulation-resistance test is made with direct-current rather than alternating-current, and is not a measure of ____ strength as such.

1. conductor
2. dielectric
3. terminal
4. equipment

8. A conducting connection, whether intentional or accidental, between any of the conductors of an electrical system whether it be from line-to-line or from line to the grounded conductor describes a ____.

1. phase fault
2. short circuit
3. overload
4. ground fault

9. An unintentional electrically conductive connection between an ungrounded conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth best defines which of the following____.

1. phase fault
2. overload
3. system ground
4. ground fault

10. In a dc electrical circuit, the total opposition to current is due primarily to _____.

1. current
2. voltage
3. impedance
4. resistance

11. In an electrical circuit, current in the circuit will always attempt to return to which of the following____.

1. the earth
2. the service
3. the source
4. the load

12. For current to be present there must be a complete ____.

1. grounding conductor
2. conduit system
3. circuit
4. overcurrent protective device

13. Current in an electrical circuit will take _________ to return to the source.

1. only the path of least resistance
2. any and all paths available
3. a high impedance path only
4. the path in the earth

14. The total opposition to current in an AC circuit is the_______ of the circuit.

1. resistance
2. impedance
3. capacitance
4. inductance

15. The severity of an electrical shock is dependent on the ____________.

1. the frequency of the circuit
2. the path through the body
3. the amount of current through the body and how long it exists
4. all of the above

16. The higher the impedance or resistance of a circuit, the ______ the amount of current in the circuit.

1. lower
2. higher
3. same
4. different

17. The *NEC* in recent cycles has continued to migrate away from the use of the _______ conductor for grounding of equipment downstream of the main bonding jumper at the service or the system bonding jumper at a separately derived system.

1. equipment grounding
2. grounded (neutral)
3. bonding
4. grounding electrode

18. Alternatives for grounding include which of the following conditions ____.

1. guarded
2. insulated
3. isolated
4. all of the above

19. A 480-volt, 3-phase circuit is connected to an electric heater rated at 480 volts, 3-phase/7500 watts. The current in this circuit is _______ amperes.

1. 13.6
2. 9.02
3. 15.7
4. 27.9

20. The phrase "likely to become energized" generally means____.

1. near energized electrical equipment
2. high-voltage electrical equipment
3. equipment that is exposed to lightning
4. failure of insulation on

21. The equipment grounding conductor system normally only carry current in a ______ situation.

1. fault
2. normal
3. unbalanced
4. emergency

22. The equipment grounding conductor serves to ____.

1. provide an effective ground-fault current path

2. ground the equipment or its enclosure by connecting to the grounding point of the system
3. perform bonding functions
4. all of the above

23. “Connected to establish electrical continuity and conductivity” best defines which of the following _______.

1. grounded (grounded)
2. bonded (bonding)
3. adequately bonded
4. effectively grounded

⏚ Chapter 2
To Ground or Not to Ground

Objectives to understand

- Grounded systems vs. ungrounded systems
- Grounding rules for ac systems 1000 volts or less
- Grounding rules for ac systems over 1000 volts
- Systems required to be grounded
- Systems permitted to be grounded
- Systems not permitted to be grounded
- Systems that can be operated ungrounded
- Purpose of grounding and bonding
- Use of ground detection systems for ungrounded systems
- Factors to consider regarding system grounding

The term electrical system generally refers to the system as a unit of a specific voltage (potential) and often amperage (current or capacity).

For example, a common system is 480Y/277-volts, 3-phase, 4-wire at some capacity such as 1600 amperes. Often, the premises are supplied by an electric utility but could be from one or more separately derived systems. These systems are either over 1000 volts (often referred to as primary systems) or 1000 volts or less (often referred to as secondary systems). In addition, the system is referred to as single-phase or three-phase. Some two-phase, 5-wire systems still exist but are less common. Most systems are 60-hertz alternating current although some direct-current systems are in use. With a number of changes included in the 2014 and 2017 *NEC* and introductions of new technologies, more building systems are now being supplied at direct current with various voltages. These systems are being installed in industrial and commercial installations, and even residential, to directly supply products with dc power and to save the numerous dc power supplies that have had to been plugged or wired in to support these products.

In addition, systems are established or created at various voltages, phases, and sometimes different frequencies on-site. The most common way to create a new electrical system is through a transformer or generator. In the case of a transformer, other than an autotransformer, one electrical system ends at the primary winding(s) and another system begins at the secondary winding(s). The only “connection” between these two sides is through magnetic coupling.

An example is a plant that has a service at 480 Y/277-volts and it is necessary to supply receptacle outlets at 120 volts. A single-phase, 480-volt to 120/240-volt transformer is installed with the winding on the secondary center-tapped to result in a 120/240-volt, single-phase system. In this example, the branch of the 480-volt system ends at the primary windings and a new 120/240-volt system begins at the secondary winding. In other cases, a 208Y/120-volt system is derived by installing the appropriate transformer(s). Similar examples can be shown for generator-supplied systems.. A new source voltage and phase arrangement is developed by the transformer or generator. For the purposes of grounding, the treatment of the grounded system conductor (often a neutral) determines whether the system is considered to be separately derived for grounding purposes (see chapter twelve for more information on this subject).

Definitions

The following terms have been previously defined in Chapter 1 and if a review is needed, please refer back to that discussion.

- ***Ground Fault.***
- ***Ground-Fault Current Path.***
- ***Effective Ground-Fault Current Path.***

Effective ground-fault current paths are created by effectively bonding together all of the electrically conductive materials that are likely to be energized by the wiring system. Effective bonding is accomplished through the use of equipment grounding conductors, bonding jumpers or bonding conductors, approved metallic raceways, connectors and couplings, approved metallic sheathed cable and cable fittings, and other approved devices. A ground-fault path is effective when it will carry the maximum ground-fault current likely to be imposed on it.

The *NEC* has been revised in recent cycles for the definitions of these terms that are used in Article 250 as well as elsewhere in the *Code*. In the 2011 cycle, the definition of ground fault was relocated to Article 100, since this term is used in more than just Article 250. The 2014 revision cycle relocated the terms effective ground-fault current path and ground fault current path from 250.2 to Article 100 because they are used in more than just Article 250. These definitions help provide a clearer understanding of some important performance characteristics of ground faults and effective ground-fault current paths. These terms enhance the ability to properly apply the prescriptive grounding and bonding requirements in the later parts of Article 250 as well as the other articles in the *Code* where they now appear.

Grounded Systems

Section 250.4 is divided into two main parts. Part A includes the performance requirements for grounded systems, and Part B includes the performance requirements for ungrounded systems (see figure 2.1).

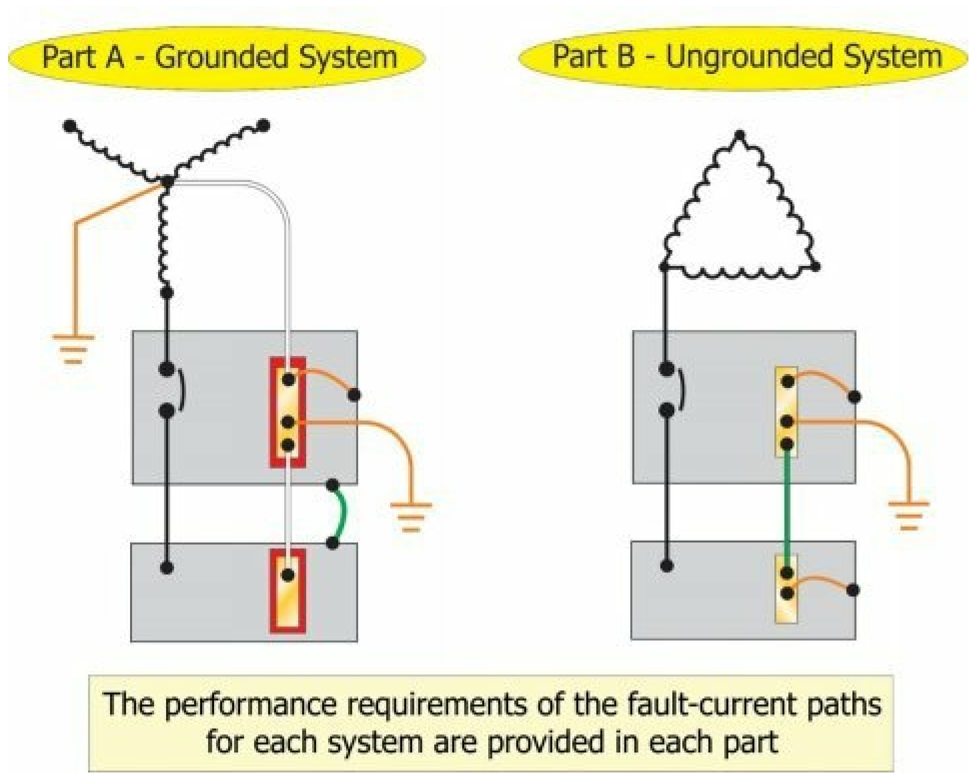


Figure 2.1 General requirements for grounding and bonding

"**250.4 General Requirements for Grounding and Bonding.** The following requirements identify what grounding and bonding of electrical systems are required to accomplish. The prescriptive methods contained in Article 250 shall be followed to comply with the performance requirements of this section.

"**(A) Grounded Systems.**

"**(1) Electrical System Grounding.** Electrical systems that are grounded shall be connected to earth in a manner that will limit the voltage imposed by lightning, line surges, or unintentional contact with higher-voltage lines and that will stabilize the voltage to earth during normal operation."

The Informational Note to 250.4(A)(1) indicates that important considerations for limiting imposed voltages are to minimize excessive lengths and to avoid unnecessary bends and loops in ground and bonding conductors. It should be noted here that informational notes are a recommendation and not a requirement as explained in 90.5(C).

"**(2) Grounding of Electrical Equipment.** Normally, non–current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected to earth so as to limit the voltage to ground on these materials.

"**(3) Bonding of Electrical Equipment.** Normally, non–current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected together and to electrical supply source in a manner that establishes an effective ground-fault current path.

"**(4) Bonding of Electrically Conductive Materials and Other Equipment.** Electrically conductive materials that are likely to become energized shall be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path.

"**(5) Effective Ground-Fault Current Path.** Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a low-impedance circuit facilitating the operation of the overcurrent device or ground detector for high impedance grounded systems. It shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point on the wiring system where a ground fault may occur to the electrical supply source. The earth shall not be considered as an effective ground-fault current path."

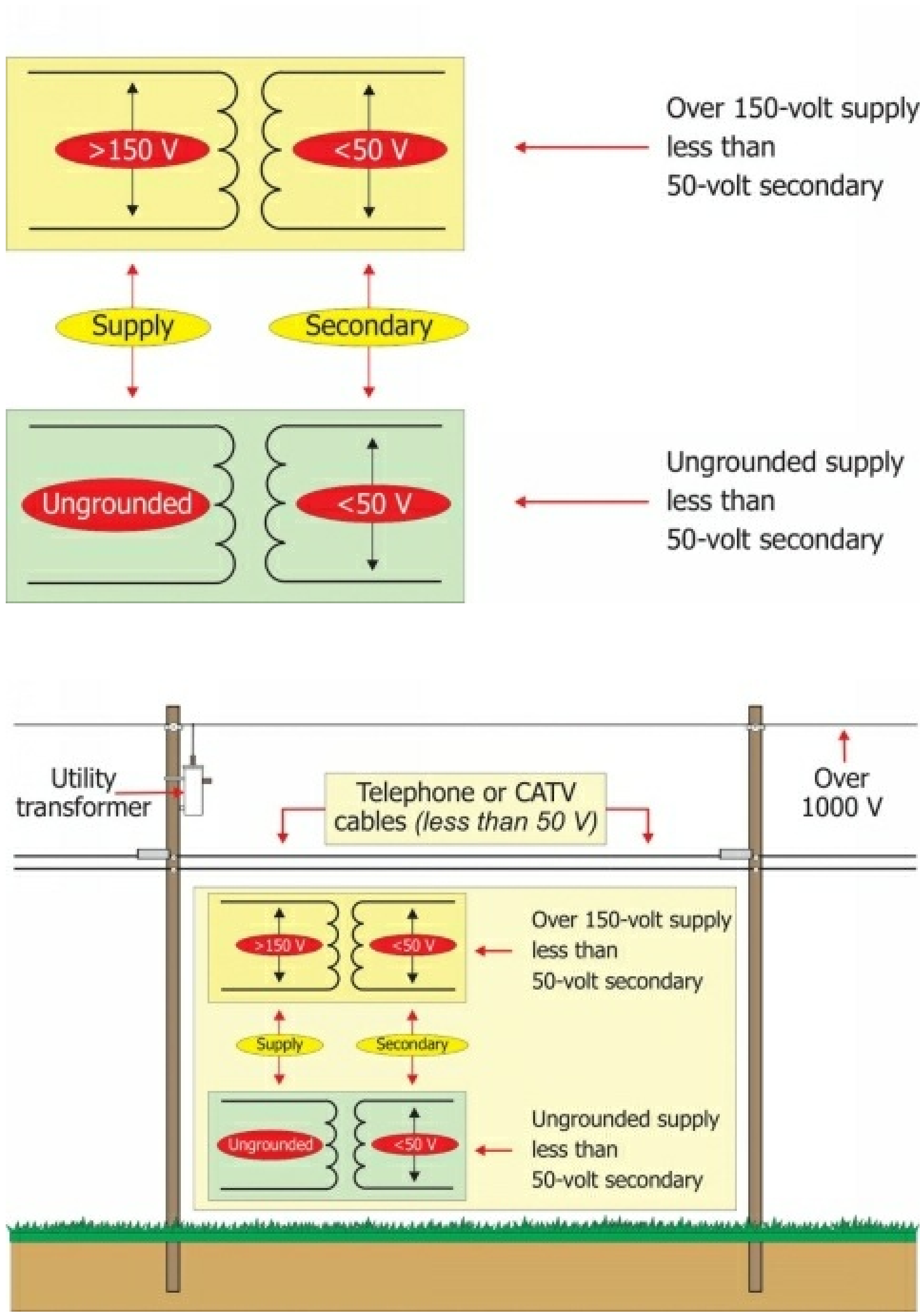
Grounding Electrical Systems

Over the years, there have been great debates over the merits of grounding electrical systems versus installing and operating them ungrounded.

Many of the decisions about whether or not to ground electrical systems are made for us. The *National Electrical Code* requires that certain electrical systems falling within the parameters of 250.20 be grounded. Other electrical systems are permitted to be grounded, while some systems are not permitted to be grounded due to special conditions. Some systems, primarily in the industrial or agricultural sector, are operated ungrounded. Common reasons for choosing to operate an electrical system ungrounded are continuity of service for critical operations and minimizing downtime. Another more recent option is to have an impedance grounded system. This is discussed in detail in chapter four. These decisions are usually mutually agreed upon between the building owners and operators, the designers and engineering team, and others. The last sentence of 250.20 indicates that whether the system is required to be grounded, or is grounded by choice, the applicable grounding rules for grounded systems must be followed.

Systems Required to Be Grounded

In accordance with 250.20, the alternating-current systems that must be grounded are: (A) alternating-current systems of less than 50 volts [see figure 2-2], (B) alternating-current systems of 50 volts to 1000 volts [see figure 2-3], (C) alternating-current systems of over 1000 volts [see figure 2-4], and (D) impedance grounded neutral systems. Each of these systems is discussed in the following sections.



Figures 2.2 and 2.2a Systems less than 50 volts that are required to be grounded

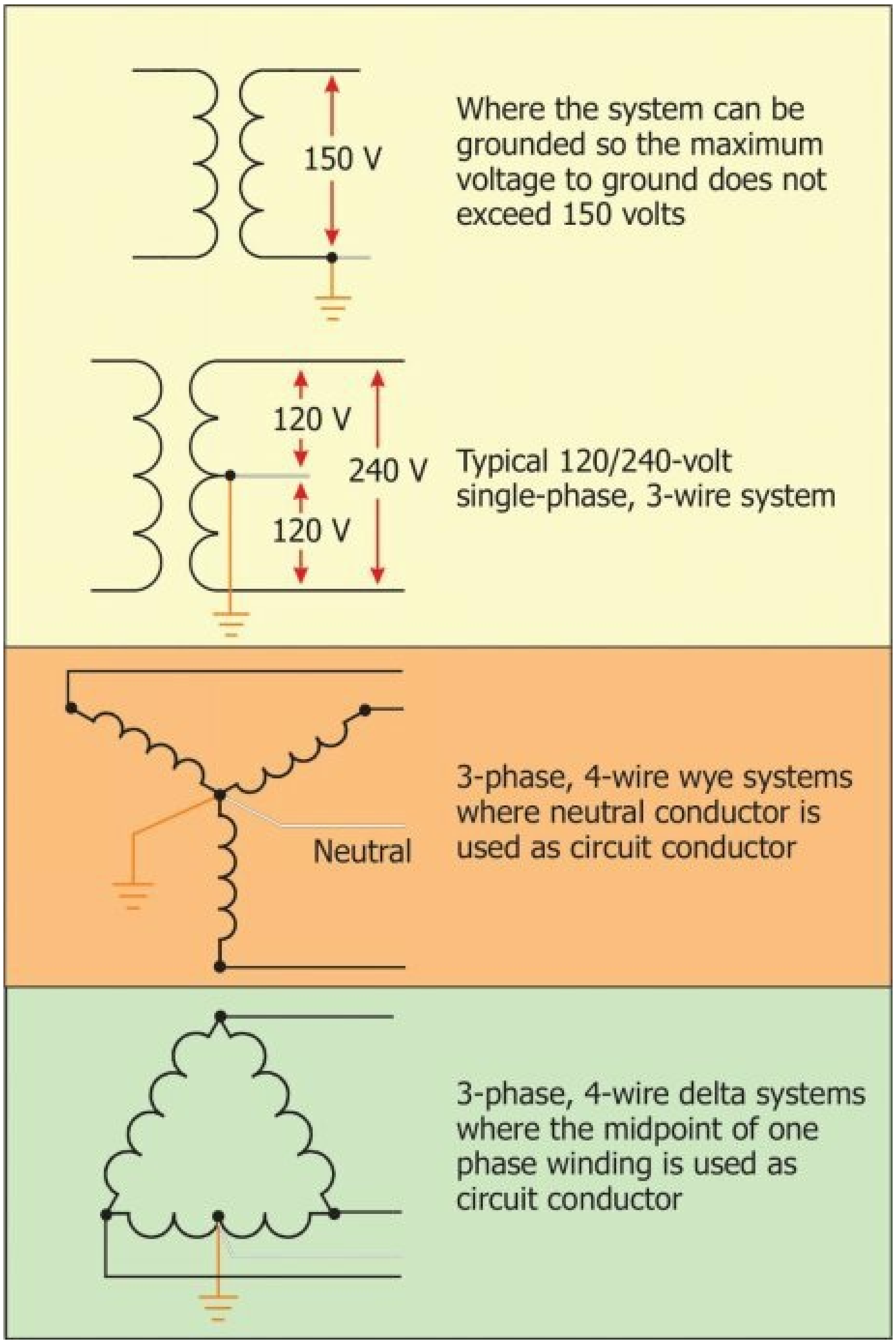


Figure 2.3 Systems rated 50 to 1000 volts that are required to be grounded

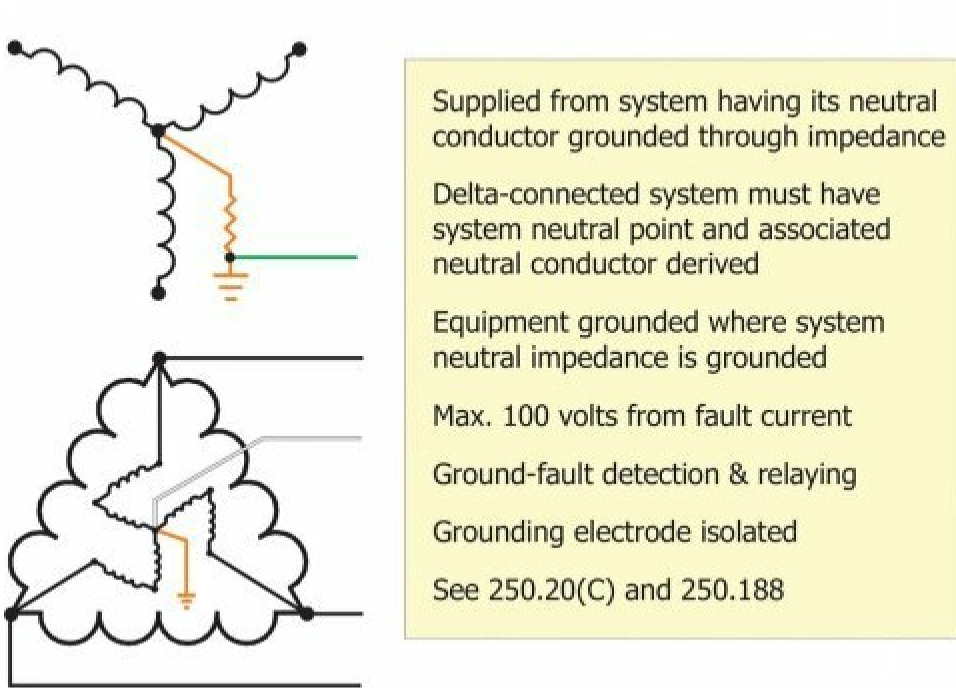


Figure 2.4 AC systems of over 1000 volts supplying portable or mobile equipment

Less than 50-volt systems

The following systems that are less than 50 volts, such as on the secondary of a transformer must be grounded, where:

- Supplied by transformers if the supply system voltage (primary) to the transformer exceeds 150 volts to ground
- Supplied by transformers if the transformer supply system (primary) is ungrounded
- Installed as overhead conductors outside of buildings.

AC systems of 50 to 1000 volts

Alternating-current systems of 50 to 1000 volts that supply premises wiring systems are required to be grounded under any of the following conditions, where the system:

1. can be grounded so the maximum voltage to ground from the ungrounded conductors does not exceed 150 volts. Typical systems include:

- 120-volt, 1-phase, 2-wire
- 120/240-volt, 1-phase, 3-wire, and
- 208Y/120-volt, 3-phase, 4-wire.

2. is 3-phase, 4-wire wye-connected and where the neutral conductor is used as a circuit conductor. Typical systems include:

- 208Y/120-volt, 3-phase, 4-wire, and

- 480Y/277-volt, 3-phase, 4-wire.

3. is 3-phase, 4-wire delta-connected in which the midpoint of one phase winding is used as a circuit conductor. Typical systems include:

- 120/240-volt, 3-phase, 4-wire, and
- 240/480-volt, 3-phase, 4-wire.

It should be noted that a system may be 480Y/277-volt, 3-phase, 4-wire where there are no line-to-neutral loads and, therefore, grounding of this system is not required but would be optional under 250.21. But a 208Y/120-volt system would require grounding even though there are not any line-to-neutral loads by 250.20(B)(1).

Alternating-Current Systems of Over 1000 Volts

AC systems supplying mobile or portable equipment shall be grounded as specified in 250.188. Where supplying other than mobile or portable equipment, such systems shall be permitted to be grounded.

Systems supplying portable or mobile equipment over 1000 volts, other than substations installed on a temporary basis, are required to comply with the rules in (A) through (F) below.

> “(A) Portable or Mobile Equipment. Portable or mobile high-voltage equipment shall be supplied from a system that has its neutral conductor grounded through an impedance. Where a delta-connected over 1000 volts is used to supply portable or mobile equipment, a system neutral point and associated neutral conductor shall be derived.” This is usually accomplished by means of a zigzag grounding transformer (see chapter three of this text for additional information on grounding systems by using zigzag grounding transformers).
>
> “(B) Exposed Non–Current-Carrying Metal Parts. Exposed non–current-carrying metal parts of portable or mobile equipment shall be connected by an equipment grounding conductor to the point at which the system neutral impedance is grounded.” This point may be at the service or source of a separately derived system.
>
> “(C) Ground-Fault Current. The voltage developed between the portable or mobile equipment frame and ground by the flow of maximum ground-fault current shall not exceed 100 volts.” This requirement, no doubt, necessitates an engineering study to determine the voltage drop across the equipment grounding conductor.
>
> “(D) Ground-Fault Detection and Relaying. Ground-fault detection and relaying must be provided to automatically de-energize any component of a system over 1000 volts that has developed a ground fault. The continuity of the equipment grounding conductor must be continuously monitored so as to automatically de-energize the circuit of the system over 1000 volts to the portable or mobile equipment upon loss of continuity of the equipment grounding conductor.
>
> “(E) Isolation. The grounding electrode to which the portable or mobile equipment system neutral impedance is connected shall be isolated from and separated in the ground by at least 6.0 m (20 ft.) from any other system or equipment grounding electrode, and there shall be no direct connection between the grounding electrodes, such as buried pipe, fence, and so forth.
>
> “(F) Trailing Cable and Couplers. High-voltage trailing cable and couplers of systems over 1000 volts for interconnection of portable or mobile equipment shall meet the requirements of Part III of Article 400 for cables and 490.55 for couplers.”

This type of equipment is commonly found in mobile rock crushing plants and batch plants. Other applications are for open pit mining operations. Note that self-propelled mobile surface mining machinery and its attendant electrical trailing cable are not covered by the *Code* [see 90.2(B)(2)]. Even though exempted from the *Code*, many requirements for this equipment are incorporated by regulations enforced by the Mine Safety and Health Administration (MSHA).

Other ac systems over 1000 volts are permitted but are not required to be grounded.

Separately Derived Systems

Section 250.30(A) requires electrical systems derived from a battery, a stand-alone solar photovoltaic system, or from a generator, transformer, or converter windings that have no direct connection, of circuit conductors in a derived system to the supply conductors originating in another system, except through grounding and bonding connections, to be grounded if the system that is derived meets the conditions in 250.20(A) or (B). Where an alternate source such as an on-site generator is provided and includes transfer equipment that introduces a switching action in the grounded conductor, the alternate source (derived system) is required to be grounded as specified in 250.30(A).

Examples of systems that are separately derived include:

- Inverters or batteries such as for uninterruptible power systems where there is not a bypass circuit interconnecting a grounded circuit conductor (neutral) between the supply system and UPS output system
- Solar photovoltaic systems, wind generation systems, or fuel cells in stand-alone systems
- Transformers with no direct connection, except for grounding and bonding connections, between the primary and secondary
- Generator systems that supply power such as for carnivals, rock crushers or batch plants where the neutral is not connected to the utility or other generator system
- Generator systems used for emergency, legally required standby or optional standby power that have all circuit conductors, including a neutral, isolated from the neutral or grounded conductor of another system usually by a transfer switch
- AC or DC systems derived from inverters or rectifiers (see figure 2.5).

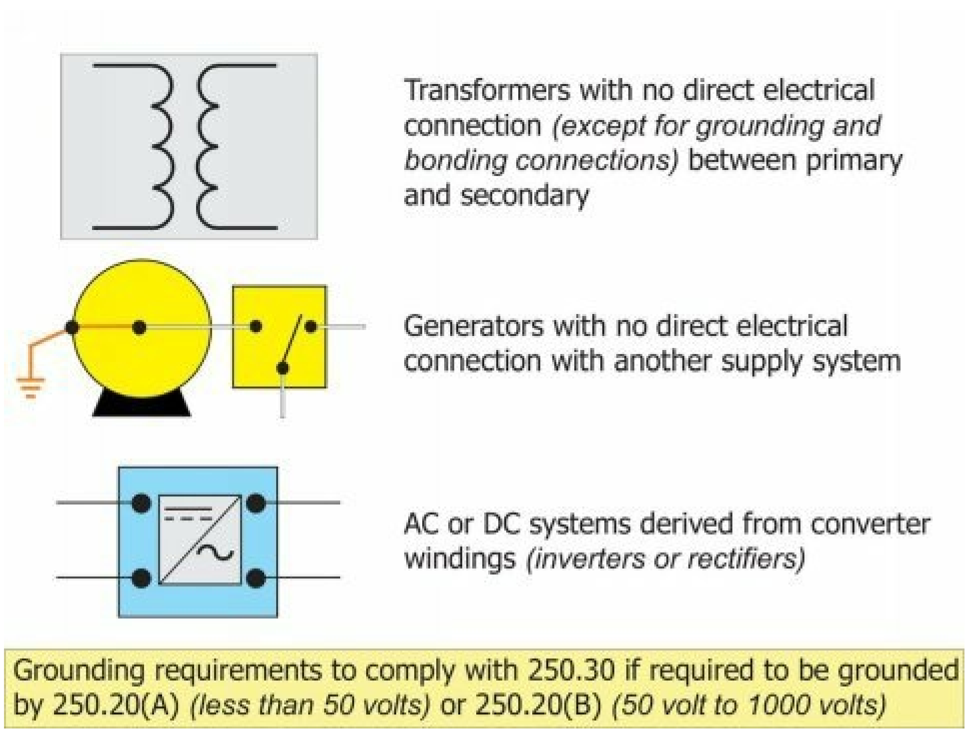


Figure 2.5 Separately derived systems to be grounded

Figure 2.6 illustrates systems that are not separately derived and thus do not fall under the grounding requirements of 250.30. These systems include:

- A system supplied by an autotransformer since autotransformers by design have a conductor that is common to both primary and secondary
- Systems from a generator that do not have all conductors, including the grounded system conductor (often a neutral), switched by a switching mechanism in a transfer switch
- Wind or solar photovoltaic systems where the AC inverter output is grid interactive — connected to the grid by a backfed breaker or connected by taps to the service supply bus.

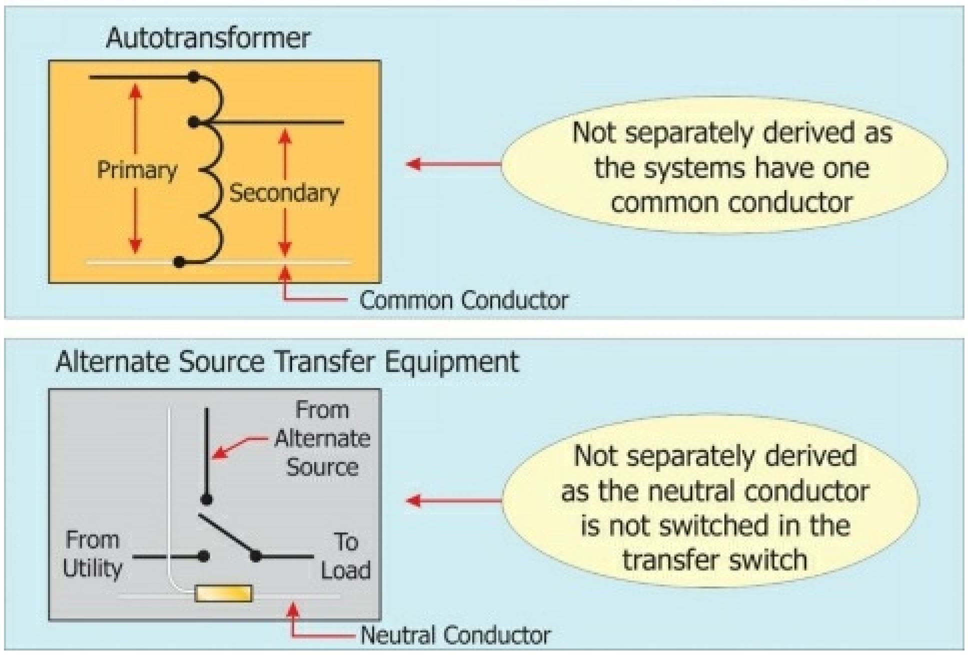


Figure 2.6. Not separately derived systems

The key to determining whether a generator supplied system is to be grounded as a separately derived system is often to examine electrical connections in the transfer switch (see figure 2.5).

If all the phases and the neutral or grounded conductor is switched by the transfer switch, the generator is a separately derived system that must be grounded in compliance with 250.30(A). If the neutral or grounded conductor is not switched, the system produced is not to be grounded as a separately derived system and the neutral must not be grounded at the generator (see chapter twelve of this text for thorough information on grounding and bonding requirements for separately derived systems.)

High-Impedance Grounded Systems

High-impedance grounded systems are often considered in electrical designs where the facility operation cannot tolerate electrical system disruption from the first ground fault. This system has all the advantages of an ungrounded system, so far as operation of the plant or system with one phase faulted to ground is concerned, with none of the disadvantages of an ungrounded system. While the initial cost of the system is more, it can pay for itself many times over the installation cost by operational savings in more reliable and uninterrupted electrical system operation (see chapter four of this text for additional information on high-impedance grounded neutral systems.)

Ungrounded Systems

The term *ungrounded* is defined as "not connected to ground or to a conductive body that extends the ground connection." Ungrounded systems are derived electrical systems that have no circuit conductor of the system purposefully grounded, either solidly or through any resistance or impedance. Theoretically, there is no potential between any of the system conductors and ground because there is not a connection of any conductor of the system to ground. Because in an AC system there is capacitance between the insulated conductors and other grounded objects, such as raceways and equipment enclosures, the system is capacitively coupled to ground. Section 250.4(B), Ungrounded Systems, includes four subsections (1) Grounding of Electrical Equipment, (2) Bonding of Electrical Equipment, (3) Bonding of Electrically Conductive Materials and Other Equipment, and (4) Path for Fault Current.

"(B) Ungrounded Systems

"(1) Grounding of Electrical Equipment. Non–current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected to earth in a manner that will limit the voltage imposed by lightning or unintentional contact with higher-voltage lines and limit the voltage to ground on these materials.

"(2) Bonding of Electrical Equipment. Non–current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected together and to the supply system grounded equipment in a manner that creates a low-impedance path for ground-fault current that is capable of carrying the maximum fault current likely to be imposed on it.

"(3) Bonding of Electrically Conductive Materials and Other Equipment. Electrically conductive materials that are likely to become energized shall be connected together and to the supply system grounded equipment in a manner that creates a low-impedance path for ground-fault current that is capable of carrying the maximum fault current likely to be imposed on it.

"(4) Path for Fault Current. Electrical equipment, wiring, and other electrically conductive material likely to become energized shall be installed in a manner that creates a low-impedance circuit from any point on the wiring system to the electrical supply source to facilitate the operation of overcurrent devices should a second ground fault from a different phase occur on the wiring system. The earth shall not be considered as an effective fault-current path."

Circuits That Are Not to Be Grounded

Five types of circuits are not permitted to be grounded, in accordance with 250.22 (see figures 2.6 and 2.7). They are as follows:

1. Circuits for electric cranes that operate over combustible fibers in Class III locations [see 250.22(1) and 503.155]. This action reduces the likelihood that sparks from faulted equipment will fall onto combustible fibers below the crane, causing a fire.
2. For health care facilities, those isolated power circuits in hazardous (classified) inhalation anesthetizing locations are required to be supplied by an isolation transformer or other ungrounded source [see 517.61(A)(1)]. In addition, receptacles and fixed equipment in wet locations of hospital patient care spaces as defined in 517.2 must be protected by ground-fault circuit-interrupter devices where interruption of power to equipment under fault conditions can be tolerated. Where interruption of power under fault conditions cannot be tolerated, protection of these receptacles and fixed equipment is to be supplied from isolated, ungrounded sources by ungrounded electrical systems [see 250.22(2) and 517.20(A)].
3. Circuits for electrolytic cells as provided in Article 668. Equipment located or used within the electrolytic cell line working zone or associated with the cell line dc power circuits are not required to comply with Article 250 [see 250.22(3) and 668.3(C)(3)].
4. Lighting systems as provided in 411.6(A). Article 411 covers lighting systems operating at 30 volts or less. The secondary circuits are required to be insulated from the branch circuit by an isolating transformer. Secondary circuits from these transformers are not permitted to be grounded [see 250.22(4) and 411.6(A)].
5. Lighting systems for swimming pools and similar installations supplied by a listed isolating winding transformer having a grounded metal barrier between the primary and secondary windings are not permitted to be grounded [see 250.22(5) and 680.23(A)(2)].

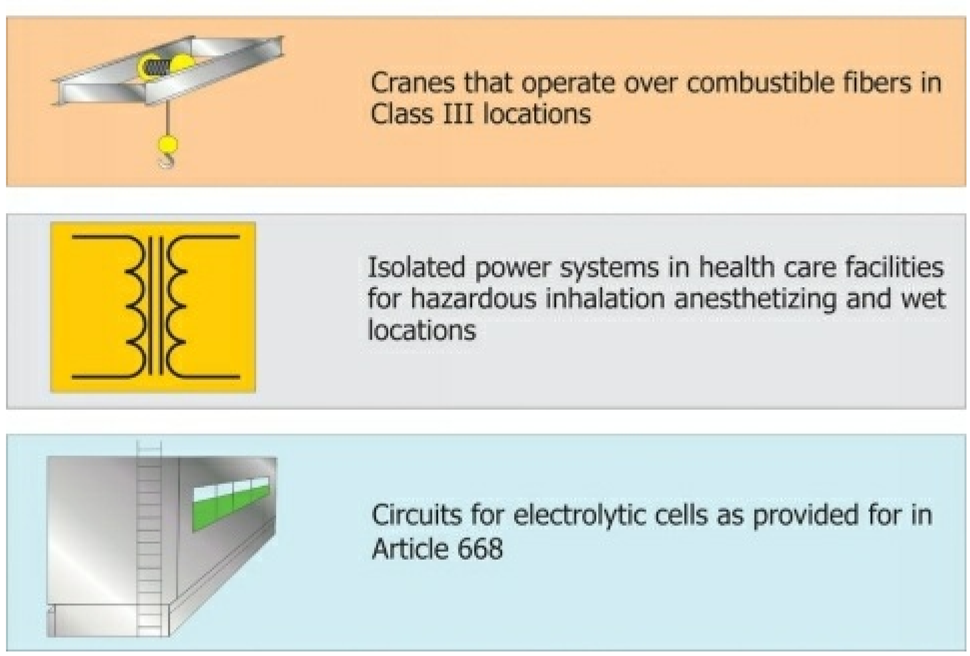


Figure 2.7 Circuits not permitted to be grounded

Systems Permitted but Not Required to be Grounded

Electrical systems that fall outside the requirements for grounding in 250.20(A), (B), (C) or (D) and are not on the list of systems prohibited from being grounded in 250.22, may or may not be grounded It should be noted that whether the system is required to be grounded or is grounded by choice, all grounding and bonding requirements for grounded systems must be followed (see 250.21). At times, the plant owner or engineer or combination will collectively choose to operate electrical systems ungrounded. These systems usually are found in industrial or agricultural applications and often are either 240-volt or 480-volt, three-phase, three-wire systems. Some higher voltage systems are also used in heavy-industrial applications. Where ungrounded systems are installed, the engineering decision is often based on an effort to obtain an additional degree of service continuity while providing equal and effective means for safety of equipment by the use of ground-fault indicator equipment.

These alternating-current systems are:

"Electric systems used exclusively to supply industrial electric furnaces for melting, refining, tempering, and the like (see photo 2-1)

"Separately derived systems used exclusively for rectifiers that supply only adjustable-speed industrial drives

"Separately derived systems supplied by transformers that have a primary voltage rating of 1000 volts or less, provided that all the following conditions are met:

a. "The system is used exclusively for control circuits.

b. "…only qualified persons service the installation.

c. "Continuity of control power is required.

4. "Other systems that are not required to be grounded in accordance with the requirements of 250.20(B)."

Ground detection is required for ungrounded ac systems addressed in 250.21(A)(1) through (4) where the system operates at not less than 120 volts and at 1000 volts or less [250.21(B)].

For three-phase ac systems of 480 to 1000 volts or less that are high-impedance grounded-neutral systems, see 250.36. An impedance device, usually a resistor, limits the current of the first ground fault to a low value. All of the following conditions must be met before high-impedance grounded (neutral) systems are permitted:

1. Only qualified persons service the system.
2. Ground detectors are installed.
3. Line-to-neutral loads are not supplied.

Typical systems (see figure 2.8) that are operated ungrounded include:

- 240 volt, 3-phase, 3-wire, delta-connected
- 480 volt, 3-phase, 3-wire, delta-connected
- 2300 volt, 3-phase, 3-wire, delta-connected
- 4600 volt, 3-phase, 3-wire, delta-connected
- 13,800 volt, 3-phase, 3-wire, delta-connected

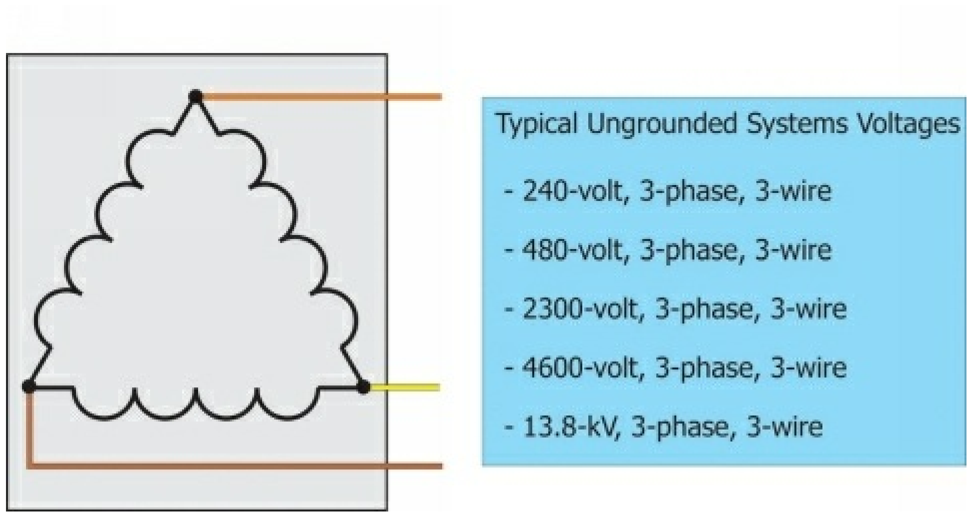


Figure 2.8 Systems permitted to be ungrounded

Ungrounded systems are required to be legibly marked, with a label or some other identifying means, "Caution Ungrounded System Operating– _____Volts Between Conductors." This marking shall be located at the source or first disconnection means of the system. This marking must be of "sufficient durability" to withstand the surrounding environment, such as an outdoor wet location [see 250.21(C) and figure 2.9].

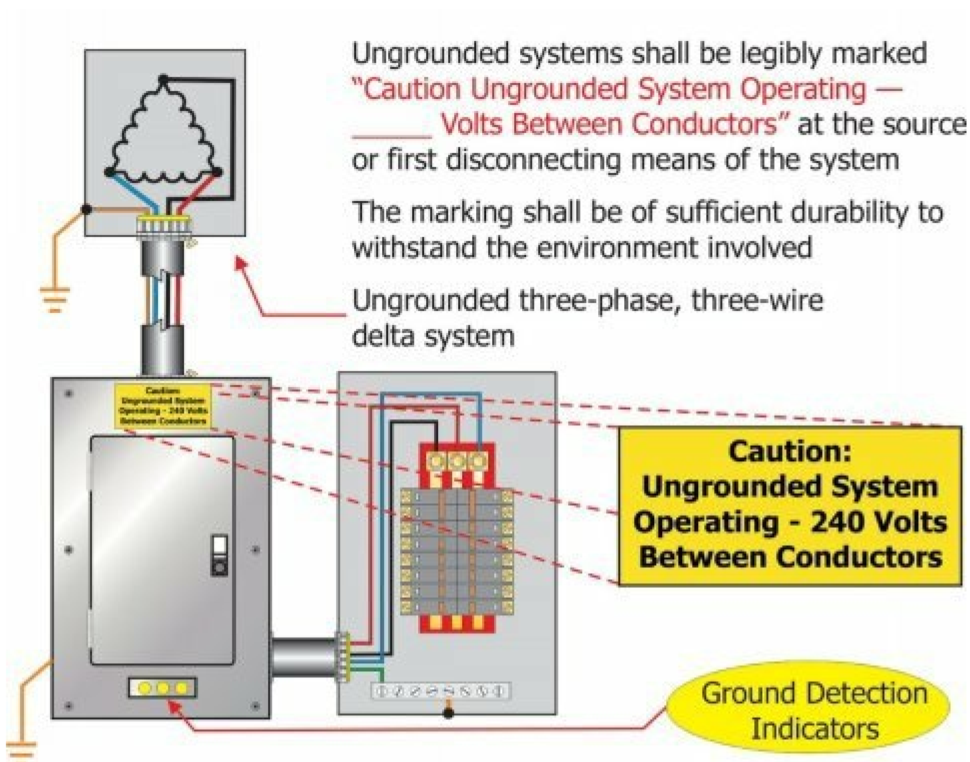


Figure 2.9 Ungrounded systems are required to be marked "Caution Ungrounded Systems Operating – ____ Volts Between Conductors."

Since the system is ungrounded, the occurrence of the first ground fault (not a short circuit or line-to-line fault) on the system will not cause an overcurrent protective device for the service, feeder, or branch circuit to open or operate. This fault does, however, ground the system but usually accidentally and through ineffective means (higher impedance) and in unspecified and uncontrolled locations (see figure 2.10). In essence, this system accidentally becomes a corner-grounded delta system. There will be little, if any, current when this first ground fault occurs (see chapter three of this text for additional information on equipment and enclosure grounding requirements for these ungrounded systems).

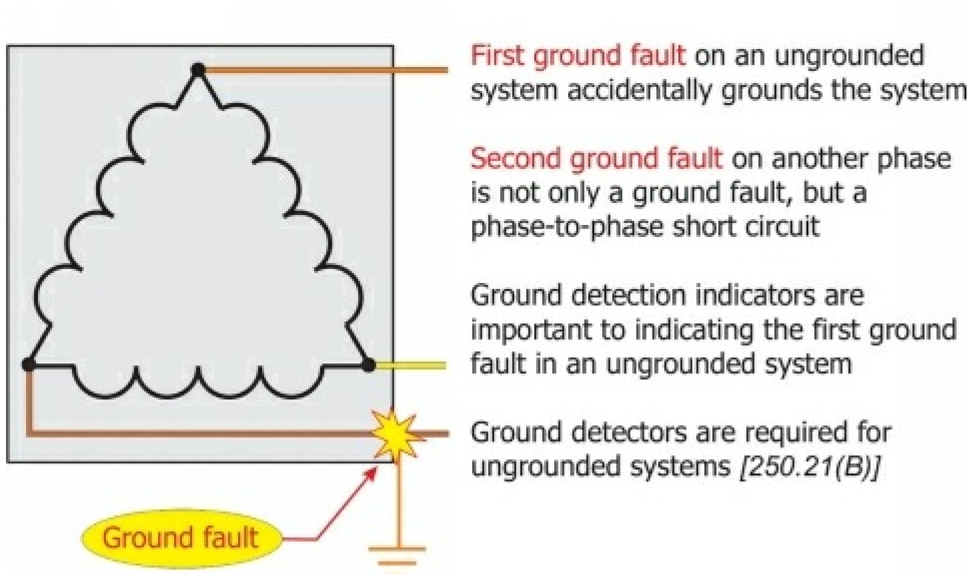


Figure 2.10 First ground fault on ungrounded systems

When an ungrounded system with one ground fault experiences a second ground fault on a different phase, the result is a phase-to-phase fault on the system through the equipment grounding conductor path(s). This will usually cause one or more over-current protective devices to open or operate, provided there is adequate current in this path. A major concern for this type of system happens where the first and second faults are located some distance apart (see figure 2.11). Often, these faults are from line-to-conduit or metallic enclosures, such as wireways, pull boxes, busways or motor terminal housings in different parts of the plant. Where this occurs, a relatively high-impedance path for current is often established. In some cases, it has been found that a great deal of heat along with arcing and sparking is produced along this fault path due to loose connections or inadequate bonding. Every conduit coupling and locknut connection to enclosures in the fault-current path must be tight to provide an adequate and low-impedance path and to reduce this arcing and sparking.

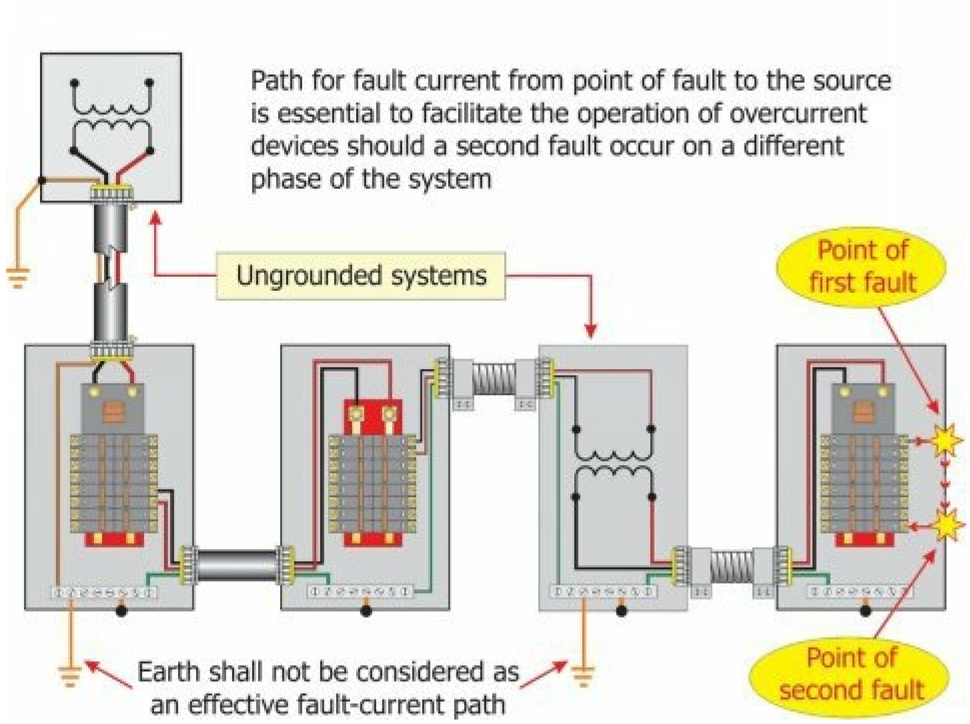


Figure 2.11 Second ground fault on an ungrounded system

It is important for safety reasons and for system continuity that maintenance personnel locate and eliminate ground faults when first identified on ungrounded systems. This should be done as soon as practical and especially before the second ground fault on a different phase occurs on the system.

Ground-Detection Indicator Systems

Commercially manufactured ground-detection equipment is available. This equipment, which can be located at the service equipment or in feeder distribution panels, can be set to operate an overcurrent relay or shunt-trip circuit breaker or to operate a visual or audible signaling system to indicate a ground-fault condition.

This monitoring equipment is now required by the electrical code in 250.21(B). Successful operation of an ungrounded electrical system depends on good system maintenance and prompt elimination of the first ground fault. Sophisticated equipment is now available to identify the part of the electrical system where the fault is located while the system is energized. This significantly speeds detection and repair.

Ground Detectors

In the past, ground detector lights or neutralizer or "potentializer" plugs were installed to indicate that a ground fault had occurred on the ungrounded system. The 7 ½ -watt indicator lights are connected to the lines through 18,000-ohm resistors. A tap is made to each resistor to give 120 volts to the lamp. The lamp burns until its phase goes to ground, at which time there is no or little potential across the lamp and it stops glowing, thus identifying the faulted phase (see figure 2.12).

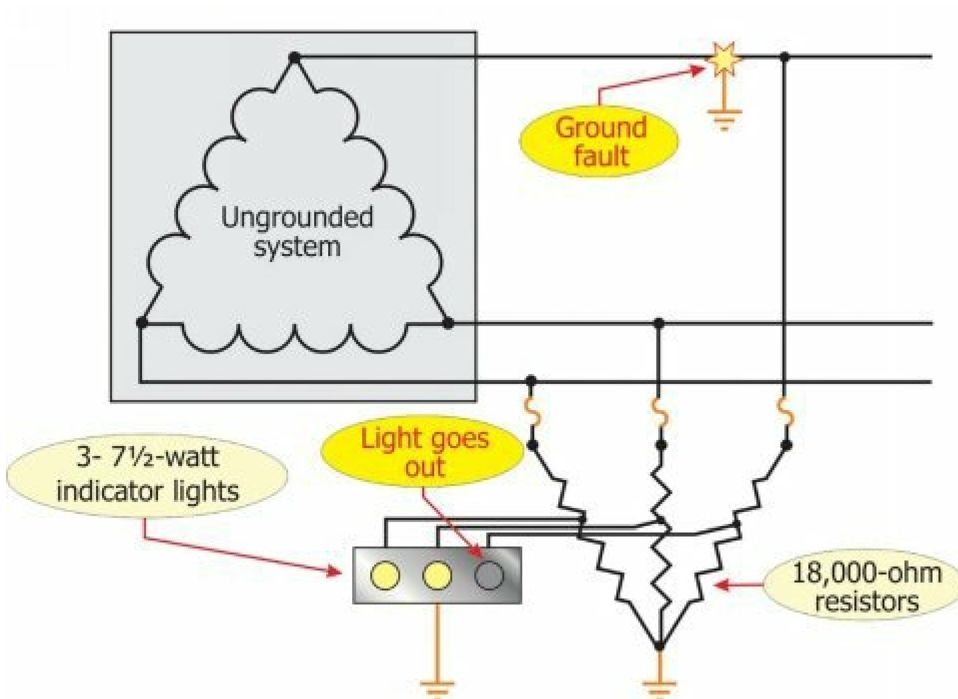


Figure 2.12 Ground detectors for ungrounded systems

More modern types of ground detection indication equipment are available and offer the added benefits of no system ground connection, not even through a resistor as was the case in the older ground detection light systems. These systems are typically equipped with transformers (windings) between the indication circuit and the ungrounded conductors of the system (see figure 2.13).

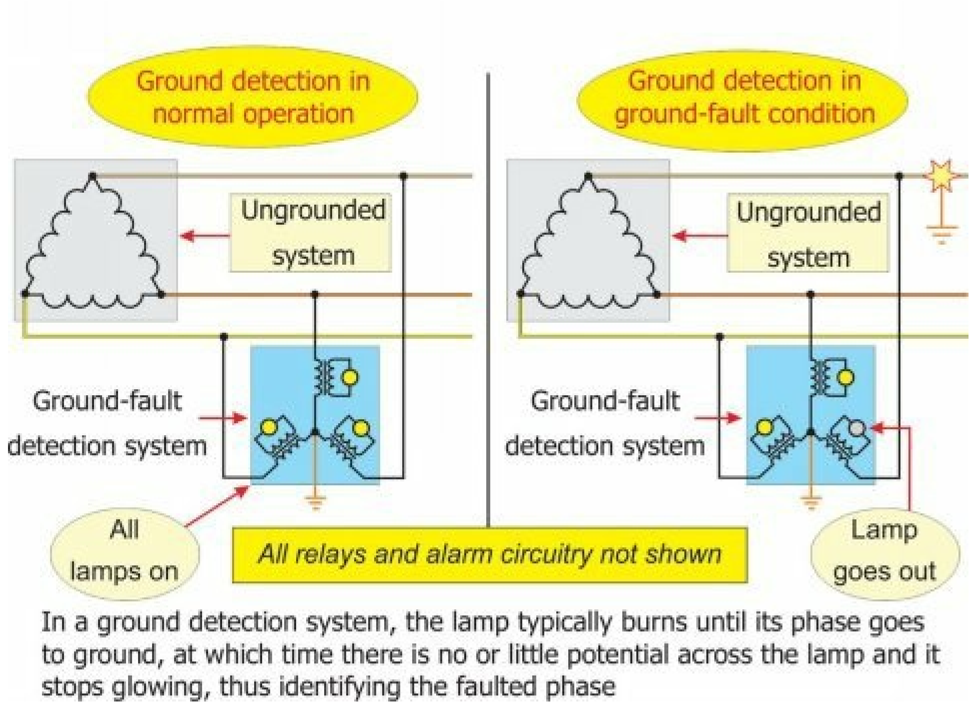


Figure 2.13 Ground detection is required on ungrounded systems (not all circuitry shown)

Ground-fault indication is intended to alert the maintenance personnel to the problem so the ground fault can be corrected during hours when the plant is not operating or that part of the plant can be shut down. The plant can continue to operate with one-phase grounded, thus preventing costly production downtimes. In some cases, downtime in production plants can cost thousands of dollars per minute. While the plant can continue to operate with one ground-fault, this condition cannot be ignored for long due to the risk of a second ground fault on another phase occurring with possibly catastrophic damage.

A wide variety of "homemade" systems have been installed over the years, some of which are downright dangerous. Some of these have consisted of nothing more than two lampholders with 240-volt lamps that are connected in series from phase-to-ground on 480-volt systems. Only proven and tested designs for ground detection systems should be used. Listed equipment is available for use on ungrounded system.

Ungrounded System Problems

An ungrounded system exists only in theory, in a laboratory or at the electrical distribution transformers hanging on the pole before connection to the plant electrical system. In the real world, ungrounded systems having insulated conductors installed in metallic enclosures are grounded to varying degrees through the distributed leakage capacitance of the system (see figure 2.14). Physically, a capacitor exists whenever an insulating material separates two conductors that have a difference of potential between them.

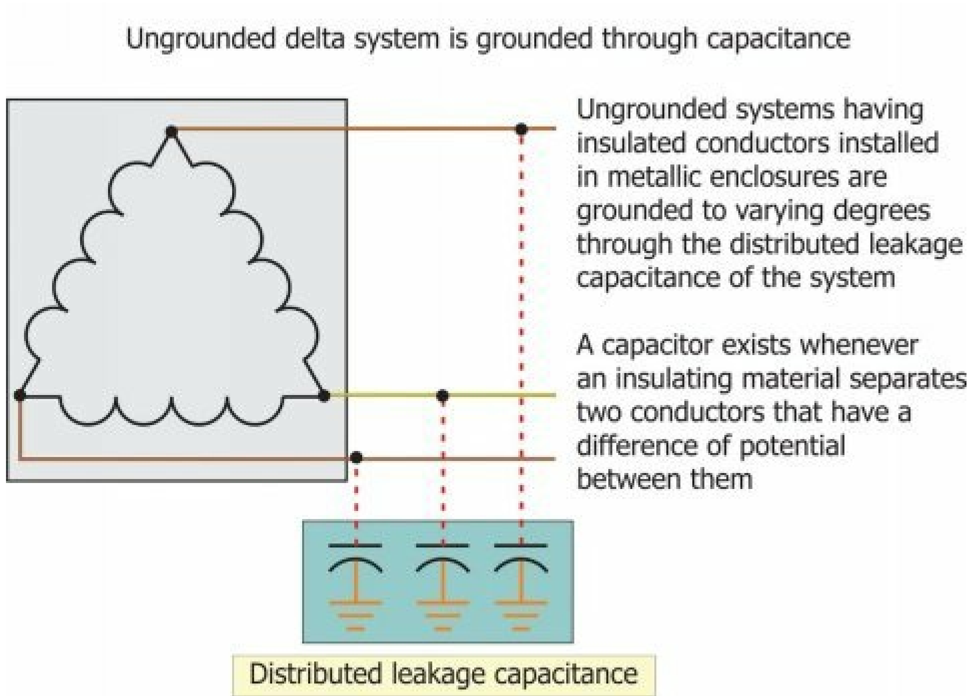


Figure 2.14 Actual ungrounded delta system indicating the presence of distributed leakage capacitance

When any conductor is installed in close proximity to grounded metal, there is a capacitance between them that is increased as the distance between the conductors is reduced. In 600-volt systems, the two greatest sources of capacitance to ground are conductors in metal conduit and windings on a steel core, such as for motors and transformers. In both cases, conductors are separated from grounded metal by fairly thin insulation. The capacitance to ground is known as the leakage capacitance, and the current from the conductors to ground is known as the leakage current or charging current. This capacitance is distributed throughout the electrical system but electrically acts like it is a single, lumped capacitance.

Disadvantages of operating systems ungrounded include but are not limited to the following:

- Power system overvoltages are not controlled. In some cases, these overvoltages are passed through transformers into the premises wiring system. Some common sources of overvoltages include: lightning, switching surges and contact with a high-voltage system.
- System voltages above ground are not necessarily balanced or controlled.
- Destructive arcing burndowns can result if a second fault occurs before the first fault is cleared.

- Transient overvoltages are not controlled, which, over time, can result in insulation degradation and failure.

Ungrounded systems have the characteristic that they are subject to relatively severe transient overvoltages. Such overvoltages can be caused by external disturbances as well as internal faults in the wiring system and easily can reach a value of five to six times normal voltage. An actual case involved a 480-volt ungrounded system. Line-to-ground potentials in excess of 1200 volts were measured on a test meter. The source of the trouble was traced to an intermittent or sputtering (arcing) line-to-ground fault in a motor starting autotransformer. These faults are not uncommon on 480-volt ungrounded systems. During the two-hour period this arcing fault existed, between 40 and 50 motor windings had failed due to the added stress on the motor winding insulation from this elevated voltage.

Circuit-switching operations can also be responsible for the creation of transient overvoltages in ungrounded systems. These generally are of short duration and typically reach only two to three times nominal system voltage.

Experience has shown that these overvoltages that easily reach several times the system voltage increases voltage stress, and can cause failure of insulation at locations on the system other than at the point of the fault, and can result in future system failures. This often occurs at a system weak point such as in a motor or transformer winding.

Locating the ground fault on an ungrounded system can be troublesome. While it is easy to spot a ground fault on a one-line diagram, locating it in a plant with a complex electrical system can be much more difficult, unless sophisticated ground-fault detection equipment has been installed. The first step is to open the feeders one at a time and observe the ground detection indicator. After finding the feeder with the ground fault, branch circuits are disconnected, one at a time, until the offending circuit is located. A significant loss of plant operation time can occur during this process. This is contrasted with a grounded system where only the offending equipment is taken off the line by the circuit protective devices.

Often, overcurrent devices are set above the current level of the fault in ungrounded systems. When arcing faults occur, destructive burndowns of electrical equipment can result. The arcing fault releases a tremendous amount of energy such that conductors and metal enclosures in the vicinity are destroyed.

When the first ground fault occurs on the 480-volt ungrounded system, the other conductors of the system rise to a level of 480 volts-to-ground. This presents an additional risk of shock to operation and maintenance staff. This can be contrasted to a 480Y/277-volt grounded wye system where the voltage to ground does not exceed 277 volts while the phase-to-phase voltage is 480 volts, even under ground-fault conditions.

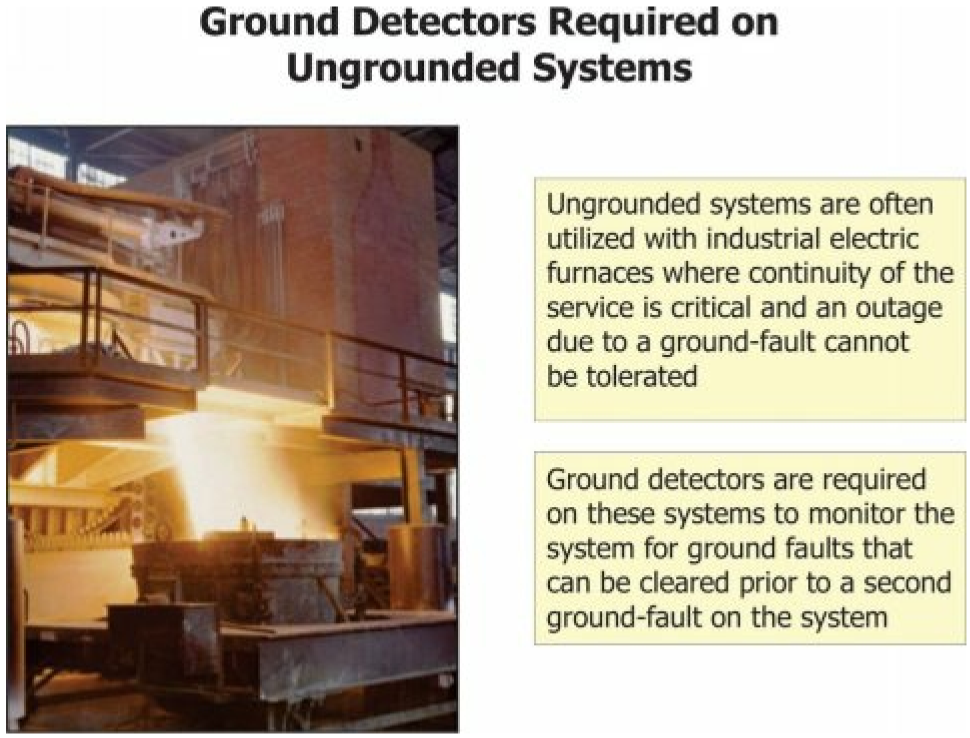


Photo 2.1 Industrial electric furnace

Factors to Consider Regarding System Grounding

Where grounding of the electrical system is optional, the advantages and disadvantages of grounding must be carefully weighed by the plant owner or electrical designer to make the best decision.

In the long run, greater service continuity may be obtained with grounded systems rather than ungrounded ones. Faults can be isolated to the feeder or circuit affected and cleared without disrupting the entire system. This is obviously a major consideration if the equipment or circuit affected is critical to the plant operation. This has to be balanced against the ungrounded system's tolerance of the first line-to-ground fault but with possible deterioration of conductor insulation from transient overvoltages and possible serious damage caused by a second ground fault on the system.

Bolted Faults

A common myth is that ground-faults are always bolted or solidly connected and that there will be a great deal of fault-current, which will cause the overcurrent device to open or operate and clear the fault. Bolted faults rarely occur, while sparking, intermittent or arcing faults are really the more common fault condition. The higher impedance in the arc limits the total current, so standard overcurrent devices can be ineffective.

Arcing faults produce a great deal of heat in the vicinity of the fault and can lead to destructive burndowns of electrical switchboards and motor control centers.

Photo 2.2 Ground faults rarely occur at bolted connections

This is the reason the *Code* requires equipment ground-fault protection systems for 3-phase, 4-wire, wye-connected systems of certain voltage and amperage services and feeders (see chapter fourteen of this text for additional information on this subject).

Bolted faults are usually utilized in testing laboratories under controlled conditions. A bolted fault, typically a 3-phase bolted fault, is used for the purposes of determining interrupting ratings of overcurrent protective devices as well as bracing of busbars, and so forth. This is generally considered to be the worst-case condition that causes the greatest amount of fault current. For example, UL Standard 891 requires short-circuit current testing of equipment to determine the overall short-circuit current rating for a switchboard. For additional information, see UL 891 *Standard for Switchboards* and UL 67 *Standard for Panelboards*.

Review Questions

1. Where operating at less than 50 volts, alternating-current systems are required to be grounded where supplied by transformers if the transformer supply system exceeds ____ volts to ground.

   1. 100
   2. 110
   3. 140
   4. 150

2. Where operating at less than 50 volts, ac systems are required to be grounded where supplied by transformers if the transformer supply system is ____.

   1. bonded
   2. ungrounded
   3. identified
   4. approved

3. Conductors installed on the outside of buildings where ac systems operate at less than 50 volts are required to be grounded when they are installed outside as ____ conductors.

   1. overhead
   2. underground
   3. optical fiber
   4. Type IGS

4. Alternating-current system grounding is required for 50 to 1000 volts systems supplying premises wiring or premises wiring systems where the system can be grounded so the maximum voltage to ground on the ungrounded conductors does not exceed ____ volts.

   1. 180
   2. 150
   3. 240
   4. 208

5. Alternating-current system grounding is required for 50 to 1000 volts systems supplying premises wiring or premises wiring systems where the system is 3-phase, 4-wire, wye-connected in which the neutral is used as a ____ conductor.

   1. bonding
   2. circuit
   3. equipment grounding

4. isolated

6. Alternating-current system grounding is required for 50 to 1000 volts systems supplying premises wiring, or premises wiring systems where the system operates at 3-phase, 4-wire, delta-connected in which the midpoint of one-phase winding is used as a ____.

1. bonding jumper
2. equipment grounding conductor
3. circuit conductor
4. switch leg

7. Alternating-current system grounding is not required for 50 to 1000 volts electric systems used exclusively to supply industrial electric furnaces for ____.

1. melting
2. refining
3. tempering
4. all of the above

8. Alternating-current system grounding is not required for 50 to 1000 volts separately derived systems used exclusively for rectifiers supplying only ____.

1. motor control centers
2. adjustable speed industrial drives
3. commercial buildings
4. Class III hazardous (classified) locations

9. Alternating-current system grounding is not required for 50 to 1000 volts separately derived systems supplied by transformers that have a primary voltage rating of 1000-volts or less if which of the following conditions is or are met. ____

1. system is used for only control circuits.
2. only qualified persons service installation, ground detectors are installed on the control system.
3. continuity of power is required.
4. all of the above

10. Alternating-current system grounding is not per-mitted for 50 to 1000 volts systems supplying premises wiring, or premises wiring systems where ____ are permitted or required for flammable anesthetizing systems in health care facilities.

1. grounded power systems
2. isolated power systems

3. impedance grounded systems
4. medium voltage power systems

11. High impedance grounded neutral systems are permitted for premises wiring, or premises wiring systems where the three-phase, ac systems is rated 480 to 1000 volts if which one of the following conditions is or are met____.

1. only qualified persons will service the system.
2. ground detectors are installed.
3. line-to-neutral loads are not served.
4. all of the above.

12. AC systems of 50 volts to ____ must be grounded if they supply mobile or portable equipment as specified in Section 250.188.

1. 250 volts
2. 1000 volts
3. 480 volts
4. 600 volts

13. Ac systems operating at 50 volts to ____ volts are permitted (not required) to be grounded where they do not supply mobile or portable equipment.

1. 1000
2. 300
3. 277
4. 480

14. Equipment operating at over ____ volts is commonly found in mobile rock crushing plants and batch plants. Other applications are for open pit mining operations.

1. 277
2. 300
3. 600
4. 1000

15. A ____ premises wiring system is one that is derived from a source of electric energy or equipment other than a service such as, a generator, transformer or converter windings that have no direct connection to the circuit conductors originating in another system, except through grounding and bonding connections.

1. identified
2. open neutral
3. isolated power

4. separately derived

16. Separately derived systems that are grounded must be grounded as specified in Section ____.

1. 250.24(A)
2. 250.36
3. 250.30(A)
4. 250.32(A)

17. An example of a separately derived system include(s) ____ with no direct connection between the primary and secondary, other than grounding and bonding connections.

1. phase converters
2. transformers
3. elevator motors
4. Class 1 systems

18. Examples of separately derived systems include generator systems used for emergency, required standby or optional standby power that have all circuit conductors including a neutral isolated by ____.

1. double pole
2. single pole
3. transfer equipment (transfer switches)
4. backfed device

19. Examples of separately derived systems include ac or dc systems derived from ____.

1. inverters
2. rectifiers
3. generators
4. all of the above

20. Certain systems are permitted to be operated ungrounded and usually are located in industrial or agricultural applications. Typical systems that are operated ungrounded include which of the following ____.

1. 240-volt, three-phase, three-wire, delta-connected.
2. 480-volt, three-phase, three-wire, delta-connected.
3. 13,800-volt, three-phase, three-wire, delta-connected.
4. all of the above

21. Ground detector indication systems are required to be installed to indicate that a ground fault has occurred on the ____ systems.

1. ungrounded
2. grounded
3. bonded
4. identified

22. For an ungrounded electrical system, the first phase-to-ground fault ____.

1. does nothing
2. causes a fuse to blow
3. unintentionally or accidentally grounds the system
4. none of the above

23. For an ungrounded electrical system, a second ground fault on a different phase of the system ____.

1. does nothing
2. usually causes an overcurrent device to operate, provided there is adequate current in this path.
3. grounds the system
4. none of the above

24. Disadvantages of operating an ungrounded electrical system include ____.

1. power system overvoltages are not controlled
2. transient overvoltages are not controlled
3. destructive arcing burndowns can occur on a second ground fault
4. all of the above

25. Systems not permitted to be grounded include which of the following____.

1. 120-volt, single-phase, three-wire system
2. High-impedance grounded neutral systems
3. A transformer secondary with a primary input of 460 volts
4. Secondary circuits of a low voltage lighting system operating at 24 volts

26. Effective ground-fault current paths are created by ________all of the electrically conductive materials that are likely to be energized by the wiring system.

1. connecting to ground
2. connecting to the grounded conductor
3. bonding together

4. connecting to a grounding electrode

27. The earth shall not be considered as _______.

1. an effective ground-fault current path
2. being at zero potential
3. non-conductive
4. being round

28. Ungrounded 480-volt systems used exclusively for rectifiers that supply only adjustable-speed industrial drives are required to have_______

1. temporary grounds
2. ground detectors
3. overcurrent protection at 58 percent of the full load current
4. all of the above

29. Where a generator is the alternate source of power for a building and the transfer switch does open the (neutral) grounded conductor, the generator shall be grounded with which of the following ____?

1. 250.30(B)
2. 250.36
3. 250.30(A)
4. 250.24(A)

30. A secondary circuit for a swimming pool lighting system supplied by an isolating transformer shall meet which of the following ____:

1. It shall be grounded in accordance with 250.30(A)
2. It shall be grounded in accordance with 250.36
3. It shall not be grounded in accordance with 250.30(B)
4. It shall not be grounded in accordance with 250.22(5)

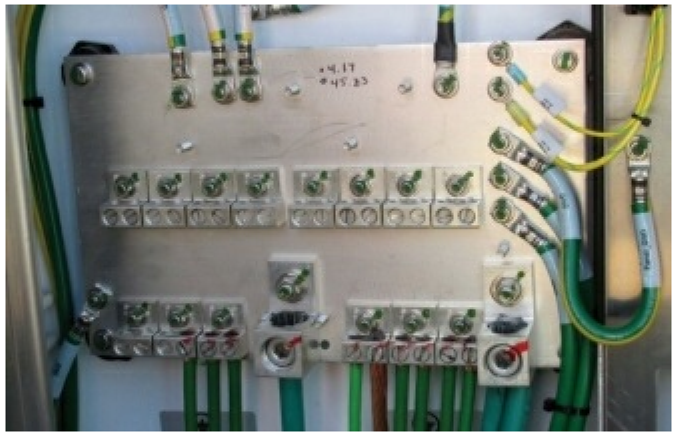
31. A ground detection indicator is required on which of the following systems ____?

1. 480/277-V, 3-phase, 4-wire grounded wye
2. 208Y/120-V, 3-phase, 4-wire grounded wye
3. 120/240-V, 1-phase, 3-wire grounded
4. 480 volt, 3-phase, 3-wire ungrounded delta

32. Ungrounded systems are required to be legibly marked at the first means of disconnect, with a label or some other identifying means. This warning label should indicate the following:

1. “Warning: Ungrounded Systems Can be Dangerous”
2. “Caution: Ungrounded Systems Do Not Include a Grounded (Neutral) Conductor”
3. “Caution: Ungrounded System Operating - _____Volts Between Conductors”
4. “Warning: Qualified Personnel Only”

Chapter 3
Grounding Electrical Systems



Objectives to understand

- Rules for which system conductor to be grounded
- Proper identification of grounded conductor
- Methods of grounding electrical systems
- Delta bank grounding
- Grounding rules for ungrounded systems
- Corner-grounded delta systems

Section 250.20 requires that many electrical systems be grounded. It is important to understand that one is dealing with the electrical system and not the service equipment, disconnecting means, or non–current-carrying metal parts or enclosures at this point.

When system grounding is being addressed, this means where one of the circuit conductors, many times the neutral point or neutral conductor, is purposefully connected to ground. For the service from the utility, the "system" grounding is determined by the utility. For "system" grounding for other than the service, the grounding is determined by the *NEC*.

Electrical energy is typically delivered to the customer by the serving utility and is provided by either a grounded or ungrounded system or sometimes by both types of systems (see figure 3.1). Electrical utilities have tariffs, standards, and service requirements that dictate whether or not they will deliver a system at a certain voltage level and phase configuration as a grounded or ungrounded system. Many utilities require that all low-voltage (1000 volts and under) systems be grounded. Others will supply 3-phase, 240-volt or 480-volt delta-connected systems ungrounded, while they insist on furnishing wye systems only in a 208Y/120, 480Y/277, or 575/332-volt, grounded-wye configuration. For 480Y/277-volt systems, there is now a growing option to supply this same wye system from the utility "ungrounded" where the user's installation design provides for a high-impedance grounded system in accordance with 250.36.

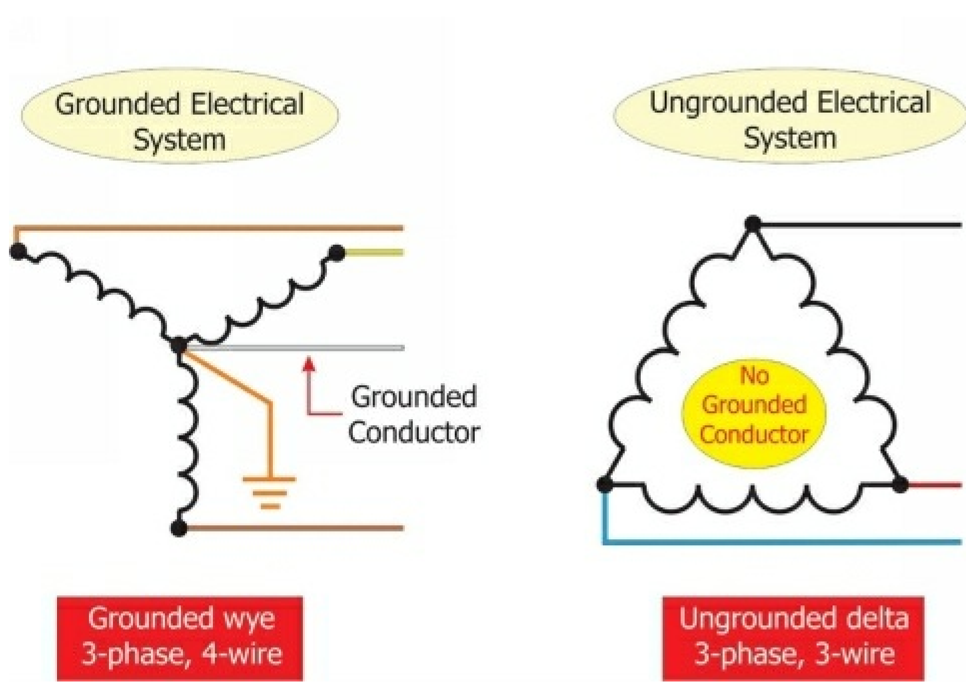


Figure 3.1 Grounded systems and ungrounded systems

Large industrial plants may purchase power at medium voltage, such as 12,470-volt, 20,800-volt or 69,000-volt or high voltage levels, such as 115,000-volt, or 230,000-volt, and may own and maintain their primary electrical distribution systems. Transformers, capacitor banks, controls, overcurrent devices and relaying systems are then installed at customer-owned switchyards or substations. Power is distributed at this higher voltage to utilization points on the premises where transformers are installed as needed to establish the utilization voltages desired. Except where prohibited in 250.22, electrical systems at the utilization level are grounded at the voltage levels and configurations as required or is permitted by the *NEC*.

Definitions

Ground. “The earth.”

Grounded (Grounding). “Connected (connecting) to ground or to a conductive body that extends the ground connection.”

Grounded Conductor. “A system or circuit conductor that is intentionally grounded.”

Neutral conductor. “The conductor connected to the neutral point of a system that is intended to carry current under normal conditions.”

Neutral point. “The common point on a wye-connection in a polyphase system or midpoint on a single-phase, three-wire system, or midpoint of a single-phase portion of a three-phase delta system, or a midpoint of a three-wire, direct-current system.”

Conductor to Be Grounded

Where the electrical system is grounded either as required by the *NEC* or by choice (250.20 and 250.21), 250.26 specifies which conductor in an alternating-current system is the one that shall be grounded. Referring to figure 3.2 and the text below, for alternating-current premises wiring systems, the conductor required to be grounded is specified below:

- Single-phase, 2-wire: one conductor (either one)
- Single-phase, 3-wire: the neutral conductor
- Multiphase systems having one wire common to all phases: the neutral conductor
- Multiphase systems requiring one grounded phase: one phase conductor.
- Multiphase systems in which one phase is used as a single-phase, 3-wire system the neutral conductor.

The *NEC* provides a clear differentiation between a neutral conductor of a system and a neutral point of a system. These two terms are appropriately used in each *NEC* rule where only the term neutral was used previously. The above definitions of the terms neutral conductor and neutral point are found in Article 100 (see figure 3.3).

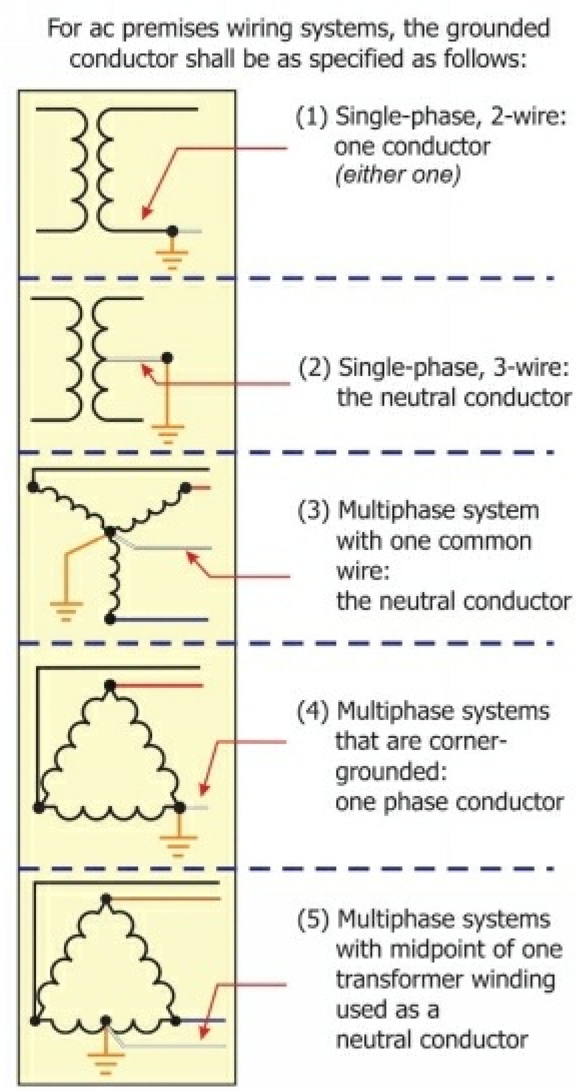


Figure 3.2 Conductor required to be grounded in grounded systems [250.26]

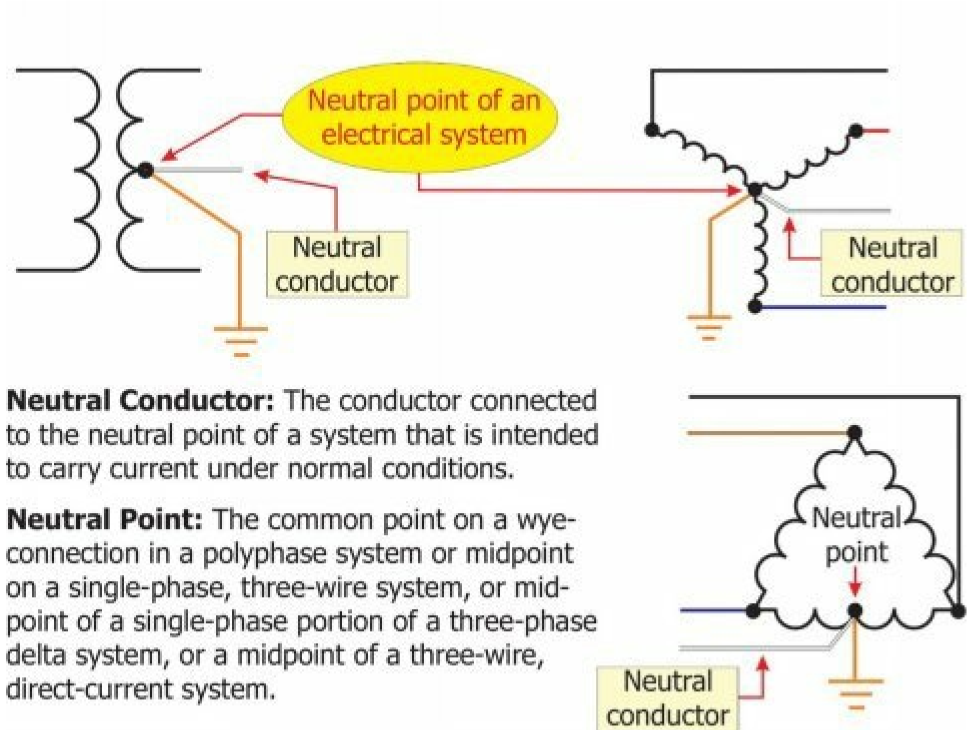


Figure 3.3 Definitions: Neutral conductor and neutral point

An important aspect of these terms is that a clear differentiation is established between neutral conductors and the point on a system where they are connected. While most neutrals in electrical systems are grounded conductors, not all grounded system conductors are neutrals. For example, a grounded phase conductor of a three-phase, three-wire, delta-connected system is a “grounded conductor” but is not a “neutral conductor” of this system configuration.

Identification of Grounded Conductor

Grounded conductors are required to be identified by the means specified in 200.6 (see figure 3.4). Requirements are provided for identification of grounded conductors of sizes 6 AWG or smaller, conductors 4 AWG and larger, flexible cords, grounded conductors of different systems, and grounded conductors of multiconductor cables.

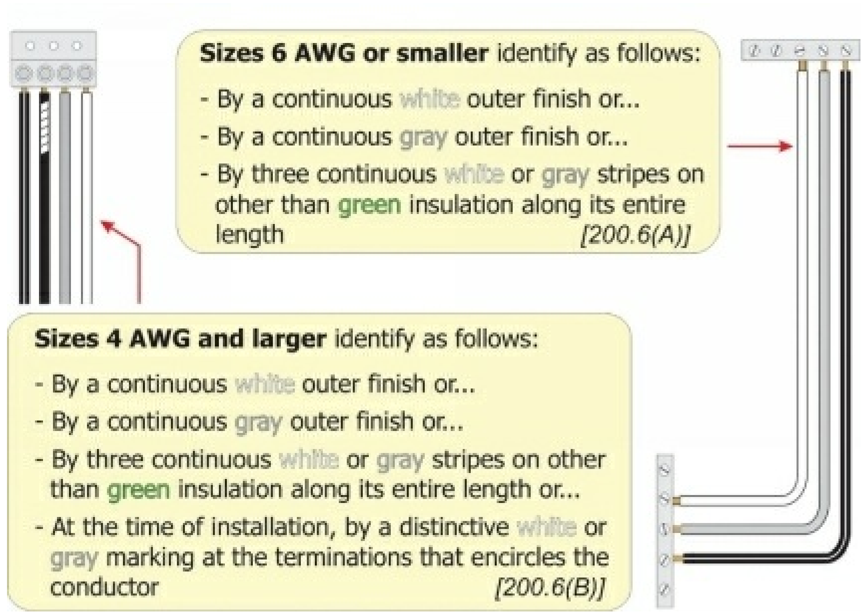


Figure 3.4

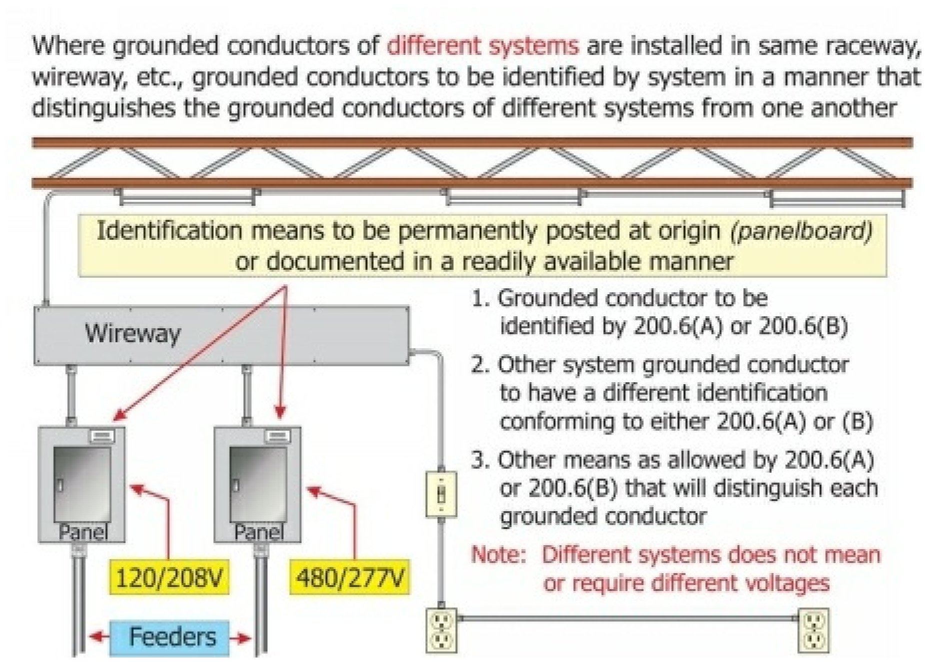


Figure 3.5 Grounded conductors of different systems

It should be noted at this time that while there may be trade practices to have a color used for a specific voltage system, the *NEC* does not specify any of these identification methods to any voltage or system type. The *NEC* permits any of the colors for identification to be used for any voltage.

6 AWG or smaller

Section 200.6(A) provides the general means of identification of 6 AWG or smaller insulated grounded conductors in list form which include:

(1) A continuous white outer finish, or

(2) A continuous gray outer finish, or

(3) Three continuous white or gray stripes on other than green insulation.

(4) Conductors with an outer finish of white or gray but also have colored tracer treads in the braid identifying the source manufacturer.

This identification must be along the entire length of the conductor. It is generally not permitted to paint or phase-tape grounded conductors of 6 AWG or smaller.

For specific conductor assemblies or applications, the following grounded conductor identification is provided regardless of size:

(5) For Type MI cable, the grounded conductor is permitted to be identified by distinctive marking at its termination at the time of installation.

(6) For single-conductor, sunlight-resistant, outdoor-rated cable for solar photovoltaic systems, as permitted in 690.31, the grounded conductor is required to be identified at terminations by distinctive white markings. This will usually be made with white adhesive vinyl marking tape.

(7) Fixture wire can be identified as provided in 402.8.

(8) For aerial cable, the grounded conductor is permitted to be identified by any of the general means identified above or by a ridge located on the exterior of the cable.

Conductors 4 AWG and larger

Conductors 4 AWG and larger are permitted to be identified either like conductors 6 AWG or smaller or, at the time of installation, by distinctive white or gray marking at each termination (see photo 3.1). This distinctive marking usually consists of adhesive vinyl tape or paint. Where so marked, the marking must fully encircle the conductor or insulation so it is visible from all sides after the installation is completed.

Photo 3.1   Grounded neutral conductor identification

Flexible cords

The grounded conductor within a flexible cord is permitted to be identified by one of the three methods included for conductors 6 AWG or smaller or by the methods included in 400.22. These additional methods include: colored braid, tracer in the braid, colored insulation, colored separator, tinned conductors, and surface marking.

Grounded conductors of different systems

Larger electrical installations commonly have more than one electrical system installed in the same enclosure, such as raceways like conduits and wireways, pull boxes and cables. For example, grounded conductors from both a 480Y/277-volt, three-phase, four-wire system and a 120/240-volt, single-phase system may be in the same raceway or other enclosure. Where this happens, one of the grounded conductors is required to be identified in accordance with the requirements stated in 200.6(A) or (B), as covered above. The system grounded conductor in each of the other systems is required to be identified differently by one of the means provided for conductors in 200.6(A) or (B) for 6 AWG and smaller or 4 AWG and larger or alternately by white or gray colored insulation with a readily distinguishable different colored stripe that is not green and runs along the insulation. Section 200.6(D) requires the means of identification of grounded conductors of different systems to be permanently posted at the location, switchboard or panelboard, where the grounded conductor for each of these different systems originates.

It should be noted that “different systems” does not only mean different voltages. There are many cases where different systems exist at the same voltage levels, for example a normal supply system at 208Y/120 volts and a system from a UPS separately derived system operating at the same 208Y/120 volts would fall under this requirement.

Grounded conductors of multiconductor cables

Insulated conductors used as grounded (neutral) conductors in multiconductor cables are required to be identified generally as specified in 200.6(A). Where only qualified persons will service and maintain the installation, grounded conductors of multiconductor cables are permitted to be permanently identified at terminations by a distinctive white marking or by other effective means.

Use of Conductors with White, Gray or Three White or Gray Stripes on Other than Green Insulation.

Section 200.7(A) limits the use of the colors white, gray, and three white or gray stripes on other than green insulation to identify grounded (neutral) conductors. Section 200.7 additionally provides requirements for the cases where conductors with a white, gray, or three white or gray stripes on other than green insulation in a cable assembly can be re-identified for use as other than a grounded (neutral) conductor. The previous permission to install conductors with white insulation in a conduit or other raceway and phase-tape them and use them as ungrounded conductors has been removed from the *NEC* (see 200.7 for additional requirements or restrictions on the use of conductors with white, gray, or three white stripes on other than green insulation).

Lastly, an informational note in 200.6 and 200.7 indicates that the color gray may have been used in the past for ungrounded conductors. It is always a good practice to verify the actual use of any conductor before opening or contacting circuit conductors and this informational note is another specific reminder to be cautious.

Methods of Grounding Electrical Systems

A variety of methods are used to ground electrical systems. The method chosen will vary, depending upon the system voltage, code requirements, plant owner specifications, engineer's philosophy, or even utility practices. The various methods commonly used are shown in figure 3.6 and are as follows:

Solidly grounded: Connected to ground without inserting any resistor or impedance device. Solidly grounded refers to the connection of the electrical system or of a separately derived system such as a generator, power transformer, or grounding transformer directly to the building or structure ground or grounding electrode system without intentionally introducing an impedance.

Surge arrester grounded: to permit the use of reduced rated (80 percent) surge arresters, the surge arresters must be rated near, but not less than, 80 percent of line-to-line voltage. This then provides for a grounded system. This will carry with it a line-to-ground circuit current of at least 60 percent of the three-phase short-circuit value.

Reactance grounded: the system is grounded through a device that introduces an impedance that is principally inductive reactance such as a reactor or grounding transformer.

Resistance grounded: the system is grounded through a device that introduces an impedance that is principally resistance such as a resistor. For resistance grounding, the system is grounded by connecting the system neutral or the corner of a delta system to ground through a resistor. The resistance values can be a "low resistance" that allows a ground-fault current of typically 200 to 400 amps or a "high resistance" as discussed in the next section.

High-resistance grounded: This is the same as resistance grounding defined above except the resistor selected is nearly the highest permissible resistance that can be inserted into the grounding connection. For high-resistance grounding, the system is grounded at the system neutral through a resistor (may be a grounding transformer) that typically limits the ground-fault current to approximately 10-amperes or less. High-resistance grounding provides for control of transient overvoltages, but might not furnish sufficient current for traditional ground-fault relaying. The protective scheme usually associated with high-resistance grounding is detection and alarm rather than immediate tripping of the disconnecting device (see 250.36 and chapter four for additional information). High-resistance grounding is typically applied to 3-phase systems such as 480Y/277-volt systems and to some medium voltage wye-connected systems, such as 12.47/7.2 kV systems.

Ungrounded: the system has no intentional system grounding connection. Ungrounded systems are used in industrial plants and where desired for manufacturing processes to give an additional degree of service continuity. While a ground fault on one phase of an ungrounded system generally does not cause a service interruption, the occurrence of a second ground fault on a different phase before the first fault is cleared does result in an outage. A ground detection system is required, and adequate maintenance and repair will minimize interruptions. Sections 250.21 and 408.3(F)(2) now require field installed signage at all ungrounded system switchboards and panelboards to indicate that a system is ungrounded and what the ungrounded line-to-line voltage should be.

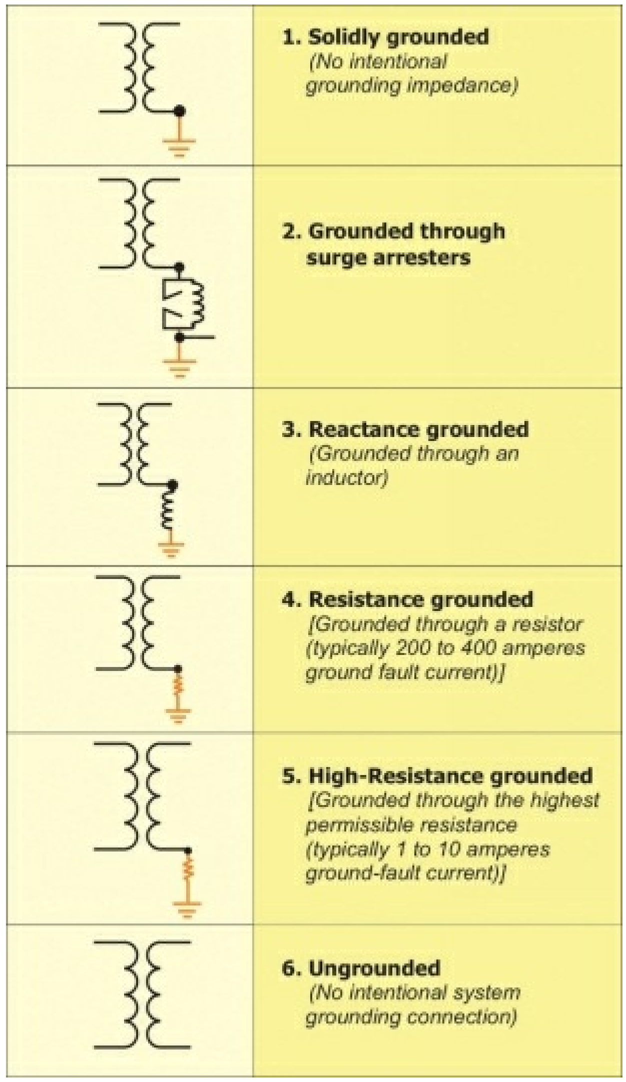


Figure 3.6 Various methods of system grounding

Low-voltage systems, 1000 volts and below, that are grounded are almost always solidly or high-impedance grounded; medium-voltage systems are usually either solidly or resistance (low or high) grounded; and medium and high-voltage systems above 34.5 kV are nearly always grounded through surge arresters or ungrounded.

Delta Bank Grounding

Where three single-phase transformers that have center taps are connected in a delta bank, only one of the transformers may have its midpoint grounded. Any attempt to use a second transformer of the delta bank to supply a second 3-wire, single-phase source would require grounding the midpoint of a second transformer. However, since there will be a difference of potential between the midpoints of the different transformers, there would be an abnormal current through both grounded neutrals. This would ultimately cause heating or a short circuit, depending on how both neutrals were connected.

With midpoint grounding of one-phase winding in a delta bank, one of the phase conductors operates at a higher voltage to ground than the other two. In practice, this high leg is identified as required by 110.15 and 230.56 by orange color-coding or other effective means (see figure 3.7). This identification may be in addition to any other identification of phase conductors as required by 210.5 and 215.12(C).

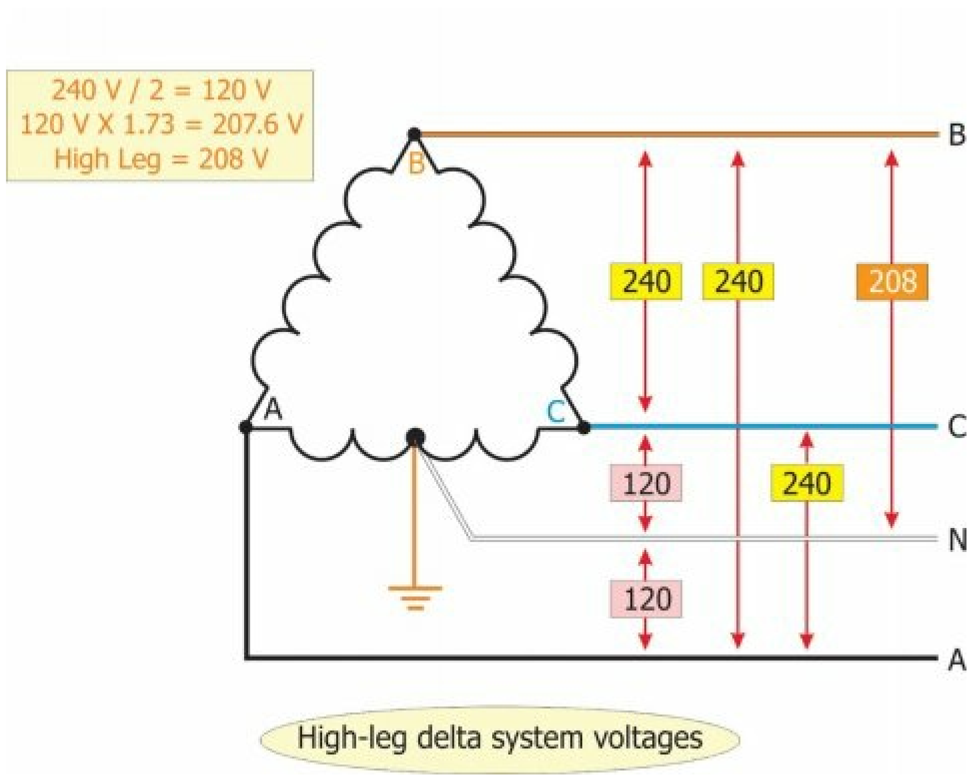


Figure 3.7 High-leg delta system voltages

The voltage of the phase conductor with the higher voltage to ground is determined by the following formula:

½ of phase-to-phase voltage x 1.732 = high-leg voltage to ground

For example, a 240-volt, 3-phase system center-tapped to establish a neutral:

½ of 240 = 120 x 1.732 = 208 V high-leg voltage to ground

Section 408.3(F)(1) requires switchboard, switchgear, and panelboard enclosures containing high-leg systems to be provided with a permanent field-applied marking as follows:

CAUTION____ PHASE HAS ____VOLTS TO GROUND

A new requirement in 408.3(F) refers the user to changes in 110.21(B) where the specific requirements for this and other such labels to be permanent, suitable for the intended environment and not to be hand written. Informational notes provide references to ANSI/NEMA Z535 standard that detail items such as color, font size, words and symbol use.

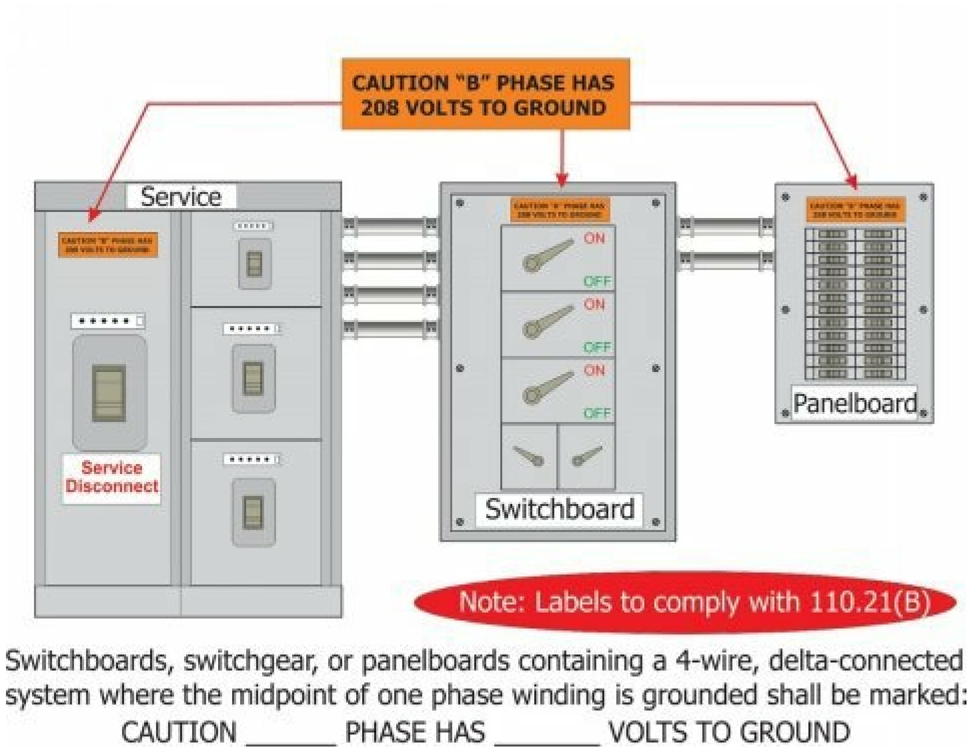


Figure 3.8 Switchboards and panelboards with "high-leg" are required to be identified.

Grounding Existing Ungrounded Systems

In some cases, it is desirable to ground electrical systems that originally were installed ungrounded or are permitted, but are not required, to be grounded (see chapter two for a thorough discussion of the subject). There are four methods commonly in use for grounding of ungrounded systems of 1000 volts or less. Solid grounding is used in all the methods. They are as follows:

Grounding the neutral of wye-connected secondary windings of a transformer

As shown in figure 3.9, this is the most universal and commonly used method of grounding a system. Standard voltages are 208Y/120 (required to be grounded), 480Y/277, 575Y/332, and 600Y/346 volts. The first two voltage systems — 208Y/120 and 480Y/277 — are in most common use today in the United States, with the growth tending in favor of the 480Y/277-volt system owing to the better economies of that system. There is a trend in some industries toward more use of the 575Y/332 volt systems that are now commonly found in Canada. In general, the primary windings of the transformers serving those wye systems are delta-connected.

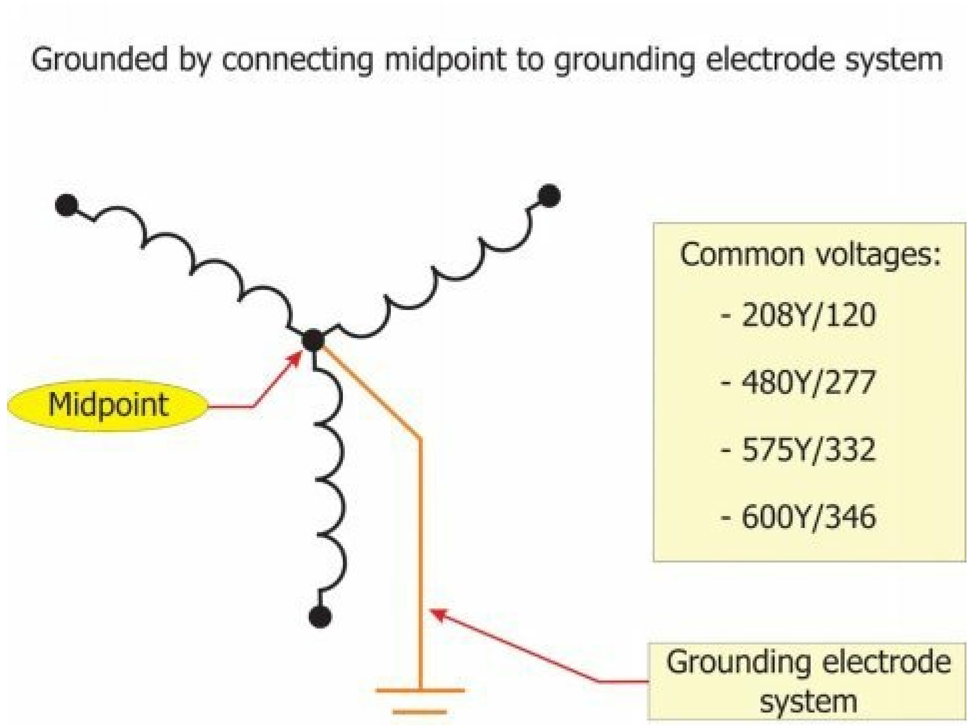


Figure 3.9 Grounding a Wye-connected system

Grounding a delta bank with a zigzag grounding transformer

This method is best adapted to an existing 3-wire, 3-phase delta-connected distribution system that is ungrounded, and where it is desired to ground the system to obtain the advantages gained through operating the system grounded but also retain the continuity of service the ungrounded system provides. The overall system is impedance grounded by use of the transformer winding impedance between the original system and the earth connection of the zigzag transformer. For new systems, the use of transformers in the zigzag configuration with a wye-connected secondary is advisable to obtain a grounded system. The neutral derived from the zigzag transformer can be used as a system current-carrying conductor if the zigzag grounding transformers are sized for the maximum unbalanced current (see 220.61 for the method of calculating the maximum unbalanced current on the grounded conductor).

A zigzag transformer, shown applied to a delta system in figure 3.10, obtains its name from the manner in which the windings are installed and connected. Windings for each phase are on the same core leg. All windings have the same number of turns but each pair of windings on the same core leg is wound in opposite directions. The impedance of the transformer to 3-phase currents is so high that under normal conditions there will be only a small magnetizing current provided from the delta system. If a ground fault develops on one phase of the delta system, the transformer impedance to ground current is so low that there will be a high ground current to facilitate either an alarm or tripping system. The high ground current will divide into three equal parts in the three phases of the grounding transformer.

Such a 3-phase zigzag transformer has no secondary winding. This type of grounding transformer is required to carry rated current for only a short time (the duration of the ground fault). The short-time kVA rating of such a grounding transformer may thus be equal to the rating of a regular 3-phase transformer, yet be only about 10 percent of the physical size.

Electrically, a zigzag grounding transformer connection appears to superimpose a wye-connected system inside the delta-connected transformers. This wye-type connection permits the transformer to be used like a wye transformer, with phase-to-neutral loads to be utilized. In this case, it is important for the zigzag transformer to be sized for the calculated or connected load that may be more than the fault duty current that would be imposed.

A wye-delta grounding transformer may also be used to provide a neutral for an existing delta-connected ungrounded system, but the use of the zigzag grounding transformer is more practical and economical.

The grounding transformer should be connected directly to the system, as shown in figure 3.10, at the power transformer secondary. Where a grounding transformer is so connected, one grounding transformer is required for each delta-connected power transformer bank. In this manner, the switching out of any one transformer bank will not disturb the secondary system ground. The grounding transformer and the power transformer are considered a single unit, both being protected by the overcurrent protective means provided for the main power transformer.

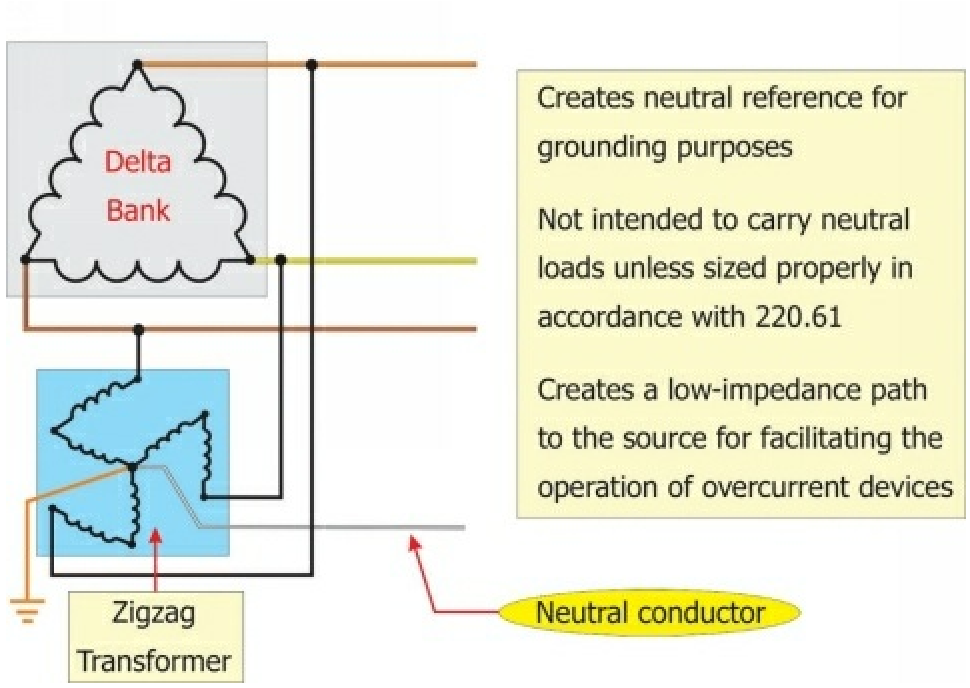


Figure 3.10 Grounding a delta system using a zigzag grounding transformer

The grounding transformer also may be connected directly to the main bus through its own overcurrent protection means. In that event, an alarm should be provided to indicate the system is operating ungrounded if the grounding transformer should be disconnected from the line.

Where a grounding transformer is used on low-voltage systems (1000 volts and below), it is important that the equipment grounding conductor be connected to the neutral of the grounding transformer in such a way as to provide a low-impedance path for ground-fault currents to return back to the system. The same connection point should be used for the neutral of the grounding transformer, the equipment grounding conductor(s) and a grounding electrode conductor.

The same disconnecting means and overcurrent protection means for the system would be used as described under method 1.

Additional information about grounding auto-transformers that are zigzag or T-connected to ungrounded systems is provided in 450.5.

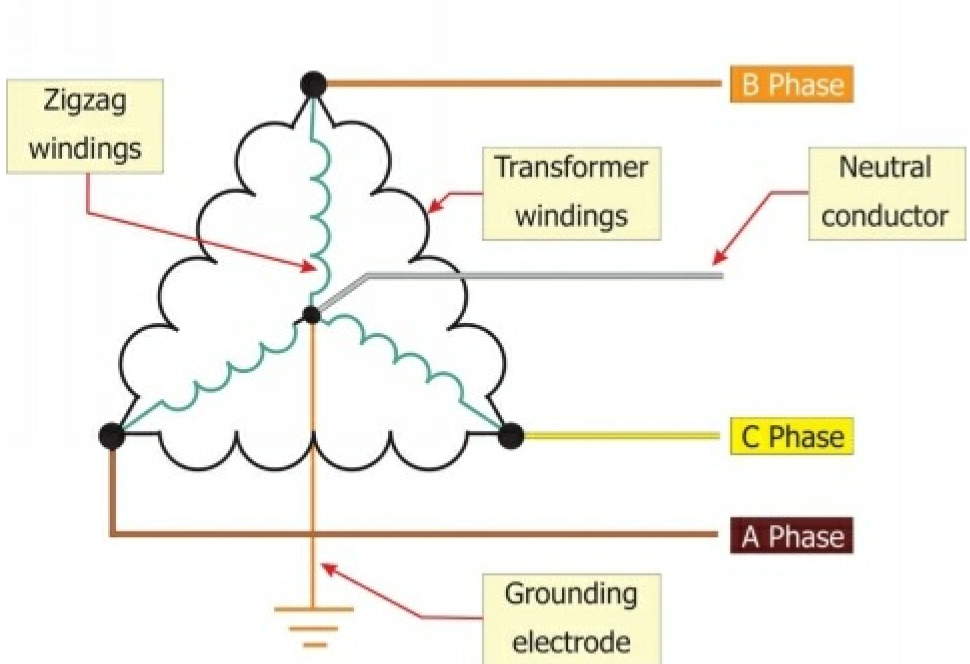


Figure 3.11 Relationship of zigzag transformer to delta bank transformer

Grounding the midpoint of one of the transformers in a delta-connected system

This method of grounding is commonly used, especially in smaller distribution systems, to provide a three-phase power source and a three-wire single-phase lighting source from the same transformer bank. This, then, becomes a three-phase, four-wire delta-connected system, commonly referred to as a high-leg delta system. The delta transformer bank provides the 3-phase power and at the same time, the advantages of a neutral grounded system are obtained. It is common for the serving utility to use three single-phase transformers connected in a delta configuration for this system. In such a system, the single-phase transformer that additionally supplies the lighting load usually is sized larger than the other two single-phase transformers, which supply the power load only (see figure 3.12).

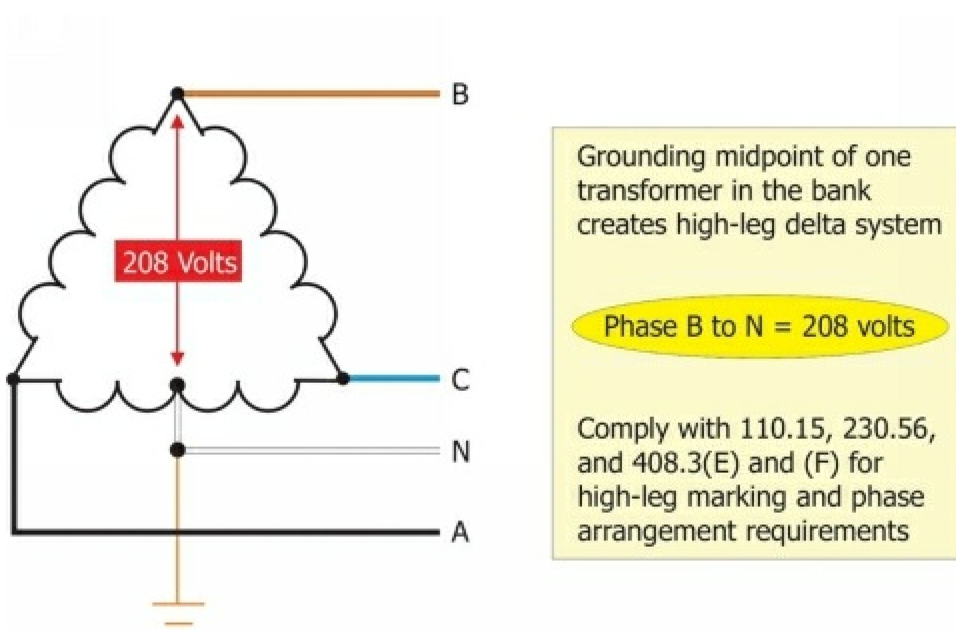


FIgure 3.12 Grounding a delta bank, creating a high-leg grounded delta system (closed delta shown)

Since the conductors supplying the 3-phase power will now be from a grounded source, the grounded conductor must be run to the service equipment. There, it must be connected to the service equipment neutral terminal or bus and also to the equipment grounding conductor of the power system and the grounding electrode. The connection of the equipment grounding conductors is usually accomplished with the main bonding jumper. This provides a ground-fault current return path of low impedance. Such a connection enhances the safety of the power system. If the power service and the lighting service go to the same building, which is usually the case, the grounding electrode conductor from the power service, as well as the grounding electrode conductor from the lighting service, must be connected to the same grounding electrode (see chapter four for additional information on this subject).

Grounding one corner of a delta system

In the past, most three-phase ungrounded delta distribution systems comprised three single-phase transformers that were connected delta-delta. The main reason was to be able to continue operating if one transformer failed by disconnecting the faulted transformer and operating the bank open-delta, although at reduced capacity.

When the advantages of grounding became very apparent, it first was the practice to ground one corner of the delta (see figure 3.13). In this configuration, the grounded conductor must be positively identified throughout the system in accordance with 200.6. This grounded conductor is not a neutral conductor of the system. This system is commonly referred to as a corner-grounded delta system.

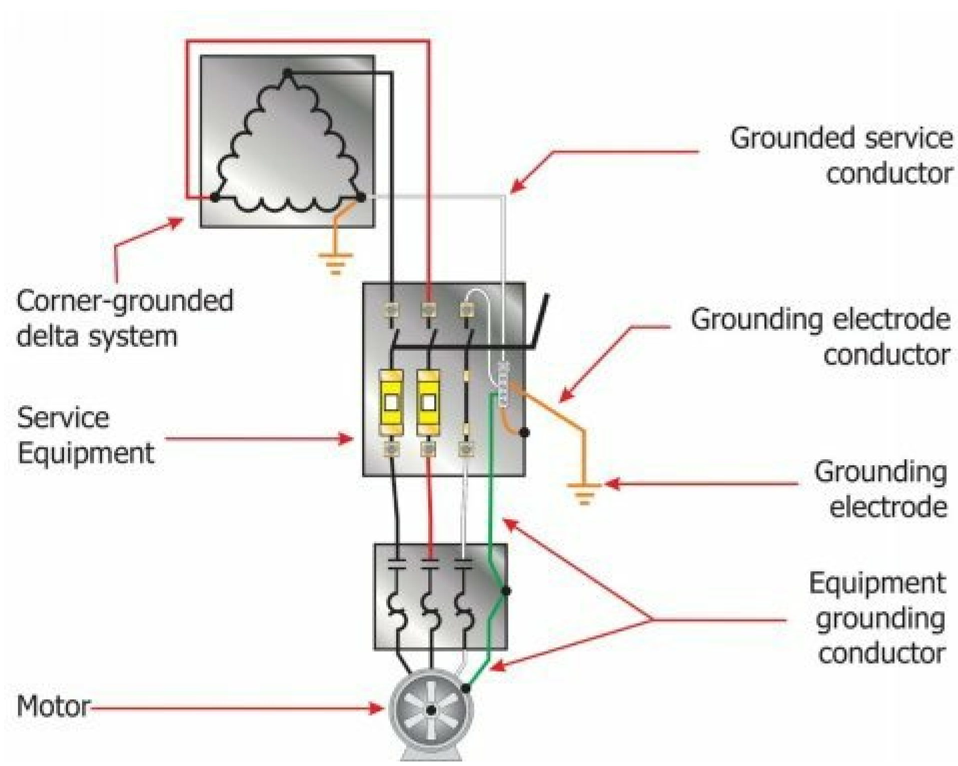


Figure 3.13 Corner-grounded system showing the use of a fused switch

Where the grounded conductor is disconnected by the switch or circuit breaker, it is important that a bonding connection be made on the line side of the disconnect switch or circuit breaker as shown in figure 3.13. If this is not done, the electrical equipment will become electrically isolated from the grounded conductor when the switch or circuit breaker is in the open position. In this case, any fault that occurs would raise the voltage on the enclosure to a hazardous potential above ground equal to the system voltage.

Generally, fuses are not permitted to be installed in the grounded conductor. One method of installation uses a two-pole fused switch with fuses in the ungrounded phases. Alternately, a three-pole switch may be used with a solid link in the grounded phase. For services, 230.90(B) does not allow an overcurrent device, other than a circuit breaker that opens all conductors simultaneously, to be inserted in the grounded service conductor. Section 240.22 generally prohibits connecting an overcurrent device in series with any conductor that is intentionally grounded. Section 240.22(1) permits an overcurrent device to be used that "opens all conductors of the circuit, including the grounded conductor, and is designed so that no pole can be operated independently."

This requirement means that three-pole circuit breakers can be used for this purpose while a three-pole switch with a fuse in series with each phase could not, as the switch is not the overcurrent device, the fuse is. Figure 3.13 shows an acceptable use of a fused switch for corner-grounded systems.

Section 430.36 permits a fuse to be inserted in the grounded conductor for the purpose of providing motor overload protection. However, based on the examination of *Code* requirements discussed in the previous paragraph, this application would be limited to being located downstream from the service equipment.

Keep in mind that 250.24(C) requires that the grounded system conductor be run to each service disconnecting means and be bonded to the service disconnecting means enclosure. This is usually accomplished by connecting it to a terminal bar that is mounted inside the service enclosure. Nothing permits this bonding connection to be interrupted by a switch or circuit breaker.

Section 200.2(B) does not permit electrical enclosures, raceways, or cable armor to be used to establish and maintain continuity of the grounded conductor. Grounded conductors (often neutral conductors) must be terminated to a grounded conductor terminal bar within equipment. (This is discussed more in depth in chapter four).

At the service where it is desirable to disconnect the grounded system conductor from the feeder, it is acceptable to route the conductor from the terminal bar through the switch or circuit breaker.

For purposes of installing or grounding a corner-grounded delta system, it is helpful to think of it as a single-phase system. This is illustrated in figures 3.13 and 3.14. The system is grounded at one corner of the delta. Three conductors are taken to the service where the two ungrounded conductors connect to the disconnecting means or circuit breaker. The grounded service conductor is connected to the neutral terminal bar where it is bonded to the enclosure and connected to the grounding electrode conductor. While this logic helps for installing disconnects and overcurrent protection, it must be remembered the grounded conductor is carrying full-phase current at all times. A change to 250.24(C)(3) in the 2011 *NEC* makes it clear that this grounded conductor is not permitted to be reduced in size and is to be the same size as the other two ungrounded conductors.

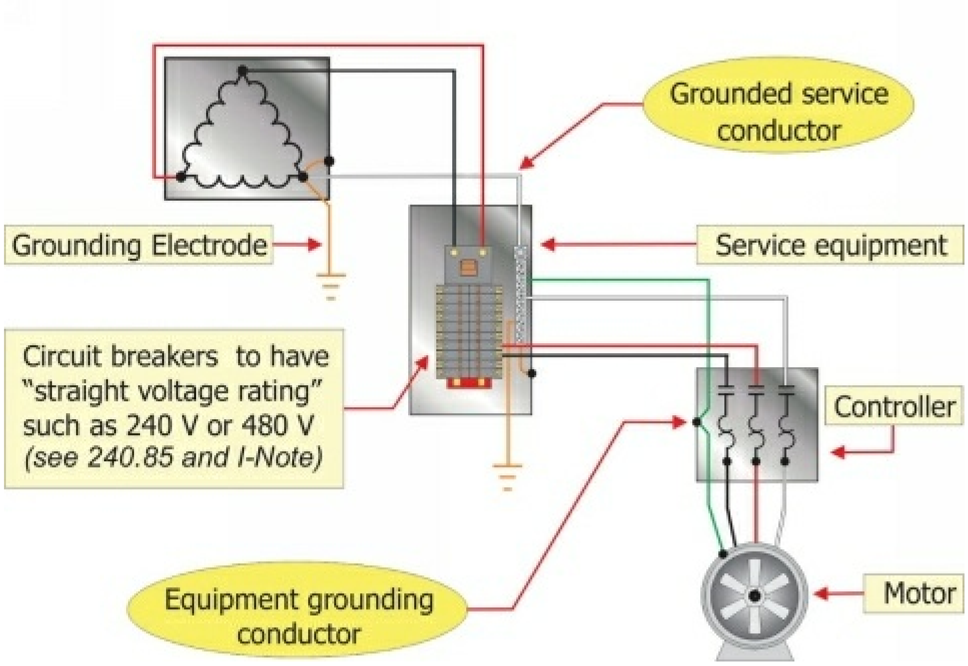


Figure 3.14 Corner-grounded system showing breakers installed in the system

Where circuit breakers are used as the disconnecting means for corner-grounded systems, they must be marked with a voltage rating suitable for the system voltage and will have a straight voltage rating such as 240 V or 480 V (see photo 3.2). Slash-rated breakers provide two voltage ratings such as 120/240 or 480Y/277 (see photo 3.3). The slash rated breaker is only listed to interrupt the lower voltage on any one pole and therefore would not be suitable to interrupt the line-to-line voltage of this type system. Two-pole circuit breakers that are suitable for a corner-grounded delta system are marked "1-phase/3-phase" (see 240.85 and figure 3.14).

Photo 3.2 Breakers with straight voltage rating (240 V)

Photo 3.3 Breaker with slash voltage rating (120/240 V)

From the service and throughout the system, the grounded conductor must be insulated from equipment and enclosures [see 250.24(A)(5)]. An equipment grounding conductor is run with the circuit to provide grounding and bonding of equipment and enclosures, such as disconnecting means, motor controllers, and other non–current-carrying equipment that are required to be grounded.

Review Questions

1. “The earth” best defines which of the following terms ____?

   1. grounded conductor
   2. ground
   3. grounding electrode
   4. bonded conductor

2. “Connected (connecting) to ground or to a conductive body that extends the ground connection” best defines which term ____?

   1. grounded (grounding)
   2. a grounded conductor
   3. being identified
   4. being bonded

3. “A system or circuit conductor that is intentionally grounded” best defines which of the following ____?

   1. insulated
   2. bonded
   3. a grounded conductor
   4. an equipment grounding conductor

4. ____ AWG and smaller insulated grounded conductors are generally required to be identified by a continuous white or gray outer finish.

   1. 6
   2. 4
   3. 2
   4. 1

5. For installations that will be serviced by qualified persons only, grounded conductors of ____ cables are permitted to be marked at their terminations.

   1. Type IGS
   2. Type TFFN
   3. multiconductor
   4. single

6. Grounded conductors sizes 4 AWG or____ are permitted to be identified either like

conductors 6 AWG or smaller, or at the time of installation, by distinctive white or gray marking at their terminations.

1. of aluminum or smaller
2. of copper or smaller
3. smaller
4. larger

7. Insulated grounded conductors 6 AWG or smaller are permitted to be identified by which of the following methods?

1. a continuous white outer finish
2. a continuous gray outer finish
3. three white sizes 4 AWG or gray stripes on other than green insulation
4. all of the above

8. In practice, a “high-leg” is generally required to be identified by a (an) ____ color coding or other effective means.

1. green
2. brown
3. orange
4. yellow

9. Grounding of surge arresters rated near, but not less than, ____ percent of line-to-line voltage constitutes an effectively grounded system.

1. 70
2. 60
3. 50
4. 80

10. For resistance grounding, the system is grounded by connecting the system neutral to ground through a ____.

1. resistor
2. terminal
3. ground rod
4. generator

11. The insertion of nearly the highest permissible resistance into the grounding connection results in a system that is ____.

1. extra low resistance grounded

2. medium resistance grounded
3. low resistance grounded
4. high resistance grounded

12. High-resistance grounding maintains control of transient overvoltages, but may not furnish sufficient current for ground-fault ____.

1. detection
2. relaying
3. alarms
4. conditions

13. Low-voltage systems operating at 1000 volts and below are almost always solidly grounded; medium-voltage systems are usually either solidly or resistance grounded; and high-voltage systems above ____ kV are nearly always grounded through surge arresters or ungrounded.

1. 12.7
2. 10.4
3. 15.3
4. 34.5

14. A wye-delta grounding transformer may be used to provide a neutral for an existing delta-connected ungrounded system, but the use of the ____ grounding transformer is considered as being more practical and economical.

1. converter
2. autotransformer
3. zigzag
4. Scott

15. Where a grounding transformer is used on low-voltage systems operating at 1000 volts and below, it is important that the equipment grounding conductor be connected to the neutral of the grounding transformer in such a way as to provide a ____ path for ground-fault current to return to the system.

1. high-impedance
2. low-impedance
3. current limiting
4. straight

16. The same connection point should be used for the ____ of the grounding transformer, the equipment grounding conductor(s) and a grounding electrode conductor used for both the

equipment grounding conductor.

1. unidentified conductor
2. equipment grounding conductor
3. bonding jumper
4. neutral

17. In the past, most 3-phase ungrounded delta distribution systems were comprised of three
single-phase transformers that were connected ____.

1. wye-delta
2. delta-wye
3. delta-delta
4. delta

18. For purposes of installing or grounding a corner-grounded delta system, it is helpful to think of it as a ____ system, even though it is a three-phase, three-wire system.

1. three-phase
2. single-phase
3. 5-wire
4. 4-wire

19. Circuit breakers installed and used for corner-grounded delta systems must be marked _______.

1. with a voltage rating such as 120/240
2. for at least 600-volt operation
3. with a straight voltage rating, such as 240 V or 480 V
4. none of the above

20. Fuses are permitted to be inserted in a grounded conductor_______.

1. as desired
2. for grounded systems only
3. for ungrounded systems only
4. for motor overload protection

21. Where grounded conductors of different systems occupy the same enclosure, they must be identified differently and ____.

1. the means of identification is to be permanently posted at each branch-circuit panelboard

2. have insulation that is all of the same rating
3. be separated by permanently installed barriers
4. be provided with an additional jacket or sleeve

22. Many utilities require that _______.

1. all grounded conductors be uninsulated
2. metering equipment be located indoors
3. all 1000 volt and under systems be grounded
4. all ungrounded conductors be un-insulated

23. Solidly grounded means _______.

1. connected to an electrode with a pressure type connector
2. without intentionally introducing any resistor or impedance device.
3. connected using irreversible or exothermic connections
4. connected to multiple grounding electrodes

24. Continuity of the grounded conductor shall not depend on a connection to which of the following ____?

1. a metallic enclosure
2. a metal raceway
3. a cable armor
4. all the above

Chapter 4
Grounding Electrical Services

Objectives to understand

- Important requirements for grounding electrical services
- Proper location of service grounding connection
- Rules for low-impedance grounding electrode connections
- Grounded conductor sizes for dwelling unit services and feeders
- Proper sizing of grounded service conductor
- Rules for parallel service conductors
- Rules for multiple services to one building
- Rules for high-impedance grounded systems
- Grounding requirements for instrument transformers, relays, etc.
- Hazards of services from grounded systems without grounded conductor

Electrical services are furnished to the premises by the serving utility as either grounded or ungrounded. At the service disconnecting means, the system is either solidly grounded, left ungrounded, or may be resistance or reactance grounded. How the services are treated regarding grounding depends on the type of system installed, design criteria, Code rules, and how the utility grounded the supply system.

Definitions

Grounded Conductor. A system or circuit conductor that is intentionally grounded.

Service. The conductors and equipment for delivering electric energy from the serving utility to the wiring system of the premises served.

Grounded Electrical Services

Important requirements for grounded services are contained in 250.24(C) (see figure 4.1). This section requires that: where an ac system operating at 1000 volts or less is grounded at any point, the grounded conductor (usually a neutral conductor) shall be run to each service disconnecting means (see figure 4.2). A change added in 250.186 provides the requirements for supplying a neutral or supply-side bonding jumper to services over 1000 volts. See chapter twenty for more information on this change.

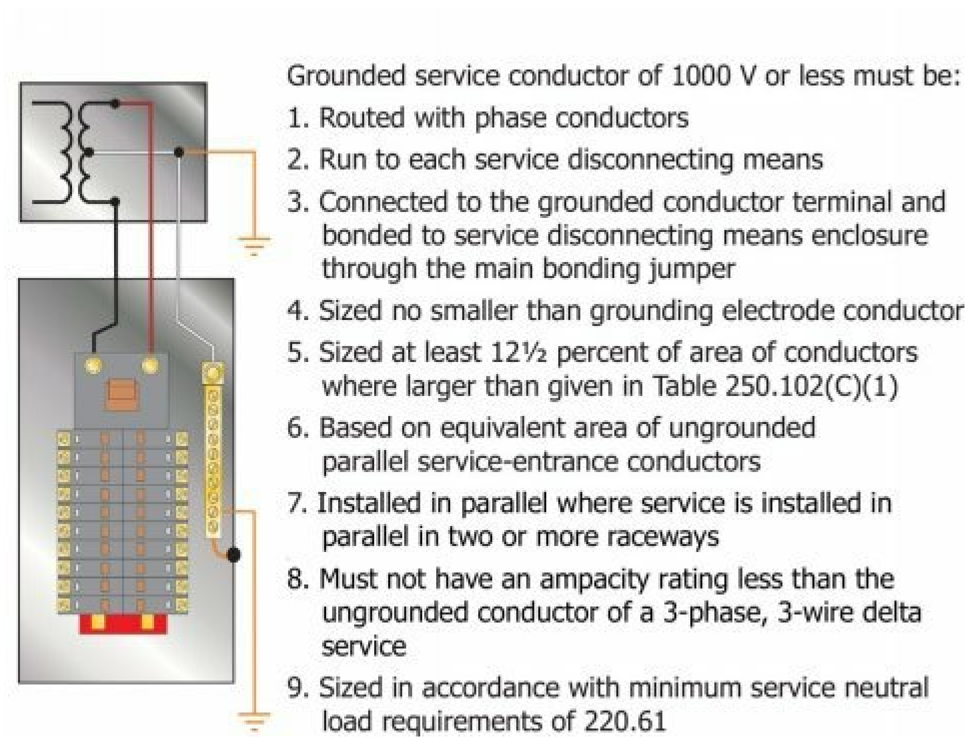


Figure 4.1 Important requirements for grounded electrical systems [250.24(C)]

Table 250.102(C)(1) Grounded Conductor, Main Bonding Jumper, System Bonding Jumper, and Supply-Side Bonding Jumper for Alternating-Current Systems

Size of Largest Ungrounded Conductor or Equivalent Area for Parallel Conductors (AWG/kcmil)		Size of Grounded Conductor or Bonding Jumper* (AWG/kcmil)	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	See Notes 1 and 2	

Notes:

1. If the ungrounded supply conductors are larger than 1100 kcmil copper or 1750 kcmil aluminum, the grounded conductor or bonding jumper shall have an area not less than 12 ½ percent of the area of the largest ungrounded supply conductor or equivalent area for parallel supply conductors. The grounded conductor or bonding jumper shall not be required to be larger than the largest ungrounded conductor or set of ungrounded conductors.
2. If the ungrounded supply conductors are larger than 1100 kcmil copper or 1750 kcmil aluminum and if the ungrounded suppy conductors and the bonding jumper are of different materials (copper, aluminum or copper-clad aluminum), the minimum size of the grounded conductor or bonding jumper shall be based on the assumed use of ungrounded supply conductors of the same material as the grounded conductor or bonding jumper and will have an ampacity equivalent to that of the installed ungrounded supply conductors.
3. If multiple sets of service-entrance conductors are used as permitted in 230.40, Exception No. 2, or if multiple sets of ungrounded supply conductors are installed for a separately derived system, the equivalent size of the largest ungrounded supply conductor(s) shall be determined by the largest sum of the areas of the corresponding conductors of each set.
4. If there are no service-entrance conductors, the supply conductor size shall be determined by the equivalent size of the largest service-entrance conductor required for the load to be served.

*For the purposes of applying this table and its notes, the term bonding jumper refers to main bonding jumpers, system bonding jumpers, and supply-side bonding jumpers

Table 250.102(C)(1) Reproduction of NEC Table 250.102(C)(1)

Where more than one disconnecting means is located in a single assembly listed for use as service equipment, an exception permits the grounded service conductor, single or parallel, to be run to the assembly (see figure 4.3). The grounded conductor must be connected to the common grounded conductor terminal or bus in the assembly enclosure. The sections of the switchboard are bolted together to form the assembly. The assembly is designed and evaluated for this purpose by the listing requirements. In addition, it is common to have an internal equipment grounding bus connected to each section. The key requirements for grounded conductors at service equipment are as follows:

- It must be bonded to each disconnecting means enclosure.
- The grounded conductor must be routed with the ungrounded conductors.
- It must not be smaller than the required grounding electrode conductor with the specified size in Table 250.102(C)(1). Table 250.102(C)(1) with accompanying notes was new in the 2014 *NEC* and had minor revisions in the 2017 cycle.
- It is not required to be larger than the largest ungrounded service-entrance conductor(s).
- For service-entrance ungrounded conductors larger than 1100 kcmil copper or 1750 kcmil aluminum, the grounded conductor shall not be smaller than 12½ percent (0.125) of the circular mil area of the largest set of service-entrance ungrounded conductor(s) [see

Table 250.102(C)(1) Note 1].

- Where the service-entrance ungrounded conductors are installed in parallel in two or more raceways, the minimum size of the grounded service conductor must be based on the area of the ungrounded service conductors in each raceway (see figure 4.9).
- The ampacity of the grounded conductor of a 3-phase, 3-wire delta service cannot be less than the ampacity of the service-entrance ungrounded conductors.
- Section 250.36 provides requirements for high-impedance grounded neutral systems grounding connection requirements.

In addition to providing the return portion of the circuit for unbalanced loads, the grounded service conductor provides a key part of the vital low-impedance path for ground-fault current to return to the source. The system grounded conductor must be run to each service disconnecting means enclosure, connected to the grounded (neutral) conductor terminal bar, and be bonded to the enclosure through a main bonding jumper, regardless of whether or not it is needed for the service or is used to supply a load (see figure 4.2).

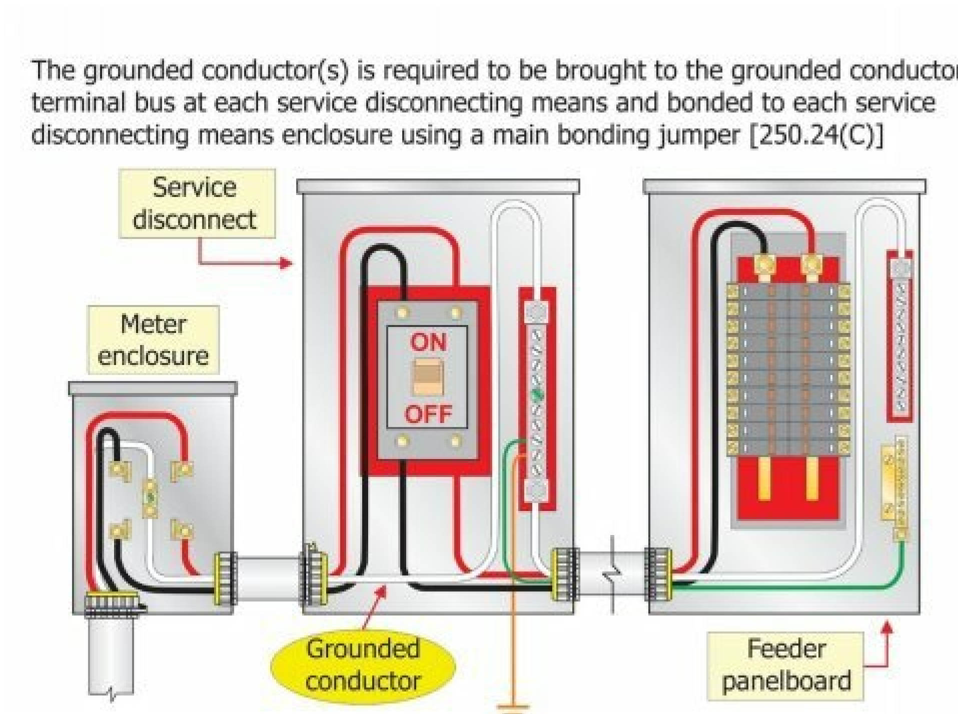


Figure 4.2 Grounded conductor is required to be run to each service disconnecting means enclosure

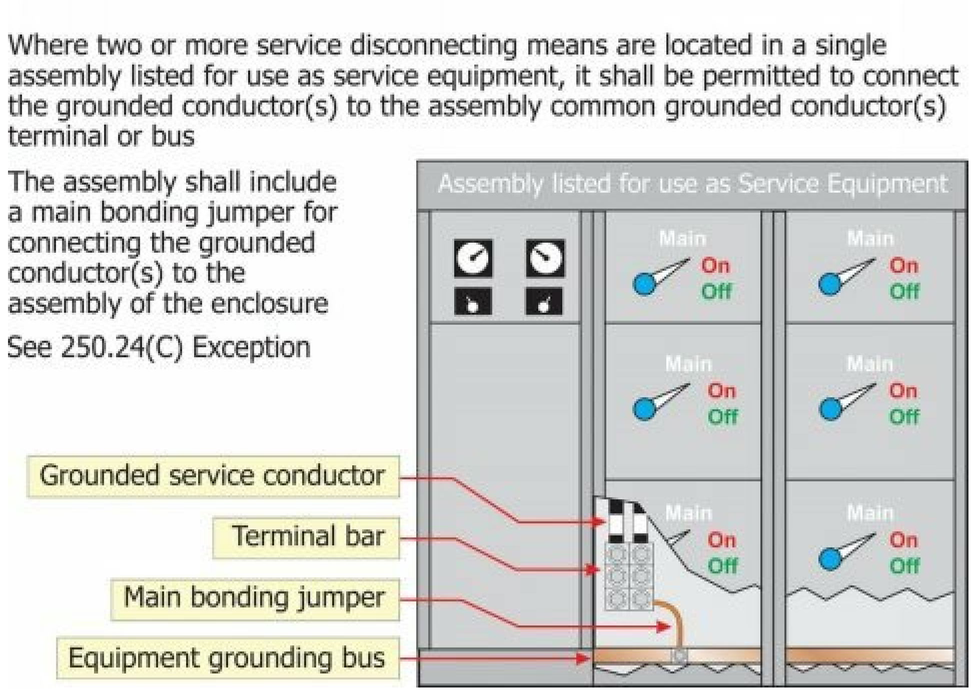


Figure 4.3 Grounded conductor to multi-section equipment that is suitable for use as service equipment (connected to the enclosure at one point).

Figure 4.4 illustrates a 3-phase service supplied from a grounded system where a ground fault has occurred. In the top drawing of figure 4.4, the grounded conductor was not installed since only 3-phase or phase-to-phase connected loads are supplied. If the grounded conductor is not run to the service, as required in 250.24(C), a ground-fault circuit of high impedance is present as shown by the dashed lines. This is also a violation of 250.4(A)(5) and it becomes virtually impossible to clear a ground fault, thus introducing an unnecessary hazard in the system.

However, the installation complies with 250.24(C) if the grounded conductor is run to service as shown in the lower drawing of figure 4.4. A low-impedance ground-fault path is provided as required by 250.4(A)(5) and the safety of the system is improved immeasurably. Since the grounded conductor is there only to provide a ground-fault path, the size of the conductor to be run will depend on the size of the phase conductors in the service. This conductor must not be smaller than the required grounding electrode conductor specified in Table 250.66. The sizing requirements for single or parallel service grounded conductors are in 250.24(C)(1) and (C)(2) and Table 250.102(C)(1).

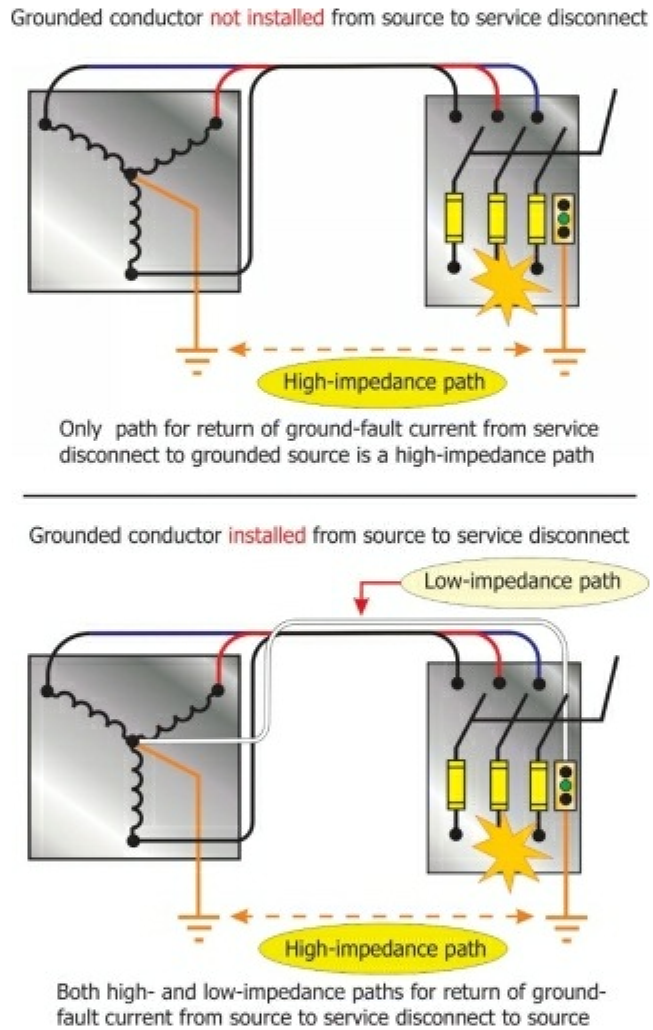


Figure 4.4 High-impedance return path as compared to the required low-impedance return path to source

Figure 4.5 represents a 3-phase, 4-wire delta system with the midpoint of one transformer grounded. Such systems are intended to supply, economically, both a 3-phase, 3-wire power service, and a single-phase, 3-wire lighting service from one transformer bank. The lighting transformer must be big enough to supply the entire lighting load plus its portion of the three-phase power load. The other transformers are sized to carry only their portions of the 3-phase, 3-wire load.

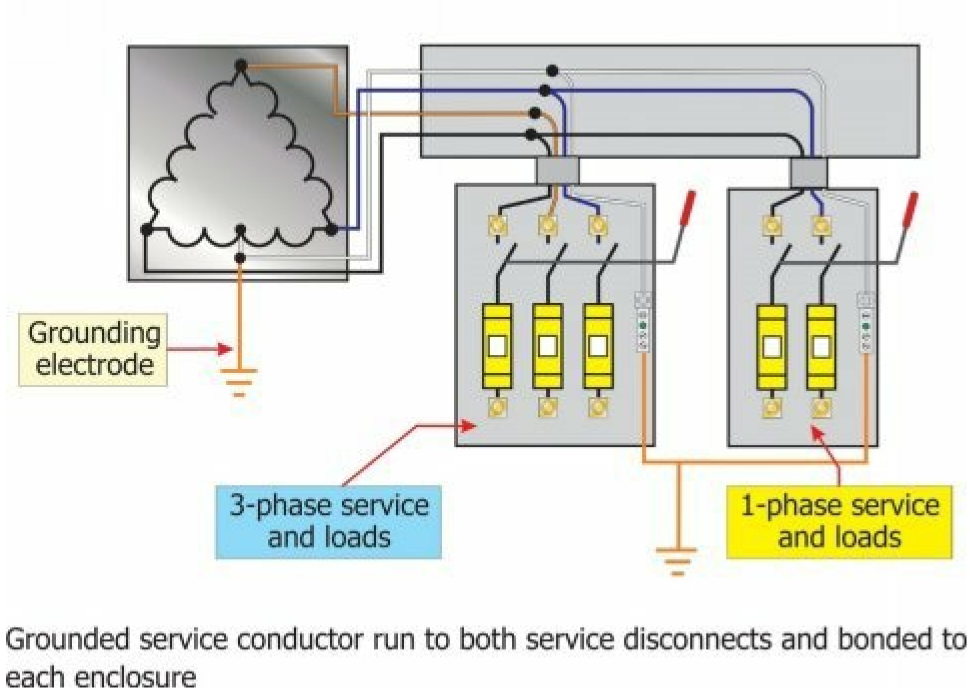


Figure 4.5 Power and lighting service disconnects for three-phase system

Though two separate service disconnects are shown for illustration purposes, all loads could be supplied from a single 3-phase, 4-wire disconnect, switchgear, switchboard or panelboard. Where this is done, the electrician needs to exercise caution in making connections for 120-volt loads. These loads must be connected to only the A and C phases as the B phase will have a voltage to ground of approximately 208 volts, which is enough to severely damage equipment designed to operate at 120 volts. Note that some utilities will supply the higher voltage phase as the “C” phase due to metering connections and this higher voltage phase needs to be transitioned to the “B” phase to comply with the *NEC*.

In figure 4.5 for the 3-phase, 3-wire service, the neutral is not used for voltage or phase purposes. This is true where no line-to-neutral loads are supplied. However, it is still required to install the grounded conductor of the supply system to the three-phase service equipment and to use the main bonding jumper to satisfactorily clear a ground fault that can develop in the service equipment or in equipment that is supplied by the service. The same is also true for the single-phase service but for this service the neutral also must carry normal neutral current.

Location of Service Grounding Connection

Section 250.24(A) requires that a grounding electrode conductor be used to connect the grounded service conductor to a grounding electrode. The connection to the grounded service conductor must be "at an accessible point from the load end of the overhead service conductors, service drop, underground service conductors, or service lateral to and including the terminal or bus … at the service disconnecting means" [see 250.24(A)(1)]. These locations include current-transformer enclosures, meter enclosures, pull and junction boxes, busways, auxiliary gutters and wireways as well as switchgear, switchboards, panelboards or motor control centers (see figure 4.6). Where there are multiple service enclosures, it is also permissible to make the service grounding connections within each service disconnecting means enclosure or within the wireway. The means and methods of connecting and sizing grounding electrode conductors are covered in chapter seven.

Many inspection authorities and serving utilities will not permit the grounding electrode connection to the system grounded conductor to be within current-transformer cans, meter enclosures, or other enclosures that are sealed by the utility. They interpret that connection to be no longer accessible, as utilities seal the metering equipment to prevent unauthorized access. On the other hand, some utilities require the connection of the grounding electrode conductor to be at the weatherhead or within the metering enclosure. It is important that the AHJ and the serving utilities are consulted before beginning a project to be certain their system grounding and access policies are complied with.

The most practical and commonly accepted location for the grounding electrode conductor connection to the grounded service conductor is within the service disconnecting means enclosure or within a wireway that is not sealed at the service equipment location. The basic requirement is that this connection be made to the neutral bus. An exception permits the connection of the grounding electrode conductor directly to the equipment grounding bus where the main bonding jumper is a wire or busbar that is directly connected to both the equipment grounding bus and the neutral bus [see 250.24(A)(4)]. The grounding electrode conductor could also be run up the side of a building and connected to the grounded conductor, on the load end of the service point, where the service grounded conductor was spliced to the utilities service drop. Some believe this provides better protection from lightning transients by diverting the lightning current without having it enter the building.

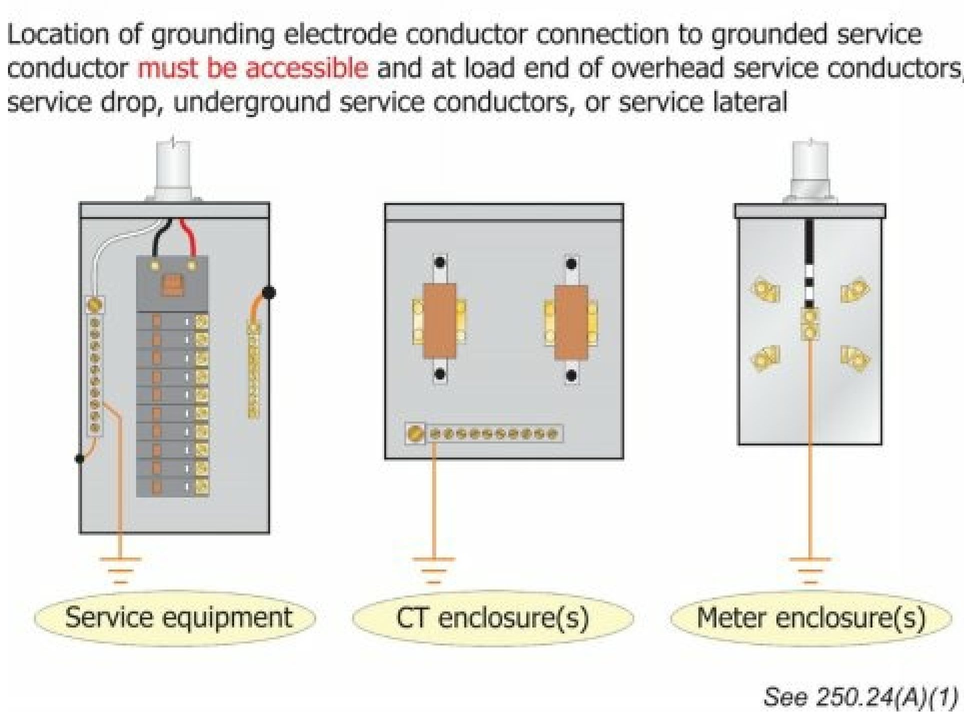


Figure 4.6 Service grounding electrode conductor connection locations are required to be accessible.

Where the service is supplied by a transformer located outside the building, an additional grounding connection to an electrode must be made outside the building, at the transformer. This connection is usually provided by the electric utility.

Section 250.24(A)(5) prohibits grounding of that system's grounded circuit conductor (often a neutral) at any point beyond the service. This prevents neutral current being imposed on unintended paths such as metal piping, cable trays, cable sheaths, and so forth. Three unique and specific exceptions to this requirement are provided in the informational note that follows 250.24(A)(5), several of which will be covered in later chapters. An additional grounding connection beyond the service is permitted: (1) an exception for separately derived systems, (2) existing installations where more than one building or structure on the same premises are supplied by a feeder or branch circuit, and (3) for existing circuits for electric ranges and dryers. The use of the words "grounded circuit conductors" is intended to cover all such conductors whether they are feeders or branch circuits.

Sizing and Routing of Grounded Service Conductor

The basic requirements for sizing of the grounded service conductor (often the neutral) varies with the load as calculated in accordance with 220.61. This becomes the minimum size grounded service conductor unless modified by 250.24(C)(1) or (C)(2).

First, a load calculation should be performed in accordance with 220.61 to determine the minimum size for the anticipated neutral load. Second, a conductor size must be determined from 250.24(C)(1) or (C)(2). Section 250.24(C)(1) requires the service grounded conductor to be sized per Table 250.102(C)(1), or per Note 1 to Table 250.102(C)(1), be 12-1/2 percent of the size of the service-entrance conductors. The final minimum service grounded conductor size must be the larger as determined from these two calculations. To bring more clarity for *NEC* users, the 2014 *NEC* cycle introduced revisions to consolidate several similar sections for sizing the grounded service conductor, the main bonding jumper, the system bonding jumper and the supply side bonding jumper. While the requirements were essentially the same, the actual wording was found to be slightly different creating some confusion. In addition, confusion was raised for these sizing requirements always referring to a table that was identified for sizing the grounding electrode conductor and related the sizing to service-entrance conductors. The introduction of the new Table 250.102(C)(1) and accompanying notes made that language and requirements for all these different applications consistent and eliminated some of the confusion found from the previous editions of the *Code.* This table will be used here and will be referred to in future chapters for sizing of the other conductors indicated in the title of the table.

For example, if a 400-ampere service is to be installed from a grounded system, 500 kcmil copper conductors are selected for the ungrounded service conductors. Table 250.102(C)(1) shows that the grounded service conductor can be no smaller than 1/0 copper or 3/0 aluminum. This conductor must be routed with the phase conductors and be bonded to the disconnecting means enclosure.

This is the minimum size grounded service conductor permitted but it may need to be larger based on the 220.61 calculation, and it must be installed as noted even though there is no neutral load on the system or if the calculated neutral load would permit a smaller conductor.

It is important to note that the minimum size of the grounded service conductor that must be run to the service disconnecting means is based on the size of the ungrounded (phase) service-entrance conductors and not on the rating of the circuit breaker or fuse that is installed in the service (see figure 4.7). It is helpful to remember that Table 250.102(C)(1) generally applies up to the service overcurrent device, and Table 250.122 applies beyond the service overcurrent device.

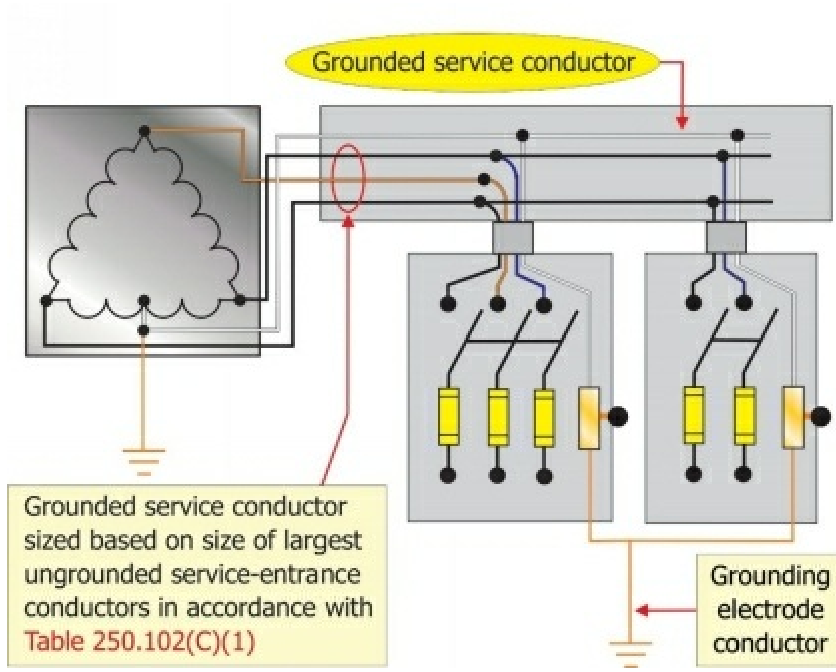


Figure 4.7 Minimum size of grounded service conductor

Dwelling Unit Services and Feeders

Special rules or provisions for sizing dwelling unit service-entrance conductors and a specific feeder are provided in 310.15(B)(7). These rules apply not only to 120/240-volt, 3-wire, single-phase dwelling services and the main power feeder, but new for the 2017 *NEC*, these rules can be applied to 208Y/120 volt single-phase systems as well. By following the conditions of the section, the specified size of service-entrance or main power feeder conductors determined by 310.15(B)(7)(1) through (4) are permitted to be used based on the standard ampacity ratings from 240.6(A) for the service or feeder rating. The application for the 208/120 volt dwelling unit supplies are only for single-family dwellings and individual units of two-family and multifamily dwellings.

For 120/240-volt, 3-wire, single-phase systems, the grounded conductor (often a neutral) is permitted to be smaller than the ungrounded (phase) conductors provided the rules of 215.2, 220.61, and 230.42 are met. The reduction in the neutral conductor is not allowed when the feeder is 208Y/120-volt single phase.

Section 215.2 provides that the feeder neutral must be adequate for the load, must be a minimum size for certain loads, and does not have to be larger than the service-entrance conductors that supply them.

Section 220.61 provides the method for calculating the feeder neutral load. The basic requirement is that the neutral conductor must carry the maximum unbalanced load from the ungrounded conductors.

Section 230.42 requires that service-entrance conductors be of sufficient size to carry the loads as calculated by Article 220. For grounded conductors in 230.42(C), the conductor cannot be smaller than required by 250.24(C).

Note that for dwelling unit services and feeders, the previous permission to size the grounded conductor not more than two sizes smaller than the ungrounded conductors given in 310.15(B)(7) has been deleted from the *Code*. As a result, the grounded system conductor now has to be sized according the above rules. It should also be noted that the feeders under 215.2 and sized per 220.61 have a separate equipment grounding conductor installed for fault current so that grounded conductor only carries the neutral current.

Parallel Service Conductors

Where parallel service-entrance conductors as permitted by 310.10(H) are installed, the minimum size grounded service conductor is determined by multiplying the circular mil area of the ungrounded conductors installed by the number of conductors installed in parallel. Installing conductors in parallel means connecting two or more conductors together at each end to form one conducting path (see figure 4.8). This is usually done for economic and practical reasons. As can be seen in Table 310.15(B)(16), the ampacity of conductors does not increase in proportion to their size. Additionally, terminating multiple smaller conductors is easier than terminating larger ones.

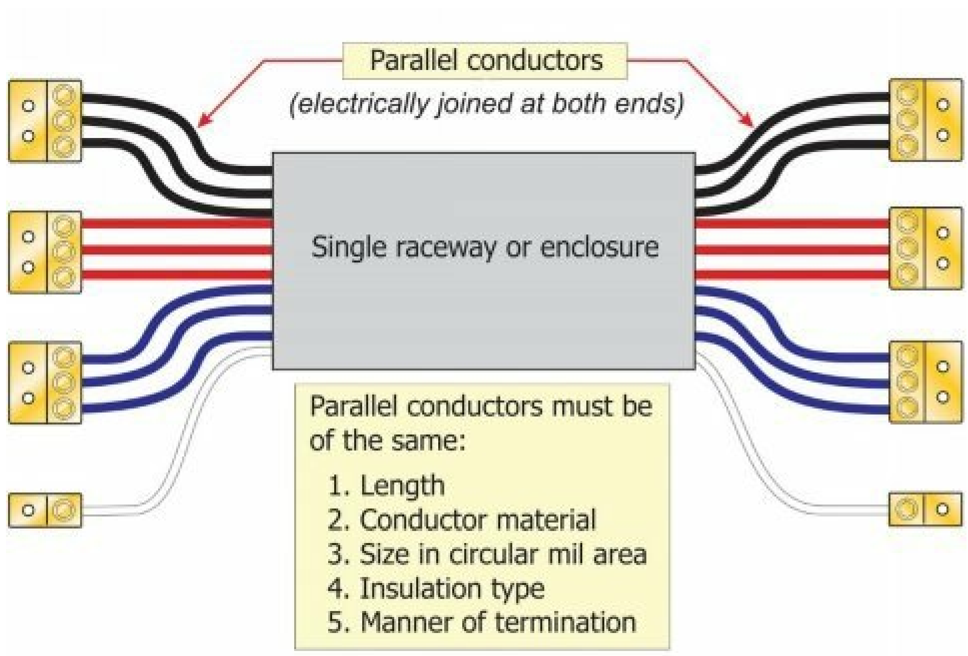


FIGURE 4.8 Parallel service conductors (all in the same raceway or enclosure)

Example No. 1. Given: Three 4/0 AWG copper conductors per phase are installed in parallel. Before multiplying the conductor size (4/0), it must be converted from the American Wire Gauge (AWG) 4/0 designation to the circular mil area.

Refer to *NEC* Chapter 9, Table 8 to determine the circular mil area of the 4/0 AWG conductors. There we find the area to be 211,600 circular mils.

3 x 211,600 = 634,800 circular mils

By referring to Table 250.102(C)(1) (Over 600 through 1100), we find the minimum size grounded service conductor is 2/0 AWG copper or 4/0 AWG aluminum.

This example assumes that all of the conductors are installed in the same raceway. This may not be practical due to the requirement that the ampacity adjustment factors of Table 310.15(B)(3)(a) be applied. This obviously has the effect of requiring larger conductors to be installed than if the individual sets of service-entrance conductors were installed in separate raceways. Where conductors are installed in sheet-metal wireways, applying the adjustment factors may be avoided if the number of conductors does not exceed 30 and the conductors do not fill more than 20 percent of the square-inch area (see 376.22 for additional information).

Where installed in separate metal raceways, 300.3(B) requires that the grounded conductor (often a neutral) must be installed in each raceway (see figure 4.9). In this case, 310.10(H) requires that the paralleled conductors not be smaller than 1/0 AWG, so the minimum size service grounded conductor permitted in parallel is 1/0 AWG.

Example No. 2

If six 4/0 AWG copper conductors are installed in parallel, the minimum size grounded service conductor is determined as follows:

As explained above, the area of a 4/0 AWG conductor (211,600 circular mils) in *NEC* Chapter 9, Table 8 is used.

6 x 211,600 = 1,269,600 circular mils

Since the total conductor area exceeds the 1100 kcmil for copper conductors given in Table 250.102(C)(1), Note 1 in Table 250.102(C)(1) must be followed. There we find a requirement that the grounded service conductor be not smaller than 12 ½ percent (0.125) of the equivalent area for parallel conductors.

1,269,600 x 0.125 = 158,700 circular mils

By again referring to Chapter 9, Table 8, observe that the conductor that is the next size larger than 158,700 circular mils is a 3/0 AWG conductor, which has a circular mil area of 167,800.

This example also assumes that all the service-entrance conductors are installed in the same raceway, which, due to ampacity adjustment requirements, may not be practical.

Again, where installed in separate metal raceways, a grounded service conductor must be installed in each raceway and must not be smaller than 1/0 AWG. The grounded service conductor must also comply with 230.42(A). This section requires that the conductor be adequate to carry the load as determined by Article 220.

Section 220.61 requires that the neutral be sized for the maximum unbalance of the load. Examples of neutral conductor load calculations are found in Annex D of the *National Electrical Code*. In addition, where the length of run of the grounded conductor from the transformer to the service equipment is long, the size of grounded conductor should be increased.

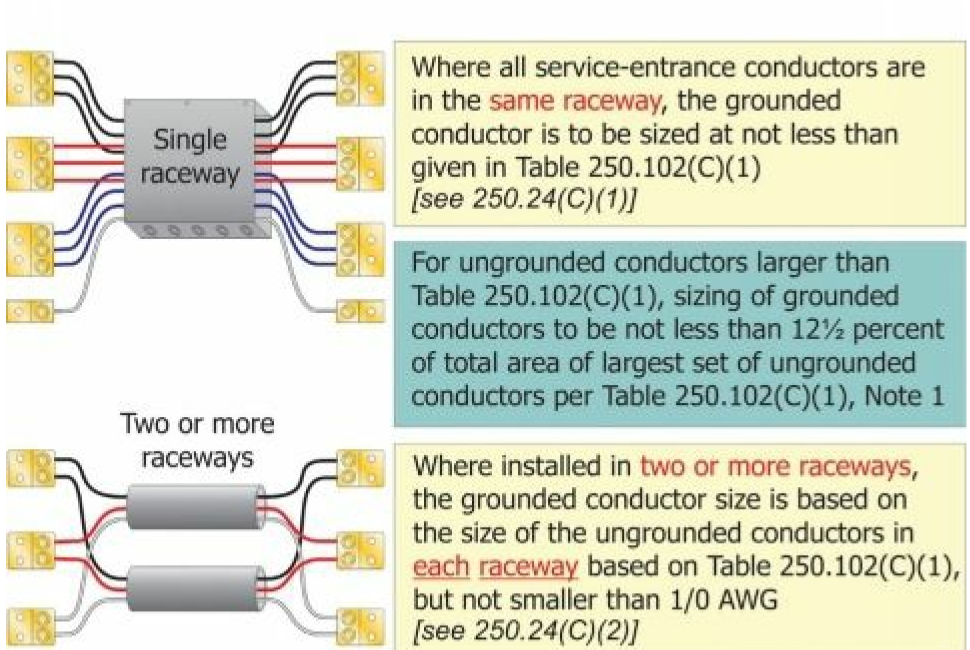


FIGURE 4.9. Parallel service conductors installed in separate raceways or enclosures

Underground Parallel Service Conductors

As illustrated in figure 4.10, for underground installations in nonmetallic raceways, it is permitted by 300.3(B)(1) Exception to install all the conductors of each phase in the same raceway. This is also permitted in 300.5(I) Exception No. 2. All the ungrounded conductors of phase A are installed in one raceway, phase B in another, C in the third, and the grounded service conductors in another. This method is often chosen to allow phase conductors to readily line up with bus terminations in bottom-fed switchboards. As can be seen in the illustration, this reduces the "rat's nest" in the bottom of these enclosures caused by many conductors crossing each other for termination.

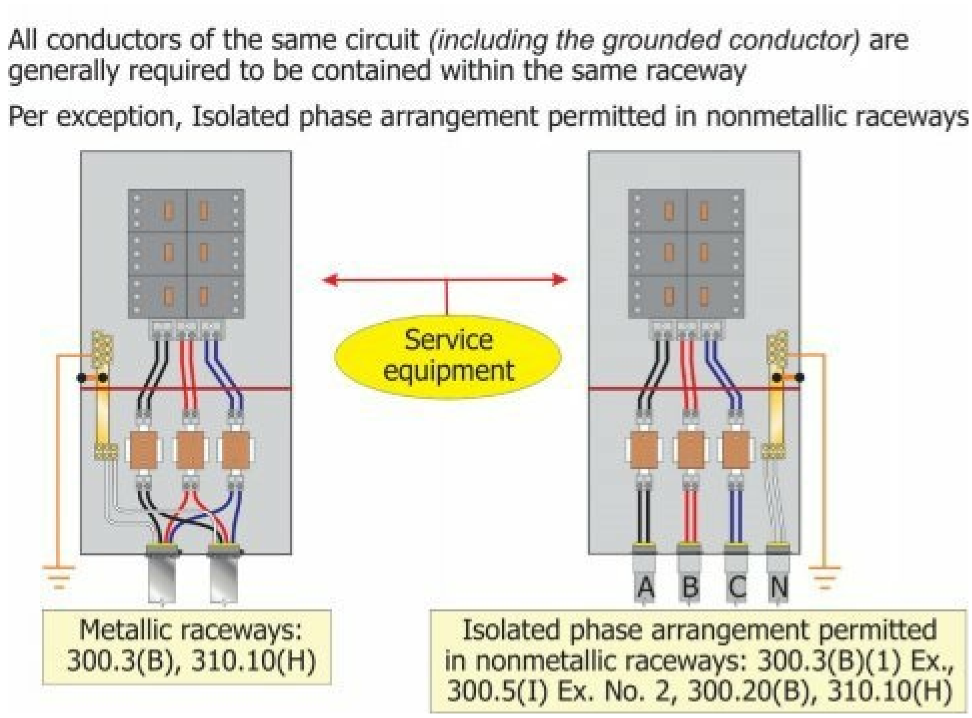


Figure 4.10 Parallel conductors installed in raceways (phases together in the same raceway and individual phases in separate raceways)

Another advantage is that it is much easier to comply with the requirement that parallel conductors be the same length. When this type of installation is made, care must be taken to eliminate the inductive heating of metal enclosures with magnetic properties by cutting a slot in the metal between the conduit entries or arranging for the manufacturer of the equipment to install a non-ferrous metal plate in the bottom of the equipment where the conduits terminate [see 300.20(A) and (B)]. Usually, a slot cut the width of a single hacksaw blade has proven to be adequate to provide the desired relief. Another option is to terminate these conduits above the floor in the compartment of an open-bottom, floor-standing switchboard.

See 408.5 where the conduit or raceways, including their end fittings, are not permitted to rise more than three inches above the bottom of the enclosure.

Multiple Services to One Building

Section 230.2 permits several services to one building under one of several conditions given. Each service that is supplied from a grounded system must be provided with a grounded service-entrance conductor. The size of the ungrounded service-entrance conductor for each service determines the minimum size of grounded service conductor for that service. Each service is considered individually for sizing the grounded service conductor to it.

For example, a building has a 400-ampere, 480-volt 3-phase and a 100-ampere 120/240-volt service (see figure 4.11). The service conductors in the example are aluminum, and the minimum size of grounded service conductor is determined as follows:

- 400-ampere service
- 750 kcmil THW aluminum ungrounded service conductors
- Table 250.102(C)(1) = 1/0 AWG copper or 3/0 AWG aluminum grounded service conductor
- 100-ampere service
- 2 AWG copper ungrounded service conductors
- Table 250.102(C)(1) = 8 AWG copper or 6 AWG aluminum grounded service conductor

It is emphasized that this method determines only the minimum size of grounded service conductor to comply with 250.24(C). A larger conductor may be required to carry the maximum unbalanced load on the neutral conductor as determined by 220.61.

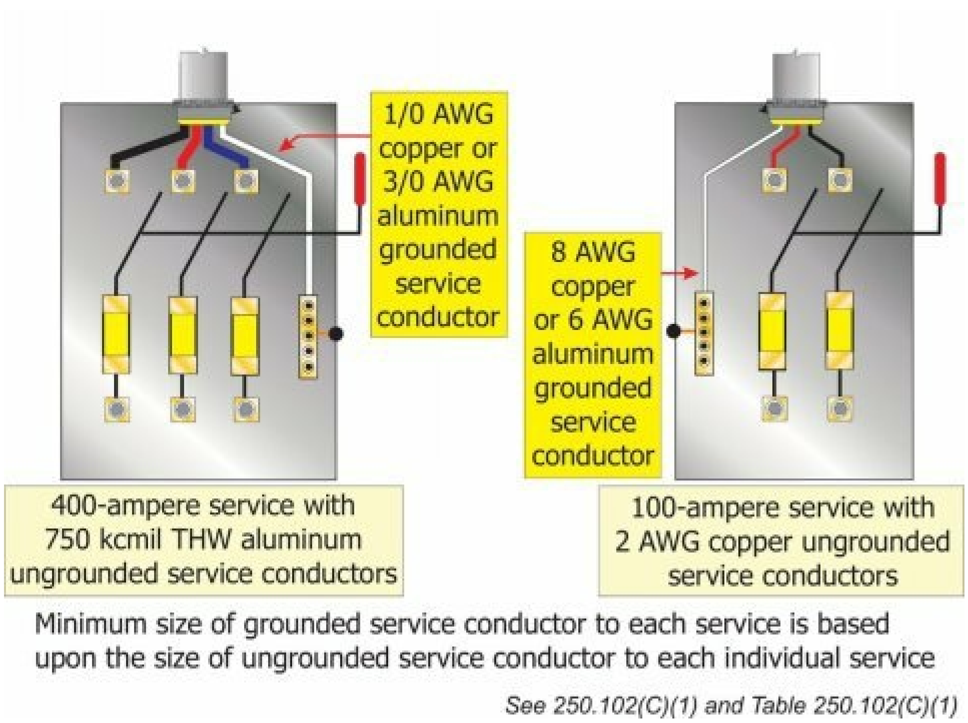


Figure 4.11 Two services to a building or structure from a grounded system (sizing grounded conductor)

High-Impedance Grounded Systems

Continuous industrial process plants and other continuous operations such as data centers often need uninterrupted electrical power and systems. It is quite common to see these plants located near a power company substation and to have more than one high-voltage service supply to improve system reliability.

Another step that is commonly taken to improve system reliability is to install high-impedance grounded neutral systems rather than solidly grounded systems. Advantages include improved reliability, the ability to have ground-fault relaying that alarms rather than trips, as well as fewer problems to the system from transient overvoltages.

Three conditions must be met before the *Code* will permit high-resistance grounded neutral systems to be installed. They are as follows:

- Qualified persons must be available to service and maintain the system.
- Ground detectors must be installed to indicate an insulation failure.
- line-to-neutral loads are not served.

Specific rules are provided in 250.36 for installing these systems. The grounding impedance, usually a resistor, is installed between the transformer supplied grounded service-entrance conductor and the grounding electrode. Usually, the impedance device is sized to a value greater than the capacitive charging current of the system. For 480-volt systems, this is usually about 10 amperes. This current level provides enough separation so that a fault will still be detected at a minimal damage level while normal charging current would not be detected causing false alarms.

A fully insulated grounded service-entrance conductor must be run to the impedance device. This conductor must have an ampacity not less than the maximum current rating of the grounding impedance. The minimum size grounded service conductor cannot be smaller than 8 AWG copper or 6 AWG aluminum or copper-clad aluminum [250.36(B)]. Since the grounding impedance will limit the fault current of the first line-to-ground fault to a low value, usually 10 amperes or less, the minimum size of neutral conductor is primarily related to the ability to withstand mechanical damage, not to its current-carrying capabilities (see figure 4.12).

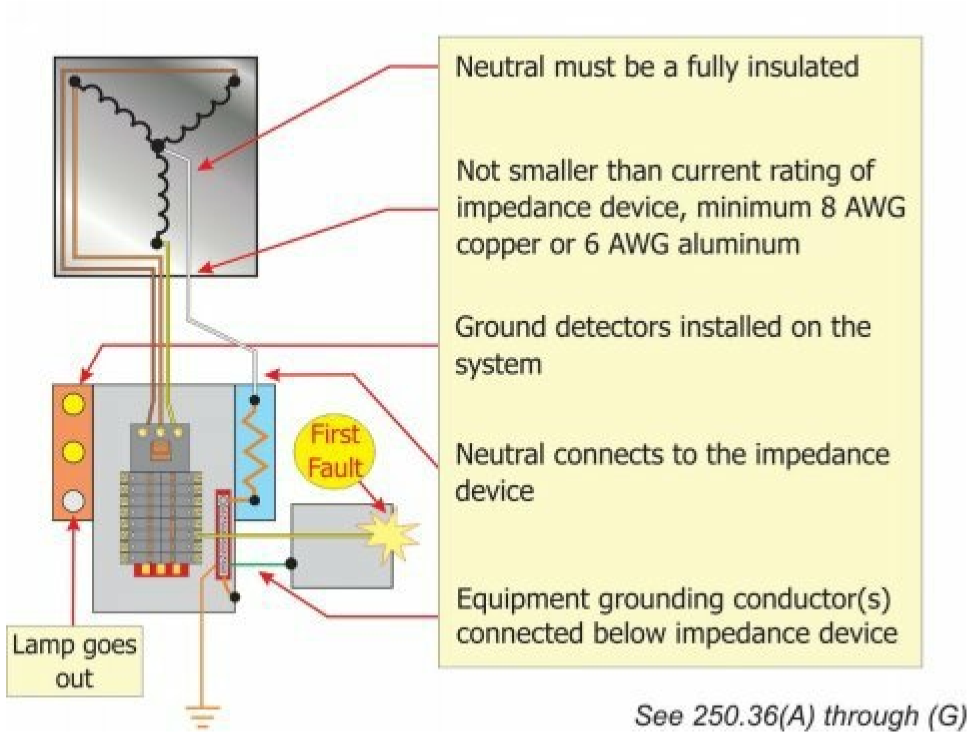


Figure 4.12 High-impedance grounded system fundamentals. See 250.36(A) through (G).

It is not required that the grounded service conductor be routed with the ungrounded service-entrance conductors since it will carry very little current in the event of a fault [see 250.36(D)]. At the service, it is connected to the impedance device that may be located outside the service enclosure to dissipate heat. An unspliced supply-side bonding jumper is installed from the load side of the impedance device to the service enclosure where a terminal bar is installed for connection of equipment grounding conductors [see 250.36(E)]. The grounding electrode conductor is permitted to be connected to any point from the grounded side of the grounding impedance to the equipment grounding connection at the service equipment or the first system disconnecting means [see 250.36(F)].

This type of system is designed to limit the fault current on the first ground fault that might occur on the system. As can be seen in figure 4-12, the impedance device is in series with the first ground fault. The electrical system will continue to function normally with the first ground fault present on the system. The ground-detection system will indicate the presence of the faulted condition by either a visual or audible signal or both. This is intended to alert qualified maintenance personnel of the ground-fault condition so corrective action can be taken, hopefully during a period the plant is not planned to be in operation (see photo 4.1).

Photo 4.1 Equipment for high-resistance grounded neutral systems
(Photo courtesy of Post Glover)

One difference from the ground-detection scheme on an ungrounded system is that the faulted circuit can be identified without shutting the plant down. But just like an ungrounded system, a second ground fault (illustrated in figure 4.13) that occurs before the first fault is cleared will be a line-to-line or phase-to-phase fault that would be cleared by the service or feeder overcurrent device, which will result in a power outage. This can, and at times has, involved two pieces of equipment in separate parts of the plant supplied by different feeders. In this situation, there can be a great deal of current in the equipment grounding circuit between the faults that can cause extensive damage to electrical equipment. Every metal conduit locknut and fitting connection must be wrench tight to avoid arcing.

Ungrounded Systems

Ungrounded systems that experience a ground fault are subject to relatively severe transient overvoltages that can reach several times normal voltage to ground (see chapter eleven for more information on this subject). Such abnormal voltages become potential hazards and often cause insulation failure and equipment breakdowns in other parts of the system. If a system has one conductor purposely grounded and is thus a grounded system, the value of such transient over-voltages as they develop is greatly reduced.

An ungrounded system must have its conductor and equipment enclosures connected to a grounding electrode system at the building or structure served (see figure 4.14). This keeps such enclosures as near to ground potential as possible and reduces shock hazards to a minimum. These service equipment enclosures are grounded by connecting them to a grounding electrode system per 250.24(E). Grounding electrodes and grounding electrode systems are covered extensively in chapter six.

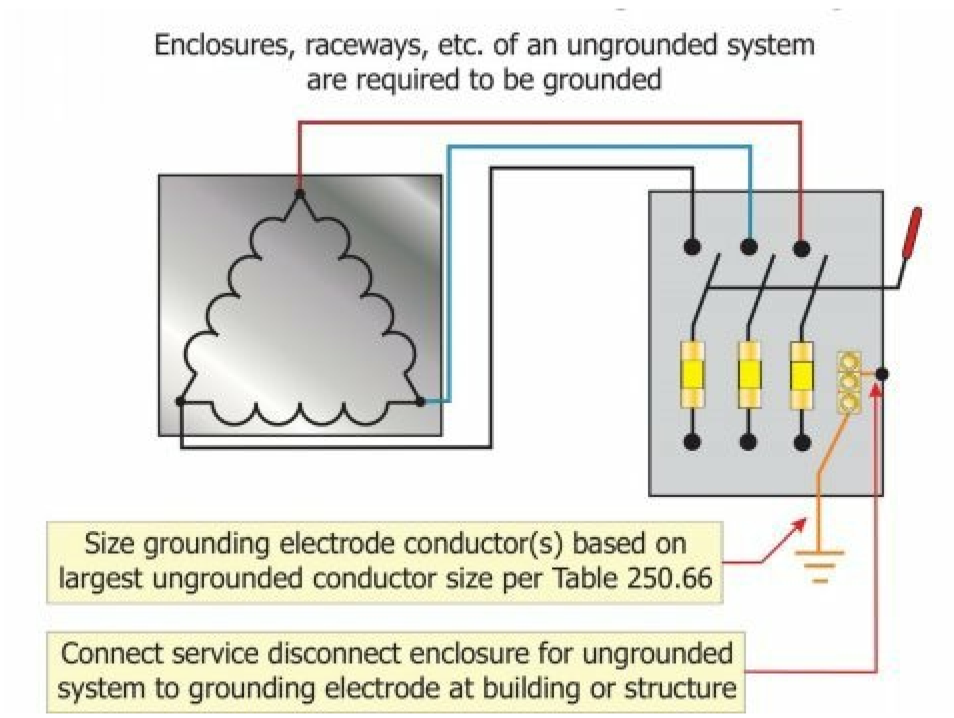


Figure 4.14

Hazard of Services without a Grounded Conductor Supplied from a Grounded System

Figure 4.15 illustrates the hazard of operating a service from a grounded system without installing a grounded service conductor. The original ungrounded service on the right in the figure existed before the service on the left was installed. The first and original service was supplied by an ungrounded utility system. The service and feeder shown supplying equipment were protected by large overcurrent devices. Sometime later, the service on the left, which included a grounded service conductor, was installed.

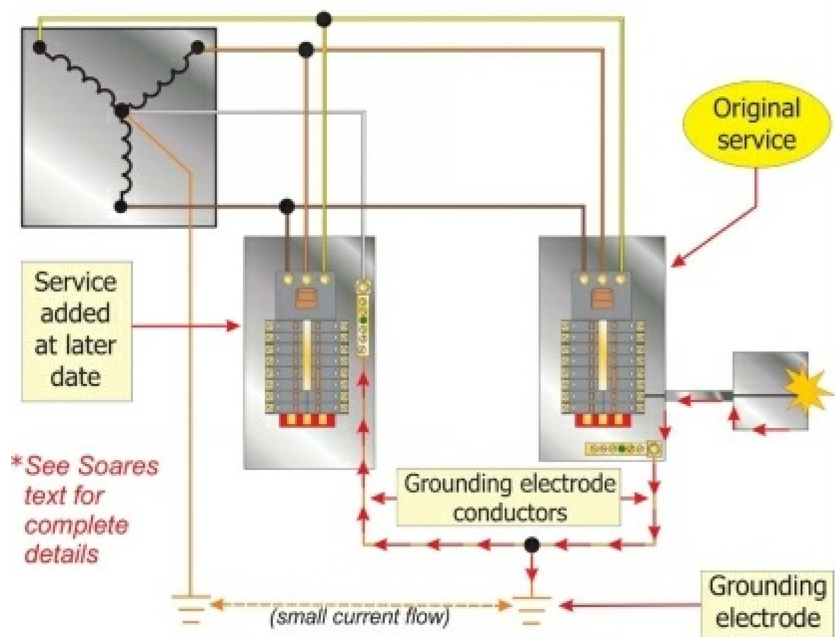


Figure 4.15 Hazard(s) of supplying an ungrounded service from a grounded system without a grounded conductor

At that time, the serving utility grounded the transformer bank and extended a grounded service conductor to the new service weatherhead. However, the grounded service conductor was not extended nor connected to the older, existing service disconnecting means. The older, existing service, which supplied only 3-phase equipment loads, continued to supply power to a portion of the building, though without a grounded conductor connection.

The two services were connected with properly sized grounding electrode conductors to a common grounding electrode system that included a metal water piping system.

Sometime later, a ground fault occurred in the equipment being supplied from the original ungrounded service equipment. Since the system supplying the equipment was now grounded, current attempted to return to the source of power to complete the circuit. The grounding electrode conductor was forced to carry current from the ungrounded service to the grounding electrode, through the grounding electrode to the newer grounded service, where the fault current returned to the transformer bank through the grounded service conductor. In this and similar situations, the current will return to the system through all available paths such as the earth shown by the dashed line. The current will divide among the paths based upon the impedance of the paths that are available.

Grounding electrode conductors are not designed or installed for the significant amount of current they had to carry in this case, which caused the conductors to get extremely hot. The resulting fire burned a great deal of the industrial plant to the ground.

The action necessary to have prevented the fire as a minimum was to install a properly sized grounded service conductor to the existing service when the new service from a grounded supply system was installed. That conductor should have been extended to the service disconnecting means and bonded to it as required in 250.24(C). The grounded service conductor would have provided a low-impedance path back to the transformer bank and would have allowed the overcurrent devices to clear the ground fault without extensive damage. In addition, if this were a 480Y/277 volt service over 1000 amperes, adding ground-fault protection for equipment may have also helped to minimize the damage from the ground fault. Methods of clearing ground faults and short circuits are discussed in detail in chapters eleven and fourteen.

Review Questions

1. The grounded service conductor is required to be run to each ac service disconnecting means where they operate at ____ volts or less and are grounded at any point.

   1. 2000
   2. 1500
   3. 1000
   4. 1200

2. Where an AC system operating at ____ volts or less is grounded at any point, the grounded conductor is required to be bonded to each disconnecting means enclosure.

   1. 1500
   2. 1200
   3. 2000
   4. 1000

3. Where an AC system operating at ____ volts or less is grounded at any point, the grounded conductor is required to be ______ with the ungrounded conductors.

   1. 1000, routed
   2. 1200, looped
   3. 1300, wrapped
   4. 2000, routed

4. Where an AC system is installed in a single raceway and operating at ______ volts or less is grounded at any point, the grounded conductor cannot be smaller than specified in Table _____.

   1. 1000, 250.66
   2. 1000, 250.102(C)(1)
   3. 1200, 250.66
   4. 2000, 250.102(C)(1)

5. For sets of ungrounded service-entrance conductors larger than 1100 kcmil copper or 1750 kcmil aluminum, the grounded conductor cannot be smaller than ____ percent of the area of the largest service-entrance phase conductor.

   1. 12 ½
   2. 14 ½
   3. 13 ¾

4. 12

6. If the ungrounded service-entrance conductors are installed in ____, the size of the grounded service conductor is required to be based on the equivalent area of the ungrounded service conductors in each raceway.

1. a raceway
2. a trench
3. parallel
4. a cable tray

7. Where two or more service disconnecting means are located in a single common assembly listed for use as service equipment, only one grounded conductor is required to be run to the assembly. It is permitted to ____ to the disconnecting means grounded conductor terminal or bus.

1. be sized at 8 AWG and bonded
2. not be bonded
3. be connected
4. be sized at 6 AWG and bonded

8. Some utility policies prohibit a grounding electrode conductor connection within metering equipment, and many inspection authorities prohibit that connection location because they interpret the connection to be no longer ____.

1. accessible
2. identified
3. serviceable
4. visible

9. The grounding electrode conductor connection to the grounded service conductor is usually made within the service disconnecting means and is connected to the ____ terminal or bus within the equipment.

1. unidentified
2. isolated ground
3. floating neutral
4. neutral (grounded conductor)

10. Where the transformer supplying the service is located outside the building, an additional grounding electrode conductor connection to an electrode is required to be made outside the building, usually at the ____.

1. transformer

2. pole
3. meter
4. grid

11. Where copper conductors sized at 500 kcmil are selected for the ungrounded service conductors supplying a 400 ampere service, and are installed from a grounded system, the minimum size of the copper grounding electrode conductor generally shall not be less than ____ AWG if a metal water pipe grounding electrode is used.

1. 8
2. 6
3. 4
4. 1/0

12. Section 310.15(B)(7) requires or permits the grounded service conductor for dwelling services and the grounded conductor for the main power feeder to be ____.

1. sized using Table 250.122
2. smaller than the ungrounded conductors
3. sized to meet the requirements of 215.2, 220.61, and 230.42.
4. both b. and c.

13. The ampacity of the grounded conductor of a 3-phase, 3-wire delta service cannot be less than the ampacity of the ________ conductors.

1. grounding electrode
2. equipment grounding
3. feeder
4. ungrounded

14. Certain conditions must be met before the *NEC* will permit high-impedance grounded neutral systems to be installed. They include ____.

1. qualified persons must be available to service and maintain the system.
2. line-to-neutral loads are not served.
3. ground detectors must be installed to indicate an insulation failure.
4. all of the above.

15. Secondary circuits of current and potential instrument transformers where primary windings are connected to circuits of ____ volts or more to ground and, where on switchboards, are required to be grounded irrespective of voltage.

1. 300

2. 100
3. 200
4. 150

16. Where a switchboard has no live parts or wiring exposed or accessible to other than qualified persons, instrument transformer secondary circuits are not required to be grounded where the primary windings are connected to circuits of ____ volts or less.

1. 480
2. 1000
3. 277
4. 150

17. Instrument transformer cases or frames are required to be grounded where accessible to other than qualified persons. Such cases or frames of current transformers are not required to be grounded where the primaries are not over ____ volts to ground, and the current transformers are used exclusively to supply current to meters.

1. 100
2. 120
3. 130
4. 150

18. The service grounded conductor _______.

1. carries unbalanced load current
2. provides an effective ground-fault path
3. must be connected (bonded) to the service disconnecting means grounded conductor terminal or bus with a main bonding jumper
4. all of the above

19. An ungrounded service must have _______ connected to the metal enclosure of the service conductors.

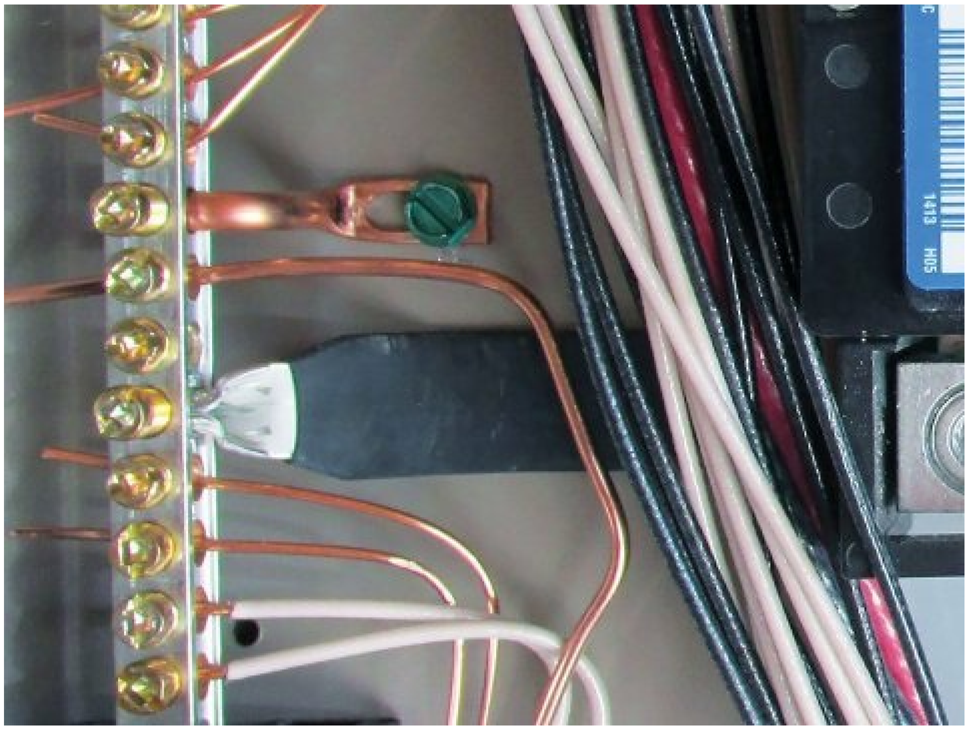
1. the grounded conductor
2. copper conductors
3. a grounding electrode conductor
4. surge protective devices (SPDs)

20. The grounding electrode conductor is generally sized based on the _______

1. largest ungrounded service-entrance or derived phase conductor
2. overcurrent device protecting the phase conductors

3. load calculations in accordance with Article 220
4. number of service disconnecting means

⏚ Chapter 5
Main Bonding Jumpers and Bonding at Services



Objectives to understand

- Definitions of bonding and bonding jumpers
- Functions of main and supply-side bonding jumper
- Sizing of main and supply-side bonding jumpers
- Methods for bonding at service equipment
- Use of neutral for bonding on line side of service
- Requirements for grounding and bonding of remote metering

The main bonding jumper is one of the most critical elements in the safety grounding and bonding system. This conductor is the link between the grounded service conductor, the equipment grounding conductor(s), and, in many cases, the grounding electrode conductor.

The primary purpose of the main bonding jumper is to carry the ground-fault current from the service enclosure and from the equipment grounding conductor system that is returning to the source during ground-fault conditions. In addition, where the grounding electrode conductor is connected directly to the grounded service conductor (neutral) bus, the main bonding jumper ensures that the equipment grounding bus is at the same potential as the earth. Where the grounding electrode conductor is connected to the equipment grounding bus as permitted in 250.24(A)(4), the main bonding jumper completes the earth connection to the grounded (neutral) conductor.

Definitions

Bonding (Bonded). "Connect (connecting) to establish electrical continuity and conductivity."

Main Bonding Jumper. "The connection between the grounded circuit conductor and the equipment grounding conductor at the service."

Supply Side Bonding Jumper. "A conductor installed on the supply side of a service or within a service equipment enclosure(s), or for a separately derived system, that ensures the required electrical conductivity between metal parts required to be electrically connected." [1]

Main Bonding Jumper

For a grounded system, 250.24(B) requires that "… an unspliced main bonding jumper shall be used to connect the equipment grounding conductor(s) and the service disconnect enclosure to the grounded conductor …" of the electrical system. This connection must be made within the enclosure for each service disconnect in accordance with 250.28 (see figure 5.1).

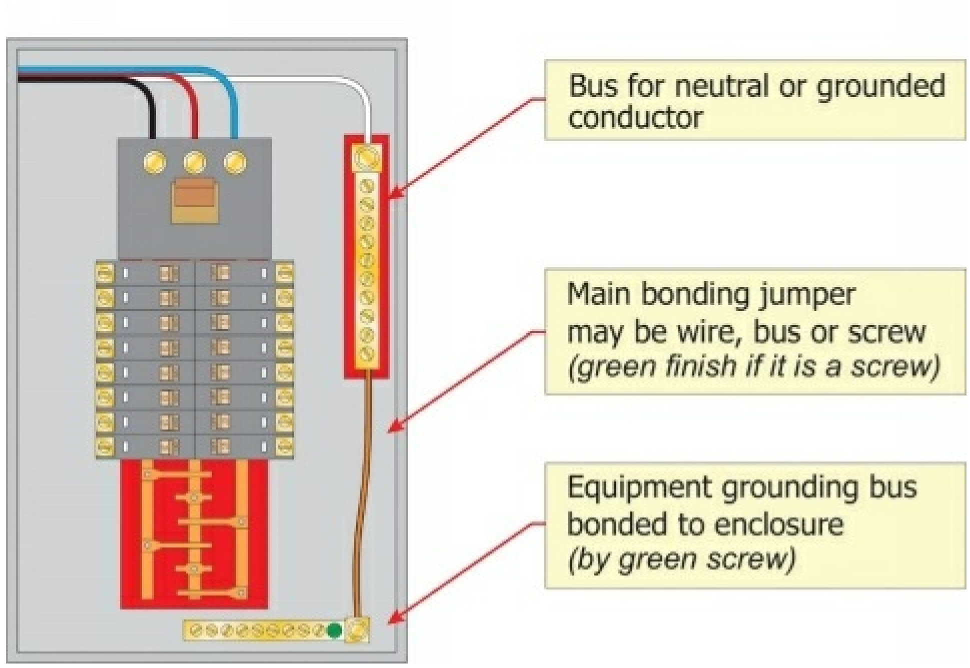


Figure 5.1 Main bonding jumper (at service by definition)

Examples of this are two or more service disconnecting means in individual enclosures that are grouped at one location (see figure 5.2). This type of installation often is made with a wireway or a short section of busway installed downstream from the metering equipment as shown. In other cases, a wireway or short section of busway is installed ahead of metering and is supplied by service conductors. Sets of service-entrance conductors supply each of the service disconnecting means through individual metering. If there are nipples between the disconnecting means and the metal or nonmetallic trough, [the trough meets the definition of a wireway] from Article 376, Metal Wireways, or Article 378, Nonmetallic Wireways, rather than an auxiliary gutter covered by Article 366, Section 250.24(C) applies. Section 250.24(C) requires that the grounded service conductor be installed to each service disconnecting means and be connected to the grounded terminal bar or bus in the equipment and bonded to the service disconnecting means enclosure. The main bonding jumper is the means to accomplish this requirement.

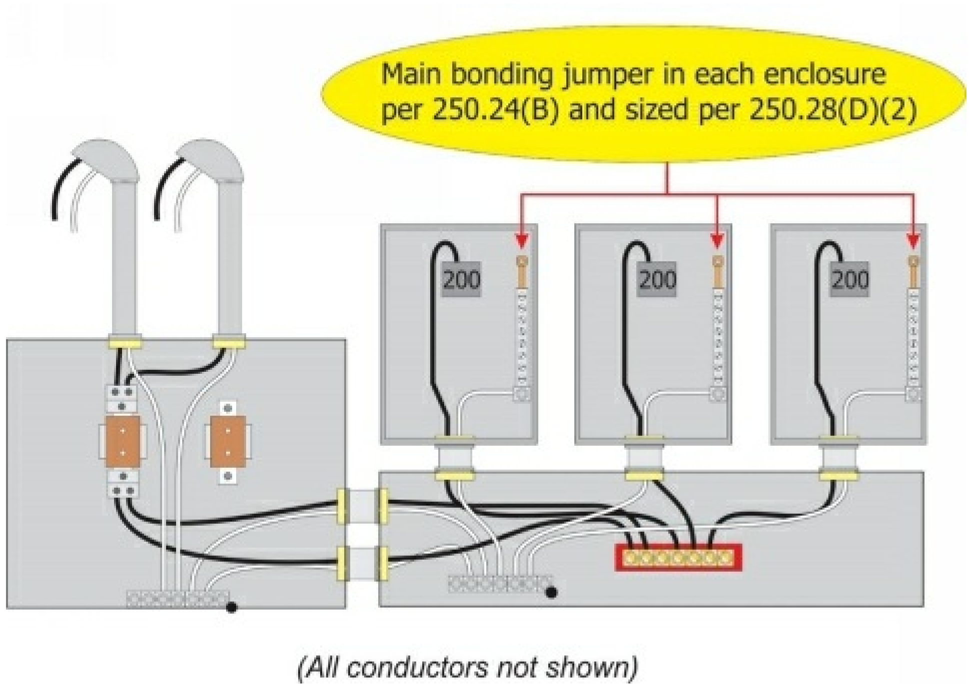


Figure 5.2 Main bonding jumpers in multiple service-disconnect enclosures

The rules are a little different where more than one service disconnecting means is in a common enclosure. This equipment usually consists of listed switchgear, switchboards, panelboards, or motor control centers. "Where more than one service disconnecting means is located in a single assembly listed for use as service equipment," 250.24(B) Exception No. 1 and 250.24(C) Exception permit the grounded service conductor(s) to be connected to a common grounded conductor terminal bar or bus in the enclosure and then be bonded to the assembly enclosure (see figure 5.3). This means that only one main bonding jumper connection is required to be installed from the common grounded conductor terminal bar or bus to the assembly enclosure. The sections of the assembly are bonded together by means of an equipment grounding conductor bus and by being bolted together.

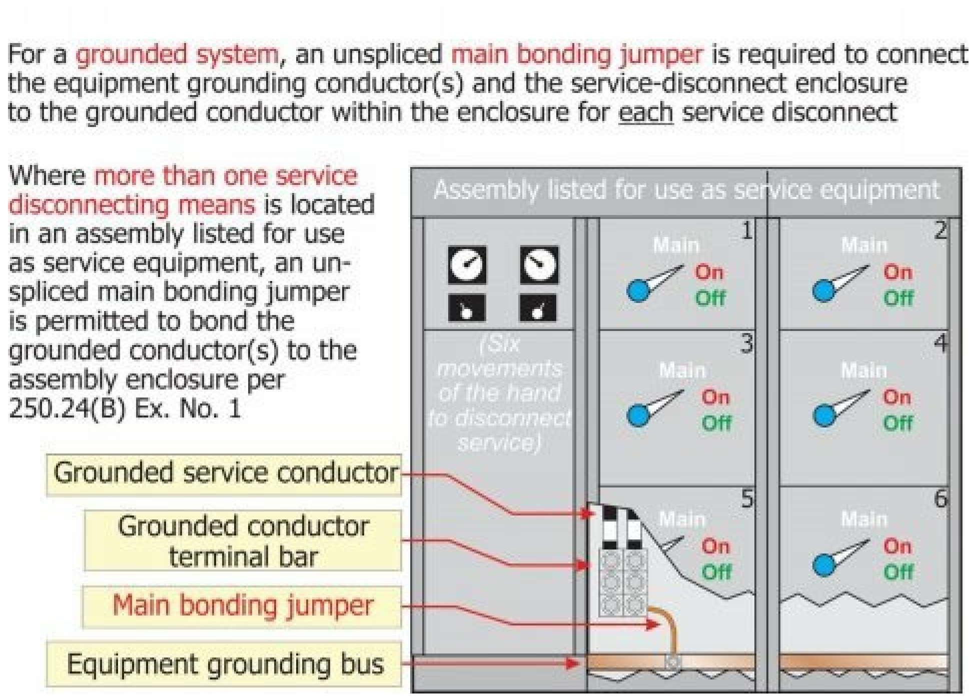


Figure 5.3 Main bonding jumper installed in listed assembly with multiple service

disconnects as permitted by exception

Exception No. 2 to 250.24(B) permits an alternate means for bonding of impedance grounded neutral systems (see chapter four for methods and requirements for grounding high-impedance grounded neutral systems). Also, see 250.36 and 250.187 for the specific requirements and allowances.

The main bonding jumper is permitted to consist of a wire, bus, screw, or other similar suitable conductor (see photo 5.1). It must be fabricated of copper or other corrosion-resistant material. Aluminum alloys are permitted where the environment is acceptable. In addition, where the main bonding jumper consists of a screw, it must have a green finish that is visible with the screw installed (see photo 5.2). This green finish assists in identifying the main bonding-jumper screw from the other screws that are on or near the neutral conductor terminal bar or bus [see 250.28(A) and (B)].

Photo 5.1 Main bonding jumper (strap type)

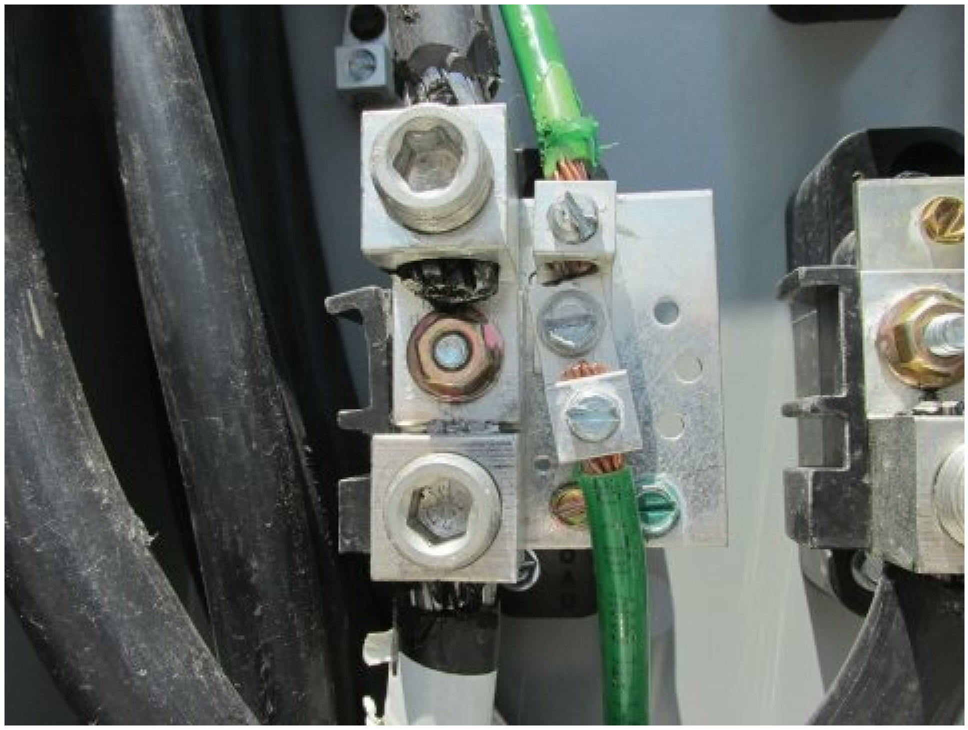


Photo 5.2 Main bonding jumper (screw type) identified with the color green

Functions of Main Bonding Jumper

The main bonding jumper performs three major functions:

1. Connects the grounded service conductor to the equipment grounding bus or conductor and the service enclosure.
2. Provides the low-impedance path for the return of ground-fault currents to the grounded service conductor. The main bonding jumper completes the ground-fault return circuit from the equipment grounding conductors and enclosure to the source via the service grounded (neutral) conductor as is illustrated in figure 5.4.
3. Connects the grounded service conductor to the grounding electrode conductor where the grounding electrode conductor is terminated on the equipment grounding bus or bar.

Under certain conditions given in 250.24(A)(4), it is permitted to connect the grounding electrode conductor to the equipment grounding terminal bar rather than the terminal or bus for the grounded service conductor. This scheme is common on larger switchboards and service equipment and is necessary for proper operation of certain types of ground-fault protection equipment (see chapter fourteen for additional information on this subject).

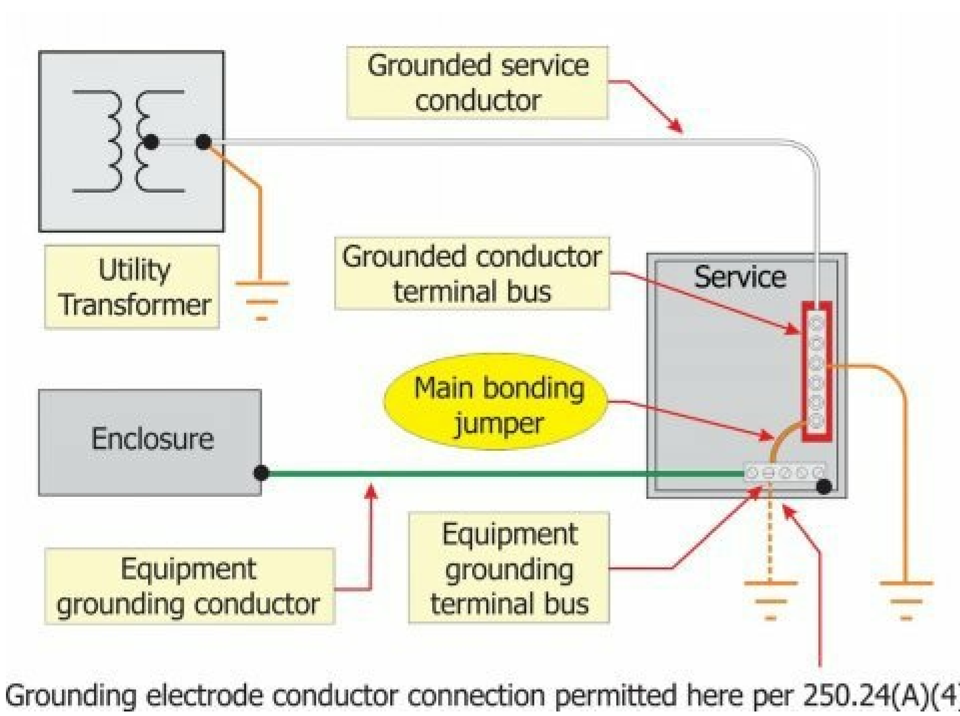


Figure 5.4 Function(s) of the main bonding jumper

Size of Main Bonding Jumper in Listed Enclosures

Where listed service equipment consisting of a switchgear, switchboard, panelboard or motor control center is installed, the main bonding jumper that is provided with the equipment is rated for the size of conductors that would normally be used for the service. The method for sizing the main bonding jumper in listed service equipment is found in the Underwriters Laboratories' safety standard for the equipment under consideration and is verified by the listing organization. Therefore, if a main bonding jumper that is a busbar, strap, conductor, or screw is furnished by the manufacturer as part of the listed equipment, it may be used without calculating its adequacy. If equipment is listed as service equipment, it will be marked with a label that identifies it as being "Suitable for Use as Service Equipment." This equipment has been evaluated for use as service equipment and will include appropriate provisions for connecting the grounded (neutral) conductor to the equipment grounding conductor(s) and bonding to the enclosure. This connection means is usually one of the forms specified in 250.28(A) or (B). Equipment that is marked "Suitable for Use Only as Service Equipment" usually is manufactured with the grounded conductor bus or terminal bar electrically and mechanically connected to the enclosure at the factory and may be installed using some non-removable means.

This type of equipment generally may be installed only in the service position. There may not be an identified main bonding jumper in equipment that is suitable for use only as service equipment, but there may be provisions in larger equipment for disconnecting the grounded conductor bus from the enclosure for testing purposes only. More information on these two ratings or identifications for equipment can be found in UL 67 *Standard for Panelboards*, UL 891 *Standard for Switchboards* and UL 869A *Reference Standard for Service Equipment.*

Size of Main Bonding Jumper at Single Service Disconnect or Enclosure

Because the main bonding jumper must carry the full ground-fault current of the system back to the grounded service conductor (which may be a neutral), its size must relate to the rating of the service conductors which supply the service. The minimum size of the main bonding jumper is determined from the requirements of 250.28(D) (see figure 5.5). For services with service-entrance conductors up to 1100 kcmil copper or 1750 kcmil aluminum, use Table 250.102(C)(1). Where the service-entrance conductors are larger than these values, note 1 to Table 250.102(C)(1) requires the main bonding jumper to be a minimum of 12½ percent of the cross-sectional area of the largest service-entrance conductor. This relationship is based on the conductor's ability to carry the expected amount of fault current for the period needed for the overcurrent device to open or operate and interrupt current.

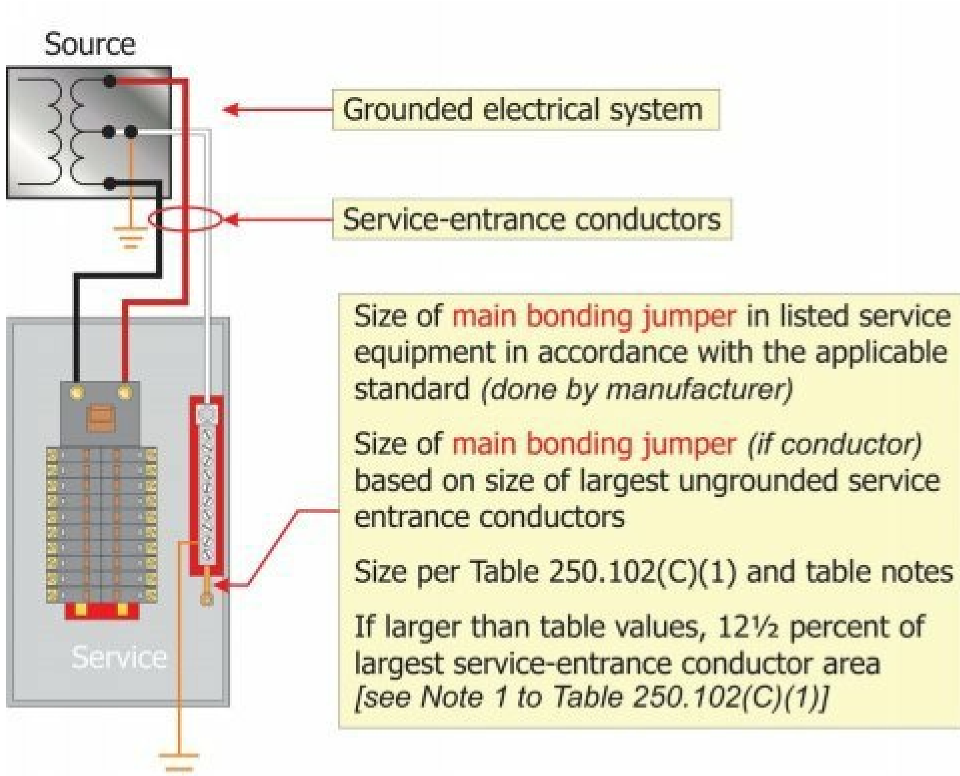


Figure 5.5 Sizing main bonding jumper for parallel service conductors

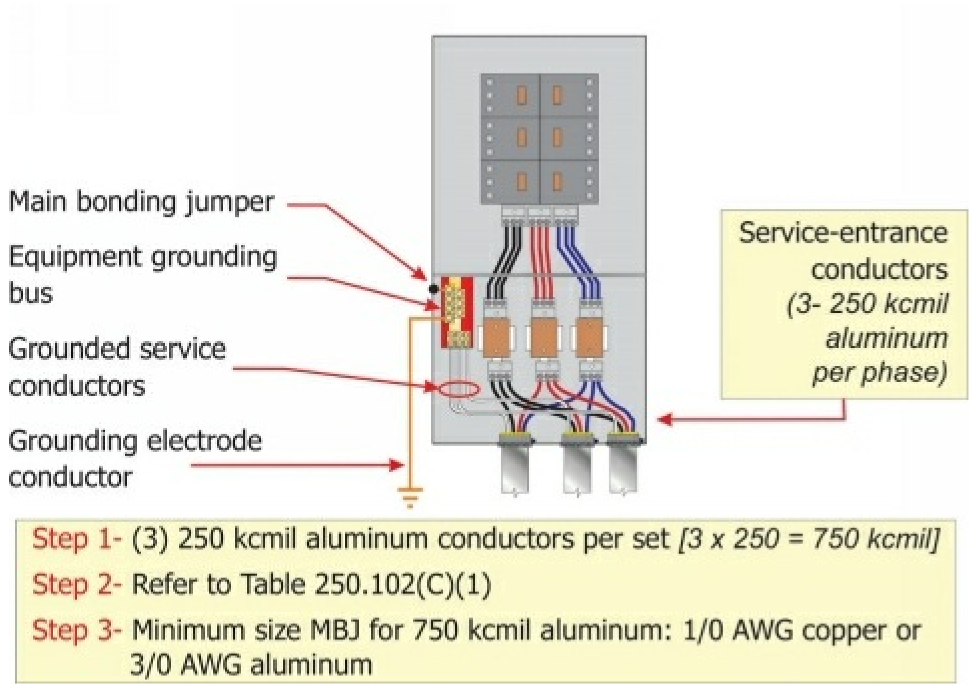


Figure 5.6 Sizing main bonding jumper for parallel service conductors

For example, where 250-kcmil aluminum service-entrance conductors are installed, the main bonding jumper is found to be 4 AWG copper or 2 AWG aluminum by reference to Table 250.102(C)(1).

Where multiple service disconnect enclosures are installed as permitted in 230.71(A), and wire-type main bonding jumpers are installed in each disconnect, the minimum size for each main bonding jumper is not less than the sizes required in 250.28(D)(1) based on the largest ungrounded service conductor serving each individual enclosure [250.28(D)(2)].

Another example is a large 2000-A service switchboard with 2 each 6 mm x 102 mm (¼in x 4 in) copper busbars per phase for the service-entrance conductors. The cross-sectional area of these conductors is larger than 1100 kcmil and would be calculated to be 1290 square mm (2 sq. in.) or 6 mm x 102 mm x 2 (0.25 x 4 x 2). The minimum main bonding jumper size is 12 ½ percent of this and would be 161 mm^2 (0.25 sq. in.) or 1290 mm^2 x 0.125 (0.125 x 2in^2) of cross-sectional area. The main bonding jumper could be a 6 mm x 25.4 mm (¼ x 1 inch) copper bus or if a wire type main bonding jumper is desired, using Table 8 of the *NEC* for area, the next largest conductor above 0.25 sq. in. is 250 kcmil copper. (4/0 is 0.219 square inches and 250 kcmil is 0.260 square inches)

The size of the main bonding jumper does not directly relate to the rating of the service overcurrent device. Do not attempt to use Table 250.122 for this purpose. Table 250.122 gives the minimum size of equipment grounding conductors for feeders and circuits on the load side of the service, feeder or branch-circuit overcurrent protection devices.

Different Conductor Material

Again, for services with service-entrance conductors larger than 1100 kcmil copper or 1750 kcmil aluminum and, where different conductor materials are used for the service-entrance conductors and the main bonding jumper Note 2 to Table 250.102(C)(1) applies. This note provides instructions on sizing the main bonding jumper when these conditions are encountered. The procedure involves assuming the phase conductors are of the same material (copper or aluminum) as the main bonding jumper and that they have an equivalent ampacity to the conductors that are installed. This is illustrated as follows:

- Assume aluminum ungrounded (phase) conductors and a copper main bonding jumper
- Three 750-kcmil Type THW aluminum ungrounded conductors are installed.
- Determine the ampacity of the ungrounded conductors from Table 310.16: 385 amperes x 3 = 1155 amperes.

The smallest type THW copper conductor that has an equivalent ampacity is 600 kcmil with an ampacity of 420.

Next, determine the total circular mil area of the copper conductors.

3 x 600 kcmil = 1800 kcmil.

1800 kcmil x .125 = 225 kcmil.

The next standard size is 250-kcmil copper, which is the minimum size main bonding jumper permitted to bond equipment at or ahead of the service equipment in this example. For service-entrance conductors smaller than 1100 kcmil copper or 1750 kcmil aluminum, the table already provided the required size of the main bonding jumper using either copper or aluminum.

Sizing of Main Bonding Jumper for Parallel Service Conductors

Where service conductors are installed in parallel (connected together at each end to form a larger electrically conductive path), the total circular mil area of the largest set of conductors connected in parallel for one phase are added together to determine the minimum size main bonding jumper required [see figure 5.6 and 250.102(C)(1)]. For example, where three 250-kcmil aluminum conductors are connected in parallel per phase, they are treated as a single 750-kcmil aluminum conductor. By reference to Table 250.102(C)(1) the main bonding jumper is 1/0 AWG copper or 3/0 AWG aluminum.

Where the service-entrance conductors are larger than the maximum given in Table 250.102(C)(1), note 1 to Table 250.102(C)(1) requires the main bonding jumper to be not less than 12 ½percent (0.125) of the area of the largest ungrounded phase conductors. This is illustrated by the following example:

Three 500-kcmil copper conductors are installed in parallel as service-entrance conductors.

3 x 500 kcmil = 1500 kcmil.

1500 x .125 = 187,500 circular mils.

Since a 187,500-circular mils conductor is not a standard size, refer to *NEC* Chapter 9, Table 8, to find the area of conductors.

The next conductor exceeding 187,500 circular mils is a 4/0 AWG conductor, which has an area of 211,600 circular mils. It is always necessary to go to the next larger size conductor since the 12 ½percent size is the minimum size permitted.

Functions of Supply-Side Bonding Jumper

The supply-side bonding jumper provides the electrical continuity between the supply source, such as the utility transformer enclosure, and the various enclosures of the service equipment. It is also used to connect bonding bushings, where used, to the service grounded (neutral) conductor in the service equipment enclosure(s). The supply-side bonding jumper functions to carry ground-fault current from ground faults that occur on the supply side of the main overcurrent protection and provide a low impedance path for the ground-fault current to return to the source. The supply-side bonding jumper can be non-flexible metal raceway or a wire type. Sometimes the service grounded conductor also serves the function as the supply-side bonding jumper.

Sizing of Supply-Side Bonding Jumper on the Line (Supply) Side of Service

Supply-side bonding jumpers on the line side of the service must be sized in accordance with 250.102(C)(1) or (C)(2). The requirement is to use Table 250.102(C)(1) where the service-entrance conductors are smaller than 1100 kcmil copper or 1750 kcmil aluminum. For example, where 250-kcmil copper conductors are installed as service-entrance conductors, Table 250.102(C)(1) requires a 2 AWG copper or 1/0 AWG aluminum conductor for the supply-side bonding jumper.

Where the sum of the circular mil area of the service-entrance phase conductors exceeds 1100-kcmil copper or 1750-kcmil aluminum, the supply-side bonding jumper must be not less than 12 ½ percent (0.125) of the area of the ungrounded phase conductors. As with main bonding jumpers, if the supply-side bonding jumper is of a different material, copper or aluminum, than the service-entrance conductors, then note 2 to Table 250.102(C)(1) provides the requirements on how to determine the correct supply-side bonding jumper size.

Sizing of Supply-Side Bonding Jumper for Parallel Conductors

Two methods are provided for bonding service raceways that are installed in parallel. The first method is to add the circular mil area of the service-entrance conductors per phase together and treat them as a single conductor. The supply-side bonding jumper size is determined from Table 250.102(C)(1) and is connected to each conduit bonding bushing in a daisy-chain fashion as shown in figure 5.7. This method often results in a supply-side bonding jumper that is quite large and difficult to work with.

For example, if five 250-kcmil copper conductors are installed in parallel for a phase, the supply-side bonding jumper for bonding the metal raceways must not be smaller than 3/0 copper.

This is determined as follows:

5 x 250 kcmil = 1250 kcmil.(This is greater than 1100 kcmil so this must be calculated at 12 ½ percent of the area).

1250 kcmil x .125 = 156,250 circular mils.

The next larger conductor size found in Chapter 9, Table 8, is 3/0 with an area of 167,800 circular mils.

In this case, a 3/0 copper supply-side bonding jumper must be connected from the grounded service conductor bus to each metal raceway in series (daisy-chain fashion from one raceway to another) [see figure 5.7]. The connection must only be to the grounded conductor bus in accordance with 250.80.

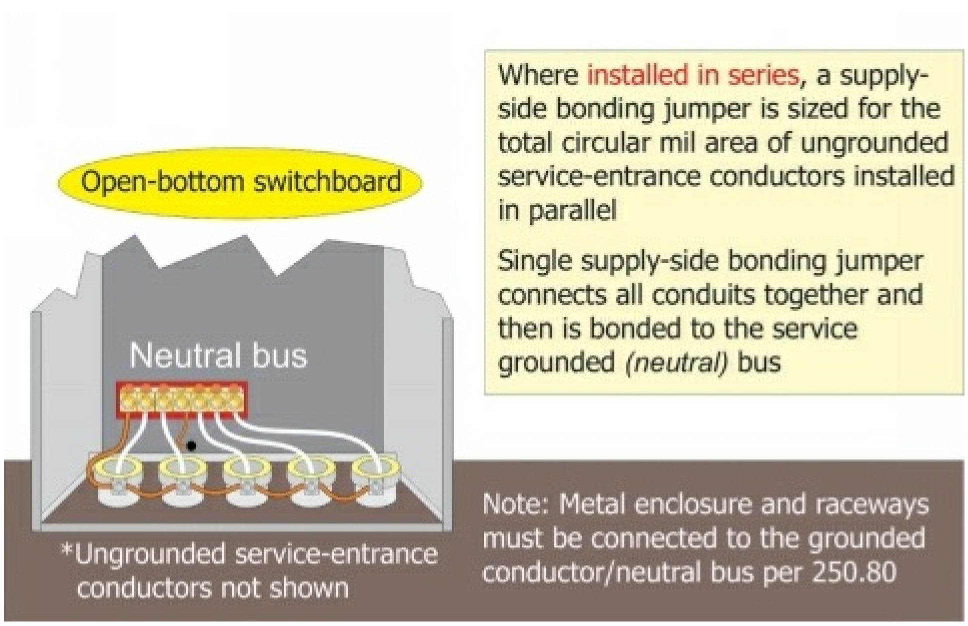


Figure 5.7 Sizing supply-side bonding jumper on line side of service disconnect (single supply-side bonding jumper in daisy-chain fashion)

A more practical method of performing the bonding for services supplied by multiple raceways may be to connect an individual supply-side bonding jumper between each raceway and the grounded service conductor terminal bar bus (see figure 5.8). This is permitted by 250.102(C)(2). This will usually result in a smaller supply-side bonding jumpers which is easier to install.

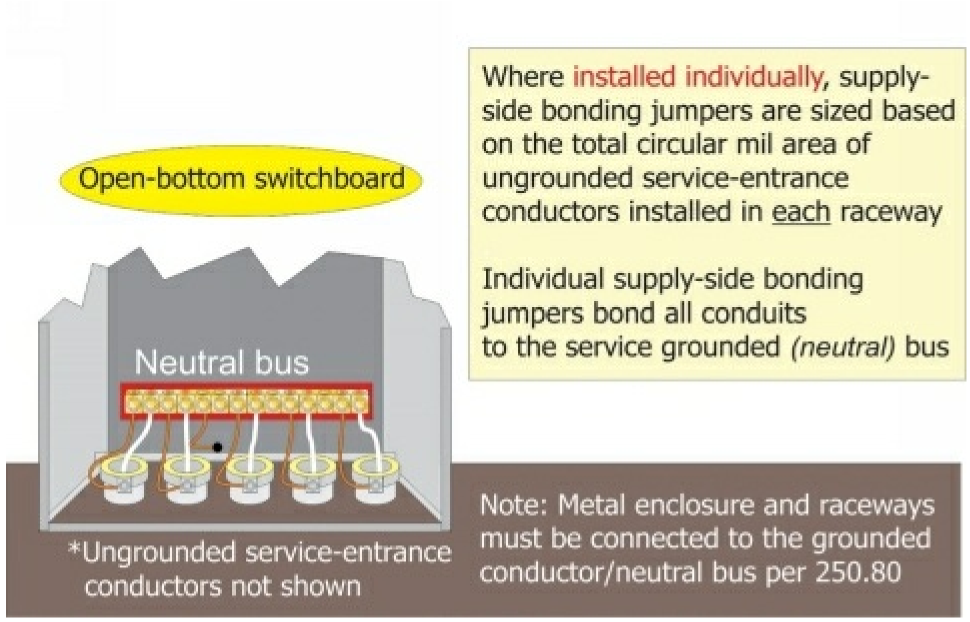


Figure 5.8 Sizing supply-side bonding jumper on the line side of the service disconnect (individually from each raceway)

Again, using the example above and referring to Table 250.102(C)(1), the minimum size supply-side bonding jumper for the individual raceways containing 250-kcmil copper service-entrance conductors is 2 AWG copper or 1/0 AWG aluminum. A properly sized supply-side bonding jumper is installed from the terminal bar for the grounded service conductor to each conduit individually. As stated above, the conduit supply-side bonding jumper connection must only be to the grounded conductor bus in accordance with 250.80.

Parallel Supply-Side Bonding Jumpers

Section 250.102(C)(2) requires that where service-entrance conductors are paralleled in two or more raceways or cables and the supply-side bonding jumper is routed with the raceways or cables, the supply-side bonding jumper must be run in parallel (see figure 5.9).

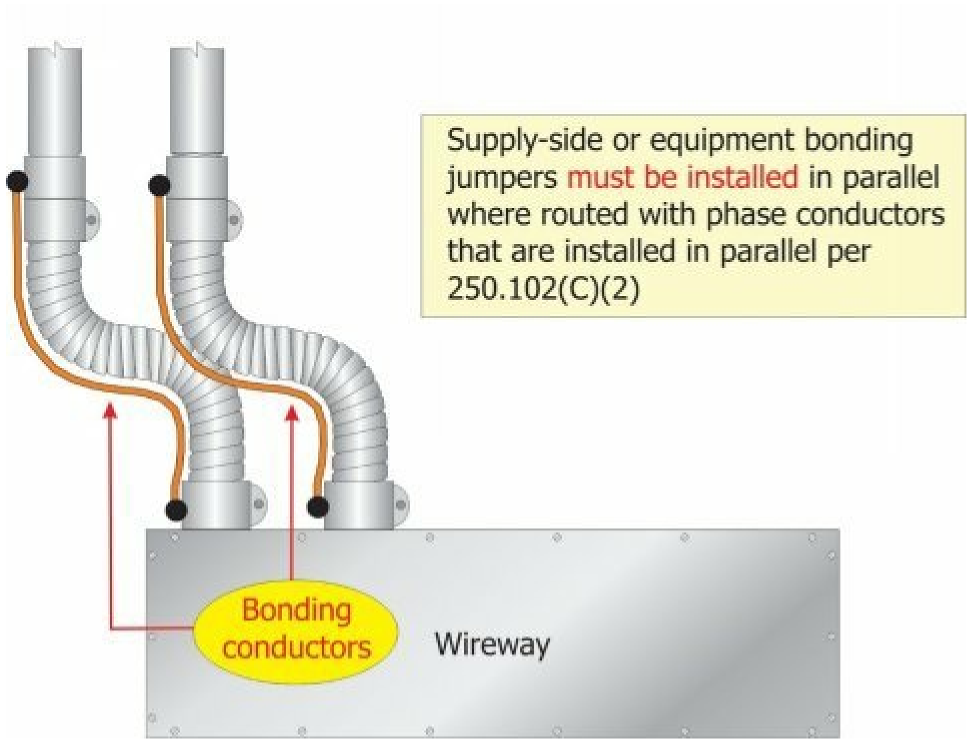


Figure 5.9 Supply-side bonding jumpers installed on the outside of the raceway or enclosure

In this case, again, the size of the bonding jumper for each raceway is based upon the size of the service- entrance conductor in the raceway by referring to Table 250.102(C)(1) and 250.102(C)(2). It is important to make the bonding jumper connections on both sides of the raceway with equipment or fittings that are suitable for that use (see photo 5.3).

Photo 5.3 There are fittings for liquidtight flexible metal conduit and flexible metal conduit that provide a means for installation of externally routed supply-side bonding jumpers. Courtesy of Thomas and Betts

Bonding Service Equipment Enclosures

Special rules are provided for bonding enclosures on the line side of the service disconnecting means. This is because this equipment does not have overcurrent protection, at its rating, on the line side, like feeders and branch circuits have. There must be a sufficient magnitude of fault current, during a short period of time, to cause the overcurrent device on the line side of the utility transformer to open or operate. The level of fault current and particularly the duration of the current can be much greater than in a feeder or branch circuit. This is because service conductors are usually not protected at their ampacity but only have overload protection as part of the service equipment.

The basic rule is that all metallic enclosures that contain service conductors must be bonded together. The bonding ensures that none of the equipment enclosures can become electrically isolated and become a shock hazard should a line-to-ground fault occur in that enclosure. The bonding also provides a low-impedance path for fault current so the fuse or circuit breaker on the supply side of the electric utility transformer will open or operate.

The *Code* requires that electrical continuity of service equipment and enclosures that contain service conductors be established and maintained by bonding (see figure 5.10). The items required to be bonded together are stated as follows in 250.92(A)(1) and (A)(2):

1. The service raceways, cable trays, cablebus frame-work, auxiliary gutters, or service cable armor or sheath except as permitted in 250.80.
2. All service equipment enclosures containing service conductors, including meter fittings, boxes or the like, interposed in the service raceway or armor.

A provision to this requirement for bonding at service equipment is referenced at 250.84, which has rules on underground service cables that are metallically connected to the underground service raceway. The *Code* points out that if a service cable with a continuous metal armor or sheath, and if the service cable also has the grounded service conductor connected on the supply side to the metal armor or sheath, then the metal armor or sheath of the cable is considered to be adequately grounded. This means that another connection at the service equipment is not required. Section 250.84(B) also permits the metal armor or sheath to be insulated from the metal raceway, but the raceway would still be required to be bonded to the service equipment.

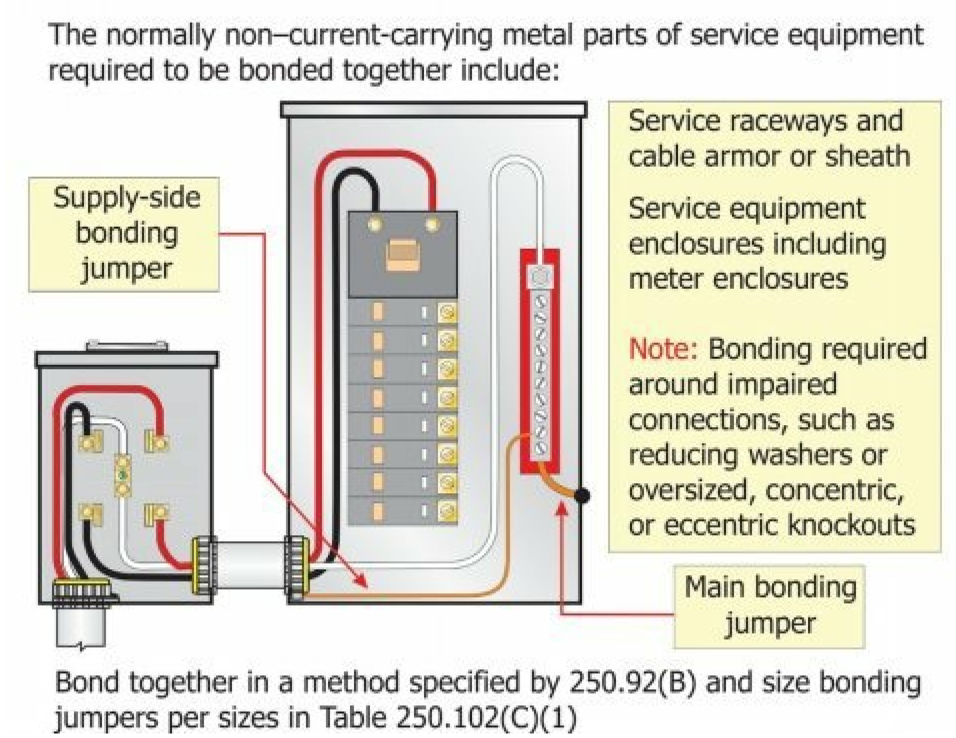


Figure 5.10 Bonding service equipment enclosures

Neutral Conductor for Bonding on Line Side of Service

Section 250.92(B) permits the use of the grounded service conductor (may be the neutral) for grounding and bonding equipment on the supply side of the service disconnecting means (see figure 5.11). This is also permitted by 250.142(A)(1). (Two other applications of this method of bonding are explored in chapter 9 of this book.) Often, connecting the grounded service conductor to equipment such as meter bases, current transformer enclosures, wireways or auxiliary gutters is a practical method of bonding these enclosures.

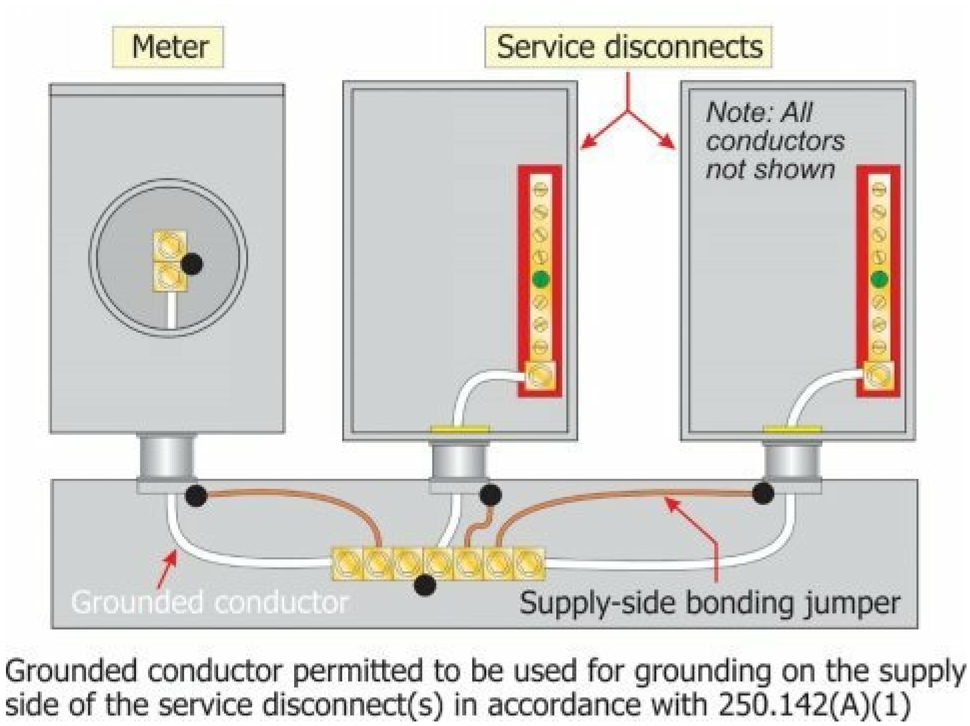


Figure 5.11 Using the grounded conductor for bonding on the supply side of the service disconnecting means

Usually, self-contained meter sockets and meter-main combination equipment are produced with the grounded conductor terminals or bus (often a neutral) bonded directly to the enclosure. The meter enclosure is then effectively bonded when the grounded conductor is connected to these terminals within the meter enclosure. No additional bonding conductor connection to the meter enclosure is required. Current from a ground fault to the meter-main enclosure will return to the source by the grounded service conductor (may be a neutral) and will allow enough current to open or operate the overcurrent protection on the line side of the utility or other transformer.

In addition, meter enclosures installed on the load side of the service disconnecting means are permitted to be grounded (bonded) to the grounded service conductor provided that:

a) service ground-fault protection equipment is not installed; and
b) the meter enclosures are located immediately adjacent to the service disconnecting means, [although there still is no distance dimension provided, it should provide more clarity for the permitted location], and

c) the size of the grounded circuit conductor is not smaller than the size specified in Table 250.122 for equipment grounding conductors.

Method of Bonding at the Service

Various methods for bonding at the service are addressed in 250.92(B) (see figures 5.12, 5.13 and photos 5.3, 5.4 and 5.5). These requirements for bonding are more restrictive at services than downstream from the service disconnect. This is very important because service equipment and enclosures can be subject to heavy fault currents in the event of a line-to-ground fault and the overcurrent protection is controlled by the serving utility.

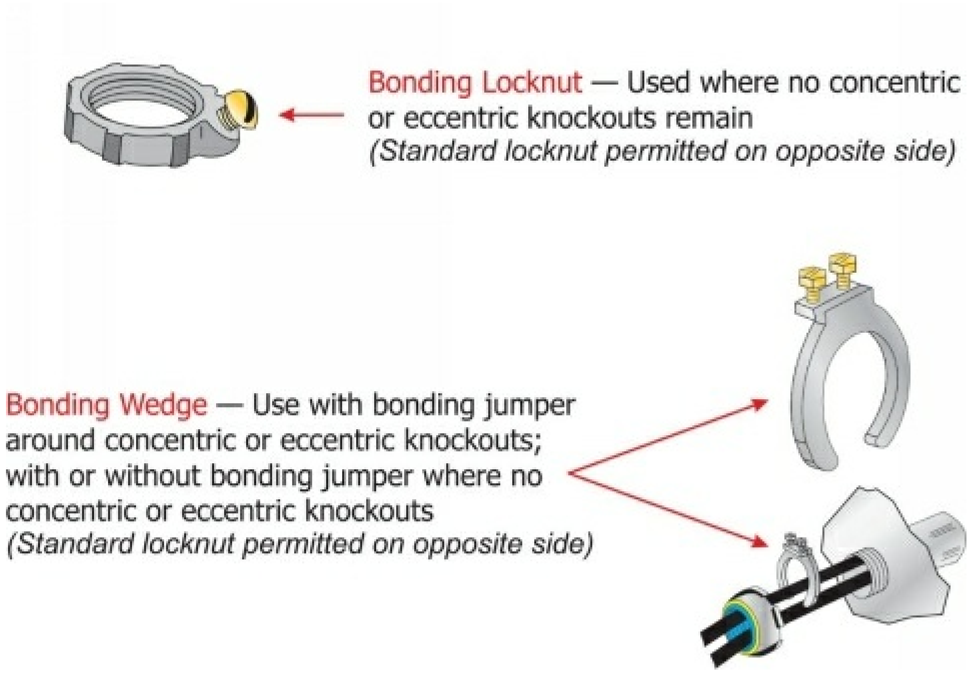


Figure 5.12. Methods of bonding at service equipment

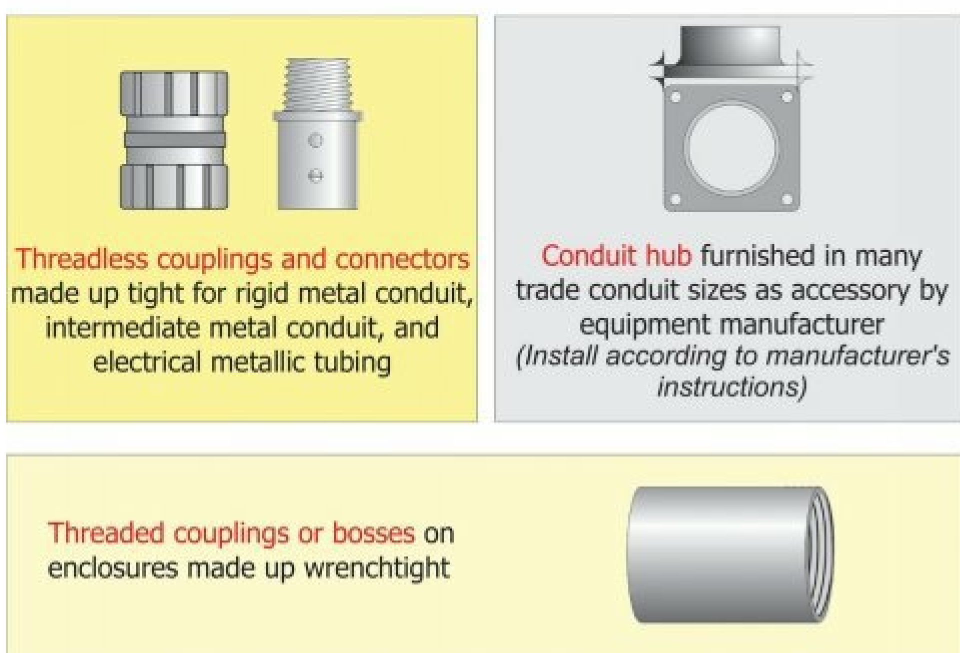


Figure 5.13 Various fittings acceptable for use in bonding on the supply side of the service disconnect

Photo 5.4   Grounding (bonding) bushing for use in bonding on the supply side of service disconnect

Photo 5.5 Close up of grounding (bonding) bushing

The service conductors in these enclosures only have short-circuit protection provided by the overcurrent device on the line side of the utility transformer. Only overload protection is provided at the load end of the service conductors by the service main overcurrent device. This is one of the reasons the *Code* limits the length of service conductors inside a building by requiring the service disconnecting means to be nearest the point of entrance of the service conductors [see 230.70].

Bonding of these enclosures is to be done by one or more of the following methods specified in 250.92(B):

1. Bonding to the grounded service conductor through the use of exothermic welding, listed pressure connectors such as lugs, listed clamps, or other listed means. These connections cannot depend solely upon solder. All the suitable means are identified in 250.8.

2. Threaded couplings and threaded bosses in a rigid or intermediate metal conduit system where the joints are made up wrench-tight. Threaded bosses include hubs that are either formed as a part of the enclosure or are supplied as an accessory and installed according to the manufacturer's instructions.

3. Threadless couplings and connectors are permitted where they are made up tight for rigid and intermediate metal conduit and electrical metallic tubing and metal-clad cables.

4. Other approved devices such as bonding wedges and bonding-type lock-nuts and bushings.

Bonding jumpers are required to be used around concentric or eccentric knockouts that are punched or otherwise formed to impair an adequate electrical path for ground-fault current. It is important to recognize that concentric and eccentric knockouts in enclosures such as panelboards, wireways, and auxiliary gutters have not been investigated for their ability to carry fault current. Where any of these knockout rings remain at conduit connections to enclosures, they must always be bonded around to ensure an adequate fault-current path (see photos 5.3, 5.4 and 5.5).

The *Code* states, "Standard locknuts or bushings shall not be the only means for the bonding required by this section." [2]

This statement does not intend to prevent the use of standard locknuts and bushings; they just cannot be relied upon as the sole means for the bonding that is required by this section.

Standard locknuts are commonly used outside the enclosure on conduit that is bonded with a grounding bushing or bonding locknut inside the enclosure. Standard locknuts are used to make a good, reliable mechanical connection as required by 300.10. A locknut should be used on one or both sides to ensure a good mechanical connection and then the bonding bushing should be installed for the bonding means. A bonding bushing alone may not provide the required tight mechanical connection required by 300.10. Locknuts and the bonding means must be tightened wrench-tight to prevent arcing due to fault current. Bonding wedges are also acceptable as a bonding means on the supply side of the service disconnecting means (see photos 5.6 and 5.7).

Photo 5.6 Bonding locknut for bonding on the supply side of the service disconnect

Photo 5.7 Bonding wedge suitable for bonding on the supply side of the service disconnect Courtesy of Thomas and Betts

Grounding and Bonding of Remote Metering

As mentioned before, 250.92(A) requires all metallic equipment containing service conductors to be bonded together and to the grounded service conductor. This includes remote (from the service equipment) meter cabinets and meter socket enclosures.

Grounding and bonding of equipment such as meters, current transformer cabinets, raceways, and auxiliary gutters to the grounded service conductor at locations on the line side of and remote from the service disconnecting means increases safety.

This equipment should never be grounded only to a grounding electrode, such as a ground rod. Figures 5.14 and 5.15 help show why. If a ground fault occurred on the line-side of this equipment, and it is not bonded as required, the only means for clearing a ground fault would be through the grounding electrodes and earth. Given the relatively high impedance and low current-carrying capacity of this path through the earth and high resistance of grounding electrodes such as rods, there will be little current in this path. No overcurrent device will open or operate, leaving the equipment enclosure(s) at a dangerous voltage-to-ground potential. Any person or animal that contacts the enclosure can be shocked or electrocuted.

The voltage drop across this portion of the circuit can easily be calculated using Ohm's law (Resistance times the current gives the voltage). There are many records of livestock being electrocuted while contacting electrical equipment that was improperly grounded. Sections 250.4 and 250.54 require that the earth not be considered or used as an effective ground-fault current path.

A practical method for grounding and bonding this line-side equipment is to bond the grounded service conductor to it. As can also be seen in figures 5.14 and 5.15, a ground fault to the equipment will have a low-impedance path back to the source through the grounded service conductor. This will allow enough current in the circuit to cause the overcurrent protection on the line side of the transformer to clear the fault.

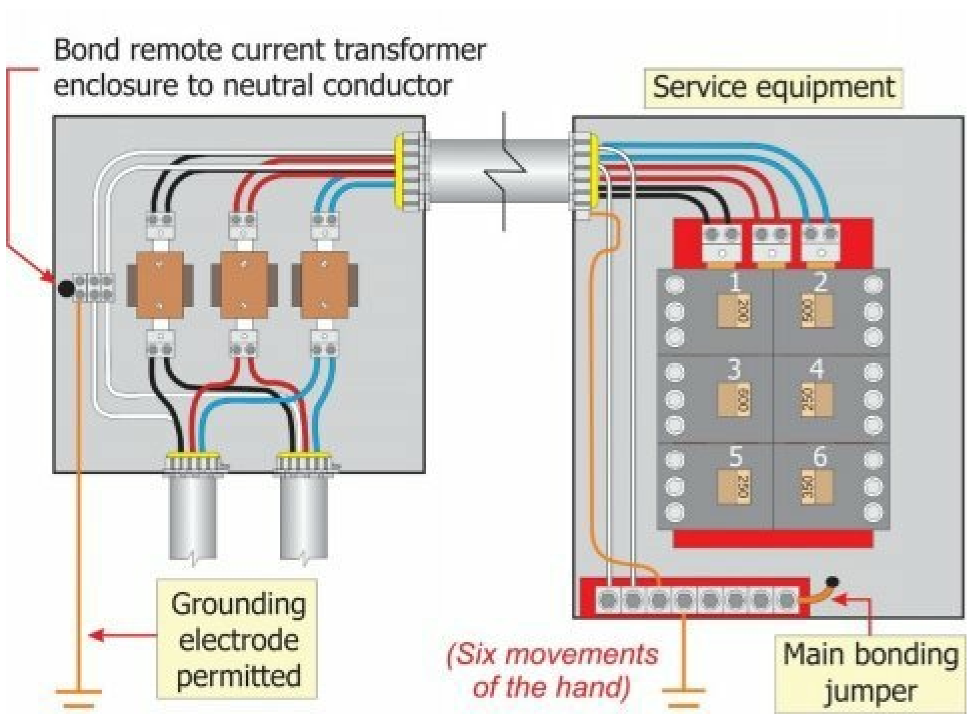


Figure 5.14 Grounding and bonding of remote metering

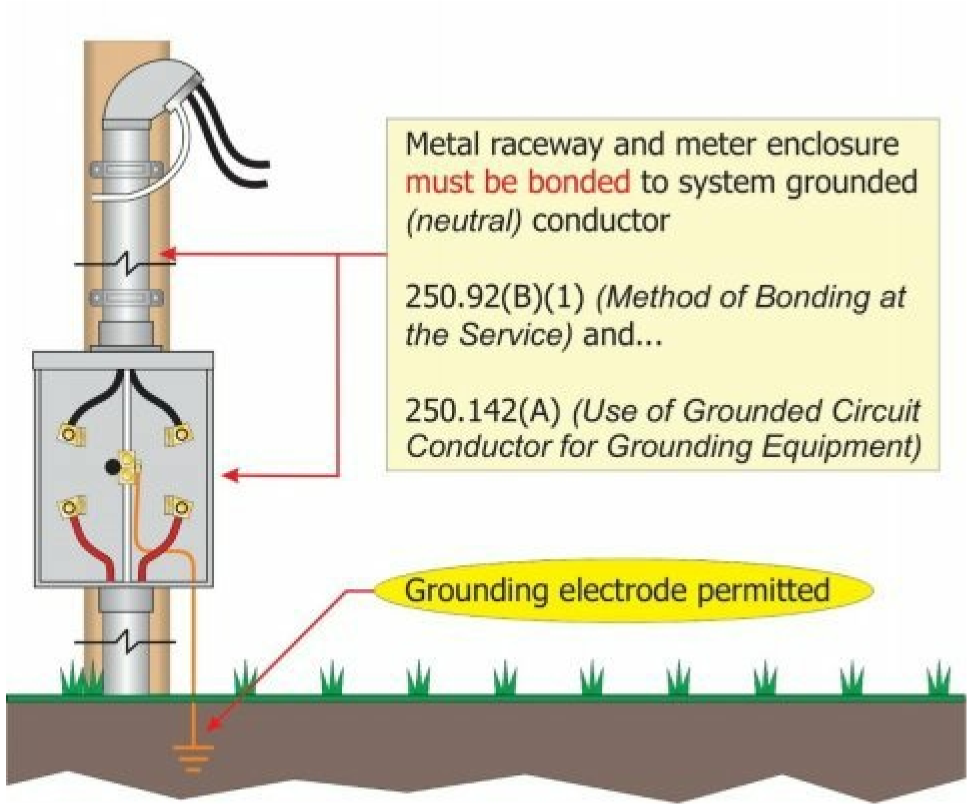


Figure 5.15 Bonding and grounding at remote meter loop

Additional Grounding Electrodes

Figures 5.14 and 5.15 show a common situation where the service metering equipment is installed on a remote pole or other location and the service equipment itself is installed at the building or structure. If the service equipment were installed on the pole, then clearly a grounding electrode and grounding electrode conductor would be required by 250.24. Since the service equipment is not present at the pole, 230.66 makes it clear that individual meter socket enclosures are not to be considered service equipment, then presently there is no clear direction from the *NEC* with regard to a grounding electrode at this enclosure. Some electric utilities require a grounding electrode at meter equipment installed remote from service equipment, such as on poles while others are silent on such a requirement. The same is true for metering equipment installed in remote current-transformer enclosures. As mentioned earlier, it is critically important that these meter enclosures be properly bonded as they often contain unfused or line-side service conductors. For the enclosures in both these examples, bonding is achieved by connection to the grounded (neutral) service conductor.

Although not specifically required, having a grounding electrode installed at the remote pole or current transformer enclosure is recommended so that enclosure is referenced to the earth at that point. This additional grounding electrode will facilitate keeping the equipment and enclosures at the earth potential in the vicinity of the meter location in the event of lightning or other abnormal event. Since the pole is remote from the building or structure being served, there is no *Code* requirement that the electrode installed at the pole and the one installed at the building or structure be directly bonded, but remember that the electrode(s) at the remote meter and those connected at the service location are bonded together by the grounded service conductor installed between the metering and service equipment.

As previously stated, these grounding electrodes should never be used as the only means for grounding or bonding these enclosures or to carry fault current. An extensive discussion of this subject is found in chapter six.

Bonding of Multiple Service Disconnecting Means

Installation of multiple services as permitted by 230.2(A) through (D) and installations of services that have multiple disconnecting means can take several forms.

Additional services are permitted by 230.2 for:

1. Fire pumps, emergency systems, legally required standby systems, optional standby, parallel power production systems, or redundant systems for enhanced reliability.

2. By special permission, for multiple occupancy buildings where there is no available space for service equipment that is accessible to all occupants or for a single building or structure that is large enough to make two or more services necessary.

3. Capacity requirement where the service capacity requirements exceed 2000 amperes at 1000 volts or less, where load requirements of a single-phase installation are greater than the serving utility normally provides through a single service, or by special permission (related to capacity requirements).

4. Different characteristics of the services, such as different voltages, frequencies, or phases, or for different uses, such as for different rate schedules.[3]

Remember that *special permission* is defined in Article 100 as the written consent of the AHJ.

The basic rule for sizing the supply-side bonding jumper for bonding these various configurations is found in 250.102(C). This section requires that the supply-side bonding jumpers on the line side of each service and the main bonding jumper be sized from Table 250.102(C)(1). In addition, the size of the supply-side bonding jumper for each raceway is based on the size of service-entrance conductors in that raceway. As discussed earlier, conductors larger than given in Table 250.102(C)(1) are required for larger services and are sized based on 12½ percent of the largest phase conductor. Since different sizes of service-entrance conductors may be installed at various locations, the minimum size of the supply-side bonding jumper and the main bonding jumper is based on the size of the service-entrance conductors at each location.

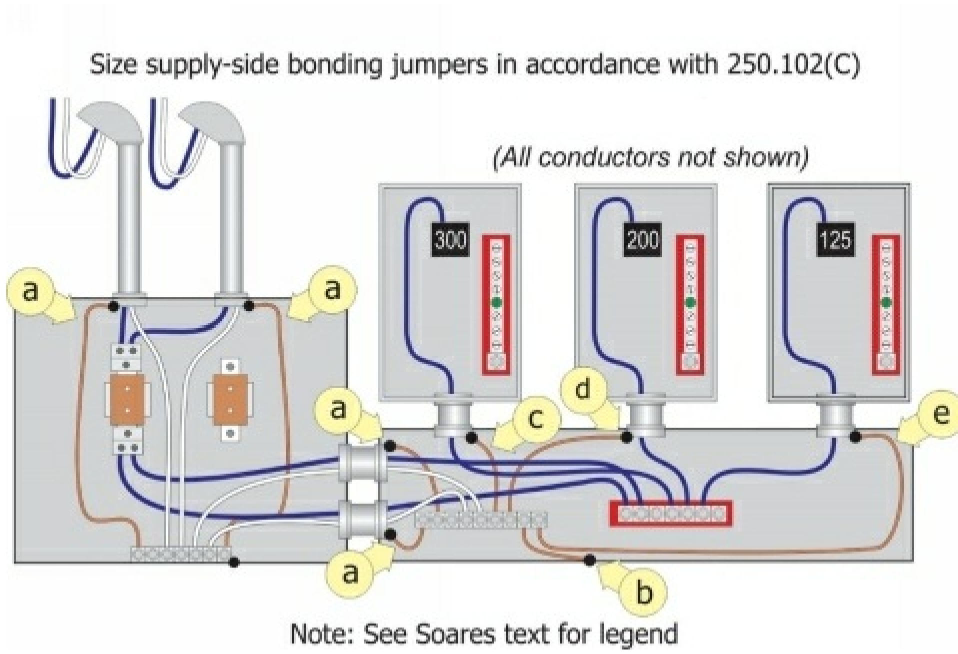


Figure 5.16 Bonding of multiple service disconnecting means

For example, the appropriate size of supply-side bonding jumper for the installation in figure 5.16 with the assumed size of conductors is as follows (all sizes copper):

a. 500 kcmil in service mast and nipple has a supply-side bonding jumper of 1/0 AWG for each connection.

b. 1000 kcmil in wireway has a supply-side bonding jumper of 2/0 AWG.

c. 300 kcmil to 300-ampere service has a supply-side bonding jumper of 2 AWG.

d. 3/0 AWG to 200-ampere service has a supply-side bonding jumper of 4 AWG.

e. 2 AWG to 125-ampere service has a supply-side bonding jumper of 8 AWG

A practical method for bonding the current transformer enclosure and wireway (sometimes referred to as a hot gutter) is to connect the grounded service conductor directly to the current transformer enclosure or wireway. This may be done by bolting a multi-barrel lug directly to the wireway and connecting the neutral or grounded service conductors to the lug. Be sure to remove any nonconductive paint or other coating that might insulate the connector from the enclosure. As previously discussed, the grounded service conductor must also be extended to each service disconnecting means and be bonded to the enclosure. Also remember that 200.2(B) states that "the continuity of a grounded conductor shall not depend on a connection to a metallic enclosure, raceway, or cable armor."

1, 2, 3 NFPA 70, *National Electrical Code 2017* (Quincy, MA, National Fire Protection Association, 2016).

Review Questions

1. “Connected (connecting) to establish electrical continuity and conductivity” best defines which of the following____.

   1. grounding
   2. bonded (bonding)
   3. welded
   4. grounded

2. The connection between the grounded circuit conductor and the equipment grounding conductor at the service is defined as the ____.

   1. main bonding jumper
   2. grounding electrode conductor
   3. equipment bonding jumper
   4. neutral conductor

3. A conductor installed on the supply side of a service or within a service-equipment enclosure(s), or for a separately derived system, that ensures the required electrical conductivity between metal parts required to be electrically connected defines which of the following ____.

   1. main bonding jumper
   2. supply-side bonding jumper
   3. equipment grounding conductor
   4. system bonding jumper

4. The main bonding jumper is permitted to consist of a ____ or other suitable conductor.

   1. wire
   2. bus
   3. screw
   4. all of the above

5. Where the main bonding jumper consists of a ____ only, it is required to have a green finish that is visible with the ____ installed.

   1. bus, bus
   2. screw, screw
   3. wire, wire
   4. jumper, jumper

6. Where ____ kcmil aluminum service-entrance conductors are installed, a wire-type main

bonding jumper is required to be 4 AWG copper or 2 AWG aluminum.

1. 1/0
2. 2/0
3. 3/0
4. 250

7. Where the service-entrance conductors are larger than the maximum sizes given in Table 250.102(C)(1), the main bonding jumper cannot be less than ____ percent of the area of the largest phase conductor.

1. 9 ½
2. 10 ½
3. 11 ½
4. 12 ½

8. Where service-entrance conductors are installed in parallel, and the sum of the circular mil area exceeds ____ kcmil copper or ____ kcmil aluminum, the bonding jumper must be not less than 12 ½ percent of the area of the largest ungrounded phase conductor.

1. 1100 - 1750
2. 1000 - 1650
3. 1050 - 1500
4. 1075 - 1400

9. The *Code* requires that electrical continuity at service equipment and enclosures that contain service conductors be ensured by ____.

1. grounding
2. welding
3. approval
4. bonding

10. The grounded circuit conductor (may be a neutral conductor) is permitted to be used for grounding and bonding on the ____ side of the service disconnecting means.

1. load
2. supply
3. subpanel
4. control center

11. Grounding and bonding of equipment such as meters, current transformer cabinets and raceways to the grounded service conductor at locations on the supply side of and remote from the

service disconnecting means increases ____.

1. voltage
2. current
3. safety
4. cost

12. The supply-side bonding jumper for raceways containing service-entrance conductors must be sized according to ____.

1. Section 250.102(C)(1), Table 250.102(C)(1)
2. Table 250.122
3. Table 310.16.
4. none of the above

13. Which of the following methods are NOT permitted to be the sole means for bonding enclosures for service-entrance conductors ____?

1. bonding bushings
2. bonding locknuts
3. threadless couplings
4. standard locknuts

14. Meter enclosures on the load side of the service disconnecting means are permitted to be grounded using the grounded conductor where they are _______ the service disconnecting means.

1. located near
2. located immediately adjacent to
3. not within reach of
4. within sight of

15. The main bonding jumper must be sized large enough to carry _______ground-fault current of the system.

1. the full
2. approximately half
3. 58% of the
4. none of the

16. The main bonding jumper_______.

1. connects the grounded service conductor to the equipment grounding bus
2. provides the low-impedance path for the return of ground-fault currents
3. connects the grounded service conductor to the grounding electrode conductor

4. all of the above

⏚ Chapter 6
The Grounding Electrode System

Objectives to understand

- Definition and general requirements for grounding electrodes
- Grounding electrode system to be used
- Sizing interconnecting bonding jumpers for the grounding electrode system
- Description and installation of grounding electrodes
- Common grounding electrode
- Objectionable current flow and resistance of grounding electrodes

Grounding electrodes provide the essential function of connecting the electrical system and electrical equipment to the earth (see figure 6.1). The earth is considered to be at zero potential. In some cases, the grounding electrode(s) serves to ground the electrical system to earth.

In other instances, the electrode(s) is used to connect non-current-carrying metallic portions of electrical equipment to the earth. In both situations, a primary purpose of the grounding electrode(s) is to maintain the electrical equipment at the earth potential present where the grounding electrode(s) is located.

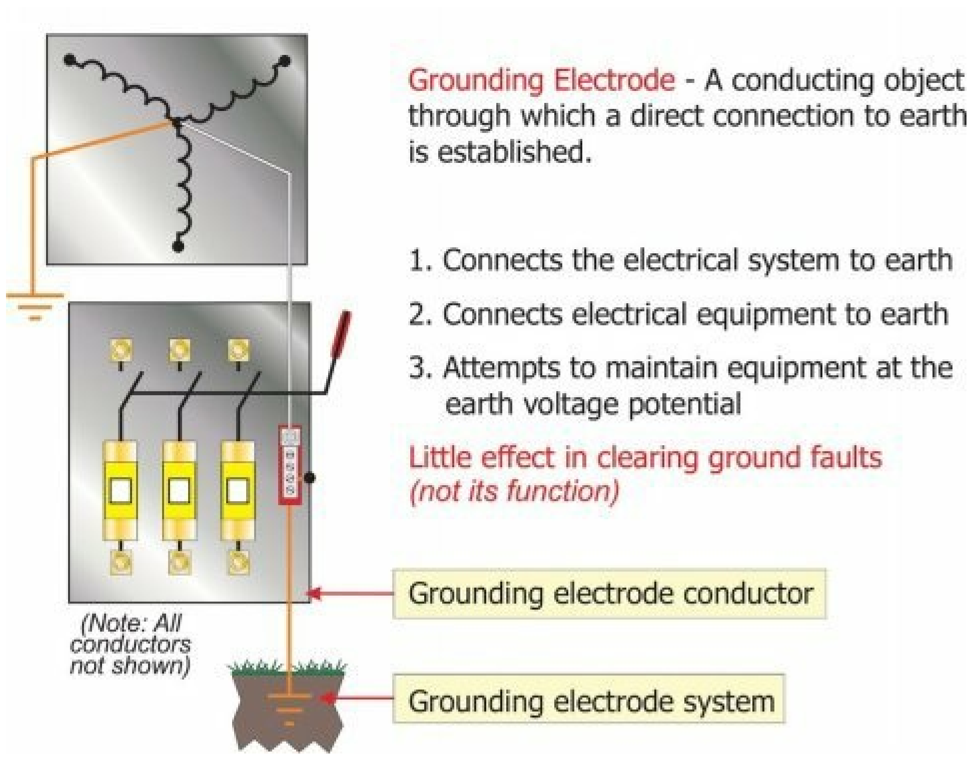


Figure 6.1 Functions of the grounding electrode

Another essential function of the grounding electrode(s) is to dissipate overvoltages into the earth (see figure 6.2). These overvoltages can be caused by high-voltage conductors being accidentally connected to the lower-voltage system such as by a failure in a transformer or by an overhead conductor dropping on the lower-voltage conductor. Overvoltages can also be caused from lightning. With more equipment, even home appliances, containing microprocessors this becomes increasingly important. Section 250.24(D) requires "… the equipment grounding conductors, the service-equipment enclosures, and, where the system is grounded, the grounded service conductor to be connected to the grounding electrode(s) required by Part III" of Article 250. The conductor used to make this connection is the grounding electrode conductor.[1]

Photo 6.1 Grounding electrode (iron core, copper-clad rod type)

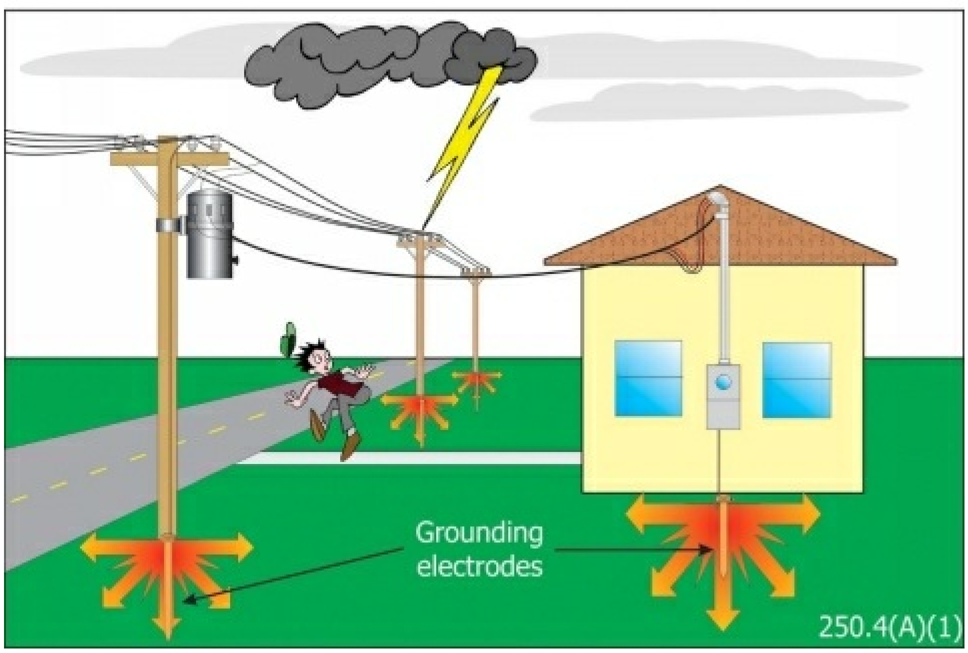


Figure 6.2 Dissipation of overvoltages

Definition

Grounding Electrode. “A conducting object through which a direct connection to earth is established.” [2]

To establish a true understanding of what constitutes a grounding electrode, the definition in the *Code* needs to be used cooperatively with the list of electrodes identified in 250.52(A). It can clearly be seen in this list of grounding electrodes that a grounding electrode can be a device or other conducting object such as a building footing or metal well casing that establishes and maintains a direct connection to the earth. The effectiveness of the connection is relative and is a variable item. The resistance in the connection between an electrode and the earth will vary based on soil conditions, electrode depth, type of electrode, and seasonal conditions or geographical location(s).

Grounding Electrode System

Section 250.50 requires that all grounding electrodes that are present at each building or structure served be bonded together to form the grounding electrode system (see figure 6.3). This generally means that where metallic water piping meeting 250.52(A)(1), metallic in-ground support structure meeting 250.52(A)(2), or a concrete-encased electrode meeting 250.52(A)(3) is part of the construction of the building or structure it shall be used as a grounding electrode for the electrical system. Section 250.50 does not require any of these three items to be installed, only used where they are installed as part of the building or structure. An exception to 250.50 has a provision for existing buildings or structures. The reinforcing bars or rods encased in concrete do not have to be exposed and used as part of the grounding electrode system if the concrete would have to be disturbed to make them accessible. This applies only to an existing building or structure, not an existing foundation or footing. For new construction, coordination between the various trades on the project is necessary to ensure that the concrete-encased electrode or the structural metal electrode(s) becomes part of the grounding electrode system.

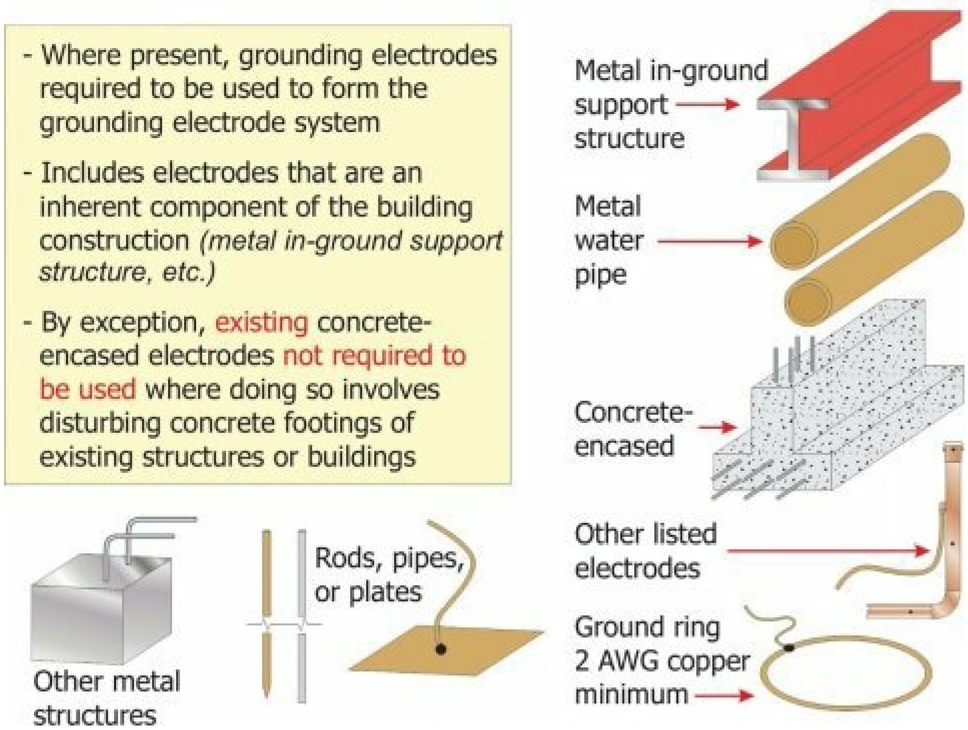


Figure 6.3 The grounding electrode system

While the definition in Article 100 opens up many possibilities of a “conductive object” that can be a grounding electrode, 250.52(A) contains the descriptions of what “objects” are considered acceptable electrodes (see figure 6-3). These include:

(A)(1) metal underground water pipes

(A)(2) metal in-ground support structure

(A)(3) concrete-encased electrodes

(A)(4) ground rings

(A)(5) rod and pipe electrodes

(A)(6) other listed electrodes

(A)(7) plate electrodes

(A)(8) other local metal underground systems or structures

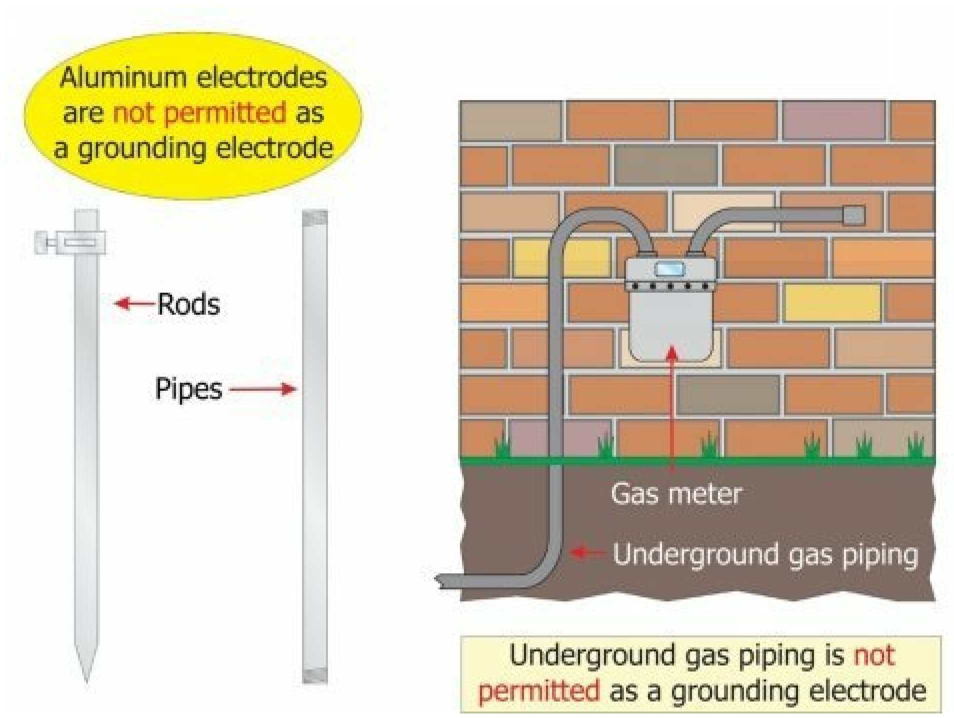
The general requirement is that bonding jumpers are required to be installed between the various grounding electrodes to bond them together to form a grounding electrode system. A grounding electrode conductor is then run from the system grounded conductor, the equipment grounding conductor, or both, at the service, at a separate building or structure, or at a separately derived system to one of the grounding electrodes or a point on the grounding electrode system. The *NEC* also provides for the option of running a separate grounding electrode conductor from the equipment to one or more of the grounding electrodes individually and then have bonding jumpers to interconnect any of the remaining grounding electrodes as provided in 250.64(F)(1) (2) and (3).

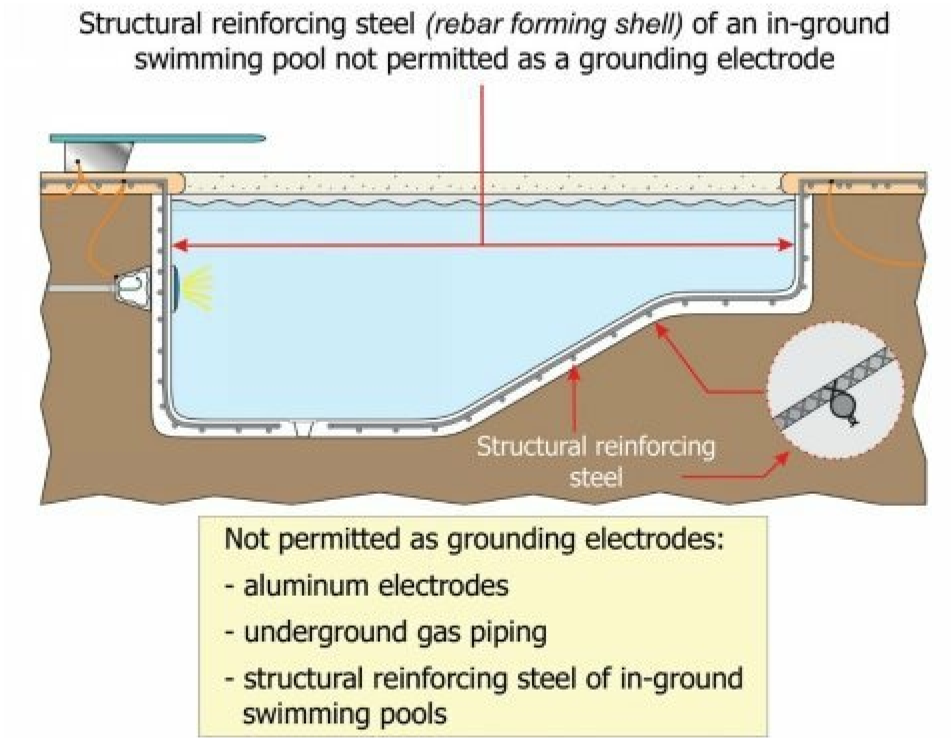
Where the interior metal water pipe is used as a part of the grounding electrode system or as a conductor to bond other electrodes together to create the grounding electrode system, 250.68(C)(1) requires that all connections to metal water piping electrodes take place within the first 5 feet from the point the water pipe enters the building. This helps minimize the possibility of having the path to this grounding electrode interrupted if the piping was replaced with nonmetallic piping. Section 250.68(C)(1) does not require that the interior water pipe be used for the purpose of interconnecting other electrodes to form the grounding electrode system. But 250.68(C)(1) does permit the use for the first 1.52 m (5 ft) of metallic water pipe for interconnection and for commercial and industrial buildings meeting exception 1, and allows use of the metallic water piping in general as a conductor for this purpose. See chapter seven for the discussion on using the interior metallic water piping system for extending the grounding electrode connection.

Any of the other electrodes, such as the concrete-encased electrode or ground ring, can be used for the purpose of interconnecting the other grounding electrodes. Where these other electrodes are used for this purpose, no restrictions are placed on where the connections are permitted to be made or how far inside the building they are permitted. Section 250.68(A) requires grounding electrode conductor connections to grounding electrodes to be accessible except for connections to a buried, driven, concrete-encased electrode, or exothermic welded or irreversible compression connections to fireproofed structural metal. The connection of the conductor to the terminal must be exothermic welded or irreversible crimped, but the connector may be installed to the structural metal by mechanical means and then the whole assembly recoated to restore the fire protection integrity. Similar to the interior metallic water piping system, an interconnected metal frame of a building can be used to interconnect grounding electrodes together in accordance with the requirements found in 250.68(C)(2). Unlike the water pipe though, the connections to the structural metal are not restricted on where they may be made. See chapter seven for the discussion on using of the metal frame of a building for extending the grounding electrode connection.

Description of the Required Grounding Electrodes

As previously stated, 250.52(A) contains a list of the grounding electrodes permitted to be used to form a grounding electrode system and 250.52(B) contains a list of the items that are not permitted to be used as grounding electrodes (see figure 6.4). Underground metal gas piping systems are not permitted to be used as a grounding electrode. This does not eliminate the requirement that metal gas piping systems installed in or on buildings or structures be bonded (see chapter eight for additional information on bonding of metal piping systems). Conductive objects made from aluminum also are not permitted to be used because aluminum would corrode in many types of soil and become ineffective as an electrode. Lastly, the metallic elements making up a swimming pool shell or frame are not to be used as a grounding electrode for the premises power system.





Figures 6.4a and b. Grounding electrodes not permitted for use as provided in 250.52(B)

All of the identified grounding electrodes are required to be used if they are present on the premises at each building or structure served. The grounding electrodes are not listed in any order of preference nor is it optional to choose which ones to use. Electrodes that are required to be used where present are as follows:

Electrodes Typically Installed as Part of Building Construction Metal Underground Water Pipe

Defined in 250.52(A)(1) as "A metal underground water pipe that is in direct contact with the earth for 3.0 m (10 ft) or more (including any metal well casing that is effectively bonded to the pipe)…." There is no minimum or maximum pipe size given. Types of metal, such as steel, iron, cast iron, copper, or stainless steel are not distinguished. The water pipe also must not be coated or otherwise insulated from direct contact with the earth. Different service applications of water pipes such as for potable water, fire protection sprinkler systems, irrigation piping, and so forth, are also not defined. As a result, all of these metal underground water pipes are required to be used if they are present at each building or structure served.

Continuity of the grounding path of the water pipe grounding electrode or the bonding of interior piping systems cannot depend on water meters or on filtering devices or similar equipment. Where a water meter or filtering equipment is in this metal water piping system, a bonding jumper is required to be installed around the equipment to maintain continuity even if the water meter or filter is removed. The bonding jumper is required to be the same size as the grounding electrode conductor and long enough to allow the meter, filter, or other equipment to be removed without disconnecting the bonding jumper [see 250.68(B)].

The Metal In-Ground Support Structure

After the change in the 2011 *NEC* to delete the concept of "effectively grounded," section 250.52(A)(2) was further revised in the 2017 *NEC* to better describe structural metal as an acceptable grounding electrode. The change in the 2017 *NEC* relocated the connection of a structure column to the footing to 250.68(C)(2) and revised the name to "metal in-ground support structure." This revision better reflects the definition of this metallic element being in the earth and differentiates this electrode from the structural metal above grade that makes up the frame of the building or structure. The remaining part requires at least 3 m (10 ft) of the structural metal item to be in direct contact with the earth either bare or with concrete encasement. The new requirements are as follows:

> "**250.52(A)(2) Metal In-Ground Support Structure(s).** One or more metal in-ground support structure(s) in direct contact with the earth vertically for 3.0 m (10 ft) or more, with or without concrete encasement. If multiple metal in-ground support structures are present at a building or structure, it shall be permissible to bond only one into the grounding electrode system.
>
> **Informational Note:** Metal in-ground support structures include but are not limited to, pilings, casing, and other structural metal."

It needs to be noted that the electrode is the part of the structural metal actually in the earth or where installed per 250.68(C)(2), the assembly of the hold-down bolts in direct contact with the concrete-encased electrode (rebar) in the footing supporting the column. The portion of the structural metal above grade is a "conductor" and not the electrode. Another note is that certain backfills, such as gravel or vapor barriers, can render the structural metal installed in the earth ineffective.

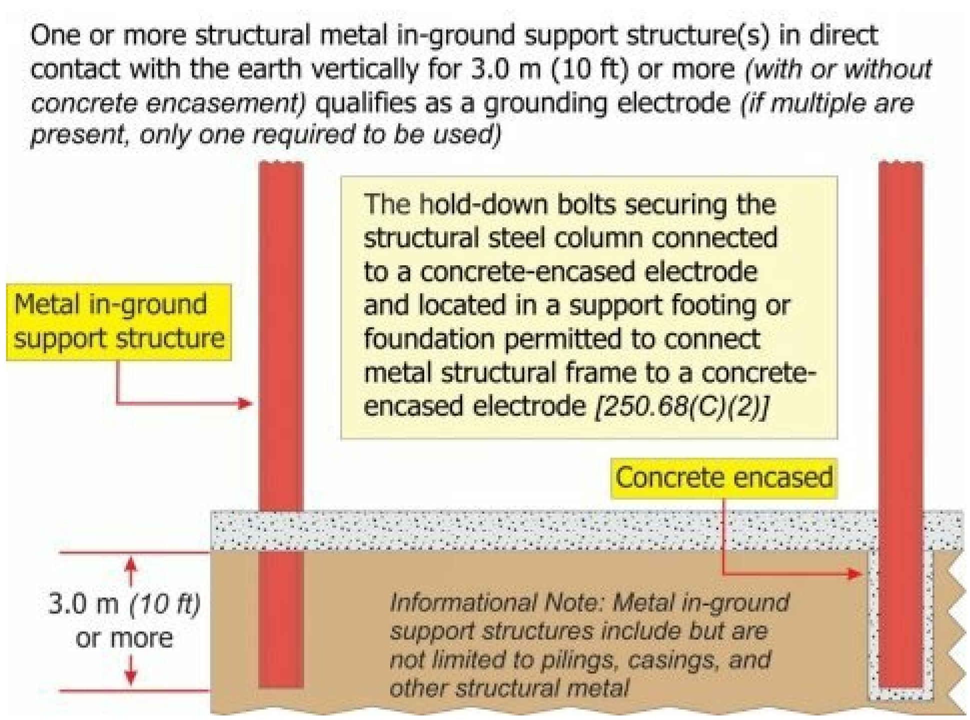


Figure 6.5 Metal frame of a building as a grounding electrode

Concrete-Encased Electrodes

Section 250.52(A)(3) defines this grounding electrode as "At least 6.0 m (20 ft) of either (1) or (2).

(1) "One or more bare or zinc galvanized or other electrically conductive coated steel reinforcing bars or rods of not less than 13 mm (½ in.) in diameter, installed in one continuous 6.0 m (20 ft) length, or if in multiple pieces connected together by the usual steel tie wires, exothermic welding, welding, or other effective means to create a 6.0 m (20 ft) or greater length; or

(2) "Bare copper conductor not smaller than 4 AWG.

"Metallic components shall be encased by at least 50 mm (2 in.) of concrete and shall be located horizontally within that portion of a concrete foundation or footing that is in direct contact with the earth or within vertical foundations or structural components or members that are in direct contact with the earth. If multiple concrete-encased electrodes are present at a building or structure, it shall be permissible to bond only one into the grounding electrode system.

Informational Note. "Concrete installed with insulation, vapor barriers, films or similar items separating the concrete from the earth is not considered to be in 'direct contact' with the earth" (see figures 6.6 and 6.7).

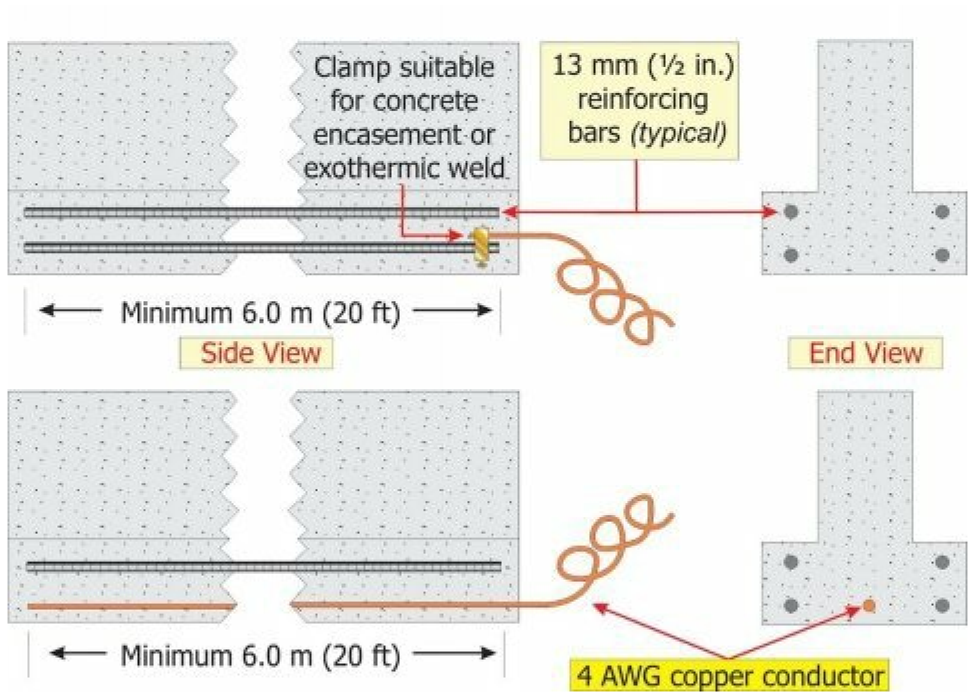


Figure 6.6 Concrete-encased electrode

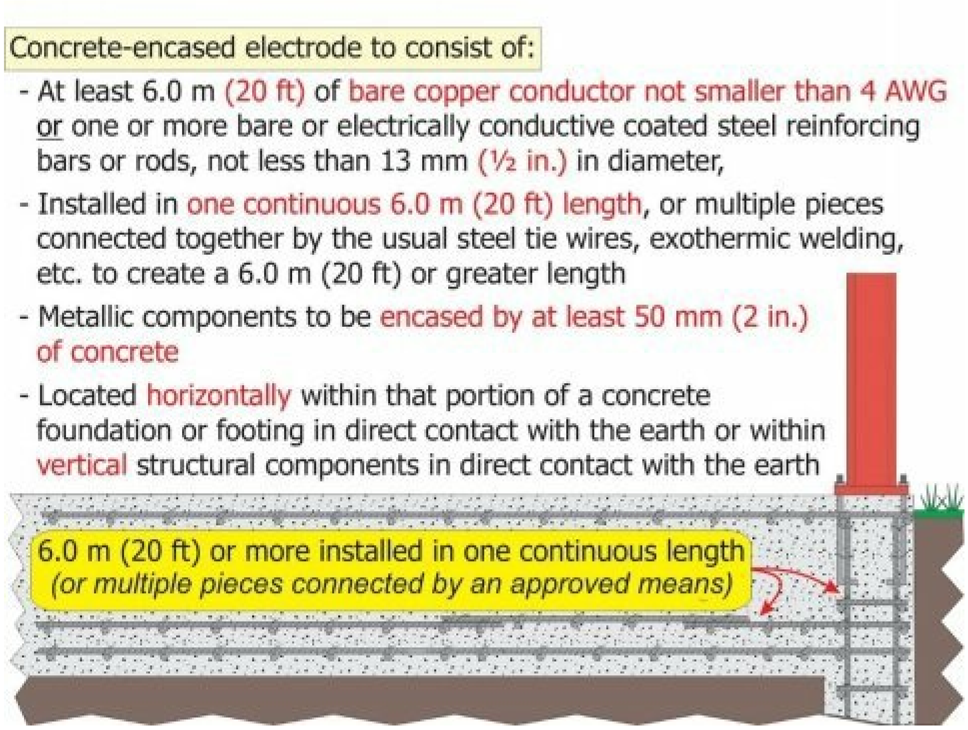


Figure 6.7 Concrete-encased electrode

A single 6.0 m (20 ft) length of reinforcing bar is not required. Reinforcing bars are permitted to be bonded together to attain the required minimum 6 m (20 ft) length by the usual steel tie wires or other effective means like welding. Where subjected to events such as lightning strikes, welding might be preferred.

Where multiple concrete-encased electrodes are present at a building or structure and are not electrically connected together, it is permissible to connect only one for the grounding electrode system, but at least one must be used to comply with 250.50.

Reinforcing bars are required to be of bare, zinc galvanized or have other electrically conductive coated steel material. Obviously, insulated reinforcement bars would not perform properly as a grounding electrode. Also use of a vapor barrier between the concrete and the earth would render the electrode ineffective. A new informational note was added to alert the users of this. Some complaints have been made that lightning surges, which can be dissipated through this electrode, break out chunks of concrete where the surge exits the footing. There has been no solid documented evidence provided to substantiate this complaint for structural footings or foundations. It is noted that in addition to the *NEC*, NFPA 780, *Standard for the Installation of Lightning Protection Systems,* recognizes a concrete-encased electrode as a suitable connection to earth specifically for lightning protection systems.

This grounding electrode is commonly referred to as the Ufer ground after H.G. Ufer who spent many years documenting its effectiveness. See Appendix A for additional information on the development of the concrete-encased electrode.

While the *NEC* does not require a concrete-encased electrode to be installed when not already part of the building construction, several electrical inspection agencies require that a concrete-encased electrode be installed or connected to the service prior to authorizing electrical service due to its proven effectiveness in most any climatic and soil condition.

Electrodes Typically Installed by Electrical Installer

Where the electrodes described in 250.52(A)(1) through (A)(7) do not exist at the building or structure served, a grounding electrode(s) is required to be installed and used (see figure 6.8). The grounding electrodes as provided in 250.52(A)(4) through (A)(8) may be one of or any combination of the following types:

"(A)(4) Ground Ring. A ground ring encircling the building or structure, in direct contact with the earth, consisting of at least 6.0 m (20 ft) of bare copper conductor not smaller than 2 AWG.

"(A)(5)(a) Rod and Pipe Electrodes. Rod and pipe electrodes shall not be less than 2.44 m (8 ft) in length and shall consist of the following materials.

"(a) Grounding electrodes of pipe or conduit shall not be smaller than metric designator 21 (trade size ¾) and, where of steel, shall have the outer surface galvanized or otherwise metal-coated for corrosion protection.

"(b) Rod-type grounding electrodes of stainless or copper or zinc coated steel shall be at least 15.87 mm ($_{5/8}$ in.) in diameter, unless listed.

"(A)(6) Other Listed Electrodes. Other listed grounding electrodes shall be permitted" (see photo 6-2 on page 110).

"(A)(7) Plate electrodes. Each plate electrode shall expose not less than 0.186 m^2 (2 ft^2) of surface to exterior soil. Electrodes of bare or electrically conductive coated iron or steel plates shall be at least 6.4 mm (¼ in.) in thickness. Solid, uncoated electrodes of nonferrous metal shall be at least 1.5 mm (0.06 in.) in thickness." Because a 1-foot square plate has two sides, it would comply with this section.

"(A)(8) Other Local Metal Underground Systems or Structures. Other local metal underground systems or structures such as piping systems, underground tanks, and underground well casings that are not bonded to a metal water pipe." [3]

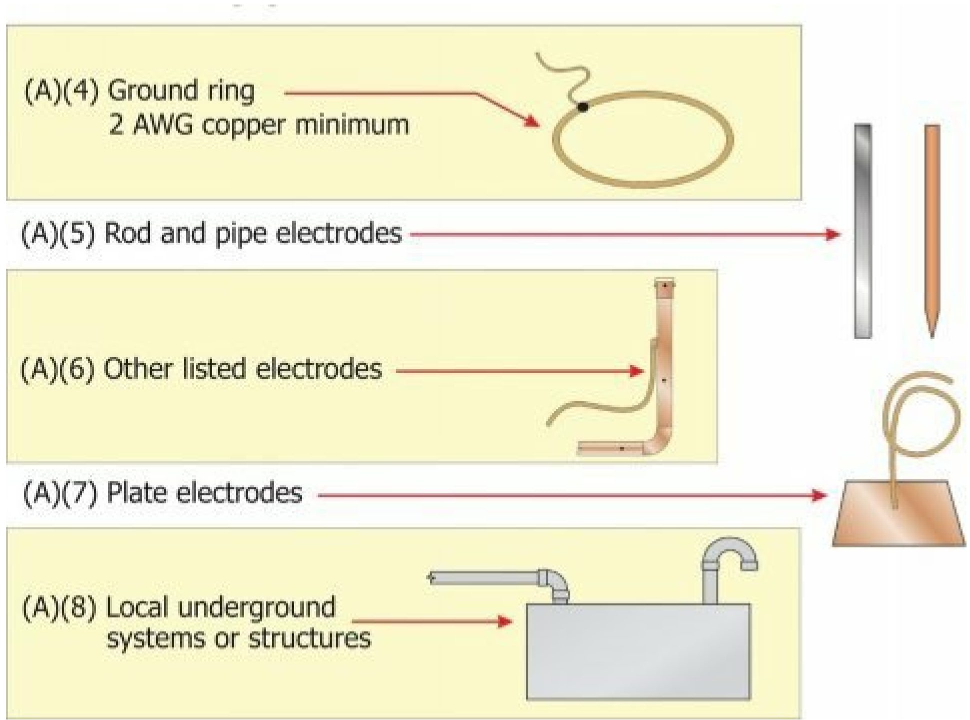


Figure 6.8 Installed grounding electrodes or underground structures or systems that can serve as grounding electrode

Ground Ring

Section 250.52(A)(4) recognizes a copper conductor, not smaller than 2 AWG and at least 6.0 m (20 ft) long, as a ground ring grounding electrode. The conductor is required to encircle the building or structure and be buried not less than 750 mm (30 in.) deep. Ground rings often are installed at telecommunication central offices, radio and cellular telephone sites. Where present on the premises served, ground rings are required to be used as one or more of the grounding electrodes making up the grounding electrode system.

Well Casings

Well casings were added to the 2005 *NEC*. This addition clarifies that metal underground well casings are not metal underground water pipes, therefore do not require a supplemental electrode as the metal water pipe does [see 250.53(D)(2)]. These objects are required to have the metal in direct contact with the earth. Protective coatings can render them ineffective as grounding electrodes.

Supplemental Electrode

Section 250.53(D)(2) requires that where the only grounding electrode present and connected at the building or structure served is a metal underground water pipe, it has to be supplemented by another grounding electrode. This electrode is required versus the auxiliary electrode in 250.54 that is permitted to be connected to the equipment grounding conductor.

Electrodes suitable to supplement the metal underground water pipe from 250.52(A) include:

(A)(2) metal in-ground support structure

(A)(3) a concrete-encased electrode

(A)(4) ground ring

(A)(5) rod and pipe electrodes

(A)(6) other listed electrodes

(A)(7) plate electrodes, and

(A)(8) other local metal underground systems or structures.

The electrode(s) chosen must still meet the requirements of 250.52 such as the specified lengths and burial depths, and the installation requirements of 250.53.

Specific locations are provided where the supplemental grounding electrode bonding jumper is permitted to be connected (see figure 6.9). The supplemental grounding electrode is permitted to be bonded only to the grounding electrode conductor from the water pipe, the grounded service-entrance conductor, the grounded non-flexible service raceway or to any grounded service enclosure. An exception in 250.68(C)(1) to this requirement permits the bonding connection to the interior metal water piping in qualifying industrial, commercial, or institutional installations to be made at any location if the entire length of interior metal water pipe that is being used as a conductor is exposed (see definition of *exposed* in Article 100). Locations where the exposed piping passes through walls or floors are required to be perpendicular to those penetrations. If all of the provisions of the exception are not met, the bonding connection must be within the first 1.52 m (5 ft) of where the piping enters the building.

Figure 6.9 Supplemental grounding electrode required

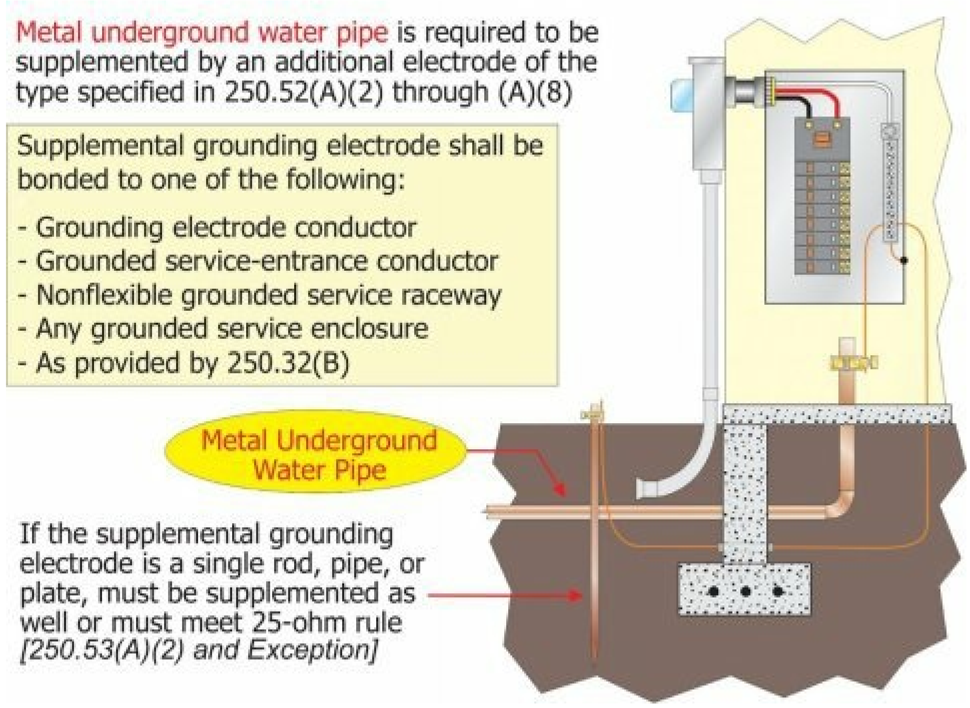


Photo 6.2 Listed grounding electrode Courtesy of Erico International

Often changes, repairs, or modifications are made to the metallic water piping systems with nonmetallic pipe or fittings or dielectric unions. In this case, it is possible to inadvertently isolate portions of the grounding electrode system from the grounding electrode conductor. This is another in several steps that have been taken over recent years to reduce the emphasis and reliance on the metal water piping system for grounding of electrical systems.

Where the supplemental grounding electrode is of the rod, pipe, or plate type, it is required to meet 250.53(A)(2): two electrodes in any combination of rod(s), pipe(s) or plate(s). The exception provides that if the supplemental grounding electrode, by itself, has a resistance of 25 ohms or less, the second electrode is not required. Note that an underground metal water pipe electrode is not recognized for providing the earth connection for a metal building frame in 260.68(C)(2). The supplemental electrode covered in 250.53(D)(2) is anticipated to be the only electrode if and when the water pipe is eventually replaced with nonmetallic components.

Size of Bonding Jumper for Grounding Electrode System

Section 250.53(C) requires the bonding jumper used to connect the grounding electrodes of the grounding electrode system together to be installed in accordance with the requirements of 250.64(A), (B), and (E) (see figure 6-10). The bonding jumper used to bond the grounding electrodes together to form the grounding electrode system is required to be sized in accordance with 250.66 based on the size of the ungrounded service-entrance conductor and to be connected in a manner specified in 250.70. The conductor that connects the grounding electrodes together is a bonding conductor and not a grounding electrode conductor. The bonding conductors are not required to be installed in one continuous length as grounding electrode conductors are. In addition, the exceptions for sizing the grounding electrode conductor in 250.66 apply for the sizing of the bonding jumpers.

For example, if the service-entrance conductor is 500-kcmil copper, the minimum size of bonding jumper between grounding electrodes is determined by reference to 250.66 and Table 250.66, and its installation falls under the requirements of the rules in 250.64(A), (B) and (E), which are as follows:

To the metal underground water pipe and the metal frame of a building; 1/0 AWG copper or 250 kcmil aluminum conductor (from Table 250.66).

To electrodes as provided in 250.52(A)(5) and (A)(7) such as pipes, rods, or plates; that portion of the bonding jumper connecting one or more rod(s), pipe(s), or plate(s) electrode(s); 6 AWG copper or 4 AWG aluminum. This permission for a maximum size is allowed as long as the bonding conductor is not first connected to a rod, pipe, or plate electrode and then extended to another type grounding electrode requiring a larger conductor [see 250.66(A)]. A clarification change in the 2014 *NEC* provides that for multiple rods, pipes or plates electrodes, only a maximum 6 AWG copper or a 4 AWG aluminum bonding jumper between them is required or as a grounding electrode conductor to any one of them.

To a concrete-encased electrode as in 250.52(A)(3); 4 AWG copper conductor [see 250.66(B)]. This permission for a maximum size is allowed as long as the bonding conductor is not first connected to concrete-encased electrode and then extended to another type grounding electrode requiring a larger conductor. For example, connecting from the equipment to the concrete electrode and then a bonding jumper to ground rods would permit a 4 AWG copper conductor to the concrete-encased electrode and then a 6 AWG bonding jumper to the one or more ground rods. But the reverse of this chain would not be permitted.

To a ground ring as in 250.52(A)(4); the conductor is not required to be larger than the ground ring conductor [see 250.66(C)]. The minimum size for the ground ring electrode is 2 AWG in accordance with 250.52(A)(4). This permission for a maximum size is allowed as long as the bonding conductor is not first connected to ground ring and then extended to another type grounding electrode requiring a larger conductor. For example, with a ground ring consisting of a 2 AWG copper conductor, connecting from the equipment to the ring and then a bonding jumper to a concrete-encased electrode would permit 2 AWG copper conductor to the ground ring and then a 4 AWG bonding jumper from the ground ring to the concrete-encased electrode. But the reverse of this chain would not be permitted.

Of course, larger bonding jumpers could be used. One last note is that the permitted installations above establish the ***maximum*** grounding electrode conductor or bonding jumper sizes and if Table 250.66 permits a smaller conductor then that is acceptable. For example, it is perfectly acceptable to install an 8 AWG copper grounding electrode conductor to a concrete-encased electrode (considering all installation requirements for physical protection are met) if the service entrance conductors are 2 AWG or smaller.

Section 250.64(A) does not permit bare aluminum or copper-clad aluminum conductors to be installed as a grounding electrode conductor where in direct contact with masonry or the earth or where subject to corrosive conditions. Where used outside, aluminum or copper-clad aluminum grounding electrode conductors shall not be terminated within 450 mm (18 in.) of the earth.

No sequence or order for installing the bonding jumper or jumpers is given. However, the minimum conductor size required to the various grounding electrodes is to be observed. In addition, the point where the grounding electrode connects to the grounding electrode system is required to provide for the largest required grounding electrode conductor. For example, it would be a violation to connect the equipment with a 4 AWG grounding electrode conductor to a concrete-encased grounding electrode and then continue on to a building steel grounding electrode which could require a 3/0 copper grounding electrode conductor. The installation would be acceptable if the 3/0 copper grounding electrode conductor connected from the equipment to the building steel and then a 4 AWG copper bonding jumper extends from the building steel to the concrete-encased electrode.

In addition, the unspliced grounding electrode conductor is permitted to run from the service equipment to any convenient grounding electrode or point on the grounding electrode system. Alternately, individual grounding electrode conductors are permitted to be installed from the service equipment to one or more grounding electrodes rather than the electrodes having to be bonded together in a circular or daisy- chained manner [see 250.64(F)]. The minimum size of each grounding electrode conductor to the individual grounding electrode is based on the electrode to which each individual grounding electrode conductor is connected (see figure 6.11) and the size of the service-entrance conductors. A grounding electrode conductor is permitted to supply or serve any number of grounding electrodes but is sized for the largest grounding electrode conductor required. (see figures 6.10 and 6.11).

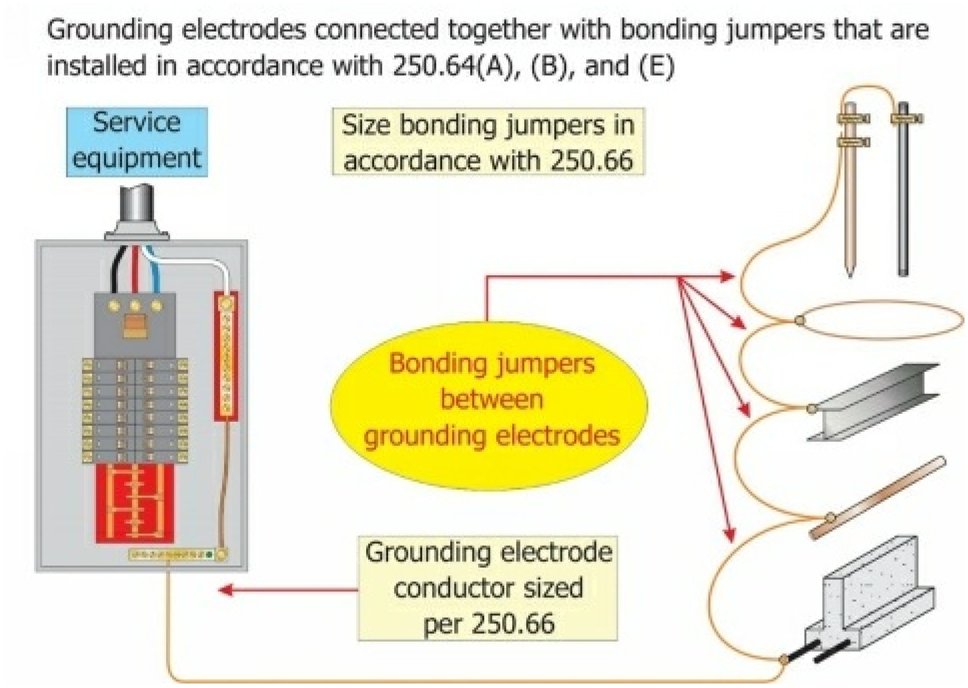


Figure 6.10 Bonding jumper(s) for the grounding electrode system

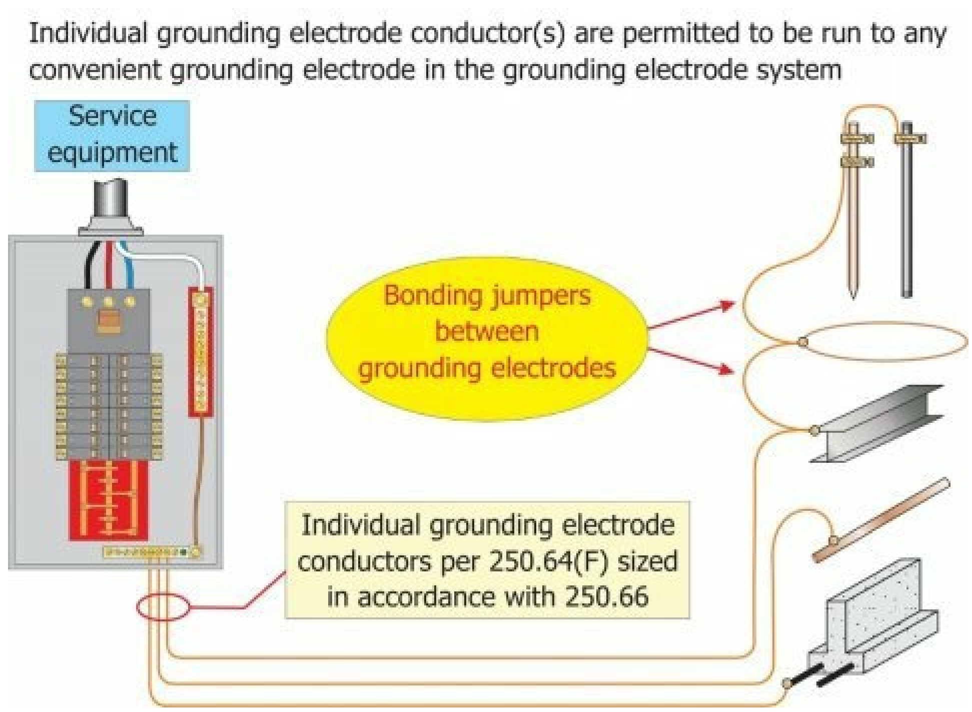


Figure 6.11 Size of individual grounding electrode conductor

Installation of Grounding Electrodes

Descriptions of the different types of grounding electrodes that are either permitted or not permitted are located in 250.52(A) and (B). Installation requirements for grounding electrodes such as depth, connections to, and electrode spacing between electrodes are covered in 250.53(A) through (H).

Field-installed electrodes such as rods, pipes, or plates are required to be installed below permanent moisture level where practicable. This is a key ingredient in establishing an effective electrode. They also are required to be free from nonconductive coatings such as paint and enamel.

Rod and pipe electrodes are required to be installed so at least 2.44m (8 ft) is in contact with the soil (see figure 6.12). They are required to be driven vertically unless rock bottom is encountered. If rock bottom is encountered which prevents the rod from being driven 8 feet vertically, the rod is permitted to be installed at an oblique angle of not more than 45 degrees from vertical. Where rock bottom is encountered at an angle up to 45 degrees, only then can the rod or pipe be buried in a trench that is at least 750 mm (30 in.) deep [see 250.53(G)].

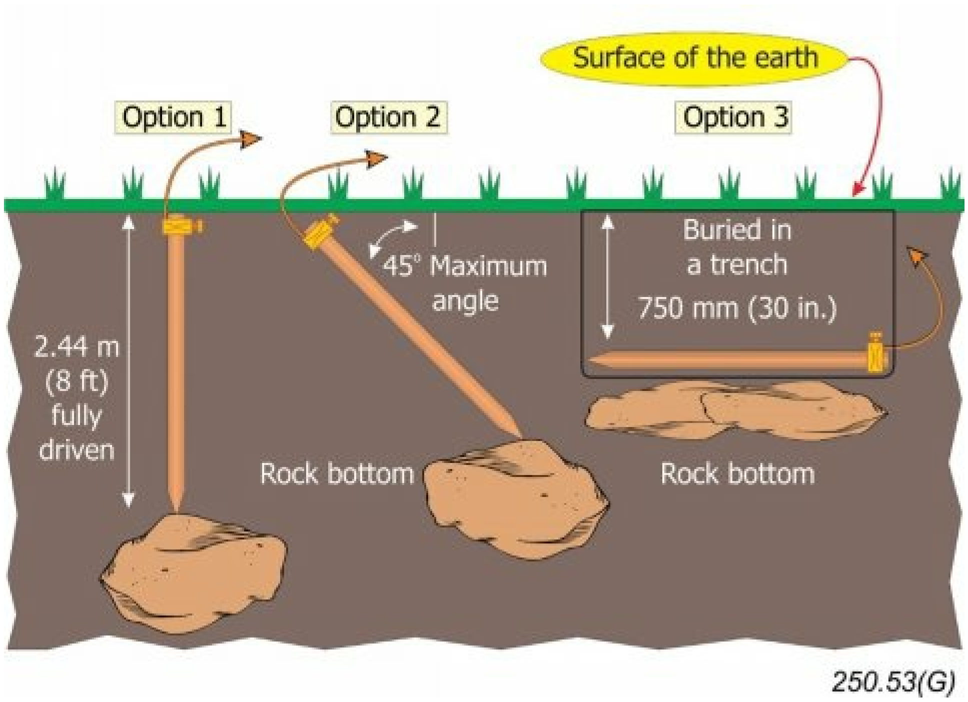


Figure 6.12 Installation requirements for rod or pipe electrodes

The upper end of the rod is required to be flush with or below ground level unless the aboveground end of the rod and the grounding electrode conductor attachment is protected from physical damage. This, of course, requires that a ground rod longer than 2.44 m (8 ft) be used if any part of the rod is exposed above ground level. Since a 2.44 meters (8 ft) ground rod or pipe must be driven the entire length, the ground clamp is required to be listed for direct earth burial.

Installation requirements for plate electrodes are found in 250.53(H) and require the plate to be buried not less than 762 mm (2 ½ ft) below the surface of the earth.

Section 250.10 requires that ground clamps or other fittings be approved (acceptable to the authority having jurisdiction) for general use without protection or be protected from physical damage by metal, wood or equivalent protective covering.

Common Grounding Electrode

Where more than one service supplies a building or structure, often there is more than one utility transformer or source. Multiple services or sources can have differences of potential between them, and where installed in the same building or structure, must use the same grounding electrode system. Section 250.58 requires that a common grounding electrode be used for all alternating-current system grounding in or at a building or structure. This is also required by 250.50. This section recognizes that where two or more grounding electrodes are bonded together, they are considered to be a single grounding electrode system.

Interestingly, the *NEC* does not specify a maximum distance between electrodes beyond which the electrodes do not have to be bonded together. Buildings or structures of large area are permitted by 230.2(B)(2) to have more than one service. However, nothing in the *Code* defines the dimensions of a large building or structure. Some inspection authorities use voltage drop of major feeders for guidance in determining when a building is one of large area. Where feeder conductors would have to be increased in size unreasonably to maintain voltage regulation, one or more additional services are permitted.

Section 250.58 requires the grounding electrodes for the multiple services be bonded together no matter how far apart they are in the same building. This bonding is important to keep all the equipment at the same earth potential. Section 250.53(C) requires the bonding jumper(s) used for this purpose to be sized from Table 250.66 and installed in accordance with 250.64(A), (B) and (E) (see chapter seven for additional information on installation of grounding electrode conductors). It is also permitted to use the structural metal frame of a building that complies with 250.68(C)(2), or where the exception to 260.68(C)(1) can be applied the metallic water system could be used as a bonding conductor. Section 250.68(C) could be interpreted to allow the concrete-encased electrode (rebar) to be used to interconnect other electrodes, but caution is advised to ensure the 250.53(C) for size is complied with. No. 4 rebar may not be adequately sized to act as a bonding conductor to interconnect other electrodes such as metallic water or metal in-ground support structures.

For example, a large building is served by four services. Where each of the services is connected to a grounding electrode system complying with 250.50 and 250.52(A), the building steel can be used to bond the various building grounding electrodes together (see figure 6.13).

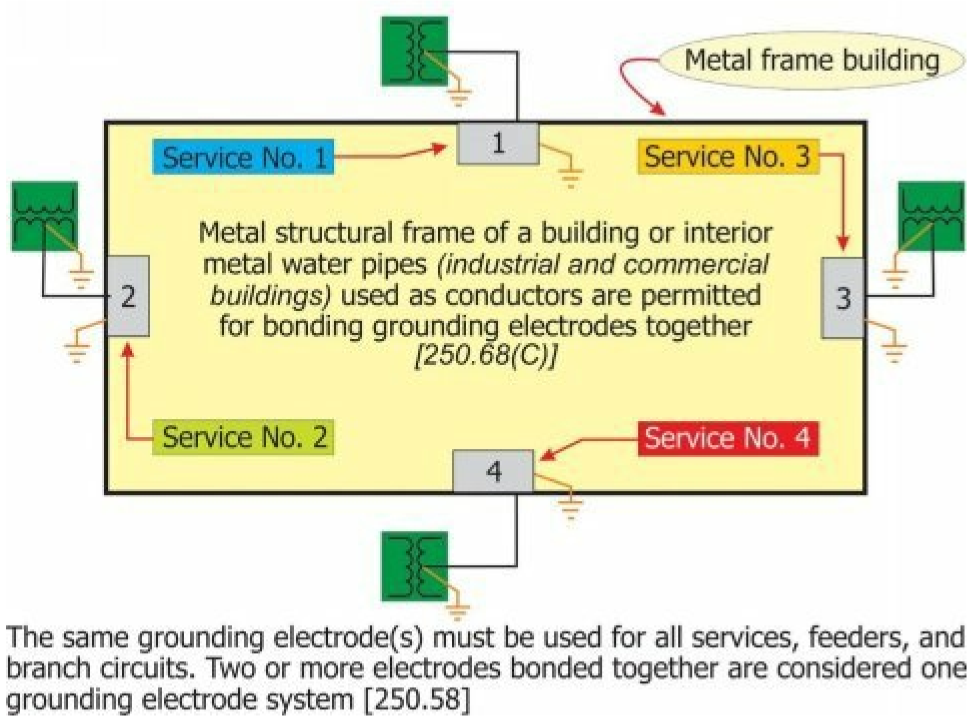


Figure 6.13 Metal building frame electrode is common to all services

Section 250.58 requires that a common grounding electrode be used to ground conductor enclosures and equipment in or on the building and that the same grounding electrode also be used to ground the system. Again this does not mean that one cannot use more than one grounding electrode, but if more than one is used, then all the grounding electrodes are required to be bonded together to form a common grounding electrode system.

Enhanced Grounding Electrodes

Grounding electrodes and grounding electrode systems are covered in Part III of Article 250. These are the minimum requirements for grounding electrodes for use in grounding services, systems, and equipment. With ever-increasing installations using information technology equipment and sensitive electronics, there is sometimes the need to exceed the minimum requirements established for the safety of persons and property. This is accomplished by installing electrodes or electrode systems that are extensive in nature and designed to establish and maintain a lower level of resistance in the connection to earth through the electrode or electrode system. There are listed products available to accomplish this additional grounding when desired for the electrical system. Section 250.52(A)(6) includes provisions for other listed electrodes.

Electrolytic Grounding Systems

Electrolytic grounding was invented by the XIT Rod Company in the late 1960s (see photo 6.3 and figure 6.14). It was specifically designed to overcome some of the limitations of other typical electrodes. This active electrode consists of a hollow copper pipe filled with natural earth salts. The salts extract moisture from the air, which forms a highly conductive electrolytic solution. The solution continually weeps into the surrounding backfill material providing improved conductivity and seasonal stability. The electrode is installed in an augured hole or trench and backfilled with specially processed bentonite clay. The clay is very conductive with nearly a neutral pH that helps protect the electrode from corrosion. Due to its high conductivity, the bentonite improves the ground system performance and also provides an excellent electrical bond between the electrode and the surrounding earth. These active electrodes are the only ones that improve with time; other electrodes become less efficient and begin deteriorating upon installation.[4]

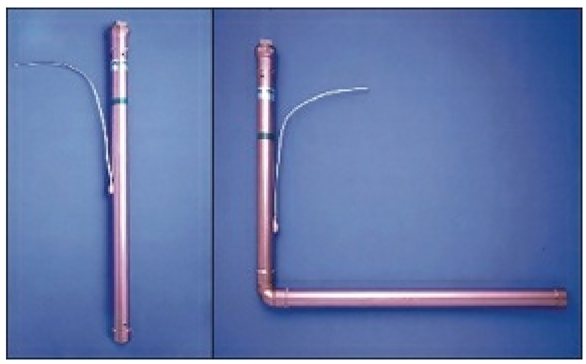


Photo 6.3 Enhanced grounding electrode Courtesy of Harger

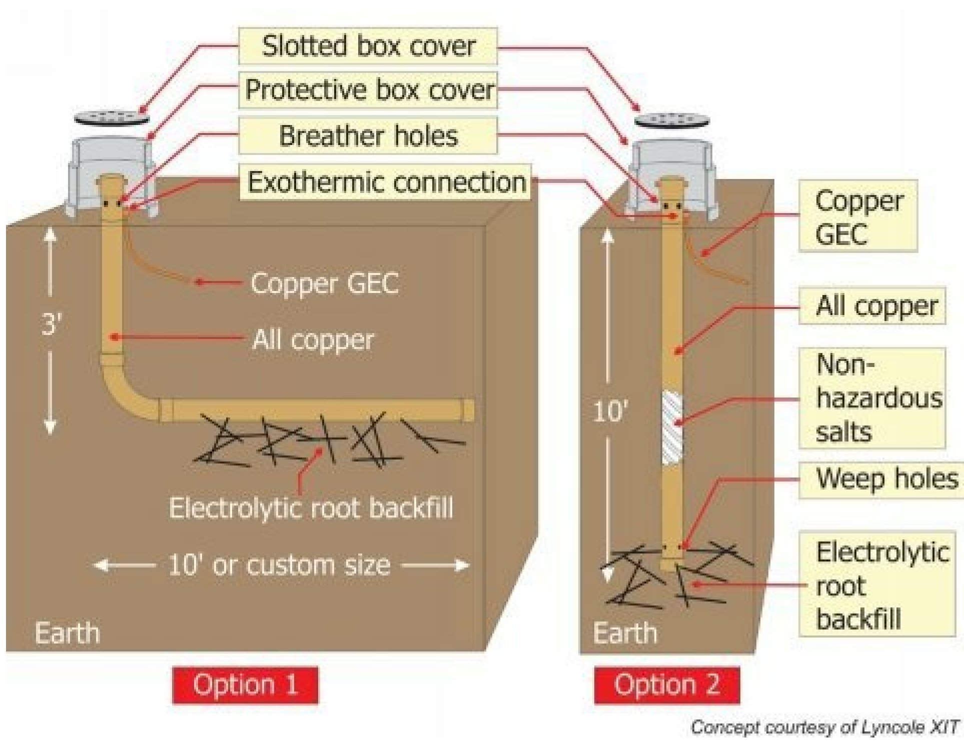


Figure 6.14 Anatomy of an enhanced grounding electrode Concept is courtesy of Lincole XIT Grounding

Enhanced Grounding Electrode Types

These enhanced electrodes can be installed in a variety of methods. The nature of these electrodes can also vary. Some are intended to be installed with no additional maintenance required. Others are installed and have to be maintained with chemicals or other effective means. The maintainable electrodes are more commonly installed under controlled conditions where there is qualified staff that will ensure proper supervision and maintenance of the electrode system. Additional information on these enhanced grounding electrodes and grounding electrode systems and their uses are covered in chapter nineteen.

Earth Return Prohibited

In discussing grounding electrodes, no mention is made to providing a low-resistance, low-impedance common grounding electrode path for clearing ground faults. The high impedance of the earth makes it an ineffective path for the levels of current common to power systems. The *NEC* in 250.4(A)(5) clearly states the earth may never be used as an effective ground-fault current path, as it is a very poor conductor. The top graphic in figure 6.15 shows that the grounding electrodes provide the only return circuit through the earth. Even if the grounding electrode resistance to the earth were very low, it would have little effect on clearing a ground fault, because the reactance of the earth and the soil in the ground-fault return path is very high. As discussed in chapter one, the greater the resistance or impedance is, the less the amount of current. Where a parallel path exists through the earth and the grounded service conductor, almost all of the ground-fault return current will return to the source through the grounded service conductor as shown in the bottom graphic of figure 6.15. A low-resistance common grounding electrode system is beneficial to the electrical installation by keeping equipment and the grounded conductor at or close to earth potential. It simply is not effective in clearing line-to-ground faults. Sections 250.4(A)(5) and 250.54 make it clear that the earth is not to be depended upon to function as an effective ground-fault current path. However, to attain a better earth connection for some equipment, auxiliary grounding electrodes are permitted to be supplementary to equipment grounding conductors and to be connected to the equipment grounding conductor(s) as provided in 250.54.

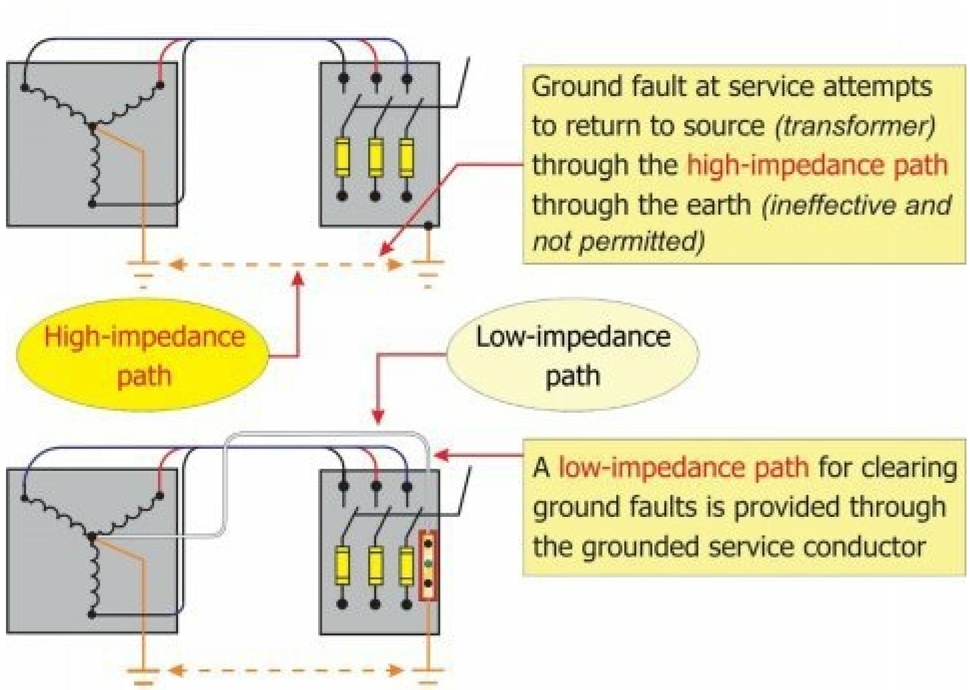


Figure 6.15 Earth is prohibited as an effective ground-fault current path (a low-impedance path is required).

If a ground fault should develop as shown in the upper drawing in figure 6.15 where two separate grounding electrodes are used, the fault-current will be through the service conductor, then through the impedance of the ground fault, the grounding electrode conductor at the service, the grounding electrode at the service, the path through the earth to the grounding electrode at the transformer, and finally through the grounding electrode conductor at the transformer to complete the circuit to the transformer. It would be a rare case where that circuit resistance would add up to less than 12 ohms (while the impedance would be higher). Even then, the fault current would not reach a value high enough to operate a 15-ampere overcurrent device on a 120 volt-to-ground circuit ($120 \div 12 = 10$ amperes).

Considering resistance only, the circuit shown has two grounding electrodes in series. Compared to the much lower resistance parallel path of the grounded circuit conductor, a resistance ratio between the two parallel paths is about 50 times for a 100-ampere service to well over 100 times for the larger services. When the impedance of the two paths is considered, the ratio will be higher. Therefore, almost all the current from a line-to-ground fault will return to the transformer over the grounded service conductor.

Under normal operating conditions there will be some unbalanced return current in the neutral back to its source. There will also be some unbalanced neutral current through the earth, but it will be a very low level compared to that through the grounded service conductor.

Any belief that the circuit to the grounding electrode can be depended on to clear a ground fault is clearly erroneous no matter how large a grounding electrode conductor is used or how good a grounding electrode is. However, when the high-impedance earth path is short-circuited by installing the grounded circuit conductor as shown in the lower drawing in figure 6.15, a low-impedance ground-fault return path is established as required in 250.4(A)(5). This path provides or allows enough current through the equipment grounding conductor and service grounded conductor to allow the branch-circuit, feeder, or service over-current device to clear the fault and thus provide the safety contemplated by the *Code*.

Resistance of Grounding Electrodes

There is no requirement in Article 250 that the grounding electrode system required by 250.50 (consisting of one or more electrodes such as metal underground water pipe, metal frame of the building, concrete-encased electrode) meet any maximum resistance to ground. No doubt it is expected that the grounding electrode system will have a resistance to ground of 25 ohms or less. The *Code* specifies a resistance of 25 ohms or less ***only*** for single rod, pipe, or plate electrode(s). Where the resistance of a single rod, pipe, or plate electrode exceeds 25 ohms, they are required to be supplemented by one additional electrode other than a metallic water pipe electrode.

The *Code* states, in 250.53(A)(2), that rod, pipe and plate electrodes must be supplemented by one other electrode. An exception to this section provides that where a single rod, pipe, or plate electrode has a resistance to ground of 25 ohms or less then no supplemental electrode is required (see figures 6.16 and 6.17). This means that where driven ground rods are installed for example, two ground rods would be the maximum required under any condition. There is no requirement that additional electrodes such as ground rods or plates be installed until the 25 ohms-to-ground resistance is obtained.

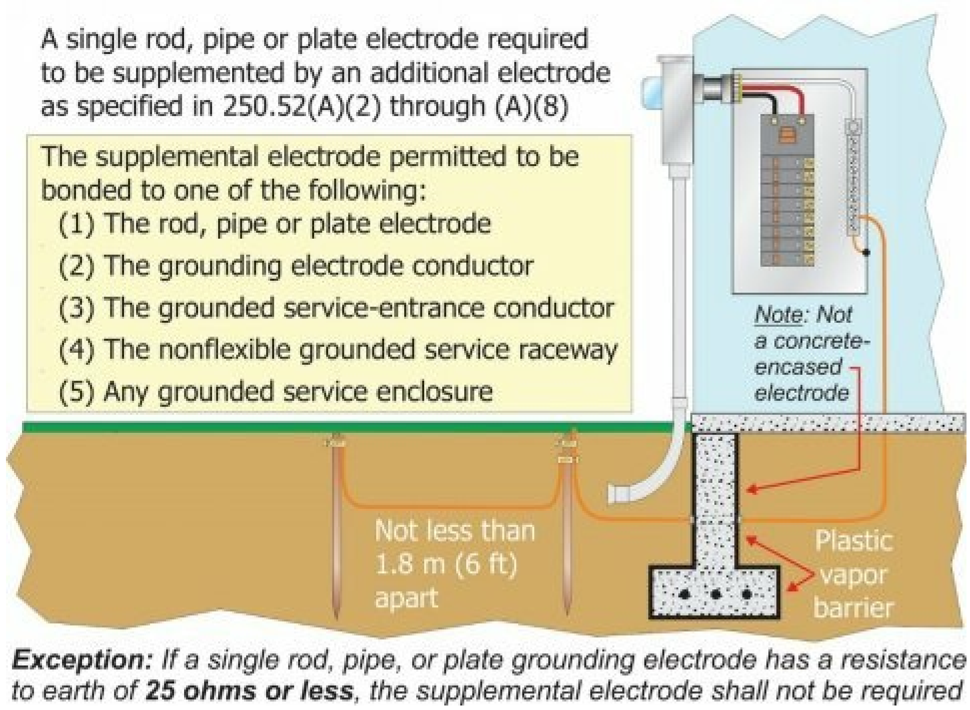


Figure 6.16 Rod, pipe, and plate electrodes required to be supplemented

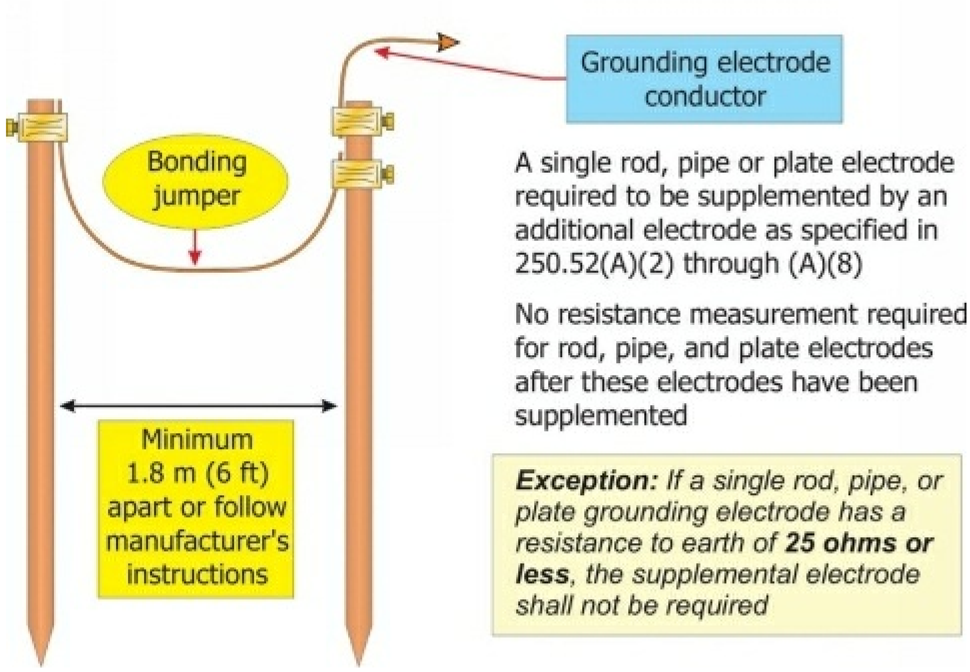


Figure 6.17 Electrode spacing requirements

In general, metallic underground water piping systems, metallic well piping systems, structural metal electrodes and similar grounding electrodes can be expected to provide a ground resistance of not over 3 ohms and in some cases as low as 1 ohm.

However, from a practical standpoint, no grounding electrode, no matter how low its resistance can ever be depended upon to clear a ground fault on any distribution system of less than 1000 volts.

Even if a system is effectively grounded, 250.4(A)(5) specifies a path of low impedance (not through the grounding electrode) is required to be provided to facilitate the operation of the overcurrent devices or ground detectors in the circuit (see chapter eleven).

The lowest practical resistance of a grounding electrode is desirable and will better limit the voltage to ground when a ground fault occurs. It is also very important to provide a low-impedance path to clear a fault promptly, because a voltage to ground can only occur during the period of time that a fault exists. Clearing a ground fault quickly enhances safety.

Even though the grounding electrode can have a low resistance to earth, it is a high-impedance circuit and plays virtually no part in the clearing of a fault on a low-voltage distribution system. This is because there is a higher resistance path through the earth than through the grounded service conductor. In addition, the remote path through the grounding electrode and earth is a high-impedance path compared to the circuit where the grounded service conductor is installed and routed with the ungrounded (phase) conductors.

Ground Electrode System Monitoring

Grounding electrode system monitoring capability has become more and more common especially where information technology equipment and other sensitive electronic equipment are utilized. This equipment is not required by the *Code*, but often desired as an essential performance option for data centers and similar facilities. Grounding electrodes and grounding electrode systems are the cornerstones (foundation) of electrical protection of a site or facility. Grounding is an integral part of safety as well as the effectiveness of lightning protection and surge suppression systems. Grounding electrode system resistance monitoring equipment measures the grounding system performance on an ongoing basis and provides an early warning of ground system degradation or loss of integrity so remedial action can be taken. Figure 6.18 provides a conceptual creation of ground resistance monitor components.

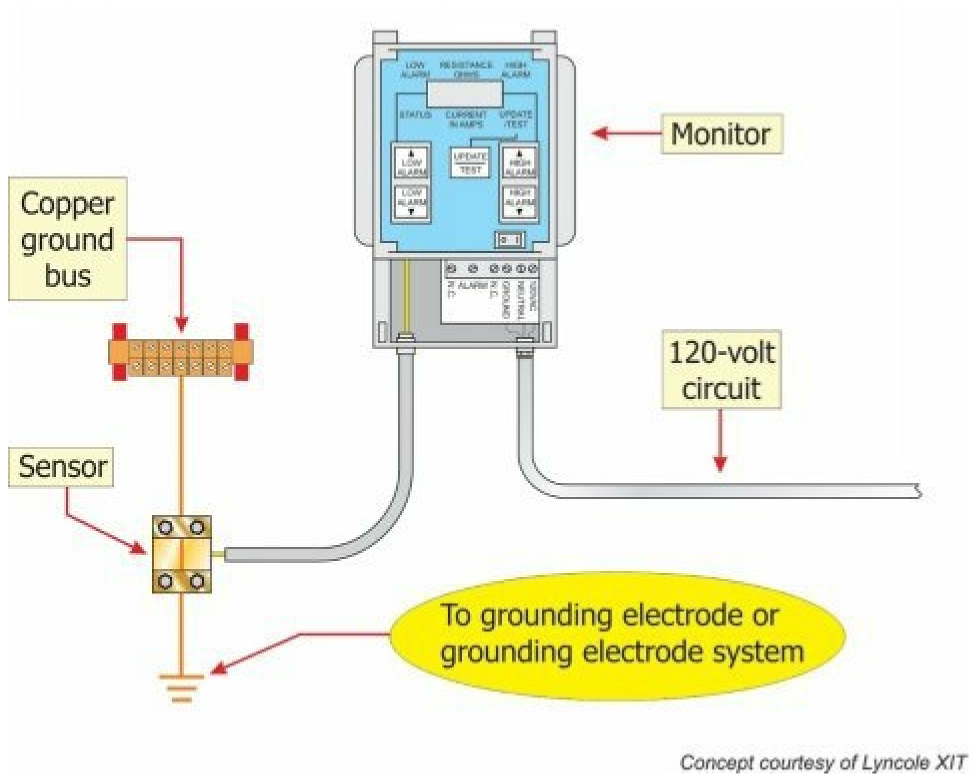


Figure 6.18 Ground resistance monitor components Concept Courtesy of Lincole XIT

The system consists of a permanent wall-mounted meter and a sensing head (attached to the grounding electrode conductor). The meter features both high and low level alarms for instantaneous notification when the pre-set resistance values are exceeded.

Features of these types of systems include but are not limited to: (1) ongoing monitoring of ground system resistance and current; (2) remote reading and control capability (3) local audible alarm; (4) high and low alarm values; and (5) adjustable sampling rate.

Ground Electrodes

The term *ground* is defined as “the earth.” The connection to ground (earth) is used to establish and maintain as closely as possible the potential of the earth on the circuit or equipment connected to it. A ground consists of a grounding electrode conductor, a bonding connection, grounding electrode(s), and the soil in contact with the electrode.

Grounding has several protection applications. For natural phenomena, such as lightning, grounding electrodes provide a path to earth to discharge the lightning energy and minimize injury to personnel or mitigate damage to system components. For other hazards due to faults in electric power systems using ground returns, effective grounding helps ensure rapid operation of the protection relays by providing low resistance fault-current paths. This provides for the removal of the hazardous voltage as quickly as possible. The grounding path should mitigate the hazardous voltage before personnel are injured and the power or communications system equipment is damaged.

Ideally, to maintain a reference potential for instrument safety, protect against static electricity, and limit the system-to-frame voltage for operator safety, a ground resistance should be zero ohms. In reality, as described further in the text, this value cannot realistically be obtained.

Last, but not least, low ground resistance is essential to meet *NEC*, OSHA, and other electrical safety standards.

Figure 6.19 illustrates a grounding rod installed as a grounding electrode. The resistance of the electrode has the following components: (1) resistance of the metal and that of the connection to it; (2) contact resistance of the surrounding earth to the electrode; (3) resistance in the surrounding earth to current; or earth resistivity, which is often the most significant factor.

More specifically:

1. Grounding electrodes are usually made of a very conductive metal (copper, copper clad, or zinc plated (galvanized)) with adequate cross sections so that the overall resistance is negligible.

2. The National Institute of Standards and Technology (NIST) has demonstrated that the resistance between the electrode and the immediate surrounding earth is negligible if the electrode is free of paint, grease or other coating, and if the earth is firmly packed.

3. The only component remaining is the resistance of the surrounding earth. The electrode can be thought of as being surrounded by concentric shells of earth or soil, all of the same thickness. The closer the shell is to the electrode, the smaller its surface; hence, the greater its resistance. The farther away the shells are from the electrode, the greater the surface of the shell; hence, the lower the resistance. Eventually, adding shells at a distance from the grounding electrode will no longer noticeably affect the overall earth resistance surrounding the electrode. The distance at which this effect occurs is referred to as the effective resistance area and is directly dependent on and related to the depth of the grounding electrode.

Grounding Electrode Resistance Testing

Section 250.53(A)(2) covers the resistance requirements of rod, pipe and plate grounding electrodes and reads as follows: "Supplemental Electrode Required. A single rod, pipe or plate electrode shall be supplemented by an additional electrode of a type specified in 250.52(A)(2) through (A)(8). The supplemental electrode shall be permitted to be bonded to one of the following:

(1) Rod, pipe or plate electrode

(2) Grounding electrode conductor

(3) Grounded service-entrance conductor

(4) Nonflexible grounded service raceway

(5) Any grounded service enclosure

Exception: If a single rod, pipe, or plate grounding electrode has a resistance to earth of 25 ohms or less, the supplemental electrode shall not be required."

Section 250.53(A)(3) goes on to require "Supplemental Electrode. If multiple rod, pipe, or plate electrodes are installed to meet the requirements of this section, they shall not be less than 1.8 m (6 ft) apart.

"Informational Note: The paralleling efficiency of rods is increased by spacing them twice the length of the longest rod" (see figure 6.17).

The 25-ohm value for a single electrode is an upper limit. Much lower values are beneficial and specified in many instances.

"How low in resistance should a connection to ground be?" An arbitrary answer to this in ohms is difficult. The lower the ground resistance is, the safer the installation; and for positive protection of personnel and equipment, it is worth the effort to aim for less than one ohm. But it is generally impractical to reach such a low resistance along a distribution system or a transmission line or in small substations. In some regions, resistances of 5 ohms or less can be obtained without much trouble.

In other regions, it can be difficult to bring resistance of driven grounds below 100 ohms.

Accepted industry standards stipulate that transmission substations should be designed not to exceed one-ohm resistance. In distribution substations, the maximum recommended resistance is 5 ohms or even 1 ohm. In most cases, the buried grid system, typically with driven ground rods installed, of any substation will provide the desired resistance.

In light industrial or in telecommunication central offices, 5 ohms resistance is often the accepted value. For lightning protection, the arrestors should be coupled with a maximum ground resistance of 1 ohm. These parameters can usually be met with the proper application of basic grounding theory. Circumstances can exist that will make it difficult to obtain the ground resistance required by the *NEC* or other safety standards. When these situations develop, several methods of lowering the ground resistance can be employed. These include parallel rod systems, deep driven rod systems utilizing sectional rods and chemical treatment of the soil. Additional methods, discussed in other published data, are buried plates, buried conductors (counterpoise), electrically connected building steel, and electrically connected concrete reinforced steel.

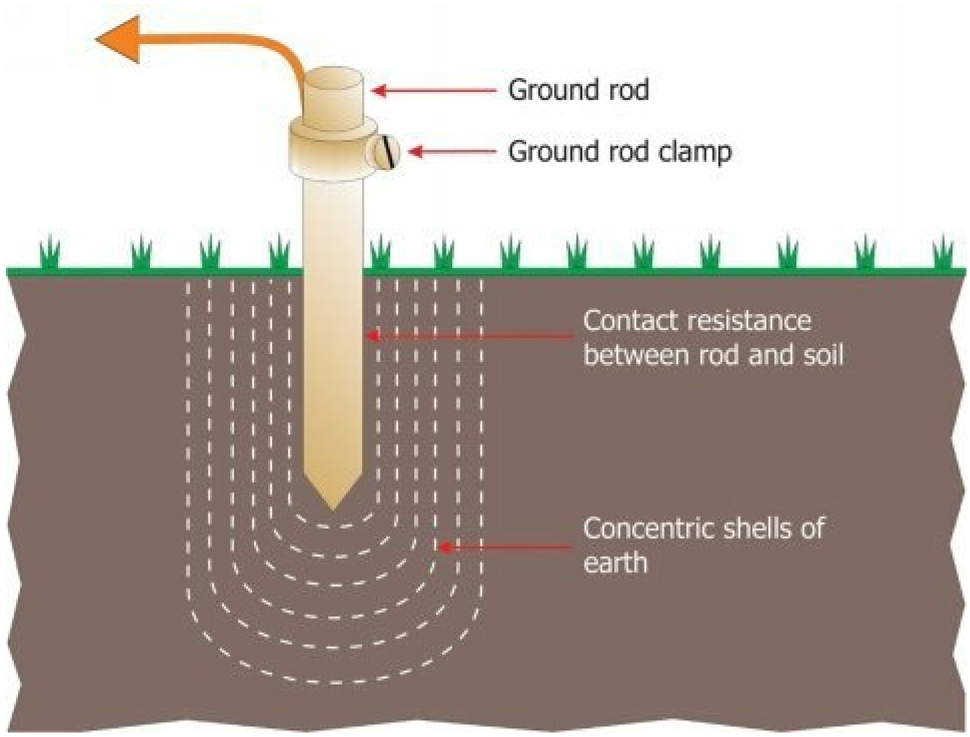


Figure 6.19 Ground rod resistance

Electrically connecting to existing water and gas distribution systems was often considered to yield low ground resistance; however, recent design changes utilizing nonmetallic pipes and insulating joints have made this method of obtaining a low resistance to ground questionable and in many instances unreliable. It should be noted that 250.52(B) prohibits the use of metal underground gas piping as a grounding electrode.

The measurement of ground resistances can only be accomplished with specially designed test equipment. Most instruments use the fall-of-potential principle of alternating current (ac), not at the power system frequency, circulating between an auxiliary electrode and the grounding electrode under test; the reading will be given in ohms, and represents the resistance of the ground electrode to the surrounding earth (see figures 6-20 through 6.22). Some manufacturers of earth resistance testing instruments have recently introduced clamp-on ground resistance testers (see photos 6.4 and 6.5).

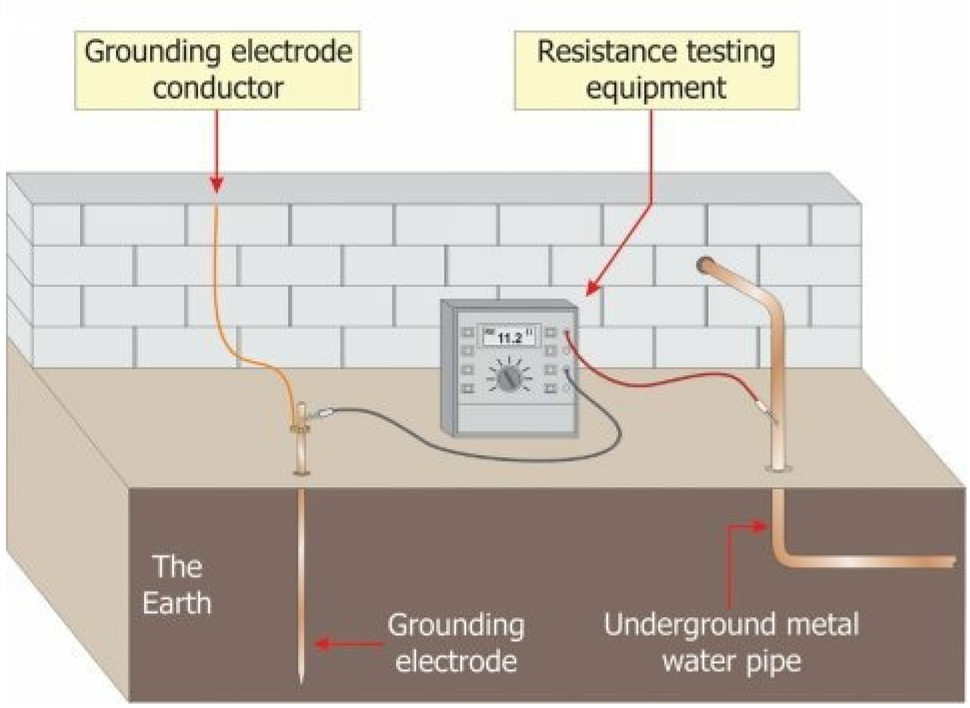


Figure 6.20 Principles of earth testing

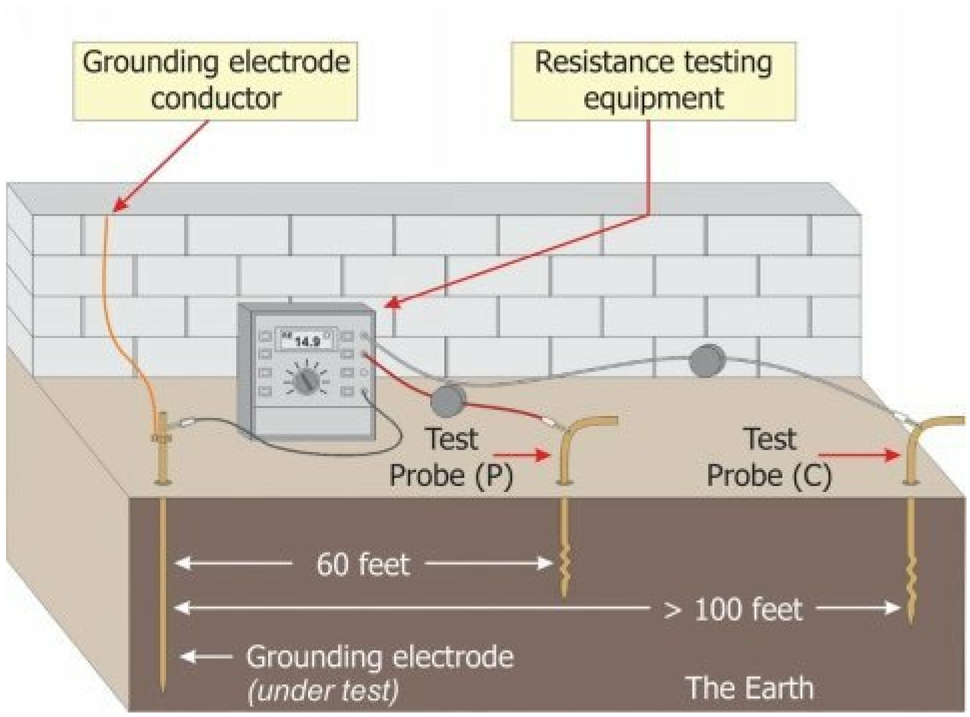


Figure 6.21 Principles of earth testing

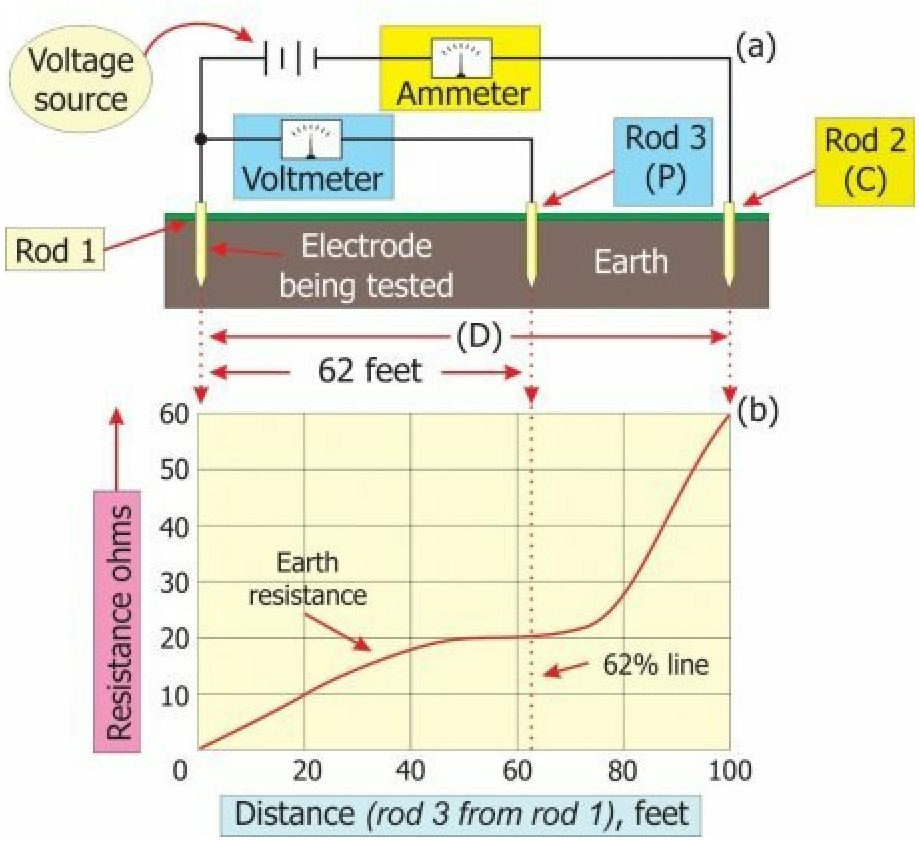


Figure 6.22 Principles of earth testing

Photo 6.4 Earth/ground resistance clamp-on tester. Courtesy of Megger

Photo 6.5 Clamp-on test instrument being used to test a facility grounding electrode Courtesy of Megger

Objectionable Currents

Section 250.6 recognizes that conditions can exist which can cause objectionable current through the grounding electrode conductor or equipment grounding conductor, other than temporary currents that can exist during fault conditions. We should recognize that grounding electrode conductors or equipment grounding conductors are not intended to carry current under normal operating conditions. They are installed for and are intended to carry current to perform some safety function.

The *Code* does not define what is meant by objectionable current. Any current through a grounding electrode conductor would create a voltage drop due to the resistance of the conductor. The equipment to which the grounding electrode conductor is connected is now energized at some voltage level when compared to the earth. This energized equipment could create a shock hazard to anyone that contacted it. Anything that prevents maintaining the equipment at earth potential would be objectionable.

Section 250.6(B) permits the following corrective actions to be taken where there is objectionable current:

- If due to multiple grounds, one or more, but not all, of such grounds may be discontinued.
- The location of the grounding connection may be changed.
- Interrupt the continuity of the conductor or conductive path causing the objectionable current.
- Other means satisfactory to the authority enforcing the *Code* may be taken to limit the current over the grounding electrode or equipment grounding conductors.

The *Code* points out that temporary currents resulting from accidental conditions, such as ground-fault currents, that occur only while the grounding electrode or equipment grounding conductors are performing their intended protective functions are not considered the objectionable currents covered in these sections.

Section 250.6(D) points out currents that introduce noise or data errors in electronic equipment are not considered to be objectionable currents. Electronic data processing equipment is not permitted to be operated ungrounded or by being connected only to its own grounding electrode without also being connected to an equipment grounding conductor with reduced “noise.”

Chapter nineteen includes special grounding provisions for installations, such as information technology rooms, where EMI (electro-magnetic interference) or noise in the grounding circuits or systems can cause data errors and loss of data. In these types of installations, the minimum grounding and bonding requirements in Article 250 may need to be expanded upon to provide better grounding (earthing) electrodes and equipment grounding conductors and installation to reduce any interference.

Lightning Protection System

Lightning protection systems should be installed in accordance with the NFPA-780, *Standard for the Installation of Lightning Protection Systems*.

The *Code* prohibits, in 250.60, the use of driven pipes, rods, or other electrodes installed for connection of the lightning protection conductors and strike termination devices for in place of the grounding electrodes required for a wiring system and for equipment. Note that where two grounding electrodes are installed, they are required to be bonded together. [See 250.106 for the requirement the lightning protection grounding electrode system be bonded to the building or structure power grounding electrode system.] (See figure 6.23).

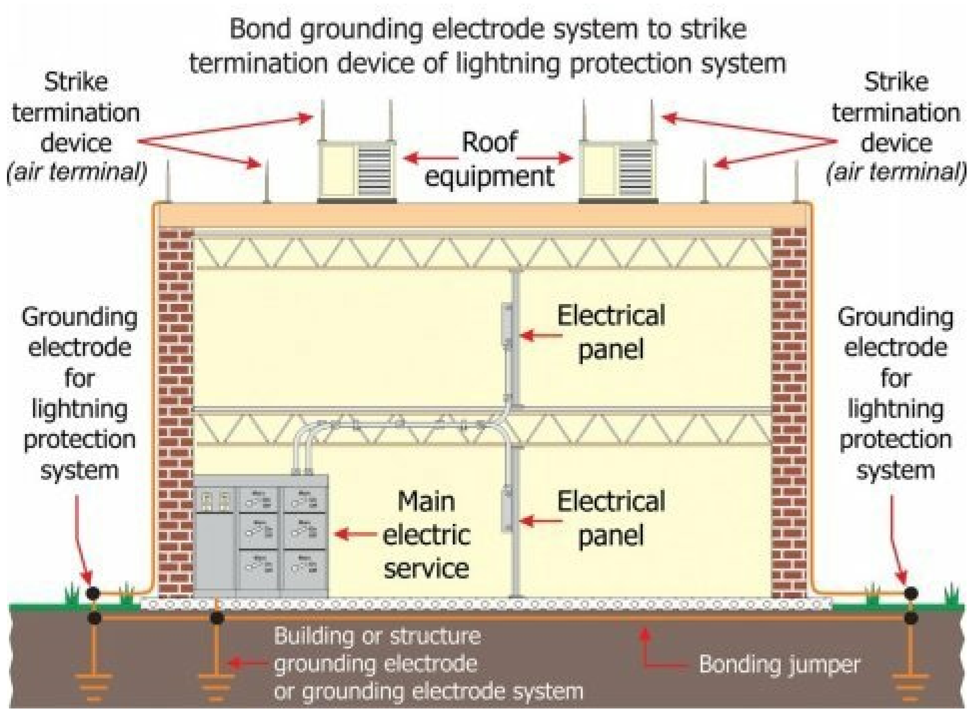


Figure 6.23 Bonding of lighting protection strike termination devices to power system grounding electrode is required

The informational notes following 250.106 provide valuable information regarding lightning protection systems. The *NEC* no longer has specific side-flash spacing requirements for separation of lightning protection system conductors from metal raceways and other metal enclosures of the building electrical system. The required spacing is typically 1.8 m (6 ft) through air and 900 mm (3 ft) through dense construction materials such as concrete, brick, or wood. Specific requirements are given in the NFPA-780, *Standard for the Installation of Lightning Protection Systems*. See chapter twenty-one for information about lightning protection systems.

Conclusion

No potential exists between a conductor or equipment enclosure and earth if the system is properly and adequately grounded, except possibly during a fault. By careful and thoughtful design, the fault clearing time can be reduced to a minimum.

While it is desirable to obtain a grounding electrode resistance as low as practical, it is also very important to provide a path of low impedance for the return of ground-fault current that will clear a ground fault when it occurs.

A hazard does not typically exist in the distribution system until there is an insulation failure to create a ground fault. The hazard only exists for the period of time it takes to clear the fault. If a ground fault clears promptly, it is unlikely that any loss of life would occur and property damage is kept to a minimum.

For maximum safety, follow a cardinal rule: for the electrical distribution system, only one grounding electrode system is required or allowed to be used in or on a building or structure. Everything that should, or is required to, be grounded is then connected to that same grounding electrode system. If more than one grounding electrode is required, they may be used providing all the grounding electrodes present or installed are bonded together to form a grounding electrode system which, in effect, becomes one common grounding electrode. Grounding electrodes should never be relied upon to provide the ground-fault return path for equipment. That is not their intended function in the electrical system and they cannot be relied upon to provide that effective ground-fault current path.

1, 2, 3 NFPA 70, *National Electrical Code* 2017, (Quincy, MA, National Fire Protection Association, 2016)

Review Questions

1. "A conducting object through which a direct connection to earth is established" best defines which of the following:

1. equipment grounding
2. grounding electrode
3. main bonding jumper
4. earthing conductor

2. "Connected (connecting) to ground or to a conductive body that extends the ground connection" best defines which of the following:

1. grounded (grounding)
2. effectively grounded
3. bonding
4. earthing

3. "One or more steel reinforcing bars or rods not less than 13 mm (½in.) in diameter, installed in one continuous 6.0 m (20 ft) length, or if in multiple pieces connected together by the usual steel tie wires, exothermic welding, welding, or other effective means to create a 6.0 m (20 ft) or greater length; or 6.0 m (20 ft) more of bare copper conductor not smaller than 4 AWG that is encased in not less than 50 mm (2 in.) of concrete" best describes which of the following:

1. butt ground
2. pole ground rod
3. feeder electrode
4. concrete-encased electrode

4. A concrete-encased electrode must be located horizontally within that portion of a concrete foundation or footing that is in direct contact with the earth or within vertical foundations or structural components or members that are in direct contact with the earth and is required to be encased by not less than ____ inches of concrete.

1. 13 mm (½ in.)
2. 25 mm (1 in.)
3. 50 mm (2 in.)
4. 150 mm (6 in.)

5. A copper conductor not smaller than 2 AWG at least 6.0 m (20 ft) encircling a building or structure, and buried at not less than 750 mm (30 in.) deep defines a ____.

1. concrete-encased electrode

2. ground ring
3. supplemental electrode
4. common bonding grid

6. Where an underground metal water pipe is the only grounding electrode that is present, and is connected at the building or structure served, it must be supplemented by another ____.

1. grounding electrode
2. main bonding jumper
3. equipment grounding conductor
4. circuit bonding jumper

7. An electrode that is considered as being suitable for supplementing the metal underground water pipe, includes a concrete-encased electrode, ground ring, other local metal underground systems or structures, or ____ electrodes.

1. rod
2. pipe
3. plate
4. all of the above

8. Where present at each building or structure served, all grounding electrodes, including ____ electrodes, are required to be bonded together to form the grounding electrode system.

1. identified
2. approved
3. rod, pipe, or plate
4. gas pipe

9. Where the electrodes described in Section 250.52(A)(1) through (A)(7) do not exist at the premises or structure served, a grounding electrode must be installed, which could include a ____.

1. local metallic underground systems or structures, tanks, etc.
2. pipe or conduit electrodes not less than 2.44 m (8 ft) in length not smaller than metric designator 21 (¾ in.), and if of iron or steel, must be galvanized or metal-coated for corrosion protection.
3. rod-type electrodes of steel at least 15.87 mm (5/8 in.) diameter.
4. any of the above

10. Where two or more grounding electrodes are bonded together, they are considered to be a ____ electrode.

1. single

2. an identified
3. an approved
4. a listed

11. The *Code* recognizes that conditions may exist that may cause an objectionable current over the grounding electrode conductor, other than temporary currents that may be set up under accidental conditions. Permitted alterations include ____.

1. abandoning one or more, but not all, of such grounding connections, if due to multiple grounding connections
2. their location can be changed
3. continuity of the equipment grounding conductor may be suitably interrupted
4. any of the above

12. Currents that introduce noise or data errors in electronic equipment are not considered to be ____.

1. dangerous currents
2. objectionable currents
3. harmonic currents
4. unsafe currents

13. A single rod, pipe, or plate electrode shall be ______ by an additional electrode of a type specified in 250.52(A)(2) through (A)(8).

1. augmented
2. supported
3. supplemented
4. buried

14. Where a single rod, pipe, or plate electrode achieves a resistance to ground of ____ ohms or less, that electrode is not required to be supplemented by an additional electrode.

1. 50
2. 40
3. 30
4. 25

15. The use of continuous metallic underground water and metal well casings, as well as the metal frames of buildings, will generally provide a ground resistance not exceeding ____ ohms.

1. 3
2. 6

3. 12
4. 25

16. Features of a grounding electrode monitoring systems include_____.

1. continuous monitoring of ground system resistance and current
2. remote reading and control capability
3. local audible alarm
4. all of the above

17. The use of strike termination device (lightning rod) conductors and ground terminals of lightning protection systems are ____ for the grounding electrode(s) or grounding electrode system required by the *Code* for a wiring system and for equipment.

1. permitted to be used
2. not permitted to be used
3. permitted by special permission
4. identified when labeled to be used

18. Auxiliary grounding electrodes are permitted by the *Code* and are required to be connected to the __________ conductor, but the _________ shall not be used as an effective ground-fault current path.

1. grounding electrode, conduit
2. equipment grounding, earth
3. bonding, ground rods
4. grounded, equipment grounding bus

19. Underground metal well casings are _______.

1. required to be used as a grounding electrode
2. required to be insulated from metal underground water piping
3. required to have at least 3.0 m (10 ft) in contact with the earth
4. considered as an "other local metal underground systems or structures" that could qualify as a grounding electrode

20. Concrete-encased electrodes that are _______ at a building or structure served are required to be part of the grounding electrode system.

1. present
2. available
3. epoxy coated
4. visible

21. The metal in-ground support structure of the building or structure must be used as an electrode_____.

1. where located below permanent moisture levels
2. where in contact with a concrete slab
3. where it has 3.0 m (10 ft) in contact with the earth
4. it is exposed

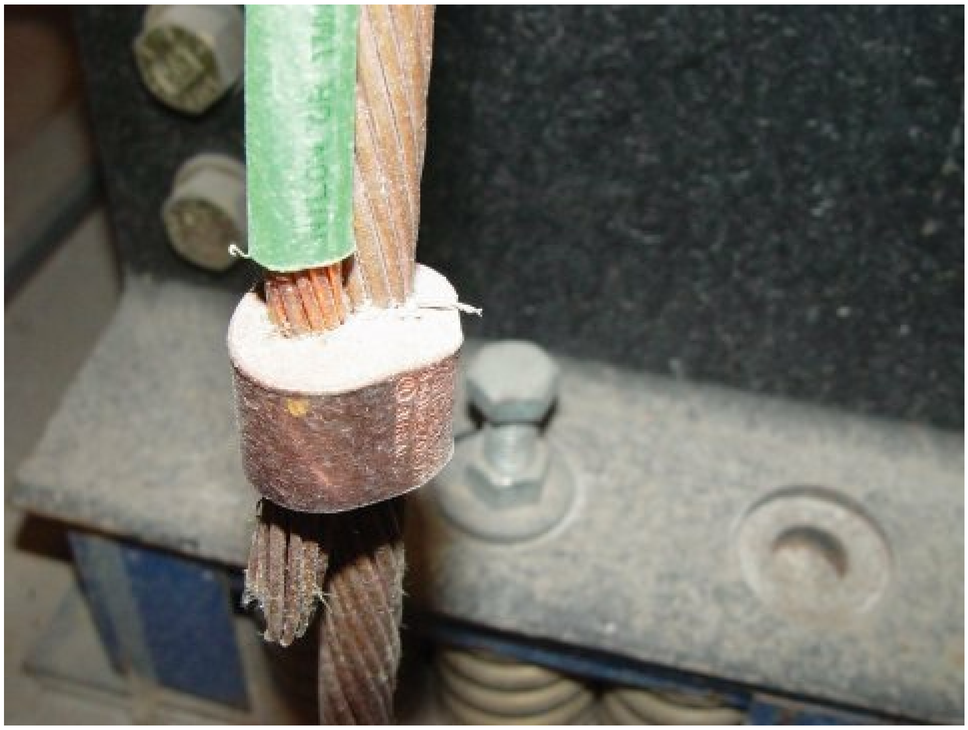
22. Where multiple separate concrete-encased electrodes are present at a building or structure served, which of the following applies ____?

1. They are all required to be bonded into the grounding electrode system.
2. They shall all meet the 25-ohm resistance value
3. It is permissible to bond only one into the grounding electrode system.
4. They shall all be supplemented by a ground rod electrode.

23. Where the metal in-ground support structure(s) ___________ is the part of the structural metal in the earth, that portion of the structural metal above grade is a ______________ and not the electrode.

1. equipment grounding conductor, ungrounded conductor
2. electrode, "conductor"
3. grounding conductor, grounded conductor
4. building steel, equipment grounding conductor

⏚ Chapter 7
Grounding Electrode Conductors



Objectives to understand

- General requirements and definitions for grounding electrode conductors
- Functions of the grounding electrode conductor
- Sizing grounding electrode conductors
- Grounding electrode conductor installation
- Grounding electrode conductor connection
- Material and protection for grounding electrode conductors

The grounding electrode conductor is used to connect the electrical system grounded conductor, or the equipment grounding conductor, or both, to a grounding electrode or point on the grounding electrode system, hence the specific term, grounding electrode conductor (see figure 7.1).

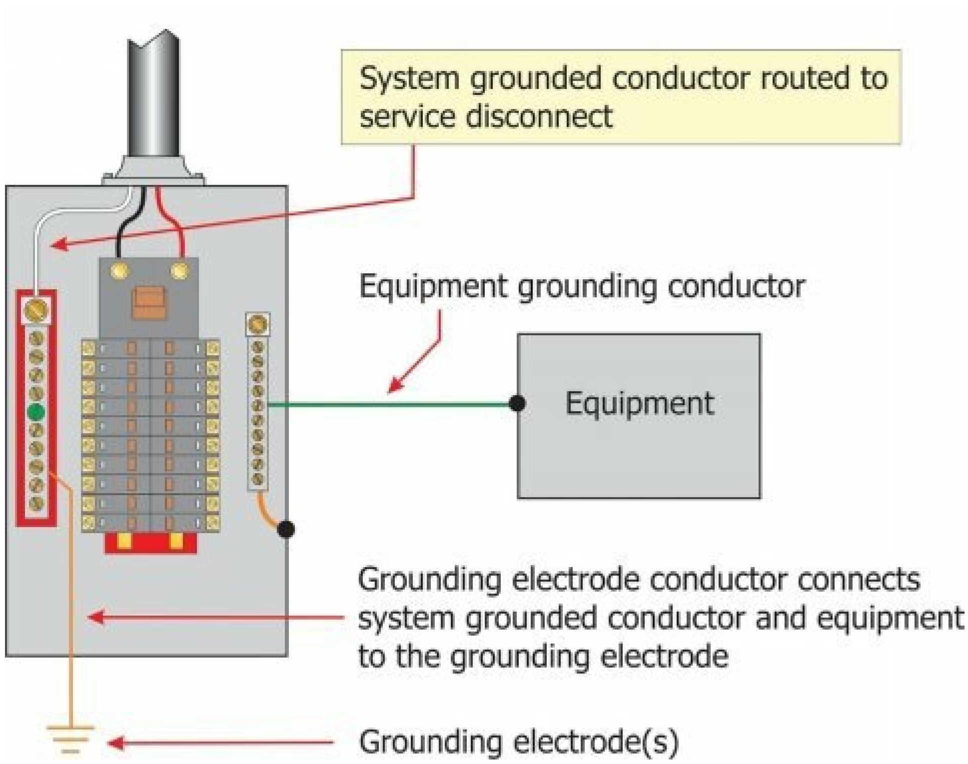


Figure 7.1 Grounding electrode conductor shown in a grounded system

It is required to be properly sized as per Table 250.66 based on the size of the service-entrance conductors or largest derived ungrounded conductors of a separately derived system, but it is not required to exceed 3/0 AWG copper or 250-kcmil aluminum or copper-clad aluminum. Specific requirements are given regarding conductor material, how it is to be installed, protected from physical damage, and connected.

Definition

Grounding Electrode Conductor. "A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system." [1]

In previous editions of the *Code* prior to the 2011 edition, there was also a definition for *grounding conductor* that was very similar to the present definition of *grounding electrode conductor*. In the 2011 *NEC* cycle, the term and definition of grounding conductor was removed from the *NEC*. Where the term *grounding conductor* was used, it was replaced with the term *grounding electrode conductor*, *equipment grounding conductor*, or *bonding conductor* as appropriate.

Function of Grounding Electrode Conductor

The grounding electrode conductor is the sole connection from the grounding electrode to the grounded system conductor (may be a neutral) and the equipment grounding conductor(s) for a grounded system; or the sole connection from the grounding electrode to the service equipment or building disconnect enclosure; and to the equipment grounding conductor(s) for an ungrounded system [see 250.24(A) and figure 7.2].

A single grounding electrode conductor is required to connect both the system grounded conductor and the equipment grounding conductor. In other words, one grounding electrode conductor cannot be used to ground the system conductor and a second grounding electrode conductor be used to ground the equipment grounding conductor even though both grounding electrode conductors are connected to the same grounding electrode.

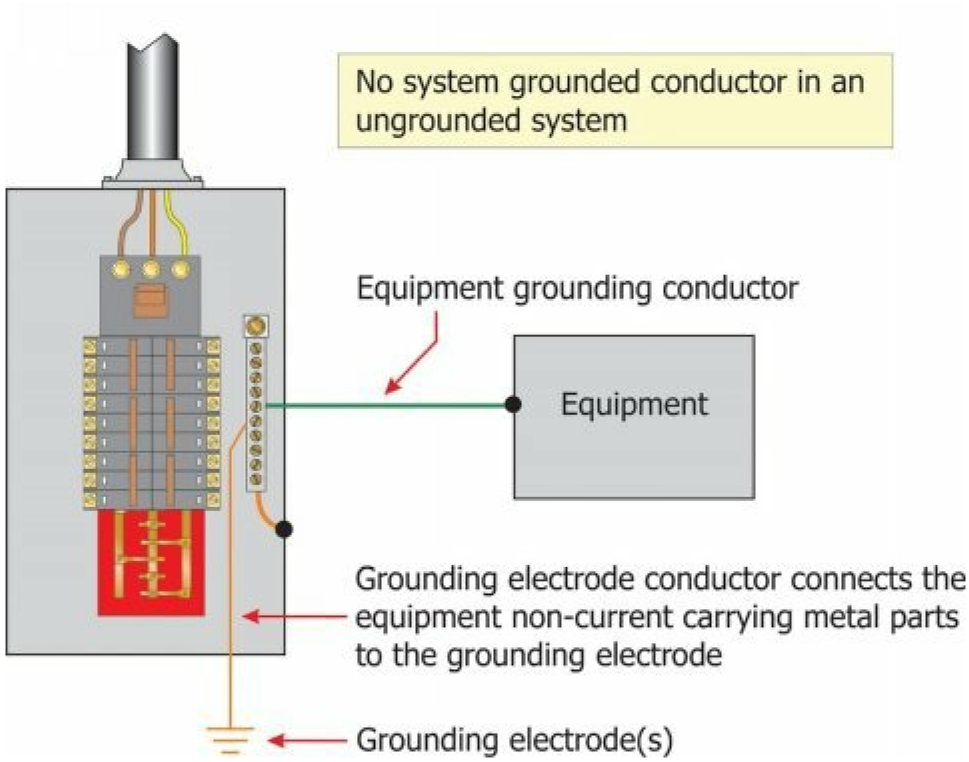


Figure 7.2 Grounding electrode conductor connected to equipment containing an ungrounded system (no system grounded conductor)

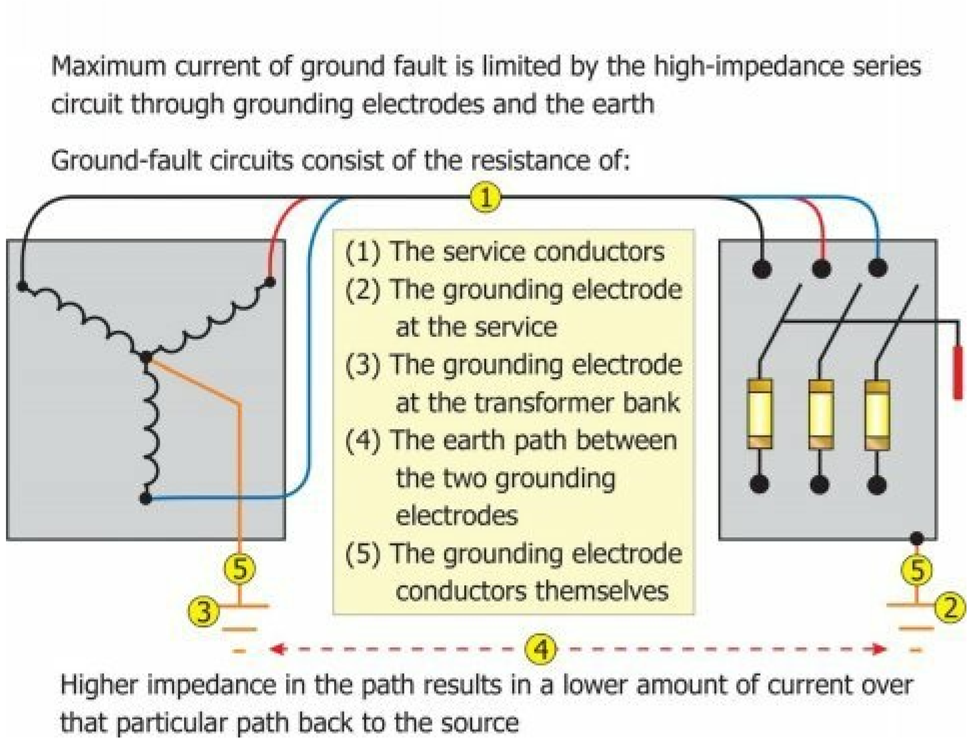


Figure 7.3 High impedance return path through the earth to the source

Maximum Current on Grounding Electrode Conductors

In all grounded systems, the maximum current in the grounding electrode conductor is limited by the impedance path through the earth. Figure 7.3 illustrates a ground-fault circuit that consists of:

- The resistance of the service conductor
- The grounding electrode at the service
- The grounding electrode at the transformer bank
- The resistance of the earth path between the grounding electrodes
- The resistance of the grounding electrode conductors themselves

In many installations, the length of the grounding electrode conductors is short enough that their resistance may be ignored. In addition to the resistances of the conductive path(s), there will be an inductive reactance component that will vary as the spacing between the supply path and the return path increases. This inductive reactance component will cause the overall circuit impedance to increase, thereby reducing the amount of current that will flow.

If we assume that the sum of these resistances is equal to 22 ohms (higher values can be common in actual practice), then, for a 120-volt-to-ground system, the maximum current through the grounding electrode conductor and grounding electrodes will be 5.5 amperes (120 volts ÷ 22 ohms = 5.5 amperes). It is obvious that this grounding connection is ineffective for facilitating overcurrent device operation. Equipment grounded only in this manner is unsafe because a ground fault would not cause an upstream overcurrent protective device to clear the fault from the equipment. The current through the high-impedance path provided by the grounding electrodes and the earth is not nearly enough to cause a 15-ampere rated fuse or circuit breaker to open. As long as the ground fault exists, voltage levels that could be fatal can be present on equipment that is grounded in this manner. In the above example, this maximum current value was determined by considering resistance only. If the reactance of the circuit is included, the overall result is an impedance value much higher than the resistance value. The actual current in the grounding electrode conductor will therefore be considerably less than what is calculated based on resistance only. Ground-fault currents through the grounding electrode conductor are not likely to attain a value anywhere near the continuous rating of the conductor even under fault conditions.

As covered in chapter six in detail, the main purpose of the grounding electrode is to establish and maintain an earth reference for the system and non-current-carrying parts of the system but not to clear ground faults.

One of the reasons for requiring the grounding electrode conductors to be larger than for the normal system current they might carry is because grounding electrode conductors also carry current from other events on the system, such as lightning strikes or from accidentally being energized from high-voltage sources such as transformers or overhead lines.

Sizing the Grounding Electrode Conductor for a Single Service

The grounding electrode conductor is required to be sized in accordance with 250.66 and Table 250.66. That conductor is required to be a minimum size of 8 AWG copper and need not be larger than 3/0 AWG copper. Where aluminum or copper-clad aluminum grounding electrode conductors are installed, they are required to be not smaller than 6 AWG or larger than 250 kcmil. The size of the grounding electrode conductor is based upon the size of the largest ungrounded service-entrance conductors or ungrounded feeder conductors such as for a separately derived system. Table 250.66 is based on a conductor size relationship and not on the rating of the circuit breaker or fuse in the service equipment (see Table 250.66).

For example, where 3/0 AWG copper service-entrance conductors are installed, the minimum size grounding electrode conductor is 4 AWG copper or 2 AWG aluminum. If 750-kcmil aluminum service-entrance conductors are installed, a 1/0 AWG copper or 3/0 AWG aluminum grounding electrode conductor is required to be used.

Sizing the Grounding Electrode Conductor for Service with Parallel Conductors

Where service-entrance conductors are installed in parallel as allowed by 310.10(H), the circular mil area of the largest set of parallel conductors is added together and treated as a single conductor for purposes of sizing the grounding electrode conductor (see figure 7.4). For example, if four 250-kcmil aluminum conductors are installed in parallel, they are considered to be a single 1000-kcmil conductor. By reference to Table 250.66, we find the minimum grounding electrode conductor for this set to be a 2/0 copper or 4/0 AWG aluminum conductor.

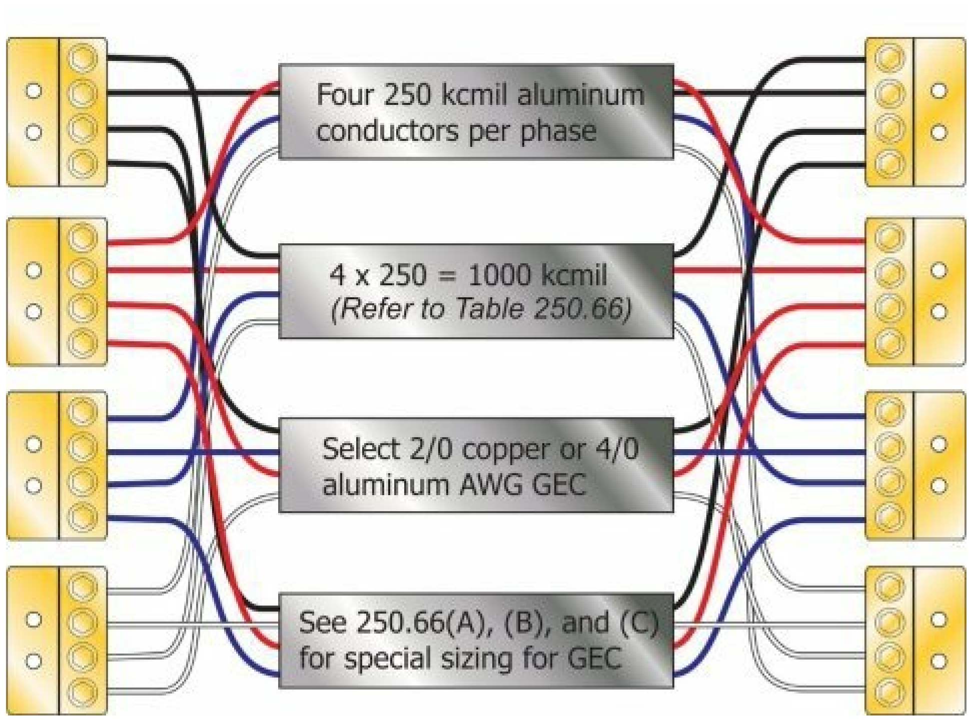


Figure 7.4 Grounding electrode conductor sizing where parallel service conductors are installed

If 1/0 AWG through 4/0 AWG conductors are installed in parallel, they are required to first be converted to circular mil area before applying Table 250.66. For example, if two 2/0 AWG aluminum service-entrance conductors are installed in parallel, first refer to *NEC* Table 8 of chapter nine (reprinted in *Soares* chapter twenty-two) for determining the conductor's circular mil area. There, we find the conductor to have an area of 133,100 circular mils. Then multiply the circular mil area of the conductors by the number of conductors connected in parallel.

133,100 circular mils;

133,100 cm x 2 = 266,200 cm.

By reference to Table 250.66 we find that a 2 AWG copper or 1/0 AWG aluminum grounding electrode conductor is required.

Table 250.66 Grounding Electrode Conductor for Alternating-Current Systems

Size of Largest Ungrounded Service-Entrance Conductor or Equivalent Area for Parallel Conductors *(AWG/kcmil)*		Size of Grounding Electrode Conductor *(AWG/kcmil)*	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	3/0	250

Table 250.66 Reproduction of table

Sizing Grounding Electrode Conductors for Multiple Enclosure Services

Services are permitted to be installed in up to six separate enclosures installed at one location or at separate locations. The method of sizing grounding electrode conductors is a matter of choice. One basic rule must be followed: size the grounding electrode conductor for the circular mil area of service-entrance conductor(s) at the point of connection, or as a common grounding electrode conductor for the size of the main service-entrance conductor(s) [see 250.64(D)(3)]. Section 250.64(D) provides for four options to make this installation.

A single grounding electrode conductor is permitted to serve separate enclosures. The common grounding electrode conductor is sized based on the main service-entrance conductors. Taps that are sized based on the individual service-entrance conductors supplying each service disconnect are connected from within each service disconnecting means to the common grounding electrode. Grounding electrode conductor taps are covered in 250.64(D)(1). It is important to understand that the alternative provided in 250.64(D)(1) addresses two conductors; the common grounding electrode conductor that is required to be installed without a splice or joint (generally) and the grounding electrode conductor tap(s) that are permitted to be connected to the common grounding electrode conductor (see figures 7.5 and 7.6).

In figures 7.5 and 7.6, assume that 2 AWG copper conductors serve each service disconnecting means from the wireway. Shown are taps to a common grounding electrode conductor. The tap conductors are required to be connected to the common grounding electrode conductor in a manner that the common grounding electrode conductor remains continuous without a splice or joint. This means that the tap conductor is required to be connected to the grounding electrode conductor with a device that allows the grounding electrode conductor to remain unbroken as the connection is made. The tap conductors are required to be connected to the common grounding electrode conductor by exothermic welding or with connectors listed as grounding and bonding equipment. Acceptable methods of grounding and bonding connections are provided in 250.8. The common grounding electrode conductor and associated tap conductors are also permitted to be connected at an aluminum or copper busbar not less than 6 mm × 50 mm (¼ in. × 2 in.). The busbar must be securely fastened and installed in an accessible location. Connections are to be made by a listed connector or by the exothermic welding process. If aluminum busbars are used, the installation has to comply with 250.64(A). Remember the conductors from the grounding electrode to the copper or aluminum busbar are “bonding jumpers” and not grounding electrode conductors. The concept of tapping the common grounding electrode conductor applies whether the sets of service-entrance conductors are tapped from a wireway or are installed individually as overhead or underground systems (see photo 7.1).

Photo 7.1 Common grounding electrode conductor and taps

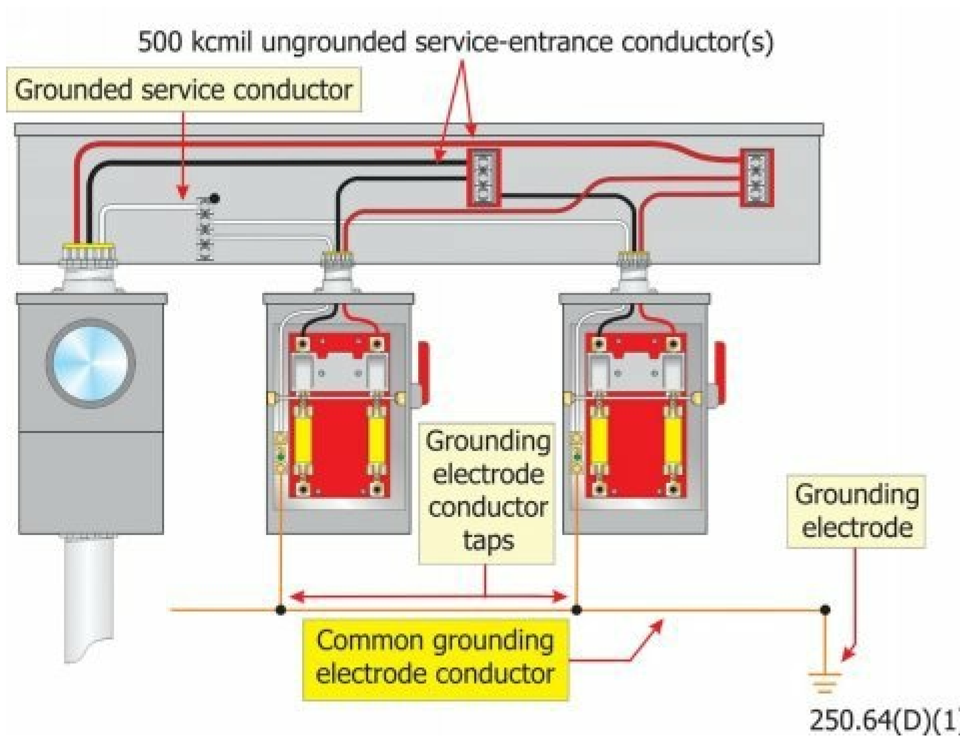


Figure 7.5 Taps to a common grounding electrode conductor [250.64(D)(1)]

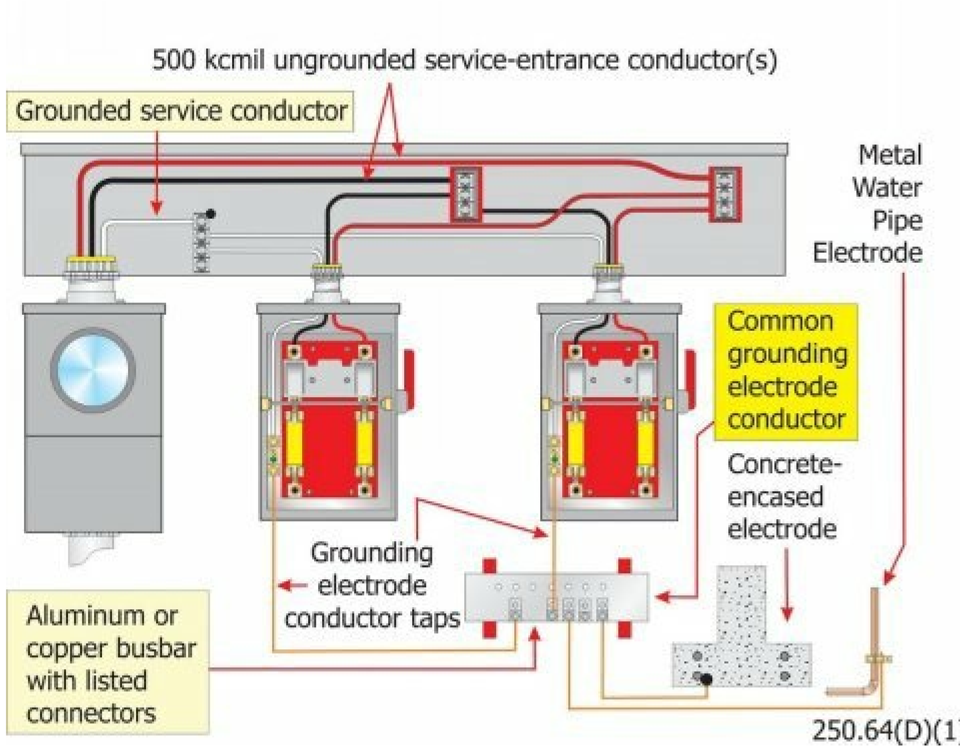


Figure 7.6 An aluminum or copper busbar is an acceptable means of connection for a common grounding electrode conductor and grounding electrode conductor taps [250.64(D)(1)]

For figure 7.5, the size of the common grounding electrode conductor is determined as follows. Assume that 500-kcmil copper service-entrance conductors supply the service and are connected in the wireway to the 2 AWG copper service-entrance conductors that serve each enclosure.

Refer to Table 250.66. The minimum size common grounding electrode conductor is 1/0 AWG copper or 3/0 AWG aluminum. This conductor is installed from the grounding electrode to the vicinity of the wireway. The grounding electrode tap conductors from the individual enclosures are sized from Table 250.66 and are either 8 AWG copper or 6 AWG aluminum. Note that there is no minimum or maximum length for these grounding electrode tap conductors.

Another option for the installer is to install the grounding electrode conductor from the individual service disconnects to the grounding electrode rather than being tapped to the common grounding electrode conductor [250.64(D)(2)]. In this case, the grounding electrode conductor is sized for the service-entrance conductor serving each individual enclosure as shown in figure 7.8.

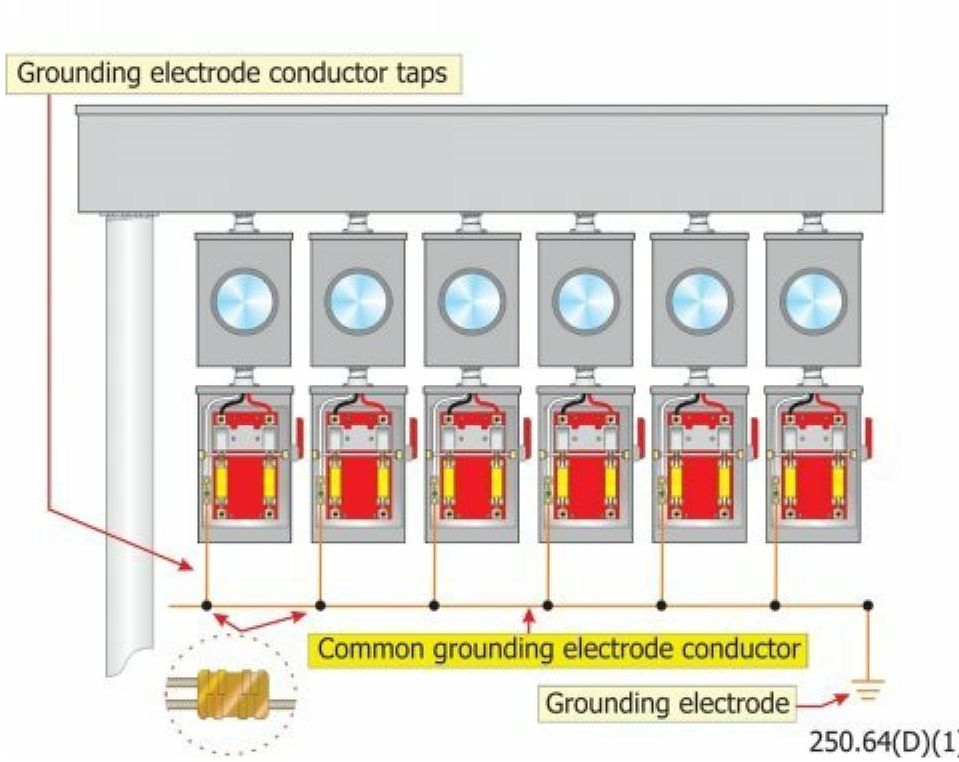


Figure 7.7 Grounding electrode conductor taps permitted to be connected to a common grounding electrode conductor [250.64(D)(1)]

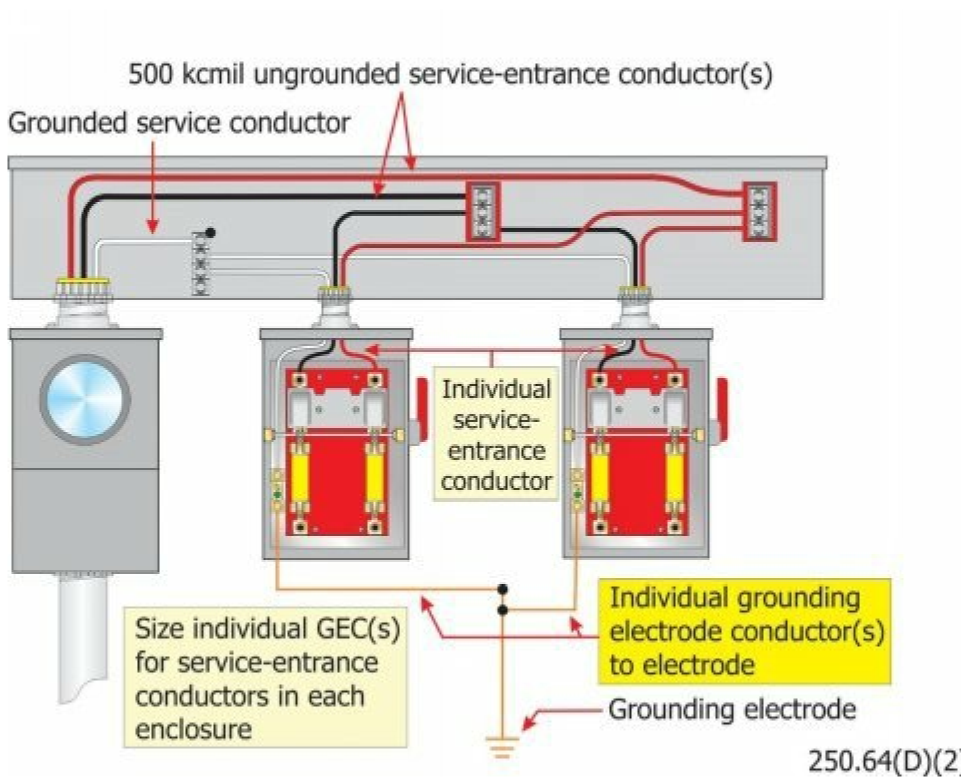


Figure 7.8 Grounding electrode conductors from individual enclosures to single grounding electrode [250.64(D)(2)]

The third option is to install a single grounding electrode conductor to the wireway or other location common to all the connected individual service-entrance conductors as shown in figure 7.9 [250.64(D)(3)]. For the example shown in figure 7.9, assume 500-kcmil copper service-entrance conductors, the service-entrance grounded conductor is shown grounded inside the wireway. By reference to Table 250.66, we find that the grounding electrode conductor to a water pipe or building steel grounding electrode is required to be 1/0 AWG copper or 3/0 AWG aluminum.

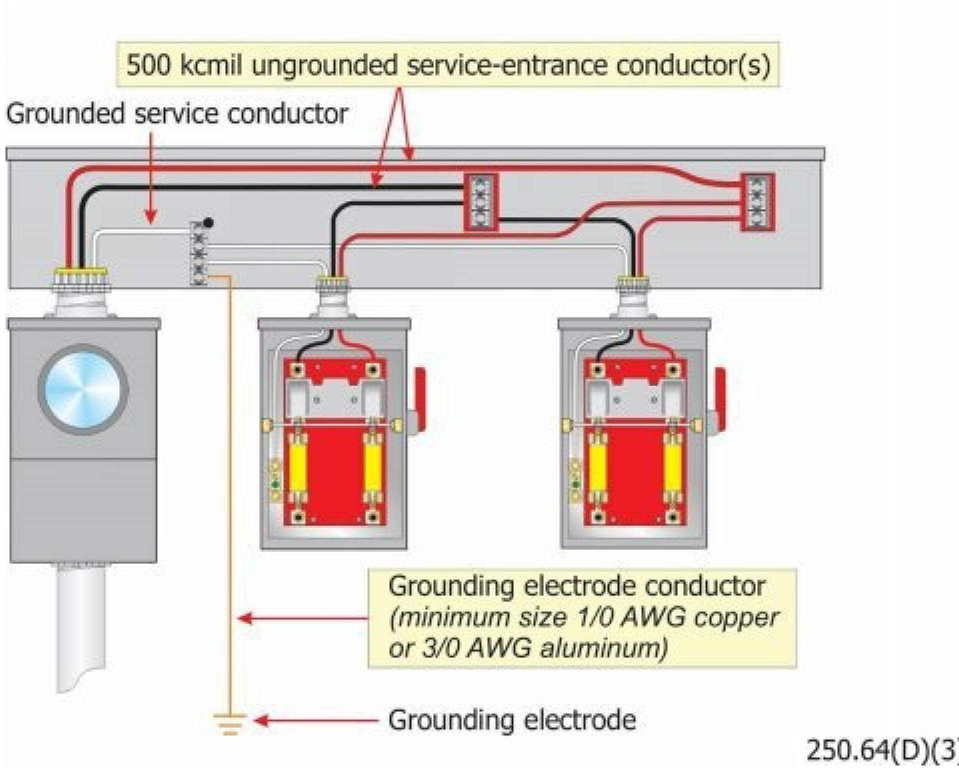


Figure 7.9 Grounding electrode conductor connection in wireway sized based on largest ungrounded service-entrance phase conductor (500 kcmil) [250.64(D)(3)]

Exceptions to Sizing of Grounding Electrode Conductor

The grounding electrode conductor is generally required to be not smaller than the values in Table 250.66 based on the size of the largest ungrounded service-entrance conductor or largest ungrounded conductor of a separately derived system. What amounts to a three-part exception to the general rule for sizing the grounding electrode conductor is provided in 250.66(A) through (C).

> Section 250.66(A) permits the grounding electrode conductor or bonding conductor to be not larger than 6 AWG copper or 4 AWG aluminum where it is connected to a rod, pipe or plate electrode. A clarification was added in the 2017 *NEC* to remove the reference to a "sole connection" and to allow this maximum size only where no other grounding electrodes requiring a larger grounding electrode conductor or bonding jumper are then connected to the rod, pipe or plate electrode(s) extending the grounding electrode system. A change to this section was made in the 2014 *NEC* clarifying that the 6 AWG copper conductor is the maximum required with single or multiple rods, pipes or plates or any combination of rods, pipes and plates.
>
> Section 250.66(B) provides that the grounding electrode conductor connection to a concrete-encased grounding electrode need not be larger than 4 AWG copper. Note that aluminum wire is not permitted for this application. The use of this smaller conductor is based on the fact that it will never need to carry a current beyond its safe short-time rated capacity, even under ideal conditions. Section 250.66(B) was revised to clarify that if a grounding electrode conductor is installed to multiple concrete-encased electrodes connected together with a bonding jumper(s), the maximum size grounding electrode conductor to the first concrete encased electrode or any bonding jumper(s) between the multiple concrete-encased electrodes is not required to be larger than a 4 AWG copper conductor. A clarification was added in the 2017 *NEC* to remove the reference to a "sole connection" and to allow this maximum size only where no other grounding electrodes requiring a larger grounding electrode conductor or bonding jumper are then connected to concrete-encased electrode(s) extending the grounding electrode system.

Section 250.52(A)(4) requires that the minimum size conductor and material for a ground ring is 2 AWG copper. 250.66(C) provides that, where connected to a ground ring, that portion of the grounding electrode conductor that is connected to the ground ring need not be larger than the ground ring conductor. That is because the electrode resistance is the limiting factor in the circuit and increasing the grounding electrode conductor size would not serve any useful purpose. Design engineers will sometimes specify ground rings of 4/0 AWG or 250 kcmil. In this case, follow Table 250.66 to determine the required grounding electrode conductor size then the allowance of not being larger than the ground ring electrode can be applied. The grounding electrode conductor is not required by the *NEC* to be larger than 3/0 AWG copper or 250-kcmil aluminum or copper-clad aluminum under any circumstances. A clarification was added in the 2017 *NEC* to remove the reference to a "sole connection" and to allow this maximum size only where no other grounding electrodes requiring a larger grounding electrode conductor or bonding jumper are then connected to the ground ring electrode extending the grounding electrode system.

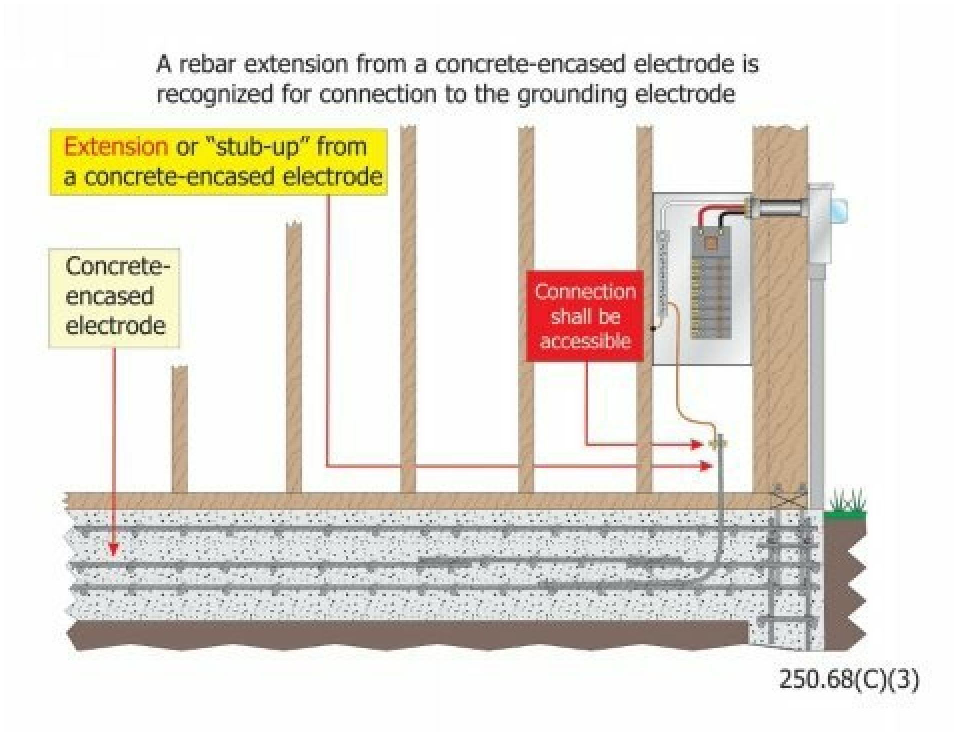


Figure 7.10 An extention from a concrete-encased electrode is permitted

What the above provisions give to the installer is the ability to create a "daisy chain" of grounding electrodes with bonding jumpers. Where the next electrode has a maximum allowance per 250.66(A), (B). or (C) and there are no other electrodes extended beyond these electrodes requiring a larger conductor the maximum size conductor can be used. For example, for a large service requiring a 3/0 copper grounding electrode conductor, the conductor to the metallic water pipe would be 3/0 copper. Going from the metallic water pipe to a 2 AWG copper ground ring would only require a 2 AWG copper bonding jumper. From the ground ring to the concrete-encased electrode would only require a 4 AWG copper and then to the one or more ground rods, pipes or plates would only require a 6 AWG copper. If the above sequence were changed, then the allowance for the stepping down the bonding jumper would not be applicable.

Grounding Electrode Conductor Connections

The *Code* requires generally that the point of connection of grounding electrode conductors and bonding jumpers to grounding electrodes shall be accessible and made in a manner that will ensure a permanent and effective grounding path. An exception provides that a connection at a concrete-encased, driven, or buried grounding electrode is not required to be accessible (see figure 7.11).

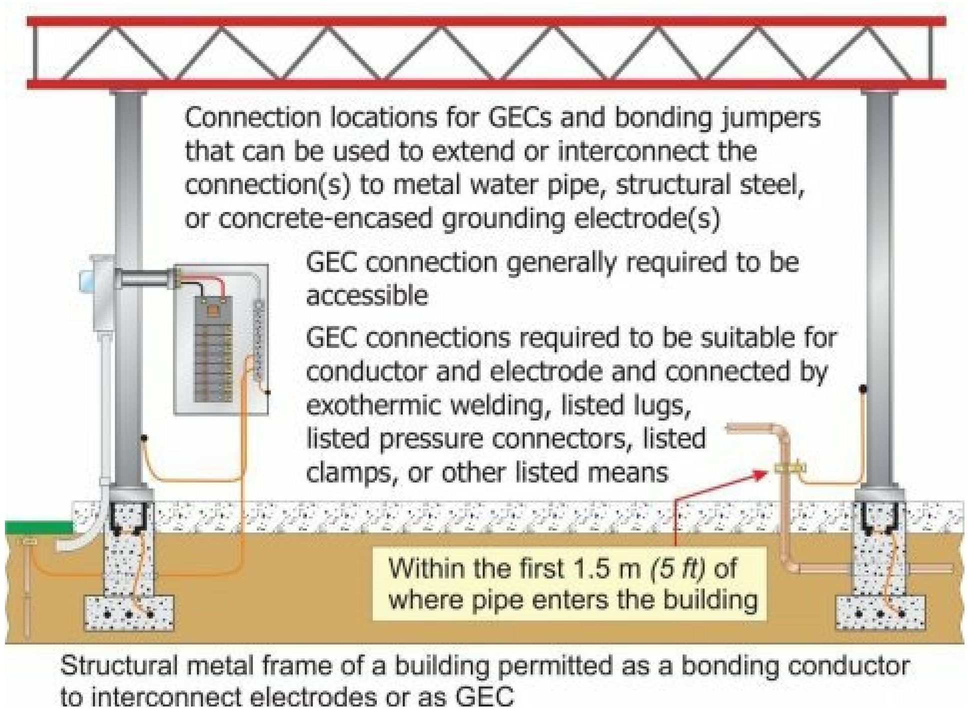


Figure 7.11 Grounding electrode conductor connections are required to be accessible (generally)

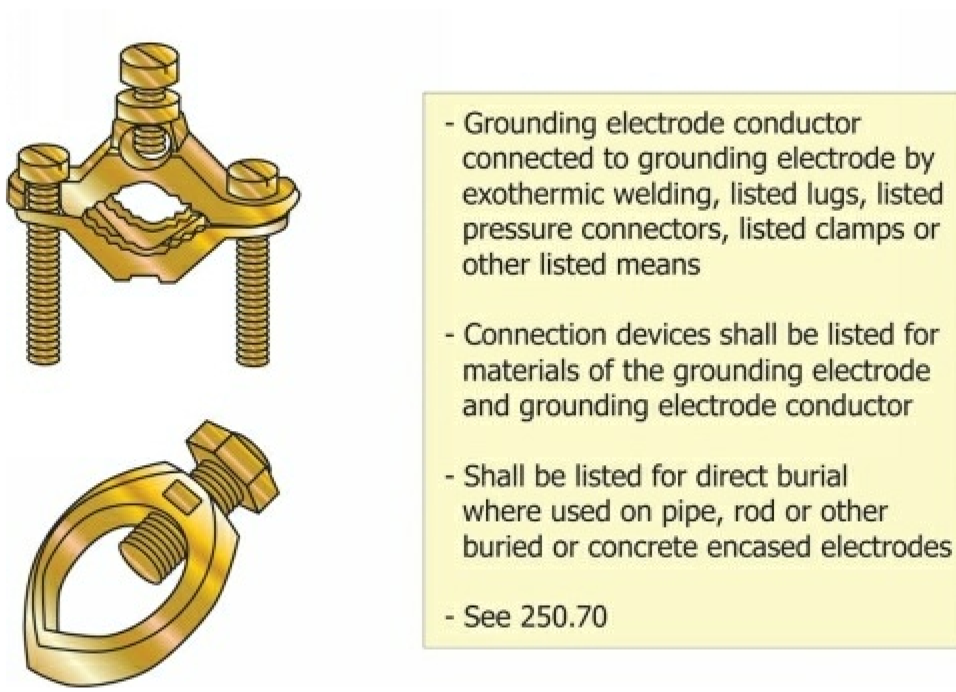


Figure 7.12 Ground clamps listed for the application(s)

Exception No. 2 to 250.68(A) provides that an exothermic or irreversible compression connection to fireproofed structural metal also does not have to be accessible [see 250.68(A) and photo 7.2]. A compression connector for the grounding electrode conductor that is attached to the structural metal building frame by mechanical means such as nuts and bolts meets this exception.

Photo 7.2 Grounding electrode conductor connection is permitted under fireproofing materials by exception. [250.68(A) Exception No. 2]

It has become a commonly accepted practice to extend a rebar-type concrete-encased electrode out of the footing or foundation before the slab or foundation is poured. This is accomplished by using another piece of rebar connected to the concrete-encased electrode and "stubbed-up" out of the poured concrete to provide an accessible connection point above the slab. Later the electrician can make the grounding electrode conductor connection after the foundation has been poured and cured. Language was added at 250.68(C)(3) for the 2014 *NEC* to recognize as permissible a concrete-encased electrode of either the conductor type, reinforcing rod or bar to be extended from the concrete-encased electrode location within the concrete to an accessible location above the concrete for connection of a grounding electrode conductor. It is important to note here that the extension or "stub-up" is not part of the concrete-encased electrode. A structural component meeting all of the conditions of 250.52(A)(3) must be present for the extension to be connected to same. The "stubbed-up" rebar adds to, or takes away nothing from the structural component that qualifies as a concrete-encased electrode (see figure 7.10). The 2017 *NEC* clarified that this "stub up" must not come out of the concrete where it would be subject to corrosion, such as stubbing out sideways at the footer into the surrounding soil. The rebar stub must come out of the concrete above the slab or foundation wall or out of the side of the foundation wall in a location where moisture or other corrosive elements would be present to cause deterioration of the rebar. The ideal installation is to stub up vertically in the wall space where the service panel will be installed. This allows access and also provides the protection for the connection required by 250.10.

Specific rules for connections of the grounding electrode conductor and bonding conductor to grounding electrodes are found in 250.70. The connections are required to be made by exothermic welding, listed lugs, listed pressure connectors, listed clamps (see photos 7.3 through 7.8) or other listed means (see figure 7.12). The only connection means not required to be listed are those made by exothermic welding, although listed exothermic weld connections are available.

Photo 7.3 Wires placed in mold

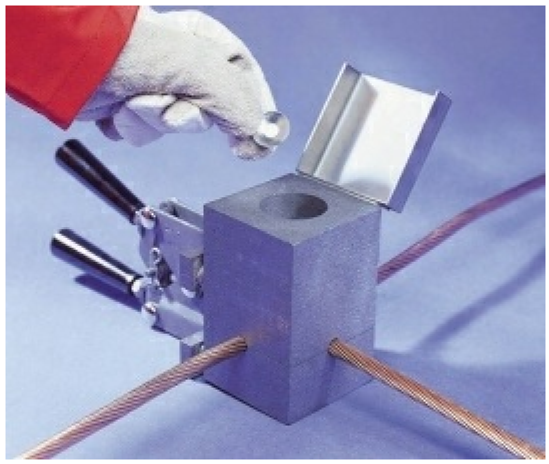


Photo 7.4 Weld disc placed in mold

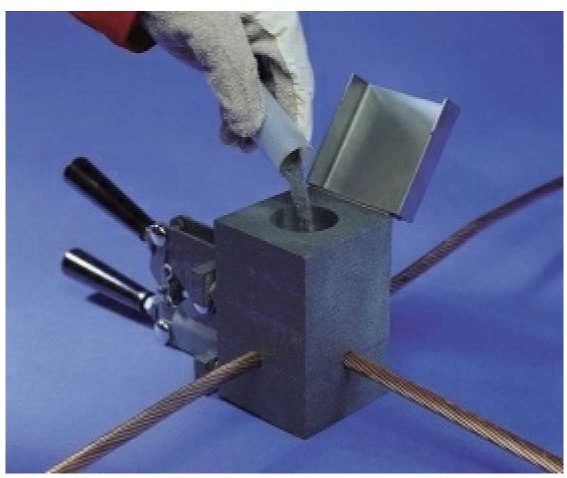


Photo 7.5 Weld metallic powder added to mold

Photo 7.6 Preparing to strike an arc at mold

Photo 7.7   Ignition of metallic weld powder

Photo 7.8   Completed weld

Connections depending solely on solder shall not be used. Other requirements state that not more than one conductor is permitted to be connected to the grounding electrode by a single clamp or fitting, unless the clamp or fitting is listed as being suitable for connecting multiple conductors. Ground clamps are required to be listed for both the materials of the grounding electrode and the grounding electrode conductor (see photo 7.10). For example, ground clamps are required to be listed for aluminum conductors to be used for such connections. Clamps used on a pipe, rod or other electrode that is buried are required to be listed for direct earth burial (see photos 7.9, 7.10, 7.11, and 7.12). Typically, these clamps are identified by the manufacturer with direct burial or DB or similar. Direct burial or DB means the clamp or fitting is also suitable for concrete encasement. Lastly, clamps for connection to rebar must be identified as suitable for rebar and will also specify the range of rebar sizes the clamp is rated to be used.

Photo 7.9 Grounding clamp Courtesy of Thomas and Betts

Photo 7.10 Grounding clamp Courtesy of Galvan Industries

Photo 7.11 Ground rod clamp Courtesy of Thomas and Betts

Photo 7.12 Pipe clamp and ground rod clamp Courtesy of Greaves

Sheet-metal-strap type ground clamps attached to a rigid metal base that are listed are permitted for indoor telecommunication purposes only [see 250.70(3)]. Also, Underwriters Laboratories' Guide Card information (KDER) states, "Strap-type ground clamps are not suitable for attachment of the grounding conductor of an interior wiring system to a grounding electrode." Use strap type ground clamps for only the type of conductor and grounding electrode as well as the environment for which it is listed and labeled, such as for communication circuits (see chapter nineteen for low voltage and intersystem bonding and grounding requirements).

It is required that ground clamps be protected from physical damage unless the fittings are approved for use without protection or are installed in a location where they are not likely to be damaged (see figure 7.13).

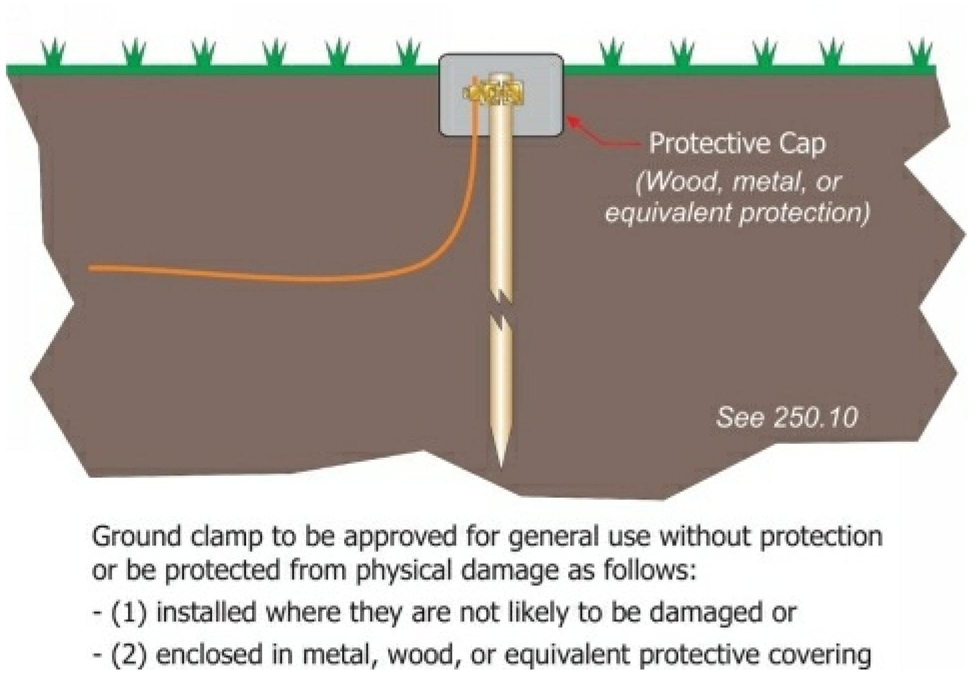


Figure 7.13 Protection of grounding electrode conductor connection to the electrode [250.10]

Protection of the ground clamp is permitted to consist of metal, wood, or equivalent materials (see 250.10).

Clean Surfaces

Section 250.12 requires nonconductive coatings such as paint, lacquer, and enamel to be removed from threads and other contact surfaces of equipment to be grounded or connected by means of fittings designed to make such removal unnecessary. (Underwriters Laboratories reported — in a June 27, 1995, letter and confirmed on June 7, 1998 — that no fittings listed by them incorporate this feature.) While there are connectors and locknuts in the marketplace with knurled bases or turned ears that scrape the paint or coating off when installed, none of these have been evaluated by UL as providing the required bonding path when installed. All these fittings have only been tested and evaluated on bare metal. Removal of paint under connections of raceways and cable fittings is critical to make a reliable connection that can carry fault current when necessary. This will ensure a good electrical connection (see chapter eight for additional discussion on the subject). It is also necessary to consider the corrosive influence the environment can have on enclosures that have the protective coating removed.

Here, again, it is important to consider that all grounding electrode conductors and their connections form a part of a circuit that is required under certain conditions to carry current. In some cases, the current is several times the full-load current rating of the conductor involved if the conductor was being used for continuous duty in an electrical circuit. Such currents are usually of short duration so the withstand rating of the conductor is not exceeded.

Grounding Electrode Conductor Material

The grounding electrode conductor is required to be of copper, aluminum, or copper-clad aluminum and may be solid, stranded, insulated, covered, or bare. The material selected shall be resistant to any corrosive condition it will be exposed to. As an option, it may be suitably protected against corrosion (see 250.62). Note that there is no color code for the grounding electrode conductor such as the identification requirements that exist for grounded conductors or equipment grounding conductors. There is no specific color identification for grounding electrode conductors but 250.119 permits the color green to be used for grounding and bonding conductors.

Grounding Electrode Conductor Installation

Where grounding of systems, equipment or both are required, grounding electrode conductors are installed and connected to the grounding electrode system. Section 250.64 provides the installation requirements for grounding electrode conductors where installed for services, separately derived systems, or for buildings or structures supplied by a feeder(s) or branch circuit(s). The installation of grounding electrode conductors is required to comply with 250.64(A) through (F) which addresses conductor type, securing, protection, splices, multiple disconnecting means enclosures, magnetic field protection, and connections to busbars.

Specific limitations are placed on aluminum and copper-clad aluminum grounding electrode conductors. These rules apply regardless of whether the conductors are insulated or bare [see 250.64(A)].

Bare conductors or bare sections of insulated or covered conductors are not permitted where they are in direct contact with masonry or the earth, or where subject to corrosive conditions. This rule does not prohibit installing conduit on masonry and pulling a bare aluminum grounding electrode conductor in it.

Where used outside and exposed, aluminum or copper-clad aluminum grounding electrode conductors are not permitted to be terminated within 450 mm (18 in.) of the earth.

Because of these restrictions on their installation, they cannot be used for connection to concrete-encased electrodes, ground rods or pipes where within 450 mm (18 in.) of the earth or for connection to plate electrodes. Aluminum conductors are otherwise permitted to be used as grounding electrode conductors where the clamp or connector is listed for both the conductor material and the electrode. Typical connectors or clamps would be marked AL/CU. The AL indicates the clamp is suitable for aluminum conductor connections.

Securing and Protection from Physical Damage

Section 250.64(B) requires that the grounding electrode conductor or its enclosure be securely fastened to the surface on which it is carried and the grounding electrode conductor protected from physical damage as follows:

- Where not exposed to physical damage, size 6 AWG or larger grounding electrode conductors are permitted to run along the surface of the building construction and do not require protection or metal covering.
- Where exposed to physical damage, size 6 AWG and larger grounding electrode conductors are required to be run along the surface of the building construction and protected by rigid (RMC) or intermediate metal conduit (IMC), rigid nonmetallic (PVC) conduit, reinforced thermosetting resin conduit type XW (RTRC-XW), electrical metallic tubing (EMT), or cable armor.
- Grounding electrode conductors smaller than 6 AWG are required to be protected by installation in rigid (RMC) or intermediate metal conduit (IMC), rigid nonmetallic (PVC) conduit, reinforced thermosetting resin conduit type XW (RTRC-XW), electrical metallic tubing (EMT), or cable armor.

Alternately, grounding electrode conductors can be installed through bored or prefabricated holes in studs where the finished wall will provide the physical protection without regard to size.

Splicing Grounding Electrode Conductor

Section 250.64(C) generally requires that grounding electrode conductors are to be installed in one continuous length without a splice or joint.

Two alternatives to this requirement are as follows:

- Where busbars are used as the grounding electrode conductor, busbars sections are permitted to be connected together to form a grounding electrode conductor [250.64(C)(1) and (2)].
- Splicing is permitted for wire type grounding electrode conductors by using irreversible compression connectors, listed as grounding and bonding equipment; or by the exothermic welding process (see figure 7.13).

It is vital that the manufacturer's instructions be carefully followed where either of these splicing methods is chosen. Where compression-type connectors are used, the correct splicing sleeve for the conductor material and size is required to be selected. Then, the compression tool, and in some cases the proper die for the sleeve to be crimped, is required to be used. These compression-type connectors are required to be specifically listed by a qualified electrical testing laboratory for splicing grounding electrode conductors. Where exothermic welding of the grounding electrode conductor is performed, the correctly sized form or mold for the conductor to be spliced is required to be used. In addition, unless specifically permitted otherwise by the manufacturer, the conductors to be spliced by this method are required to be clean and dry. Inspect the resulting splice carefully to be certain that it has been made satisfactorily without causing damage to the conductor or otherwise affecting its integrity.

Busbars are sometimes used as grounding electrode conductors in open bottom switchboards where the main bonding jumper is at the service disconnect end of the equipment and the grounding electrode conductor connects to the grounding bus at the other end of the equipment. Busbars often come in standard lengths such as 10 ft. and have to be joined together to achieve the required length. The bolted connections between the sections are actually splices in busbars.

Busbars are often installed in electrical rooms to provide a common connection point for individual grounding electrode conductors; and bonding jumpers between grounding electrodes [250.64(F)] see figure 7.15. In these applications, the connections to the busbar are not permitted to splice a wire type grounding electrode conductor unless the connection to the busbar is by irreversible crimp connector or exothermic welding to make a permanent connection.

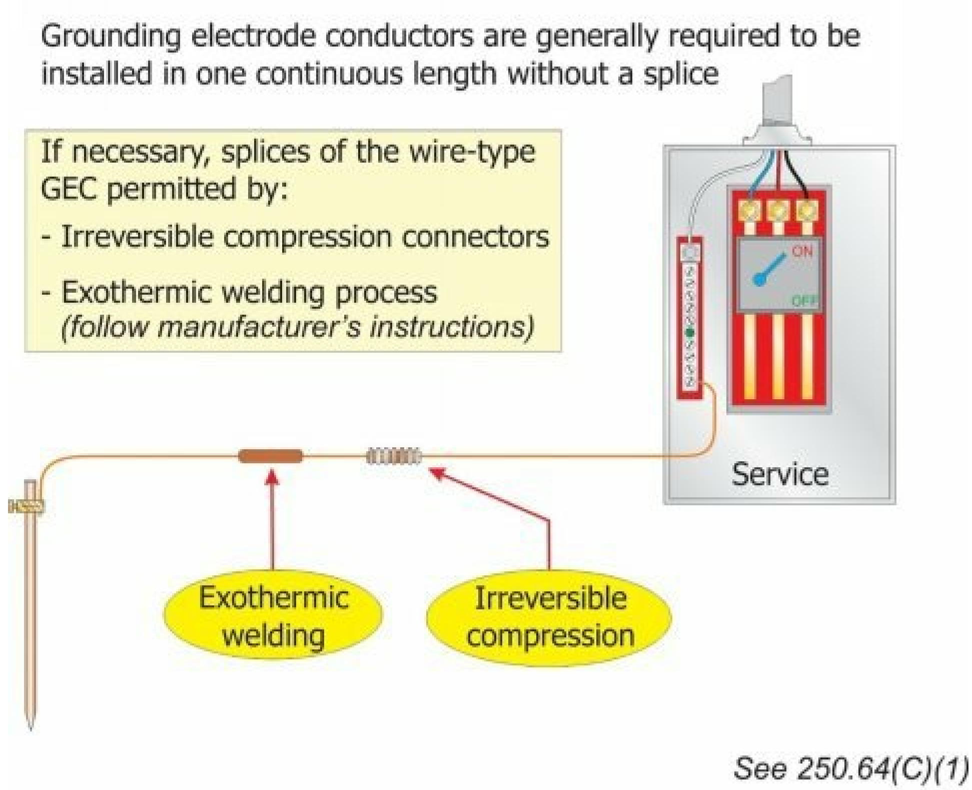


Figure 7.14 Splicing of grounding electrode conductor (generally not permitted)

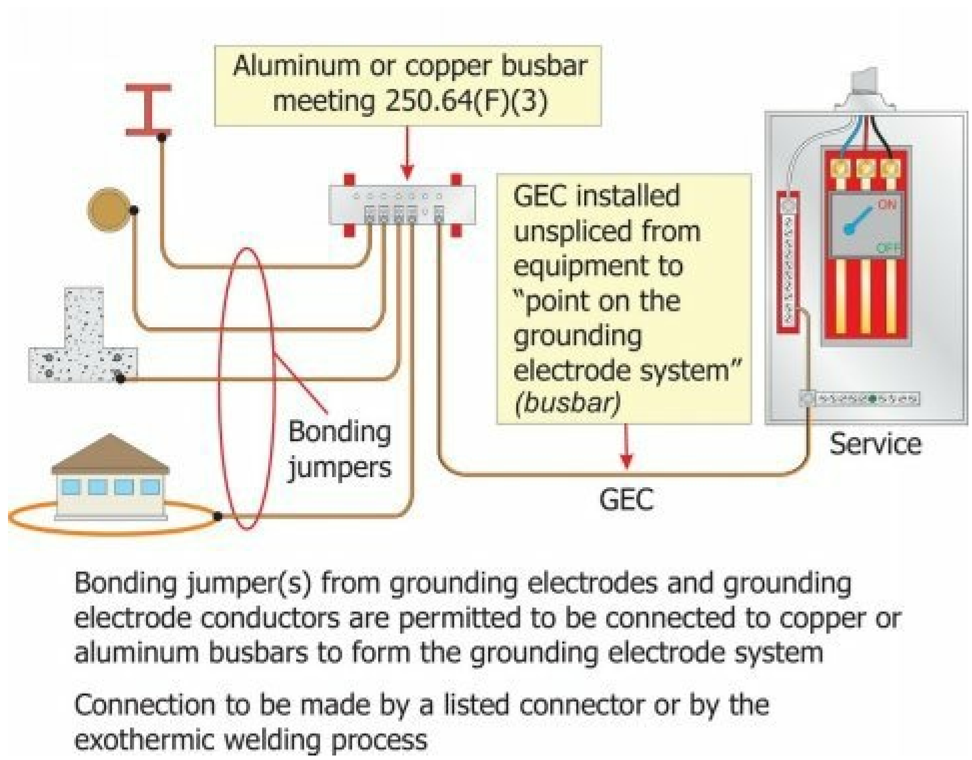


Figure 7.15 Connections permitted for bonding jumpers and grounding electrode conductors on busbars

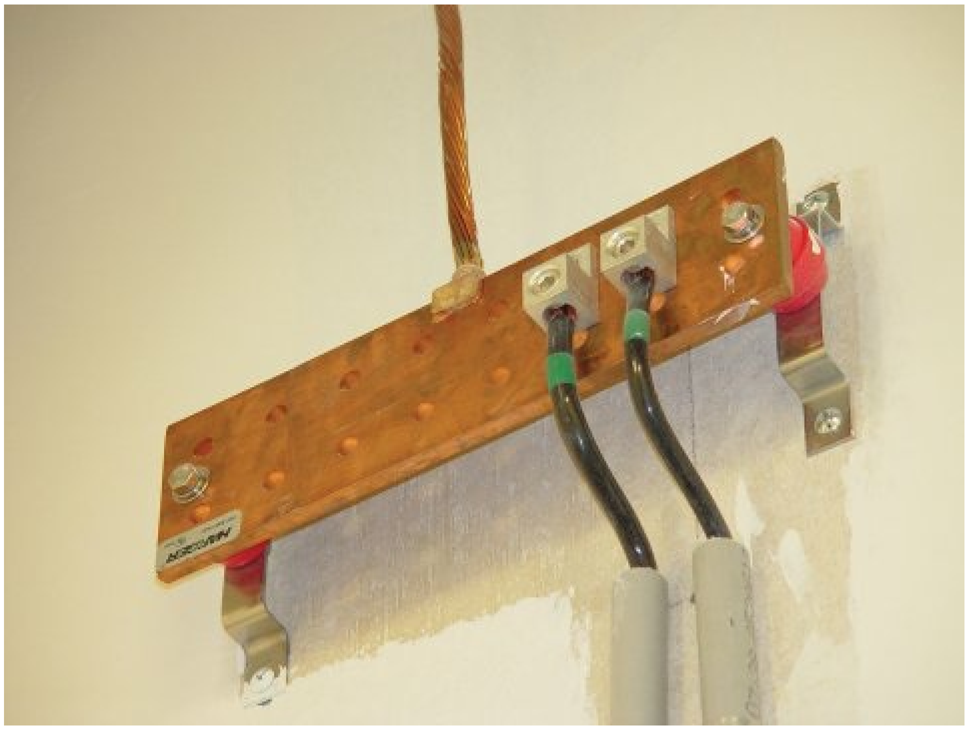


Photo 7.13 Grounding electrode conductors permitted to be spliced on busbars

With the applications for metal water pipe and structural metal as conductors in 250.68(C)(1) and (C)(2), 250.64(C) has established the requirements for connecting sections of metallic water pipe or structural metal together).

Protecting Grounding Electrode Conductor from Magnetic Field

Where ferrous metal raceways or enclosures are provided for protection of the grounding electrode conductor, one has to follow some special procedures (see figures 7.16 and 7.17). This is required by 250.64(E).

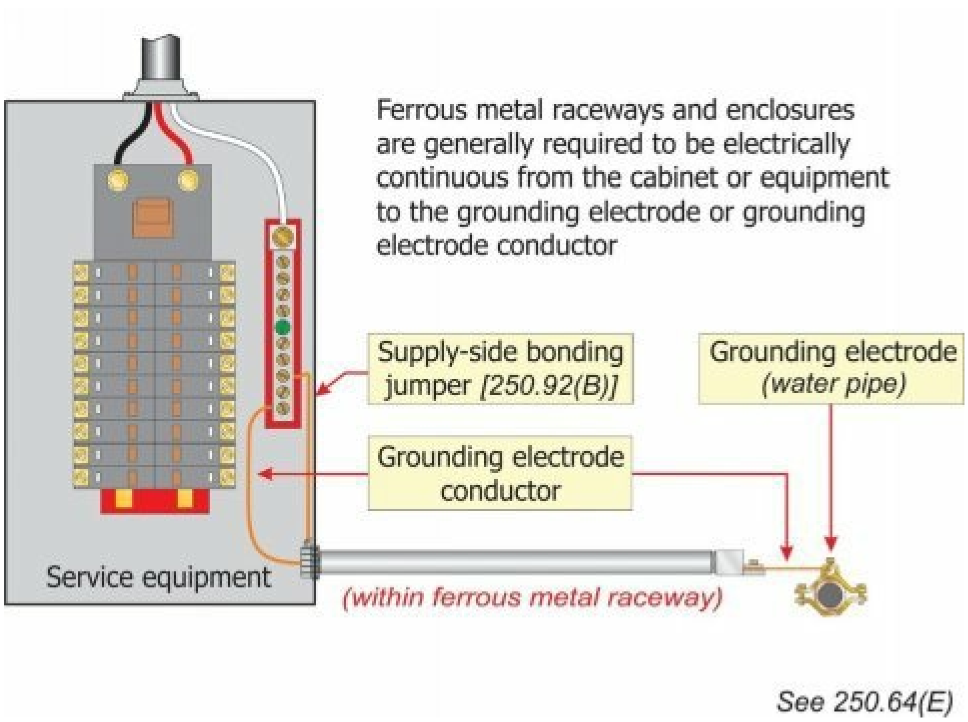


Figure 7.16 Protecting grounding electrode conductor from magnetic field as required in Section 250.64(E)

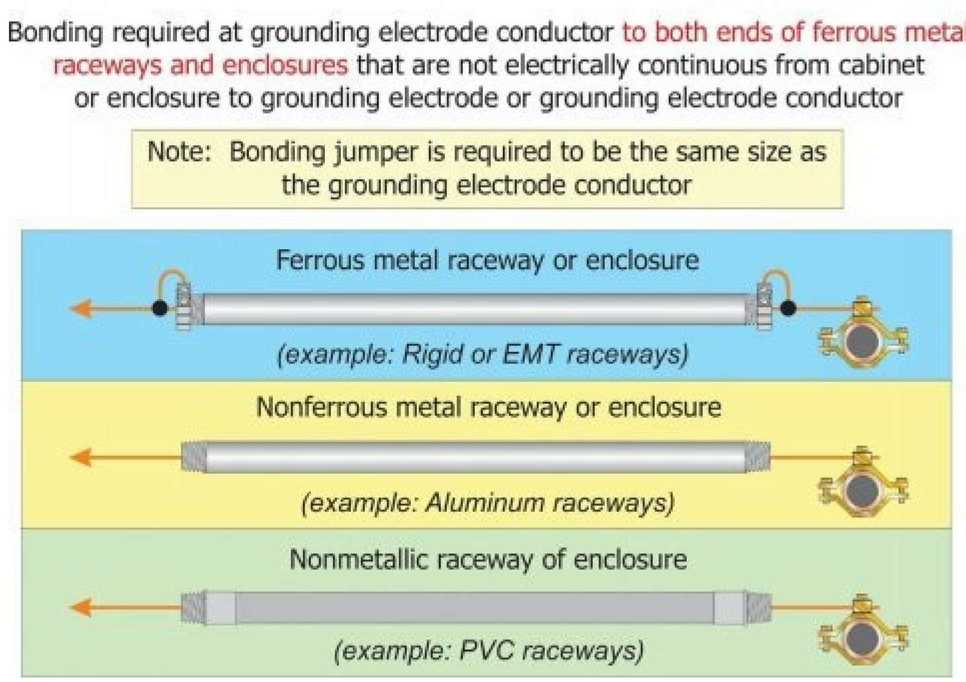


Figure 7.17 Securing and protection from damage and magnetic field

Ferrous metal raceways or enclosures must be electrically continuous from the point of attachment to cabinets or equipment to the grounding electrode or grounding electrode conductor. Nonferrous metal enclosures do not have the same effect on current because they are nonmagnetic.

The grounding electrode conductor raceway or enclosure must be securely fastened to the grounding electrode clamp or fitting.

Nonferrous metal enclosures are not required to be electrically continuous.

Ferrous metal raceways or enclosures that are not physically continuous from the enclosure to the ground clamp must be made continuous by bonding both ends to the grounding electrode conductor (see figure 7.17). This bonding requirement applies to all intervening ferrous raceways, boxes and enclosures between the cabinets or equipment and the grounding electrode. The bonding jumper must be at least the same size as the grounding electrode conductor within the raceway. If raceways are used as protection, they must also be installed according to their respective article (see photo 7.14).

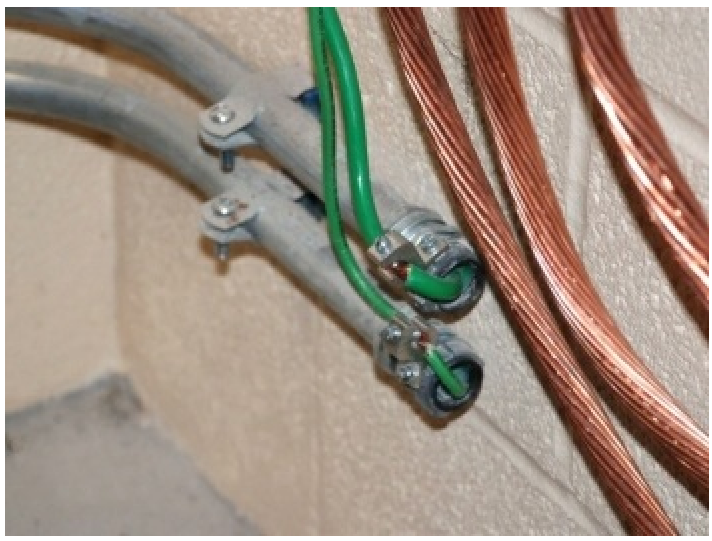


Photo 7.14 Grounding electrode conductor bonded to conduit with jumper same size as grounding electrode conductor

Photo 7.15 Grounding electrode conductor in armor cable, bonded to clamp and enclosure

It is common practice to use an 8 or 6 AWG grounding electrode conductor protected by metallic armored cable (see photo 7.15). The need for bonding the metallic armor of such cable is required in 250.64(E). Where that bonding procedure is not followed, the impedance of the grounding electrode conductor is approximately doubled with the result that its effectiveness is markedly reduced. Such bonding requirements may be avoided by protecting the 8 AWG grounding electrode conductor in rigid nonmetallic conduit (PVC) or RTRC-XW. Schedule 80 PVC is listed as impact and crush resistant and provides suitable protection.

Impedance of Conduit and Conductor

Table 22.2 of chapter twenty-two compares the continuous rating of copper grounding electrode conductors to the service conductors they are required to be used with Table 22.3 of chapter twenty-two compares the resistance and impedance of copper grounding electrode conductors where enclosed in a steel conduit for physical protection. The last two columns of that table show how the impedance of the conductor is approximately doubled where the conduit is not properly installed as required in 250.64(E). The *Code* requires that the conduit be bonded at both ends of the grounding electrode conductor to form a parallel circuit with the grounding electrode conductor. That important rule, if not observed, results in doubling the impedance of the grounding conductor. Of course, where the impedance of the installation is increased, the effectiveness of the grounding electrode conductor is reduced (see figures 7.17 and 7.18).

Division of Current in Both Paths (Conductor vs Raceway)

Conductor	Conduit Size	Total Amperes	Current in Conductor	Current in Conduit
6	½	100	3	97
6	½	300	5	295
2	¾	90	7	83
2	¾	350	10	340
2/0	1	150	15	135
2/0	1	590	5	585
4/0	1¼	225	15	210
4/0	1¼	885	15	870

The above test data confirms that, for all practical purposes, the impedance of a conductor enclosed in steel conduit (when the conduit is bonded at both ends) is approximately equal to the impedance of the conduit

**Data from Grounding ElectroMagnetic Interference (GEMI) analysis software*

Figure 7.18 Table showing division of current between conduit and conductor (test data)

Where grounding electrode conductors are used on an alternating-current circuit and enclosed in ferrous metal conduit, it is necessary to compare the impedance values and not the resistance values.

The data in table 20.3 of chapter twenty shows that if an 8 AWG copper conductor is installed in ferrous metal conduit and properly bonded at each end, the impedance of the circuit is about the same as if the 8 AWG copper conductor was used alone.

For all other sizes of copper conductors installed in the proper sized conduit, the impedance of the circuit is greater where the conduit is used, as compared to using the copper conductor alone. The impedance values are from about 40 percent more for a 6 AWG copper conductor in a metric designator 21 (¾) trade size conduit to about 500 percent more for a 3/0 AWG copper conductor in a metric designator 35 (1¼) trade size conduit, as compared to not using a metal conduit enclosure for physical protection.

Design Considerations for Grounding Electrode Conductor

The short-time rating of a copper conductor is related to the I^2t (current x current x time) rating of the conductor for a given temperature rise which will not damage adjacent insulated conductors or affect the continuity established by the bolted joints. For a period of five seconds the short-time rating may be taken as approximately 1 ampere for every 42.25 circular mils area. A 6 AWG copper conductor has an area of 26,240 circular mils and is thus capable of carrying about 621 amperes for five seconds safely.

Based on the safe I^2t values for the circuit comprising the various grounding electrode conductors, it can be seen that for five seconds of current, the IR drop in the different sizes of grounding electrode conductors will be approximately 37 volts per 100 ft. Using that figure as a standard, it is recommended that where a grounding electrode conductor exceeds 100 ft. in length, the conductor cross section be increased to keep the IR drop to not over 40 volts when carrying the maximum short-time current for the size conductor specified for five seconds (I^2t value). The *National Electrical Code* does not place a limit on the length of the grounding electrode conductor.

An example of selecting the proper size grounding electrode conductor for a run exceeding 100 ft. is as follows.

Given: a 1/0 AWG copper service-entrance conductor. The grounding electrode conductor specified in Table 250.66 is a 6 AWG copper and the length of the grounding electrode conductor is 45 m (150 ft).

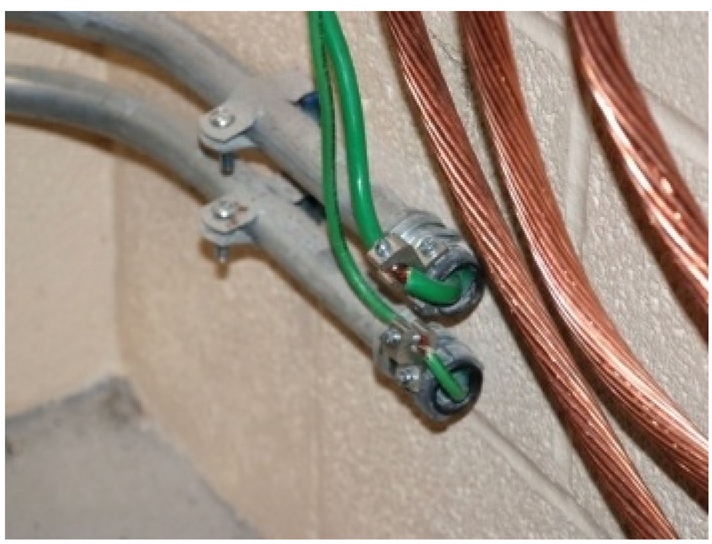


Photo 7.14

Photo 7.15

If a 6 AWG conductor is used which has 26,240 circular mils, resulting in a short-time rating of 621 amperes, and a dc resistance of 0.0737 ohms for 45 m (150 ft.) (0.491 ohms/k ft.), the voltage drop would be 621 x 0.0737 or 46 volts.

A larger grounding electrode conductor, whose resistance times the short-time rating of the 6 AWG conductor in amperes, is required to be selected and it should not exceed 40 volts.

The next larger-sized grounding conductor, a 4 AWG, has a resistance of 0.0462 ohms for 45 m (150 ft) (0.308 ohms/k ft.), so the voltage drop would be 621 x 0.0462 or 28.7 volts. That would make a 4 AWG copper grounding conductor the proper size, based on these engineering calculations, to use for a service using a 1 AWG or 1/0 AWG copper service-entrance conductor and having a grounding electrode conductor run of 45 m (150 ft).

Direct Current Systems Grounding Electrode Conductors for Direct-Current Circuits

For direct-current circuits, the size of the grounding electrode conductor is specified in 250.166. The size can be larger than would be required for the same size alternating-current circuit. That is because resistance is the only factor in determining current in a direct-current circuit. A change in the 2014 *NEC* provides that the grounding electrode conductor for DC systems does not have to be larger than 3/0 copper or 250 kcmil aluminum.

Where used on a direct-current circuit, we do not destroy the value of the grounding electrode conductor if the conduit is properly installed, that is, bonded at both ends to the grounding conductor. The resultant resistance is lower where the conduit is used for physical protection. However, that assumes a steady direct current. Special considerations are required to be given if a direct-current circuit is to be properly protected with a grounding electrode conductor against transient currents such as are produced by lightning. It is necessary to treat the selection of the grounding electrode conductor as would be done for an alternating-current circuit.

Table 22.4 of chapter twenty-two shows that where an aluminum conduit is used to enclose an aluminum grounding electrode conductor, the required conduit size has a lower resistance than the aluminum grounding electrode conductor in every case. In the case of aluminum wire size 6 AWG, the conduit is about one-tenth the resistance of the conductor.

For the largest aluminum grounding electrode conductor size, 250 kcmil, the conduit is about half the resistance of the conductor. Thus, where an aluminum grounding electrode conductor is protected with an aluminum conduit and properly bonded at both ends, we will always have a lower resistance than where the conductor is not installed in an aluminum conduit. However, aluminum is subject to certain restrictions due to chemical corrosion concerns.

Since aluminum conduit is nonmagnetic and has lower resistance as well as impedance values compared to ferrous metal conduit, the use of aluminum conduit for physical protection will provide lower impedance values.

Conclusion

All of the above means that we decrease the safety of an installation (which requires a grounding electrode conductor larger than 8 AWG) if we enclose the conductor in a ferrous metal conduit. Although we provide protection from physical damage to assure the integrity of the grounding electrode conductor, another hazard is introduced by decreasing the effectiveness of the grounding electrode conductor through increased impedance in the circuit. No better case could thus be made for restricting the use of a ferrous metal conduit on a grounding electrode conductor larger than an 8 AWG.

The obvious solution, where physical protection is necessary, is to use nonmetallic or nonferrous conduits for enclosing the grounding electrode conductor. That is especially true in view of the improvement in the art of manufacturing PVC conduit, which now can be obtained in ample physical strength to meet the requirements of proper physical protection.

1 ***NEC* 2017 *National Electrical Code,* (Quincy, MA, National Fire Protection Association, 2016)**

Review Questions

1. “A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system” best defines which of the following?

1. main bonding jumper
2. grounding electrode conductor
3. feeder bonding jumper
4. grounded

2. A grounding electrode conductor for a service must be properly sized and is based on the size or rating of the ____.

1. service breaker or fuse
2. transformer
3. largest ungrounded service-entrance conductor
4. grounding electrode

3. For service conductors sized at over 1100 kcmil copper or 1750 kcmil aluminum or copper-clad aluminum, the grounding electrode conductor must generally not be smaller than a ____ copper or ____ aluminum.

1. 2/0 AWG - 4/0 AWG
2. 1/0 AWG - 3/0 AWG
3. 3/0 AWG - 250 kcmil
4. 3/0 AWG - 4/0 AWG

4. In grounded systems, the maximum current in the ___________ is dependent on the sum of the resistance of the grounding electrode at the service, the grounding electrode at the transformer bank, plus the resistance of the earth path between the two grounding electrodes.

1. grounding electrode conductor
2. system bonding jumper
3. bonding jumper
4. equipment grounding conductor

5. Where of copper, the grounding electrode conductor is required to be sized at not less than ____ AWG.

1. 10
2. 14

3. 8
4. 12

6. Where a 3/0 AWG copper service-entrance conductor is installed, the minimum size grounding electrode conductor is ____ AWG copper or ____ AWG aluminum, or copper-clad aluminum.

1. 8 - 4
2. 6 - 6
3. 4 - 2
4. 4 - 4

7. If four 250 kcmil copper service-entrance conductors are installed in parallel per ____, the total circular mil area is considered to be that of a single 1,000 kcmil conductor.

1. service
2. feeder
3. cable
4. phase

8. Generally, the minimum size grounding electrode conductor for a service that has a 1,000 kcmil ungrounded service entrance-conductor per phase is ____ AWG copper or ____ AWG aluminum, or copper-clad aluminum conductor.

1. 1/0 - 2/0
2. 3/0 - 4/0
3. 1/0 - 3/0
4. 2/0 - 4/0

9. Services are permitted to be installed in up to ____ enclosures where they are grouped at one location.

1. one
2. two
3. six
4. eight

10. A grounding electrode conductor is required to be sized larger than ____ AWG copper or ____ AWG aluminum wire where it is the sole connection to a single or multiple rod, pipe, or plate electrode(s), or any combination thereof.

1. 8 - 8
2. 6 - 4

3. 6 - 6
4. 4 - 8

11. A grounding electrode conductor that is the sole connection to a single or multiple concrete-encased grounding electrode(s) is not required to be larger than ____ AWG copper conductor.

1. 6
2. 4
3. 8
4. 10

12. Grounding electrode conductor connections are required to be made by ____, listed clamps, or other listed means.

1. exothermic welding
2. listed lugs
3. listed pressure connectors
4. any of the above

13. Which one of the following statements is INCORRECT ____?

1. Exothermic welding connections are not required to be listed.
2. Soldered connections are permitted for connections to a grounding electrode.
3. Unless listed, not more than one conductor can be connected to the grounding electrode by a single clamp or fitting.
4. Clamps used on a pipe, rod, or other buried electrode must also be listed for direct burial.

14. Where exposed to physical damage, ____ AWG or larger grounding electrode conductors require protection.

1. 4
2. 8
3. 6
4. 3

15. Size ____ AWG grounding electrode conductors run along the surface of the building construction must be securely fastened or they are required to be protected by installation in rigid or intermediate metal conduit, rigid PVC conduit, electrical metallic tubing, reinforced thermosetting resin conduit, or cable armor. Grounding electrode conductors can be installed______ framing members.

1. 8, on
2. 6, on or through
3. 4, on or through
4. 2, at

16. Bare aluminum or copper-clad aluminum conductors are not permitted to be installed where in direct contact with masonry or earth, or where subject to corrosive conditions, and are not permitted to be terminated within ____ of the earth.

1. 300 mm (12 in.)
2. 450 mm (18 in.)
3. 350 mm (14 in.)
4. 400 mm (16 in.)

17. An exothermic or irreversible compression connection bolted to a fire-proofed structural metal grounding electrode_______.

1. shall be identified by a green color
2. shall be accessible
3. shall not be required to be accessible
4. all of the above

18. _______metal raceways and enclosures for grounding electrode conductors must be electrically continuous or made electrically continuous by bonding to the grounding electrode conductor.

1. Ferrous
2. Nonferrous
3. Nonmetallic
4. Aluminum

19. Grounding electrode conductors shall be permitted to be which of the following materials ____?

1. copper
2. aluminuim
3. copper-clad aluminuim
4. any of the above

20. A grounding electrode conductor connection to a metal water pipe electrode shall be made using which of the following ____.

1. a listed bolted clamp (cast bronze or brass)

2. a listed bolted clamp of malleable iron
3. a pipe fitting, or pipe plug
4. all of the above are acceptable

21. The secondary of a transformer separately derived system supplies a 400-ampere panelboard and the derived phase conductors are 600-kcmil copper (one per phase). What is the minimum size copper grounding electrode conductor to a metal water pipe electrode ____?

1. 1/0
2. 2/0
3. 3/0
4. 6

22. Bonding jumpers for grounding electrode systems are required to be sized according to ____.

1. 250.70
2. 260.64(A)
3. 250.64(E)
4. 250.66

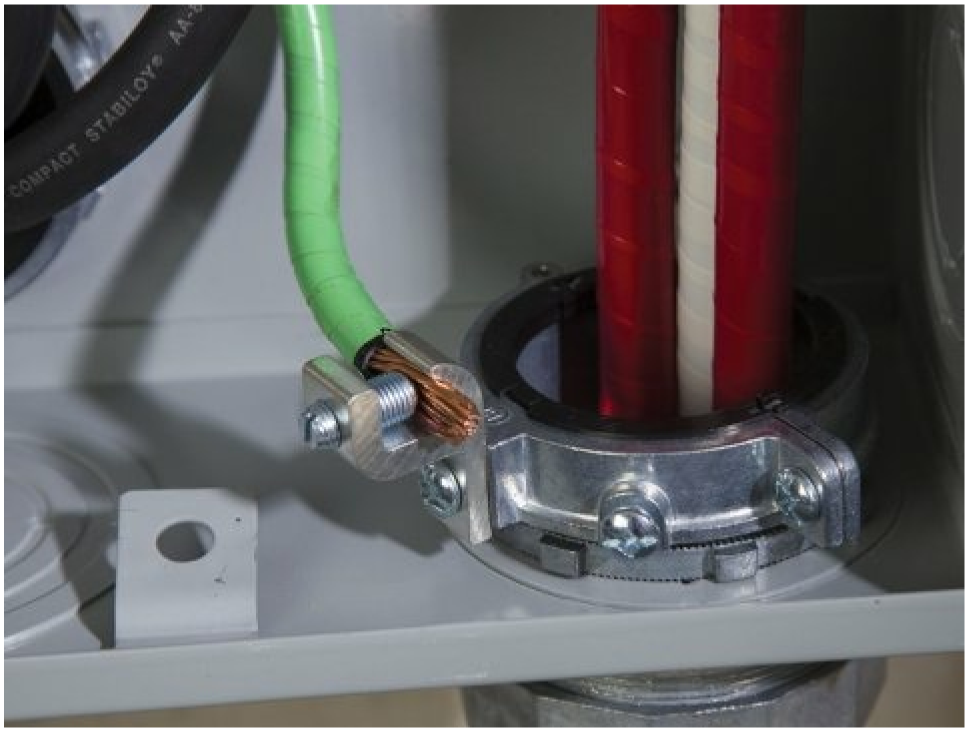
23. A "stub-up" from the concrete-encased electrode is recognized as an acceptable connection at ____ .

1. 250.70
2. 260.64(A)
3. 250.68(C)(3)
4. 250.66

24. For direct-current circuits, the size of the grounding electrode conductor is specified in _____________.

1. 250.70
2. 250.166
3. 250.64(E)
4. 250.66

Chapter 8
Bonding Enclosures and Equipment



Objectives to understand

- The purpose of bonding
- Requirements for maintaining continuity and conductivity
- Systems over 250 volts to ground
- Multiple raceway systems
- Receptacles
- Metal water piping systems
- Other metal piping systems
- Interconnected exposed structural metal framing

Bonding is an ongoing process in any electrical system from the point of service delivery to the final outlet on the system. The act of bonding metal parts or enclosures of electrical components and conductors connects them together electrically and mechanically, establishing electrical continuity and conductivity. Essentially, the desired outcome, when bonding metal parts together, is to make them electrically become one.

Bonding has a very important function electrically for both grounded and ungrounded systems. Bonding metallic parts together puts the parts at the same potential, and through the bonding connection to the grounding electrode at the service or source of separately derived system, at the ground (earth) potential. The *NEC* defines bonding in Article 100 as follows: "Bonded (bonding). Connected (connecting) to establish electrical continuity and conductivity."[1]

Definition

The definition of *bonded (bonding)* is universal with how it is used in rules of the *NEC* wherever referring to an effective path for fault current or bond to establish an equipotential bonding grid or plane such as for a swimming pool or agricultural facility (see figure 8.1).

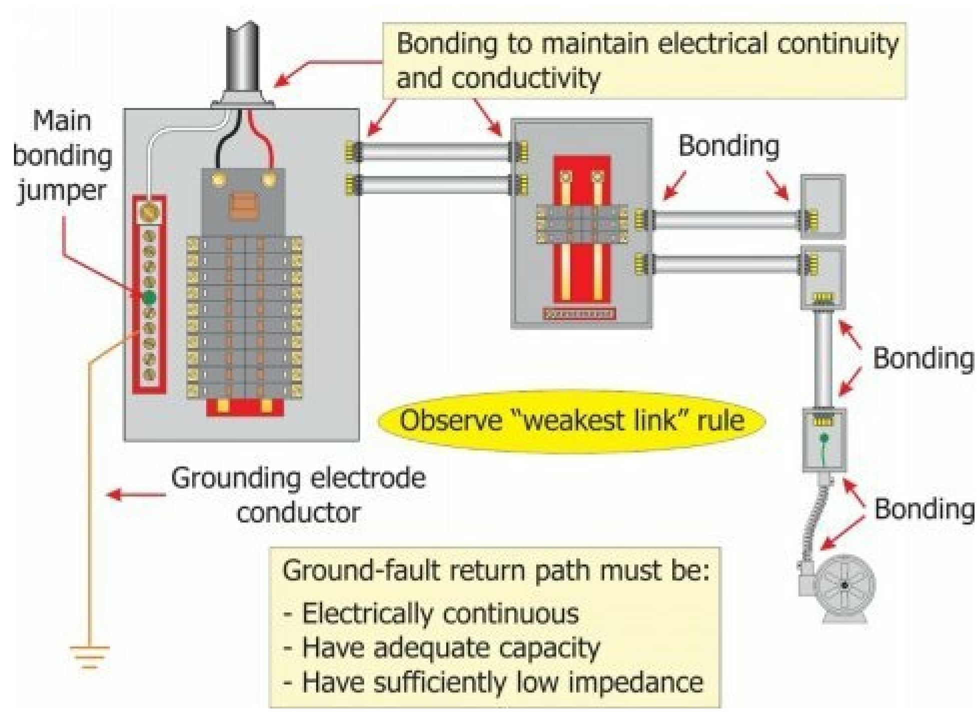


Figure 8.1 Bonding to maintain continuity

Maintaining Continuity

The physical assembly of metal parts together may achieve the intended bonding. When it does not, 250.96(A) requires that bonding be done around connections of metal raceways, cable trays, cable armor, cable sheath, enclosures, frames, fittings and other metal non-current-carrying parts used as equipment grounding conductors. This may be necessary to assure that these various components of the system have electrical continuity and sufficient current-carrying capacity to safely conduct the fault current likely to be imposed on them. Bonding of these components is required to be done regardless of whether or not a wire type equipment grounding conductor is run within the raceway. This will ensure that the raceway will not become energized due to a line-to-enclosure fault without having the capacity and capability of clearing the fault by allowing sufficient current to operate the overcurrent protective device on the line side of the fault.

Keep in mind that the weakest link rule applies to the ground-fault return path. To provide adequate safety, the effective ground-fault current path is required to be (1) electrically continuous, (2) have the capacity to conduct safely any fault current likely to be imposed on it, and (3) have sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit-protective devices [see 250.4(A)(5) and 250.4(B)(4)]. This ground-fault path is required to meet all three conditions from the farthest enclosure or equipment all the way back to the service equipment or separately derived system and ultimately to the source. This path can be through many boxes, conduits or other raceways, pull boxes, wireways, auxiliary gutters, panelboards, motor control centers and switchboards. Every connection is important. It only takes one loose locknut, broken fitting, or unclean surface to weaken or break a link in the fault-current chain.

Section 250.96(A) also refers to conditions where a nonconducting coating might interrupt the required continuity of the ground-fault path, and it points out that such coatings must be removed unless the fitting(s) is designed as to make such removal unnecessary. [See the section on Clean Surfaces in chapter seven for more information.]

In some cases, the locknut can pierce painted enclosures to establish a good electrical connection. This applies to the use of heavy-type, formed-steel locknuts or fittings that have a knurled surface to break through the paint or coating. General instructions are that the locknuts be tightened by hand, then be further tightened ¼ turn by means of a screwdriver and hammer. At that point, examine the connection to be sure any paint under the locknut has been adequately broken and a good connection is made to bare metal. If there is any question about the adequacy of the connection, remove the locknut and scrape the paint off or install a suitable bonding fitting.

Testing of Conduit Fittings

The importance of removing paint from enclosures where the conduit or raceway is intended to serve as the fault-current path is further emphasized in a report on “Conduit Fitting Ground-Fault Current Withstand Capability” issued by Underwriters Laboratories on June 1, 1992. Over 300 conduit-fitting assemblies from ten different manufacturers were subjected to a current test to simulate performance under ground-fault conditions.

A sample assembly consisted of a conduit fitting secured to one end of a two-foot length of conduit and attached to a metal enclosure. Some of the enclosures were bare metal or galvanized and others were painted with enamel coating typical of construction of enclosures in the 1990s.

After securing the conduit fitting to the conduit properly, the conduit fitting was secured to the enclosure using the locknut provided by the manufacturer. The locknut was first hand-tightened and then further tightened ¼ turn with a hammer and standard screwdriver. The fittings were installed through holes in the enclosures that were punched rather than being installed in preexisting knockouts. A pipe clamp, wire connector, conductors and a power supply were assembled to complete the testing. Thermocouples were placed at strategic locations to record pertinent temperature data. Figure 8.2 is a drawing of the sample assembly.

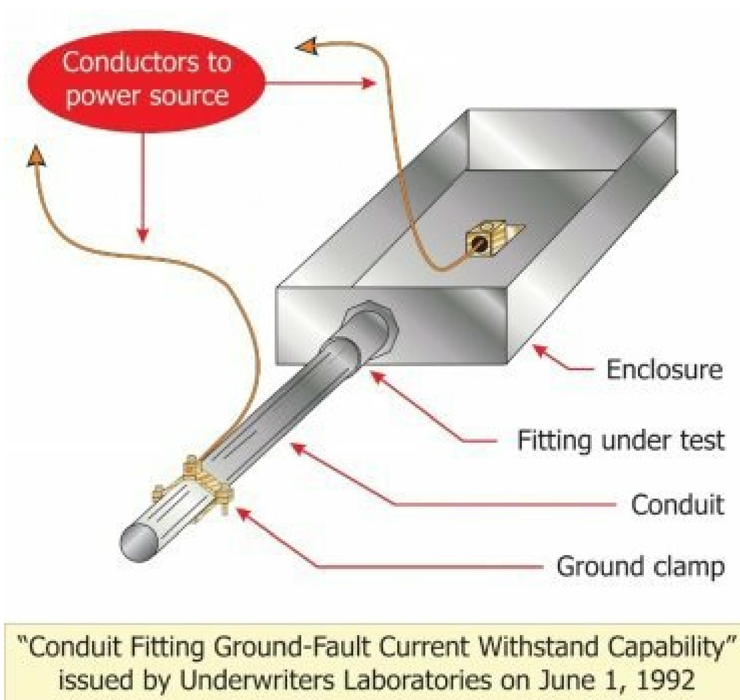


Figure 8.2 Testing of conduit fittings (sketch of actual testing assembly)

Fittings for conduit in the 10 mm (3/8-inch) through 152 mm (6-inch) trade sizes were tested. The appropriate current was applied to the fittings in the test program established by Underwriters Laboratories.

This test should not be confused with a short circuit withstand test and is not intended to test the maximum short-circuit current these fittings can withstand. Due to the time and current involved, a great deal of heat is generated in the test assembly.

Seven of the more than 300 assemblies tested sustained damage. A visual examination of sample assemblies that failed showed that melting of the die-cast zinc locknuts occurred as a result of the fault current (see photo 8.1). Melting of the die-cast zinc body occurred on five sample assemblies. The painted enclosures on which the fittings were tested were also examined. The examination indicated that melting of the die-cast zinc was probably due to the inability of the locknut to penetrate through the enclosure paint and provide good electrical contact between the fitting and metal of the enclosure.

Photo 8.1 Actual enclosure used in the testing procedure

Photo 8.2 Concentric and eccentric knockouts in boxes are acceptable for bonding.

A visual examination of all the conduit fittings with die-cast zinc locknuts showed that there were three different constructions of the locknuts. The three constructions differed in that the surface of the locknut contacting the enclosure either was flat, ribbed, or serrated. The sample assemblies with die-cast zinc locknuts that did not complete the current test with acceptable results had locknuts with flat or ribbed surfaces. All fittings having die-cast zinc locknuts with serrations completed the current tests with acceptable results. It appeared as though locknuts with serrations consistently penetrated through the enclosure paint and provided better electrical contact between the fitting and the metal of the enclosure than did the locknuts with flat or ribbed surfaces.

The fittings investigated in this work were formed of die-cast zinc, steel and malleable iron. The melting point of zinc is 420°C while the melting point of steel and malleable iron is much higher, typically greater than 1400°C. Heat generated from the fault current in some sample assemblies was obviously greater than the melting point of the die-cast zinc fittings and locknuts, but not greater than the melting point of steel or malleable iron since no melting of the steel enclosure occurred. This was further evidenced by tests of two sample assemblies where the die-cast zinc body of the fittings melted, but the steel locknuts did not.

All of the conduit fittings that were constructed of steel bodies and steel locknuts completed the test with acceptable results. A visual examination of the steel locknuts indicated that the nibs on these locknuts, which in most cases were sharp and well defined from the metal forming process, provided for better penetration through the enclosure paint than the nibs on the die-cast zinc locknuts.

For most of the sample assemblies that completed the current test with acceptable results, the maximum temperatures on the fitting bodies and locknuts were about the same as or less than the temperature of the conduit. In the case of the flexible metal conduit, the temperatures on the fittings were much less than on the conduit. This would seem to indicate that if the fitting can provide good electrical contact to the enclosure metal the fitting will provide for adequate equipment grounding and bonding of the flexible metal raceway.

Conclusions reached by Underwriters Laboratories as a result of the testing are as follows:

> "1. Over 300 conduit-fitting assemblies from ten different manufacturers were subjected to the Current Test to simulate performance under ground-fault conditions. As a result of the tests, only seven assemblies representing four different conduit fittings and three different manufacturers did not withstand the fault current without breaking or melting of the conduit-fitting assembly. All seven of these sample assemblies were compression type connectors with die-cast zinc bodies, and all but one of these assemblies utilized a die-cast zinc locknut.
>
> "2. An examination of the seven sample assemblies that did not complete the Current Test with acceptable results showed that the failures were probably due to high resistance from the inability of the fitting locknut to penetrate through the enclosure paint and provide good electrical continuity between the fitting and the metal enclosure. Heat generated by the high-resistance arcing was sufficient to melt the zinc, but not steel or iron.
>
> "3. Some of the sample assemblies that did not exhibit breaking or melting did show signs of arcing and welding between the locknut and the enclosure and/or the fitting and the conduit. These sample assemblies usually had higher temperatures during the current test, however, the temperatures were not sufficient to cause melting of the zinc or steel parts nor loss of continuity between the conduit, fitting, and enclosure.
>
> "4. Most of the sample assemblies that were subjected to the Current Test attained maximum temperatures on the fitting bodies and locknuts that were about the same as or less than the temperature of the conduit. For the tests with flexible metal conduit, the temperatures of the fittings were much less than the temperatures of the flexible conduit.
>
> "5. As a result of the tests, it was observed that if the fitting provides good electrical contact to both the enclosure and the conduit, the fitting will provide a suitable equipment ground path for fault current." [1]

Bonding for Over 250 Volts

Section 250.97 requires that for circuits having a voltage exceeding 250 volts to ground, the electrical continuity of metal raceways and metal-sheathed cables that are not used for service-conductors must also be ensured by specific methods (see figure 8.3).

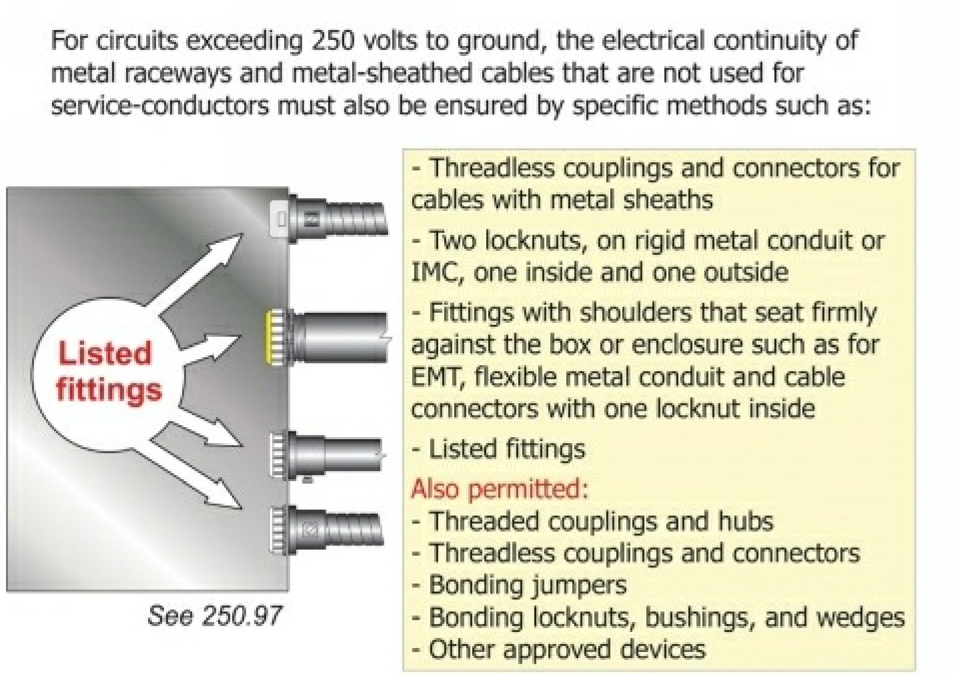


Figure 8.3 Bonding methods for circuit over 250 volts to ground

Acceptable methods include any of the methods approved for bonding at service equipment found in 250.92(B)(2) through (4) as paraphrased below. Note that standard locknuts and bushings without additional bonding means are not generally permitted for bonding equipment, which has concentric or eccentric knockouts, over 250 volts to ground. The bonding methods permitted include those for services including:

- (B)(2) For rigid and intermediate metal conduit, connections made up wrenchtight with threaded couplings or threaded hubs on enclosures.
- (B)(3) Threadless couplings and connectors made up tight for rigid metal and intermediate metal conduit and electrical metallic tubing and metal-clad cables.
- (B)(4) Other listed devices like bonding type locknuts and bushings.

In addition, bonding jumpers are permitted around concentric or eccentric knockouts that are punched or formed so as to impair the electrical connection to ground.

An exception to 250.97 provides that where oversized, concentric or eccentric knockouts are not encountered, or where concentric or eccentric knockouts have been tested and the box or enclosure is listed to provide a reliable bonding connection, the following methods of ensuring continuity for these connections are permitted:

- threadless couplings and connectors for cables with metal sheaths,
- for rigid and intermediate metal conduit, two locknuts, one inside and the other outside the boxes and enclosures,

- fittings that seat firmly against the box or enclosure or cabinet such as for electrical metallic tubing, flexible metal conduit and cable connectors, with one locknut inside the enclosure, or listed fittings.

All Listed device outlet boxes are specially designed and tested so knockouts perform satisfactorily for over 250-volt-to-ground applications (see photo 8.2). Also, see UL ProductSpec for the guide card information under category code QCIT for listing details on these device boxes. These boxes typically have only one eccentric knockout so when the solid knockout is removed, a conduit or fitting locknut makes contact with the base metal of the box to ensure good electrical and mechanical contact. These boxes, unless for multiple gang applications, without any extension rings installed also have a maximum volume of 0.001638 m^3 (100 cubic inches). Larger enclosures are covered under cabinets and cutout boxes are under UL category codes BGUZ and CYIV in UL ProductSpec.

Cabinets, Cutout Boxes and Wireways

The installer needs to be cautious in the use of equipment that has concentric or eccentric knockouts, as their ability to carry fault current must be of concern. It is very common to find nibs of adjacent rings damaged during removal of the desired knockout. This leaves less material available for carrying fault current. The safest practice is to install bonding bushings around concentric and eccentric knockouts where there is any question about their integrity.

Concentric and eccentric knockouts in equipment such as cabinets, enclosed switches, junction and pull boxes, auxiliary gutters and wireways are not tested or certified by an electrical products testing laboratory for their current-carrying ability. The specific methods provided for in 250.97 must be used if those enclosures have eccentric or concentric knockouts.

In other areas, where oversized, concentric or eccentric knockouts are not present, threadless fittings which are made up tight with conduit or armored cable or the use of two locknuts, one inside and one outside of boxes and cabinets, is acceptable for bonding.

Where loosely jointed metal raceways are used and especially where there are expansion joints or telescoping sections of raceways (see photos 8.3 and 8.4), the *Code* requires that they be made electrically continuous by the use of equipment bonding jumpers or other means [see 250.98].

Photo 8.3 Expansion coupling

Photo 8.4 Cut-away of an expansion coupling with bonding jumper Courtesy of Thomas and Betts

Reducing Washers

Reducing washers are commonly used in electrical installations where it is desirable or necessary to install conduit or fittings of a size that is smaller than the knockout available in the enclosure. These reducing washers are evaluated and listed for bonding over and under 250 volts for other than raceways used for service conductors (see UL ProductSpec, category QCRV). Bonding around reducer washers at raceways containing service conductors is required by 250.92(B). Where painted or coated enclosures are encountered and the paint or coating under the washer is not removed, one should always bond around to provide an adequate fault-return path (see photo 8.5). Also, reducing washers can only be used where all the rings of concentric or eccentric knockouts are removed. It is never permitted to install reducing washers with a ground-fault return path through any remaining rings or nibs from knockouts.

Photo 8.5 Bonding around reducing washers at coated enclosures to maintain continuity and the capacity to conduct any fault current that might be imposed. Bonding around reducing washers is always required when raceways contains service conductors (at any voltage).

Load-Side Bonding Jumper Sizes

Equipment bonding jumpers form a part of the effective ground-fault path and can carry the same fault current that the equipment grounding conductor would carry; therefore, they are required to be the same size.

The size of the bonding jumper will depend on its location and is based on the size of the overcurrent device in the circuit immediately ahead of the equipment [see 250.102(D)]. Column 1 (left) of Table 250.122 in the *NEC* gives the size or setting of the overcurrent device in the circuit ahead of the equipment. Columns 2 (middle) and 3 (right) give the minimum size of the equipment grounding conductor, whether copper or aluminum or copper-clad aluminum.

Attaching Jumpers

Where bonding jumpers are used between grounding electrodes or around water meters and similar equipment, the *Code* requires that good electrical contact be maintained and that the arrangement of conductors be such that the disconnection or removal of equipment will not interfere with or interrupt the grounding and bonding continuity of the jumper [see 250.68(B)].

Bonding jumpers are required to be attached to circuits and equipment by any of the means provided in 250.8 including exothermic welding, listed pressure connectors, listed clamps or other suitable and listed means. Bonding jumper connections and equipment grounding conductor connections are required to be made using one or more of the following methods:

- listed pressure connectors
- terminal bars
- pressure connectors listed as grounding and bonding equipment
- exothermic welding
- machine screw-type fasteners that engage at least two threads or are secured with a nut
- thread-forming screws engaging not less than two threads in the enclosure
- connections that are part of listed assemblies
- other listed means

Connections that depend solely on solder are not acceptable [see 250.8].

Bonding Multiple Raceway Systems

In general, where more than one raceway enters or leaves a switchboard, pull or junction box or other equipment and the raceway is not bonded by its connection to the enclosure, it is permissible to use a single conductor to bond these raceways to the equipment grounding terminals. The equipment bonding jumper is sized for the largest overcurrent device ahead of conductors contained in any of the raceways [see 250.102(D)]. This applies to feeder or branch-circuit conductors and not service conductors.

For example, as shown in figure 8.4 method 1, four metallic raceways leave the bottom of an open bottom switchboard or motor control center. The overcurrent protective devices ahead of the raceways are 400, 300, 225 and 125 amperes respectively. According to Table 250.122, the minimum size equipment bonding jumper for the raceway having conductors protected at 400 amperes is 3 AWG copper or 1 AWG aluminum. If this conductor were looped through a grounding bushing on each raceway, compliance with the *Code* would be obtained. Of course, the grounding bushings would need to be listed for both the size of conduit and conductor. In some cases, this method may require a larger conductor to bond some conduits than where individual bonding jumpers are installed.

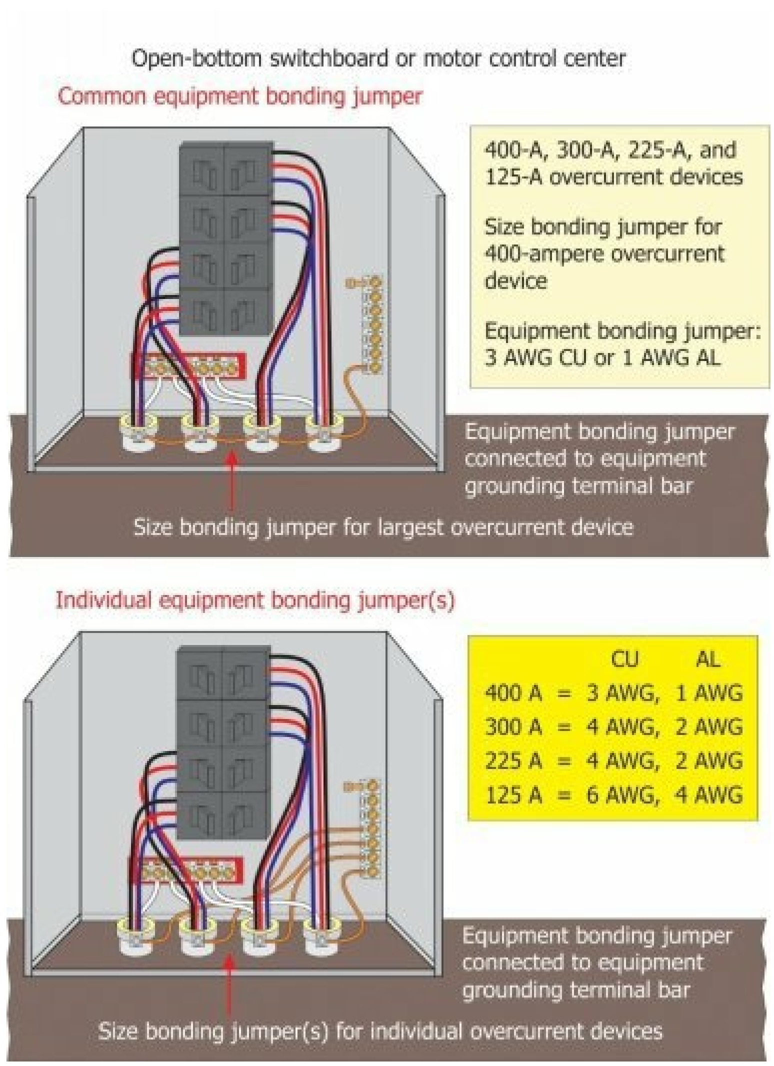


Figure 8.4 Bonding raceways to enclosures (two methods shown)

Alternatively, as shown in figure 8.4 method 2, it is acceptable to install an equipment bonding jumper individually from each raceway to the equipment grounding terminals of the equipment. Each equipment bonding conductor is sized for the overcurrent device ahead of the conductors in that raceway per Table 250.122. For services, as discussed in chapter five for services, the connection of the supply-side bonding jumper must be to the grounded or neutral bus terminals in accordance with 250.80. For other than service equipment, the equipment bonding jumper must be connected to the equipment grounding terminal or bus in the switchboard, panelboard, MCC or other equipment where the feeder or branch circuit raceways enter.

Nonmetallic Boxes

Section 314.3 permits metal raceways or metal-armored cables to be used with nonmetallic boxes only where:

- internal bonding means are provided between all raceways or metal-armored cables, or
- integral bonding means with provision for attaching an equipment bonding jumper inside the box are provided. This type of bonding means is typically molded in the box.

The equipment bonding jumpers are required to be sized in accordance with Table 250.122. It should be noted that the size of the equipment bonding jumpers given in 250.122 is the minimum size. Larger equipment bonding jumpers may be required to comply with the available fault-current requirements in 110.10 and the performance requirements of 250.4(A)(5) and 250.4(B)(4).

Bonding Receptacles

An equipment bonding jumper is required to connect the grounding terminal of a grounding type receptacle to a grounded box and to the supply equipment grounding conductor [see 250.146, 250.148 and figure 8.5]. Where one or more equipment grounding conductors enters a box, all equipment grounding conductors associated with any and all of these circuits must be spliced or joined inside the box with suitable devices to bond the box and to connect to the device. Four exceptions to the general rule requiring the bonding jumper are provided in 250.146(A) through (D) as paraphrased below.

(A) Where the box is mounted on the surface and direct metal-to-metal contact is made between the receptacle yoke and the box a separate equipment bonding jumper is not required. At least one of the insulated washers used to retain the screws must be removed so there is direct metal to metal contact from the device yoke to the box, unless the receptacle is listed as self-grounding. Cover-mounted receptacles, such as in a raised cover on 4-in. square boxes, are acceptable where the receptacle is fastened to the listed cover with screws and locking nuts or rivets and the cover is equipped with mounting holes on a flat, non-raised portion of the cover (see figure 8.6 and photo 8.6).

(B) Contact devices or yokes designed and listed as providing bonding with the mounting screws to establish the grounding circuit between the device yoke and flush-type boxes. This is the device commonly referred to as a self-grounding receptacle (see photo 8.7). The device is designed and listed as maintaining good electrical contact between the yoke and box by means of a spring-type device that maintains continuity between the device and the mounting screws. The use of a self-grounding receptacle is not allowed to be the means to ground the metal box [see 250.148(B) and (C)].

(C) Floor boxes that are listed as providing satisfactory grounding continuity.

(D) A receptacle having an isolated equipment grounding terminal that is required for reduction of electrical noise (electromagnetic interference) (see figure 8-7). In this case, the equipment grounding terminal is required to be grounded by an insulated equipment grounding conductor that is run with the circuit conductors. Section 406.3(D) requires that this receptacle be identified by an orange triangle on the face of the receptacle. This equipment grounding conductor is permitted to pass through one or more panelboards, boxes, wireways, or other enclosures so as to terminate no further than at an equipment grounding terminal of the separately derived system, service or main disconnect at a building or structure served by a feeder or branch circuit. This is a permissive allowance and the equipment grounding conductor connected to the receptacle isolated equipment ground terminal may be terminated at any point along the return path to the service, separately derived system or disconnect for a separate building, but not beyond these points.

Photo 8.6 Surface-mounted box with raised cover and receptacle

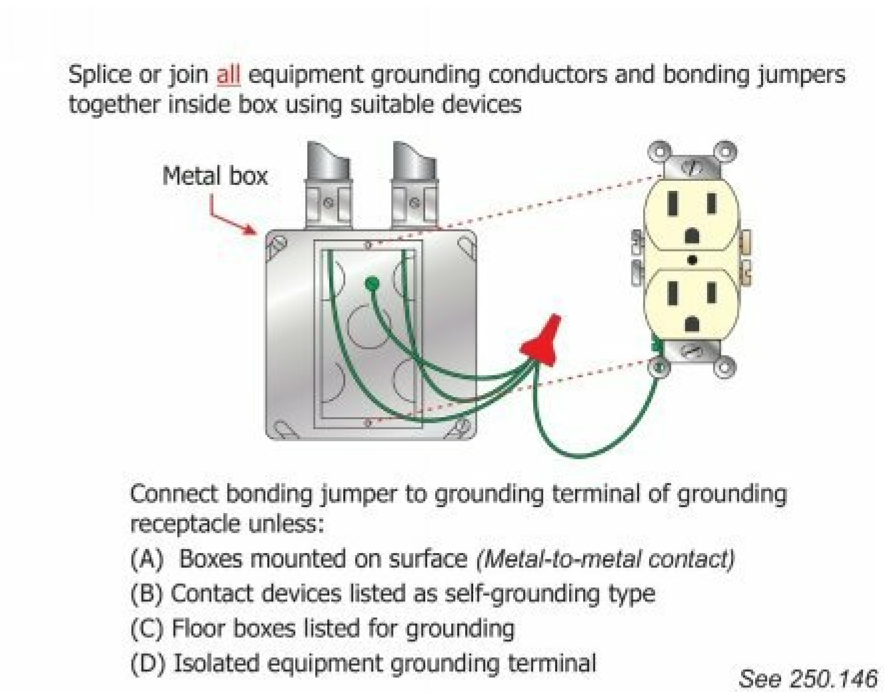


Figure 8.5 Bonding of grounding-type receptacles to boxes

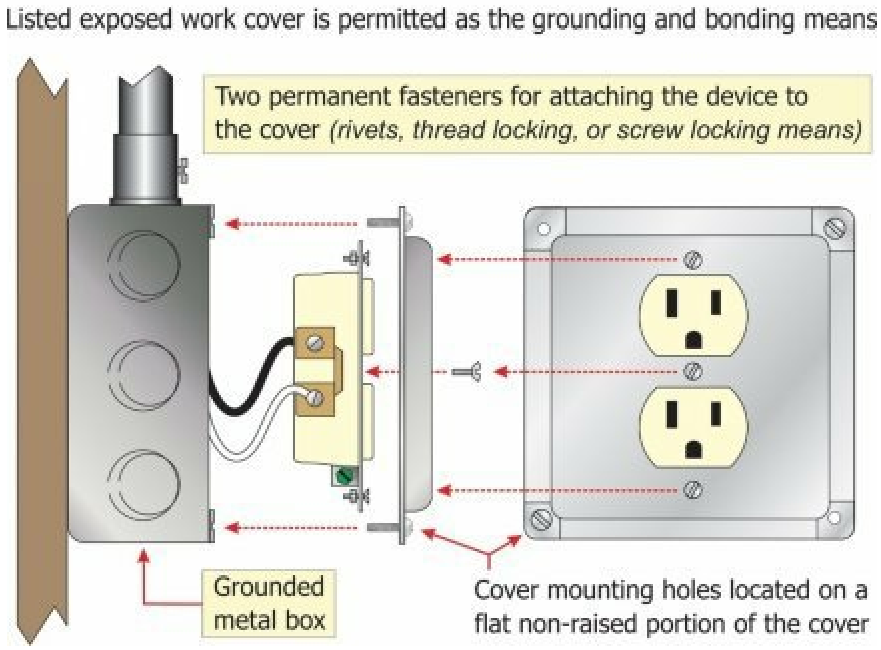


Figure 8.6 Listed exposed work cover is permitted as the grounding and bonding means for receptacle

To provide an effective ground-fault current path, the isolated, insulated equipment grounding conductor should never pass without being terminated at the separately derived system that is the source of power for the equipment being grounded. Also note that special rules are provided in 406.3(D)(2) for grounding receptacle covers where isolated ground receptacles are installed in a nonmetallic outlet box.

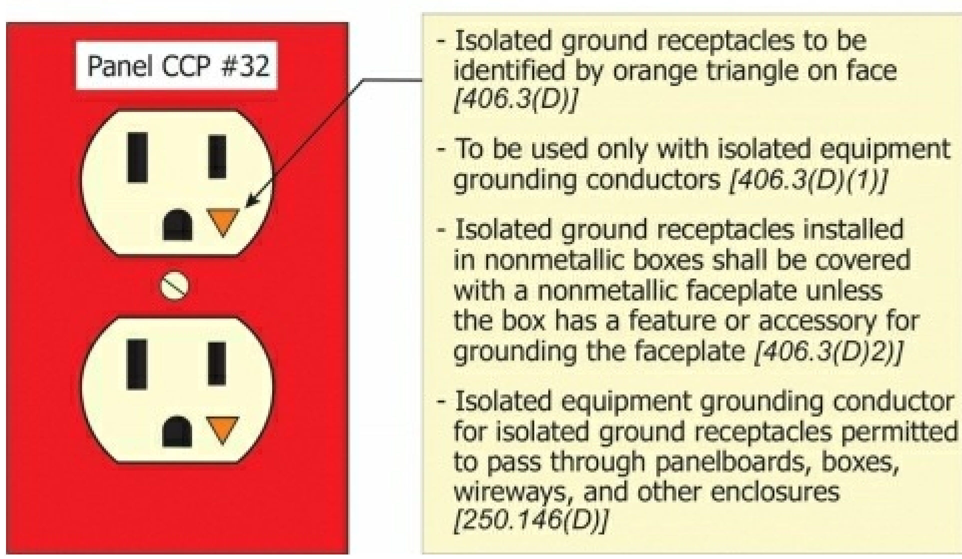


Figure 8.7 Isolated ground receptacles

Photo 8.7 Self-grounding receptacles

Installation of Equipment Bonding Jumper

Equipment bonding jumper is defined in Article 100 as “The connection between two or more portions of the equipment grounding conductor.” This definition describes the installation of equipment bonding jumpers on the load side of an overcurrent protective device. On the line or supply side, such as at the service or source of separately derived system, a change in the 2011 *NEC* now calls this jumper a supply-side bonding jumper [see 250.102(C) and 250.30(A)(2)].

The equipment bonding jumper is permitted to be installed either inside or outside of a raceway or enclosure [see 250.102(E)].

Where the jumper is installed on the outside, the length is generally limited to not more than 1.8 m (6 ft). In addition, the bonding jumper is required to be routed with the raceway. This is vital to keep the impedance of the equipment bonding jumper as low as possible (see figures 8.8 and 8.9 and photo 8.8). An equipment bonding jumper longer than 1.8 m (6 ft) is permitted at outside pole locations for the purpose of bonding or grounding isolated sections of metal raceways or elbows that are installed in exposed risers of metal conduit or other metal raceway.

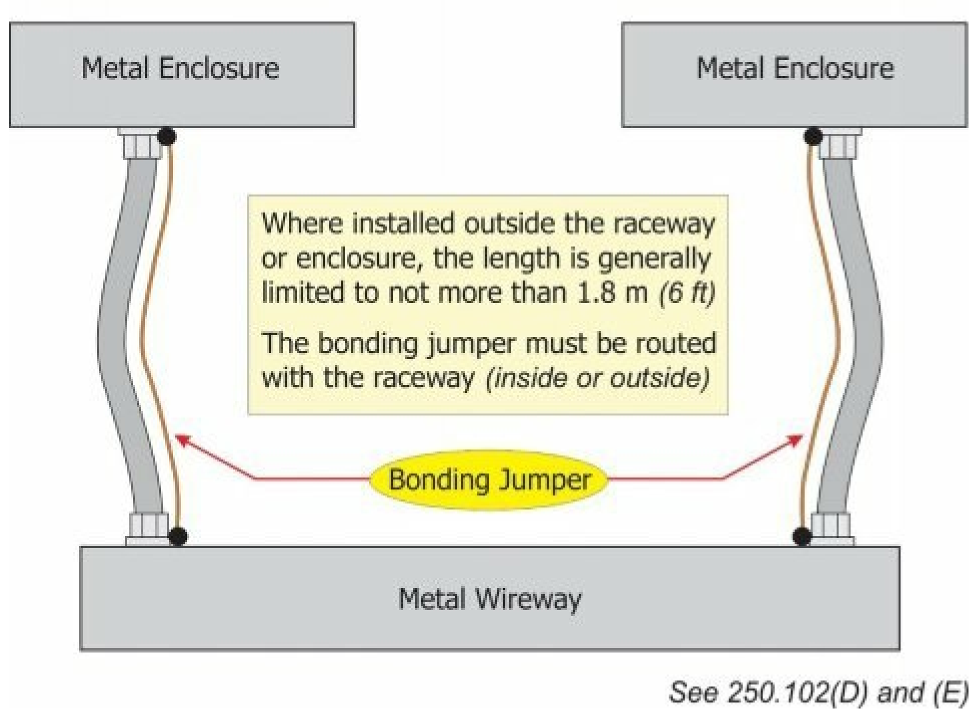


Figure 8.8 Installation of equipment bonding jumper on the outside of the raceway

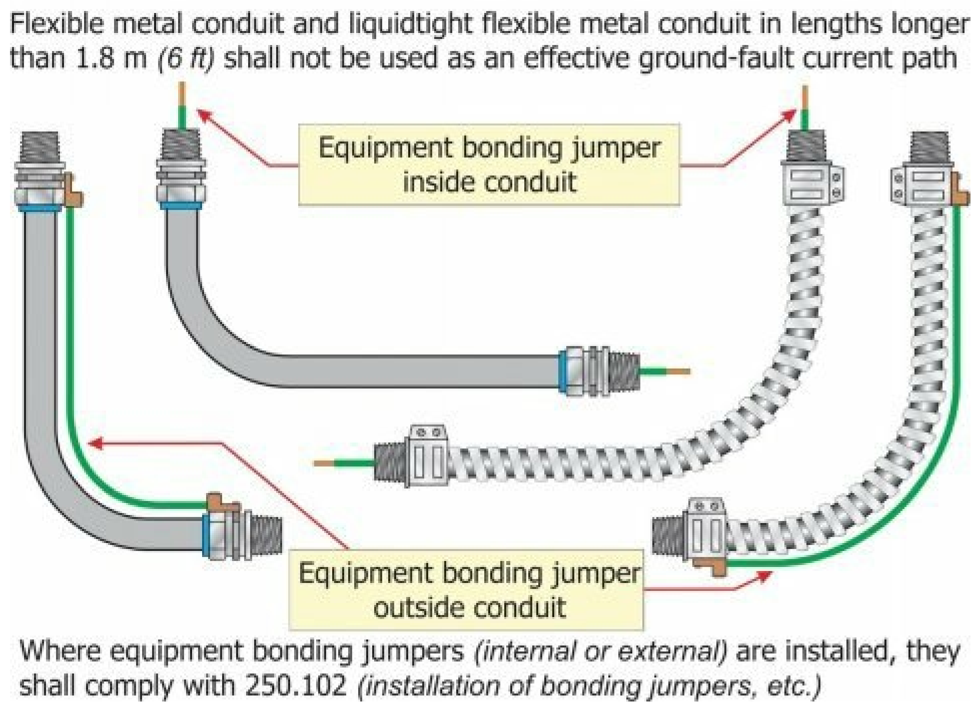


Figure 8.9 Bonding jumper installation in accordance with 250.102

Photo 8.8 Equipment bonding jumper outside raceway

Bonding of Piping Systems

Section 250.104 requires that metal water piping and other metal piping systems installed within or attached to buildings or structures be bonded (see figure 8.10). This requirement for bonding is not to be confused with the requirement in 250.52(A)(1) that metal underground water piping is to be used as a grounding electrode. Some requirements change depending upon whether the piping is metal water piping or other metal piping systems.

Photo 8.9 Connection to water piping is to be accessible.

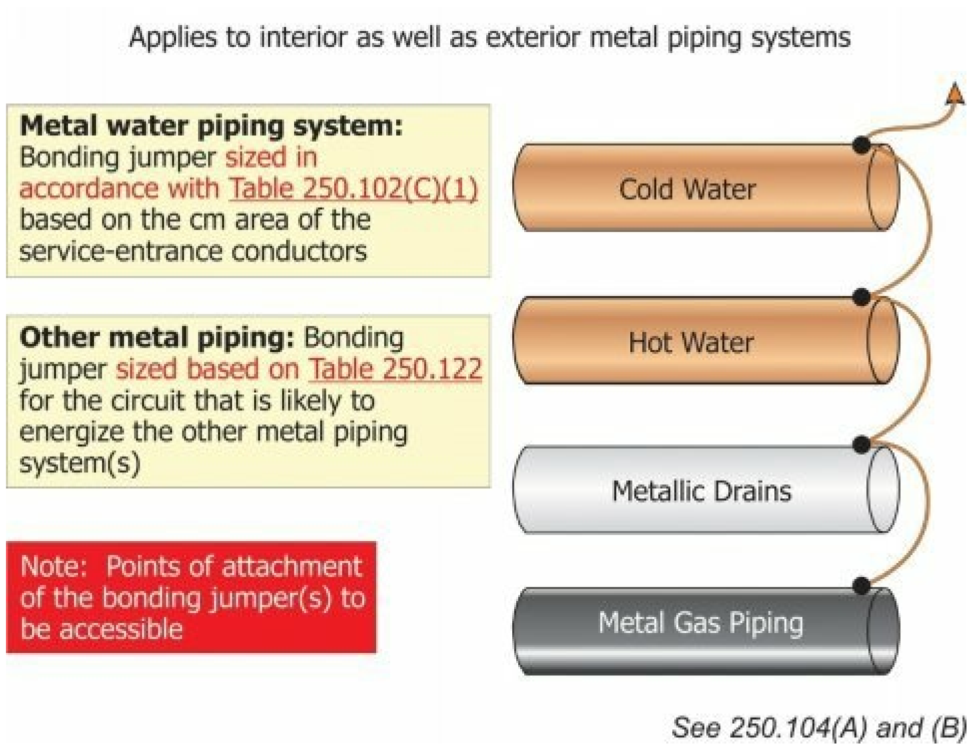


Figure 8.10 Bonding of metallic piping systems is required.

Included among the items within a building that should be adequately connected to the one common grounding electrode system are the water piping system (hot and cold) and gas and sewer piping, any metallic air ducts installed inside or on the exterior of the building, as well as such devices as TV towers, gutters provided with a deicing system, and so forth.

For the water piping system, the bonding jumper generally is required to be sized in accordance with Table 250.102(C)(1). Also, it is required to be installed in accordance with the general rules for installing grounding electrode conductors in 250.64(A), (B) and (E). They shall be connected in a manner specified in 250.70. The point(s) of attachment of the bonding jumper(s) to the water piping system is required to be accessible (see figure 8.11). For other metallic piping systems such as gas, drain or air ducts, the bonding jumper generally is required to be sized to Table 250.122 based on the overcurrent protective device of the circuit likely to energize the piping system [see 250.104(B)].

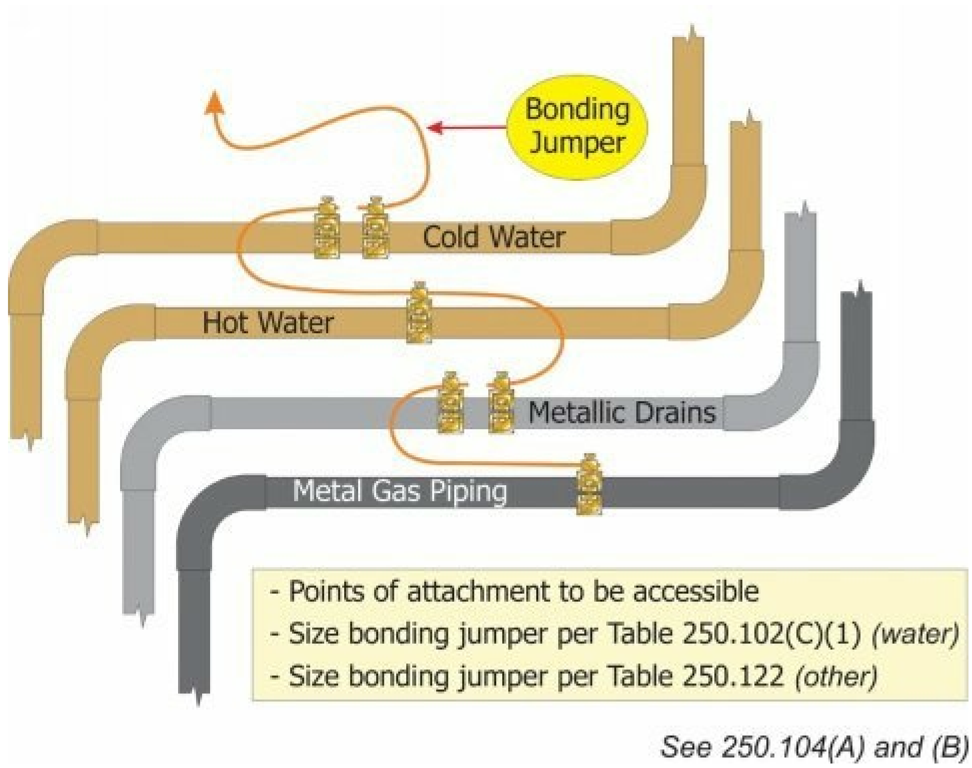


Figure 8.11 Bonding jumper connection to piping is generally required to be accessible.

Metal Water Piping

The requirement for bonding applies to all metal water piping system(s) installed within or on the exterior of the building [250.104(A)(1)]. The bonding jumper in the building where the service is located is generally required to be sized in accordance with Table 250.102(C)(1) and, thus, is based on the size of the service-entrance conductor and not on the rating of the service overcurrent device. In addition, the points of attachment of the bonding jumper to the metal water piping system are required to be accessible (see photo 8.9).

Photo 8.9 Connection to water piping is to be accessible.

The piping system is permitted to be bonded to the service equipment enclosure, the grounded conductor at the service, the grounding electrode conductor where large enough, or to one or more grounding electrodes.

For example, if Table 250.102(C)(1) requires a 2 AWG bonding jumper to the metal water piping, it cannot be connected to a 6 AWG or a 4 AWG grounding electrode conductor.

Where a metallic underground water piping system exists and is connected to a metallic interior water-piping system and there is not an insulated coupling, the interior water piping system is automatically and adequately grounded (bonded) when the metallic underground water piping system is used as the grounding electrode. However, with the expanding use of nonmetallic piping and insulated couplings it becomes more important to be sure that the interior piping not only is electrically continuous, but that also it is adequately grounded by bonding it to the same grounding electrode used for the premises. That is a mandatory and essential requirement of the *Code.*

Bonding of Metal Water Piping in Multiple Occupancy Building

Section 250.104(A)(2) allows the metal water piping system(s) to be bonded to the panelboard or switchboard enclosure (other than service equipment) under specific conditions (see figure 8.12). The conditions are as follows:

1. the building is multiple occupancy, and
2. the metallic water piping is isolated from all other occupancies by nonmetallic water piping. In other words, the metallic piping system in each occupancy is isolated from all other piping systems of the other occupancies by nonmetallic means or individual isolation.

In this case, the bonding jumper to the water piping is sized in accordance with Table 250.122, and the ampere rating of the overcurrent device supplying the feeder to the unit or occupancy determines the minimum size of the bonding conductor [see 250.104(A)(2)]. The bonding jumper for the interior metal water piping runs from the equipment grounding terminal bar in the panelboard serving the unit to the piping. In this case, the bonding jumper does not connect to the neutral terminal bar in the panelboard.

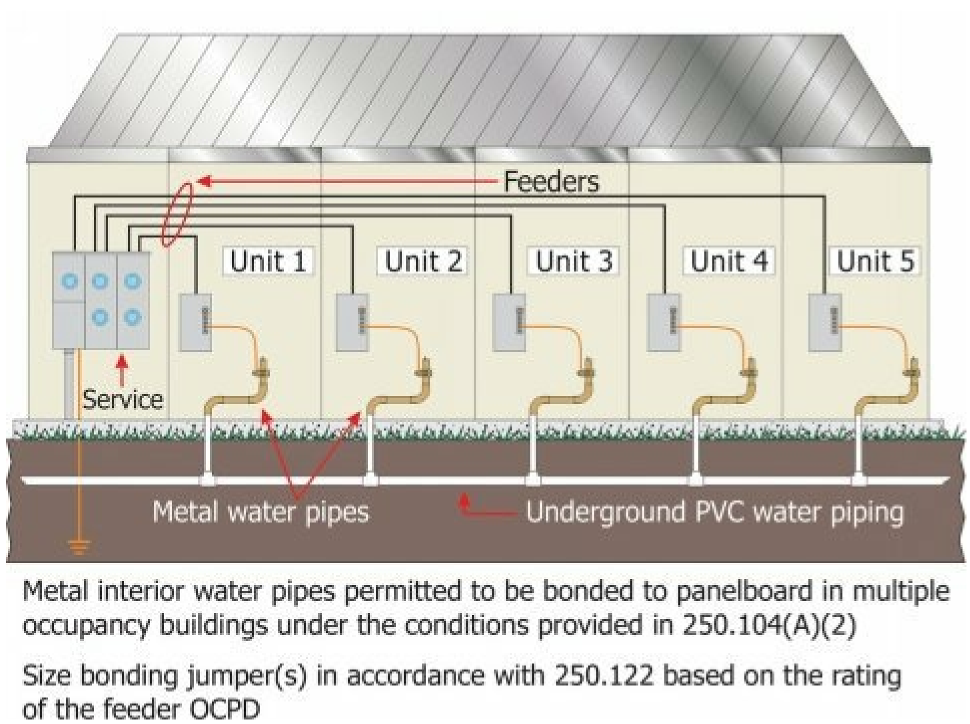


Figure 8.12 Metal water piping bonding alternative for multiple occupancy buildings

Bonding of Metal Water Piping in Multiple Buildings or Structures Supplied by Feeder(s) of Branch Circuit(s)

Where a building or structure is supplied by a feeder or branch circuit, bonding of metal water piping system(s) is required to be ensured by one of the following methods:

- Bonding to the building or structure disconnecting means where it is located at the building or structure.
- Bonding to the equipment grounding conductor that is run with the supply conductors to the building or structure. This connection would usually be made inside the building or structure disconnecting means enclosure on the equipment grounding terminal bar. Note that the equipment grounding conductor is permitted to consist of the wiring method that supplies the building or structure if recognized in 250.118.
- Bonding to the one or more grounding electrodes (grounding electrode system) used.[4]

The bonding jumper to the water piping system(s) is required to be sized according to Table 250.102(C)(1) based on the size of the feeder or branch-circuit conductors that supply the building or structure (see figure 8.13).

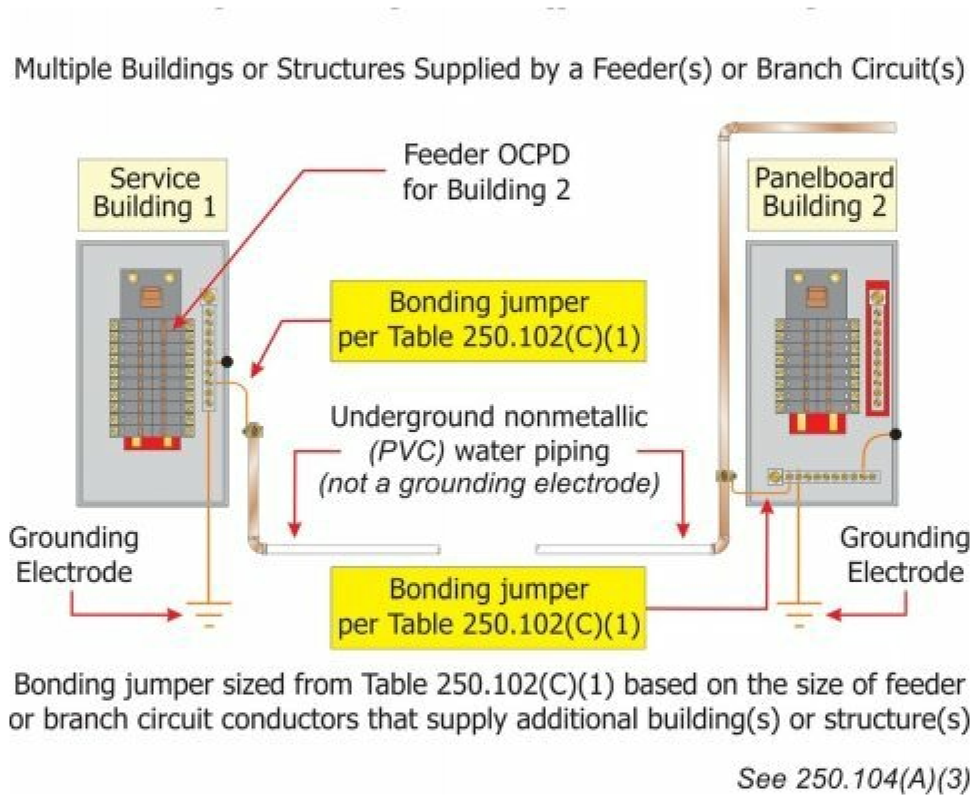


Figure 8.13 Multiple buildings or structures supplied by a feeder(s) or branch circuit(s) [250.104(A)(3)]

Bonding Other Metal Piping

Other metal piping, installed in or attached to a building or structure, including gas piping, which is likely to become energized is required to be bonded (see figure 8-14). The piping must be bonded to the service equipment enclosure, the grounded conductor at the service, the grounding electrode conductor where of sufficient size, or to the one or more grounding electrodes used. The *Code* does not give guidance on how to determine the conditions under which metal piping is likely to become energized. Because metal piping systems are conductive, bonding all of them will provide additional safety.

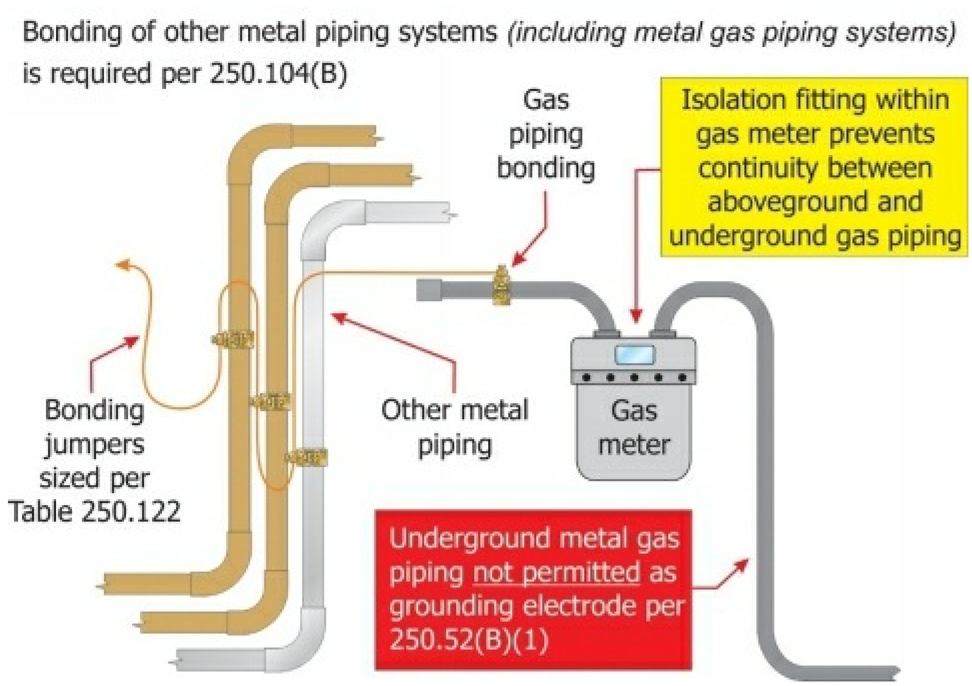


Figure 8.14 Bonding required of other metal piping systems including metal gas piping systems [250.104(B)]

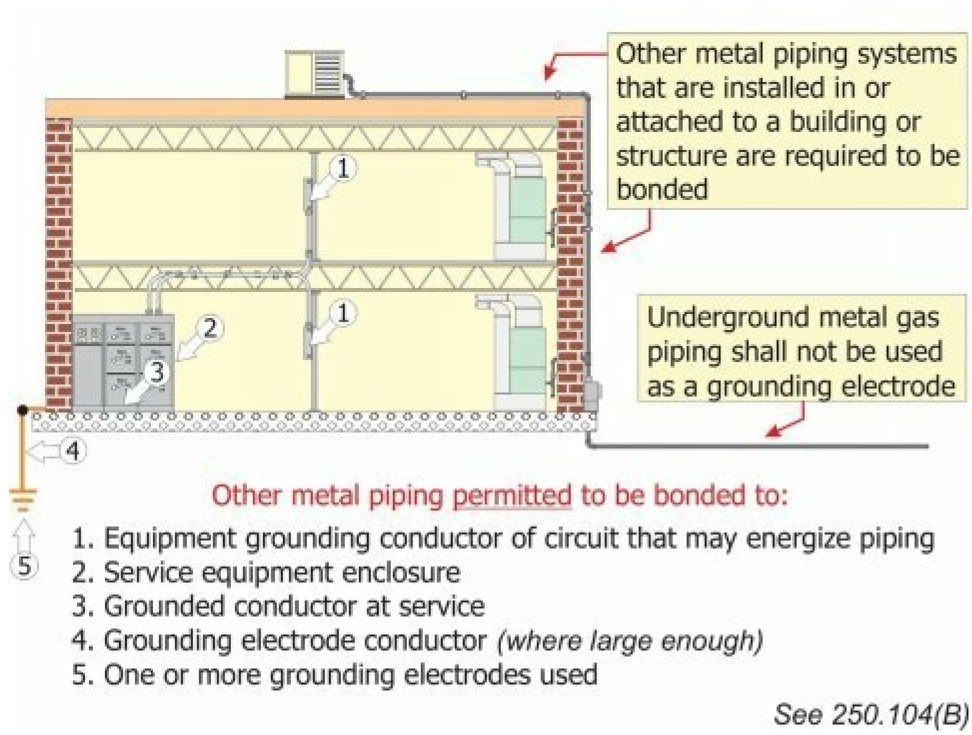


Figure 8.15 Bonding of other metal piping systems

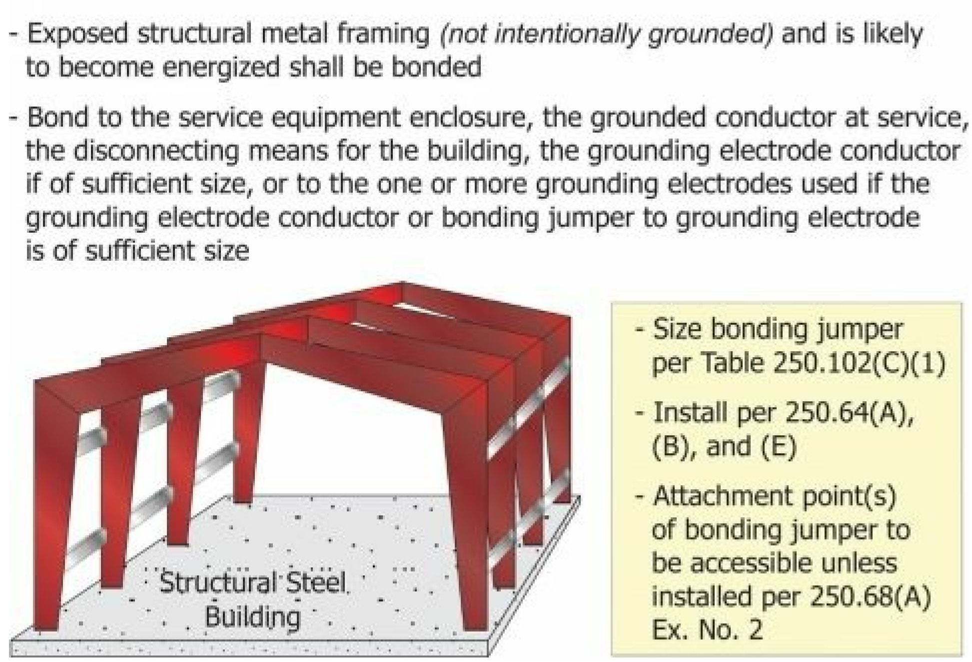


Figure 8.16 Bonding structural metal framing members of buildings or structures

Common systems that have to be bonded include interior metal: pneumatic systems; waste, drain and vent lines; and oxygen, air, and vacuum systems.

The bonding conductor is sized from Table 250.122 using the rating of the overcurrent device in the circuit ahead of the equipment.

The equipment grounding conductor for the circuit that is likely to energize the piping can be used as the bonding conductor. The point of connection of these bonding conductors to the metal piping systems is not required to be accessible as the connections to metal water piping systems are, but it is a good installation practice to locate these connections so they are accessible.

The bonding conductor is permitted to be connected to any of the following locations:

- Service equipment enclosure
- Grounded conductor at the service
- Grounding electrode conductor, where of adequate size
- One or more of the grounding electrodes used

Bonding Structural Steel

Section 250.104(C) requires exposed structural metal that is interconnected to form a steel building frame, not intentionally grounded, and is likely to become energized to be bonded (see figure 8.17 and photo 8.10). This requirement is applicable to interior or exterior structural framing members of buildings or structures. A bonding connection is required to be made to the service equipment enclosure, the grounded conductor at the service, the grounding electrode conductor where it is large enough, or to the one or more grounding electrodes used.

The bonding jumper is required to be sized in accordance with Table 250.102(C)(1) and installed in accordance with the rules in 250.64(A), (B) and (E). The points of attachment of the bonding jumper to the structural steel are required to be accessible.

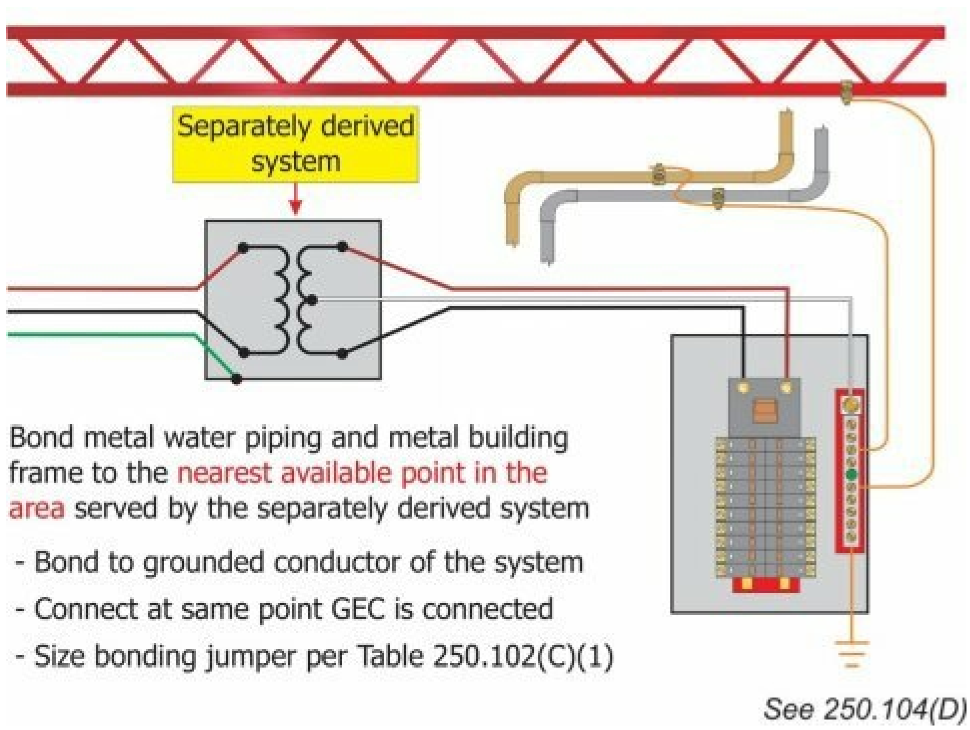


Figure 8.17 Bonding of metal piping systems and structural metal framing members to separately derived system

Photo 8.10 Bonding required of exposed structural metal framing members

Separately Derived Systems

Section 250.104(D) addresses the requirements for separately derived systems (see figure 8-17). Section 250.30(A)(8) set the requirement for separately derived systems to have bonding in accordance with 250.104(D).

Bonding a building's service to metal piping or the metal building frame does not provide a reference for the separately derived system. Bonding the separately derived system is necessary to establish a reference to the metal water piping and structural metal in the area served by the separately derived system. The area served can be determined by any equipment or outlets that are supplied from the separately derived system. Bonding also provides a fault-current path in the event the metal water piping or structural metal becomes energized due to an insulation failure. Where a common grounding electrode conductor is used it also must be bonded to the metal water piping and structural metal in the area. Exceptions allow bonding jumpers between metal water piping and structural metal with one bonding jumper to the separately derived system. Section 250.104(D) is as follows:

> **"250.104 Bonding of Piping Systems and Exposed Structural Metal.**
>
> **"(D) Separately Derived Systems.** Metal water piping systems and structural metal that is inter-connected to form a building frame shall be bonded to separately derived systems in accordance with 250.104(D)(1) through 250.104(D)(3):
>
> "(1) Metal Water Piping System(s) The grounded conductor of each separately derived system shall be bonded to the nearest available point of the metal water piping system(s) in the area served by each separately derived system. This connection shall be made at the same point on the separately derived system where the grounding electrode conductor is connected. Each bonding jumper shall be sized in accordance with Table 250.102(C)(1) based on the largest ungrounded conductor of the separately derived system.
>
> *"Exception No 1: A separate bonding jumper to the metal water piping system shall not be required if the metal water piping system is used as the grounding electrode for the separately derived system and the water piping system is in the area served.*
>
> *"Exception No 2: A separate water piping bonding jumper shall not be required if the structural metal frame of a building or structure is used as the grounding electrode for a separately derived system and is bonded to the metallic water piping in the area served by the separately derived system.*
>
> "(2) Structural Metal. If exposed structural metal that is interconnected to form the building frame exists in the area served by the separately derived system, it shall be bonded to the grounded conductor of each separately derived system. This connection shall be made at the same point on the separately derived system where the grounding electrode conductor is connected. Each bonding jumper shall be sized in accordance with Table 250.102(C)(1) based on the largest ungrounded conductor of the separately derived system.
>
> *"Exception No 1: A separate bonding jumper to the building metal shall not be required if the metal frame of a building or structure is used as the grounding electrode for the*

separately derived system.

"Exception No 2: A separate bonding jumper to a structural metal building frame shall not be required if the metallic water piping is used as the grounding electrode for a separately derived system and is bonded to structural metal frame of a building or structure in the area served by the separately derived system.

"(3) Common Grounding Electrode Conductor. If a common grounding electrode conductor is installed for multiple separately derived systems as permitted by Section 250.30(A)(3), and exposed structural metal that is interconnected to form the building frame or metal piping exists in the area served by the separately derived system, the metal piping and the structural metal member shall be bonded to the common grounding electrode conductor in the area served by the separately derived system.

"Exception: A separate bonding jumper from each derived system to metal water piping and to structural metal members shall not be required if the metal water piping and the structural metal members in the area served by the separately derived system are bonded to the common grounding electrode conductor."

[1] **"Conduit Fitting Ground-Fault Current Withstand Capability," Underwriters Laboratories, June 1, 1992.**

[2, 3, 4, 5] **NFPA 70, *National Electrical Code* 2017 (National Fire Protection Association, Quincy, MA, 2016)**

Review Questions

1. For circuits having a voltage exceeding ____ volts to ground, the electrical continuity of metal raceways and cables with metal sheaths that contain any conductor other than service conductors shall be ensured by one or more of the methods specified for services in 250.92(B), except for (B)(1).

1. 125
2. 150
3. 100
4. 250

2. Bonding jumpers are required to be attached to circuits and equipment by means of ____, or other listed means.

1. exothermic welding
2. listed pressure connectors
3. listed clamps
4. any of the above

3. Metal raceways or metal-jacketed cables are permitted to be used with nonmetallic enclosures only where ____.

1. internal bonding means are provided between all raceways
2. integral bonding means with a provision for attaching an equipment bonding jumper inside the box is provided
3. internal bonding means are provided between all cables
4. any of the above

4. Except for isolated receptacles, where circuit conductors are spliced within a box, or terminated to equipment or devices within or supported by the box, equipment grounding conductors associated with those circuit conductors must be spliced or joined with____ devices.

1. labeled
2. listed
3. suitable
4. bonding

5. For an isolated grounded receptacle an equipment grounding conductor is permitted to pass through one or more panelboards, boxes, wireways, or other enclosures within the same ____ to terminate at an equipment grounding terminal of the applicable separately derived system or service.

1. equipment
2. building or structure
3. enclosure
4. cabinet

6. Where the equipment bonding jumper is installed on the outside of a raceway, generally the length is limited to not more than ____. In addition, the equipment bonding jumper must be routed with the raceway.

1. 2.1 m (7 ft)
2. 2.5 m (8 ft)
3. 1.8 m (6 ft)
4. 3.0 m (10 ft)

7. The metal water piping system is permitted to be bonded to the service equipment enclosure, the grounded conductor at the service, the grounding electrode conductor where of sufficient size, or to one or more grounding ____.

1. clamps
2. devices
3. fittings
4. electrodes

8. Other common systems and metal piping that must be bonded include metal ____.

1. gas piping and pneumatic systems
2. waste, drain and vent lines
3. oxygen, air and vacuum systems
4. all of the above

9. The equipment grounding conductor for the circuit that may energize any other metal piping systems can be used as the ____ means for other metal piping systems.

1. equipment bonding
2. grounded
3. bonding
4. identified

10. Expansion joints or telescoping sections of metal raceways must be made electrically continuous by the use of an __________ or other means.

1. steel strap
2. equipment bonding jumper or other means

3. welding cable
4. equipment grounding conductor

11. The locknut/bushing and double-locknut types of installations are not acceptable for bonding in ____.

1. hazardous (classified) locations
2. commercial locations
3. industrial location
4. computer rooms

12. If four metal raceways have their conductors protected by overcurrent protective devices sized at 400, 300, 225 and 125 amperes and leave the bottom of an open switchboard or motor control center, the minimum size of a single equipment bonding jumper to be used to bond them together is ____.

1. 4 AWG copper or 4 AWG aluminum
2. 6 AWG copper-clad aluminum
3. 3 AWG copper or 1 AWG aluminum
4. 4 AWG copper or 3 AWG aluminum

13. The points of attachment of the bonding jumper to the metal water piping system are required to be ____.

1. acceptable
2. marked
3. accessible
4. soldered

14. Concentric and eccentric knockouts in enclosures such as wireways and panelboards ____.

1. are not suitable for grounding and bonding in circuits over and under 250 volts.
2. are tested by a qualified electrical contractors for their current-carrying ability.
3. are not tested by a qualified electrical testing laboratory for their current-carrying ability.
4. are not capable of carrying fault current.

15. Bonding connections to metal water piping systems ____.

1. are permitted to be made with solder.
2. must be accessible.
3. are permitted to be connected to the neutral in a subpanel.

4. are not required.

16. Structural metal must be bonded where ____.

    1. it is exposed.
    2. it is interconnected to form a metal building frame.
    3. it is not intentionally grounded.

2. all of the above.

17. ______ metallic parts together puts the parts at the same potential

    1. Bonding

2. Grounding
3. The grounding electrode
4. Earthing

18. For surface-mounted boxes intended for direct metal-to-metal contact for grounding of receptacles, _______the insulated washers used to retain the screws must be removed so there is direct metal to metal contact from the device yoke to the box, unless the receptacle is listed as self-grounding.

1. both of
2. none of
3. at least one of
4. all of

19. The grounded conductor of a separately derived system shall_______.

1. not be bonded to the exposed structural metal that is interconnected to form the building frame
2. be bonded to the exposed structural metal that is interconnected to form the building frame
3. always be connected to an isolated ground rod
4. be identified by green insulation or green markings

20. Where an equipment bonding jumper is used to connect a grounding type receptacle to a grounded metal box, it shall be sized in accordance with which of the following:

1. Table 250.66
2. Table 250.122
3. The same size as the circuit conductors
4. One size smaller than the circuit conductors

21. A listed exposed work cover shall be permitted as the grounding and bonding means for a receptacle under which of the following conditions?

1. The device is attached to the cover with either rivets or thread-locking or screw-locking means.
2. The raised cover provides a flat non-raised portion to contact the grounded metal box.
3. The receptacle is a self-grounding type.
4. Both a and b

Chapter 9
Equipment Grounding Conductors

Objectives to understand

- General requirements for equipment grounding conductors on grounded and ungrounded systems
- Sizing requirements for equipment grounding conductors
- Rules applied to multiple raceways or cables
- Rules for flexible cords
- Use of building steel that is properly grounded by an equipment grounding conductor
- Grounding of equipment by the grounded circuit conductor

Equipment grounding conductors provide two separate but important purposes. Equipment grounding conductors are intended to 1) connect equipment to ground (earth) and 2) to provide an effective ground-fault current path to facilitate overcurrent device operation in ground-fault conditions.

The first purpose is achieved by connecting raceways, wireways, or suitably sized wire type conductors from the system or equipment grounding point to the equipment supplied. Equipment grounding conductors also help minimize an objectionable potential above ground on conductors and equipment enclosures.

The second purpose is providing connection from the equipment back to the source for ground-fault current. The equipment grounding conductor or path for fault current must also:

1. be electrically continuous;
2. have ample capacity to conduct safely any currents likely to be imposed on it; and
3. be of the lowest practical impedance [see 250.4(A)(5)].

Ultimately, the equipment grounding conductor or path is required to extend to the grounding electrode, in a low-impedance path; and if the system is grounded, it is also required to be connected through a low-impedance path to the grounded service conductor (often a neutral conductor of a system or service). This is accomplished by the main or system bonding jumper.

Photo 9.1 Equipment grounding conductor connected to equipment enclosure

Definition

Grounding conductor, equipment (EGC). "The conductive path(s) that provides a ground-fault current path and connects the normally non-current-carrying metal parts of equipment together and to the system grounded conductor, or to the grounding electrode conductor, or both" (see photo 9.1).

Informational Note No. 1. It is recognized that the equipment grounding conductor also performs bonding.

Informational Note No. 2. See 250.118 for a list of acceptable equipment grounding conductors.

Clearly, it can be seen in this definition that the equipment grounding conductor (EGC) performs both grounding and bonding functions and this is reinforced by the informational note following this definition. Acceptable equipment grounding conductors are listed in Section 250.118.

Grounded Systems

The equipment grounding conductor or path is required to extend from the furthermost point on the circuit to the service equipment or source of separately derived system where it is connected to the grounded conductor and grounding electrode on a grounded system, or connected to the disconnecting means enclosure and the grounding electrode conductor for an ungrounded system. For the grounded system, this connection is made through the main or system bonding jumper. Often, the equipment grounding conductor or path is the conductor enclosure (conduit, cable jacket, etc.).

For enclosed panelboards typically installed at dwelling services, the grounded and equipment grounding conductors connect to the same terminal bar (see 408.40). An alternate construction is permitted where a wire or busbar type main bonding jumper connects the grounded service conductor to a separate equipment grounding conductor terminal bar that is bonded to the enclosure.

Should insulation failure occur anywhere on a phase conductor and a ground fault develop between the energized conductor and the conductor enclosure, a ground-fault circuit will be established (see figure 9.1).

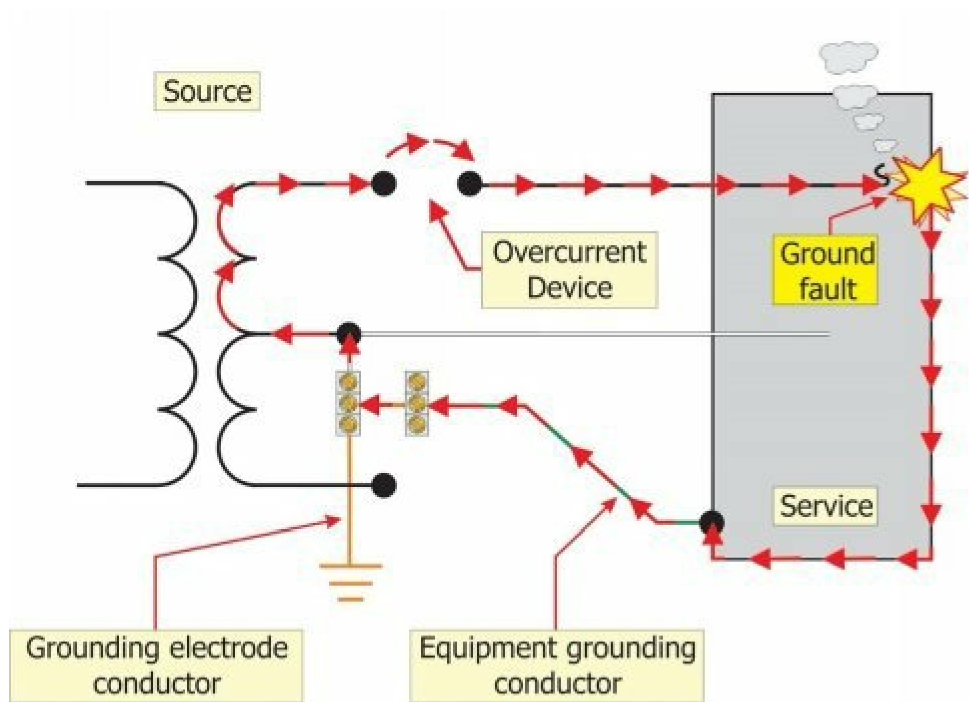


Figure 9.1 Functions of equipment grounding conductor in grounded systems

The ground-fault circuit will therefore be from the source, through the supply conductors, through the overcurrent devices, to the point of fault on the phase conductor, usually through an arc, through the equipment grounding conductor, through the main bonding jumper, to the grounded conductor (may be a neutral) and back to the source.

If this circuit is complete, of adequate capacity and low impedance, the equipment and persons who can contact it are protected because the overcurrent device will open the faulted circuit with no or minimal delay. A break in this equipment grounding circuit or other equipment grounding system failure may expose persons to possibly lethal shocks if a ground fault from a source having sufficient potential (generally considered to be more than 50 volts) energizes the enclosure and the person provides another path for current.

Ungrounded Systems

In an ungrounded system, the equipment grounding conductor or path is required to be permanent and continuous to the grounding point to keep all equipment and conductor enclosures at or near ground potential (see figure 9.2). It also provides a fault-current path in the event a second fault on another phase occurs. The equipment grounding conductor must be the same size as called for in a grounded system if we are to have maximum safety. The minimum sizes of equipment grounding conductors given in Table 250.122 apply equally to an ungrounded system and a grounded system.

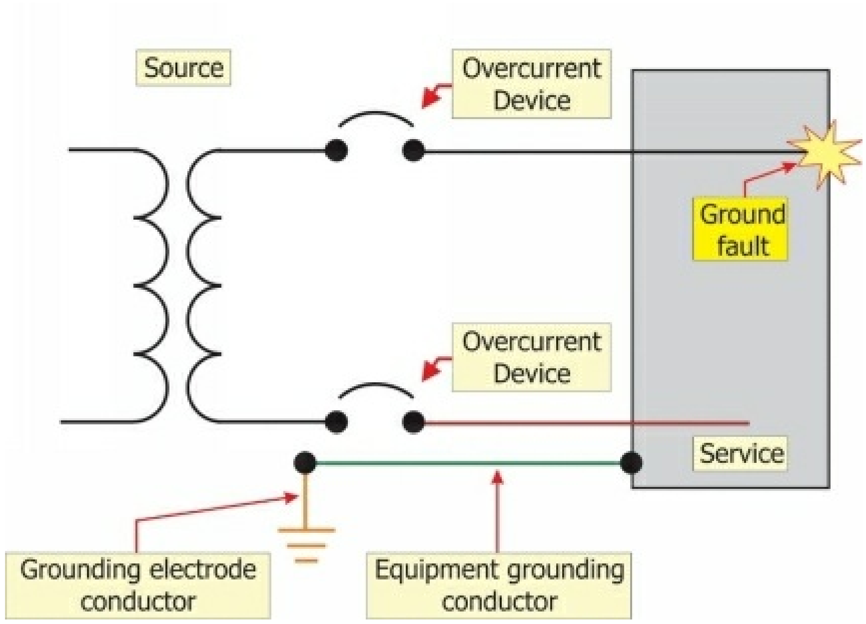


Figure 9.2 Functions of equipment grounding conductor in ungrounded systems

In general, it may be said that any conductor or equipment enclosure, be it conduit, electrical metallic tubing, raceway or busway enclosure, provides a satisfactory equipment grounding conductor for an ungrounded system if all joints are made electrically continuous. It may be necessary to use equipment bonding jumpers at certain points. Such equipment bonding jumpers are also required to be sized per Table 250.122.

Equipment Grounding Conductor Material

The *Code* specifies in 250.118 the conductors that are permitted to be used for equipment grounding conductors. They are as follows:

> "1. A copper, aluminum, or copper-clad aluminum conductor. The conductor shall be solid or stranded; insulated, covered, or bare; and in the form of a wire or busbar of any shape." [Some sections of the *Code* specifically require an equipment grounding conductor to be insulated or solid.]
>
> "2. Rigid metal conduit
>
> "3. Intermediate metal conduit
>
> "4. Electrical metallic tubing
>
> "5. Listed flexible metal conduit, meeting all the following conditions:
>
> "a. The conduit is terminated in listed fittings
>
> "b. The circuit conductors contained in the conduit are protected by overcurrent devices rated at 20 amperes or less.
>
> "c. The combined length of flexible metal conduit and flexible metallic tubing and liquidtight flexible metal conduit in the same ground-fault current path does not exceed 1.8 m (6 ft).
>
> "d. If used to connect equipment where flexibility is necessary to minimize the transmission of vibration from equipment or to provide flexibility for equipment that requires movement after installation, an equipment grounding conductor shall be installed" [2] (see figures 9.3 and 9.4).

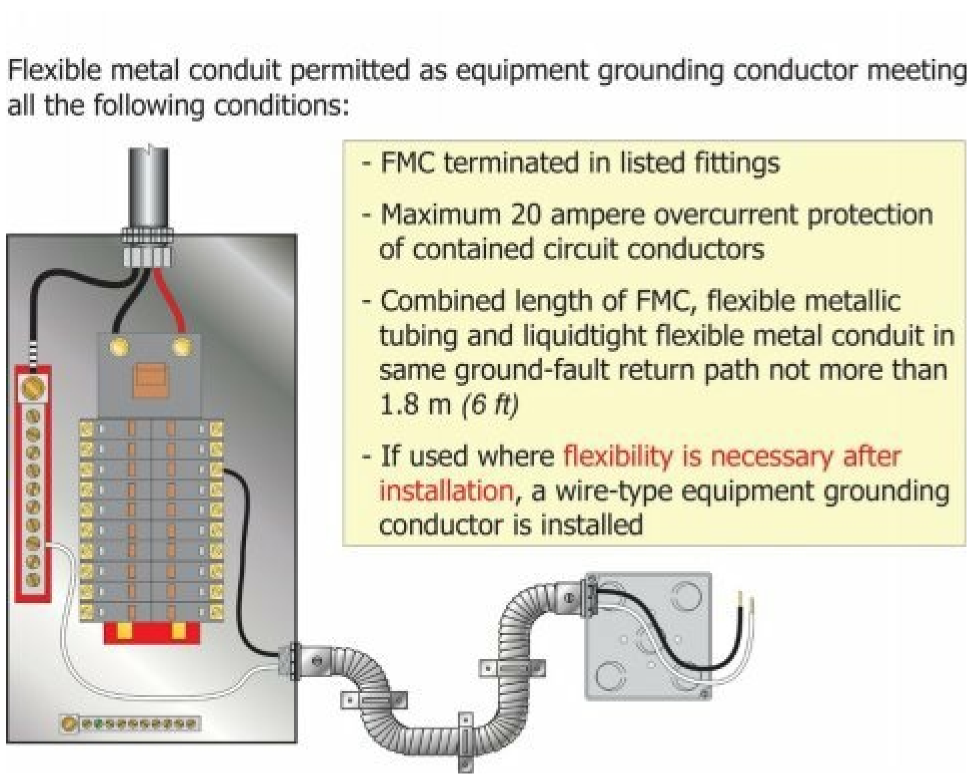


Figure 9.3. Flexible metal conduit as equipment grounding conductor

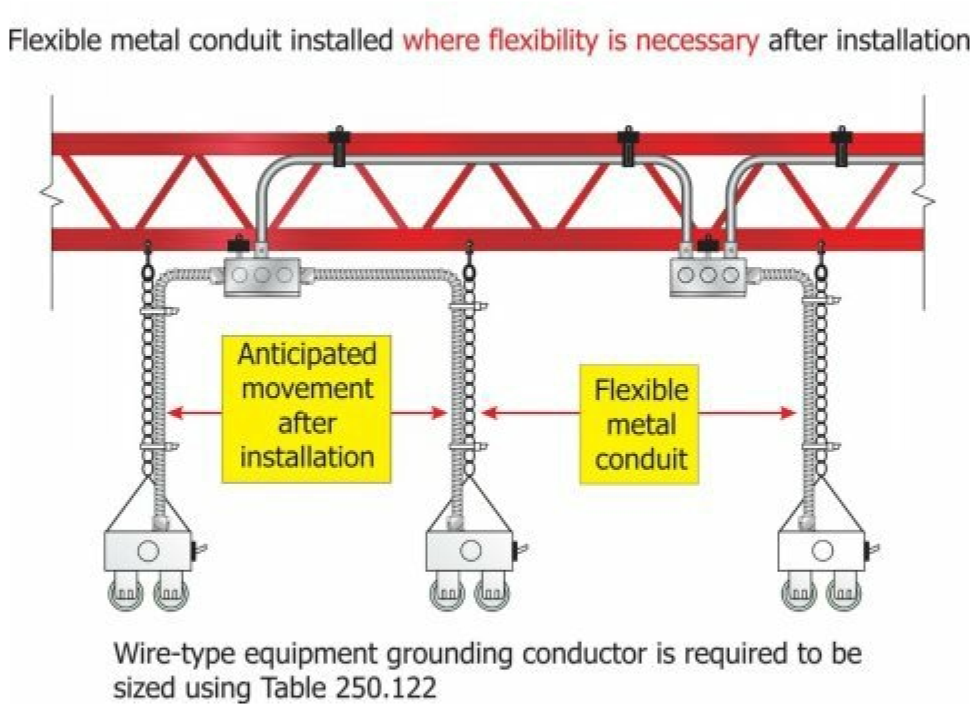


Figure 9.4 Flexibility is needed after installation so equipment grounding conductor is required

Flexible metal conduit is commonly available as a listed product but has not been listed for grounding by a nationally recognized electrical testing laboratory. The conduit has been recognized for several years for use as an equipment grounding conductor under the limitations indicated above. Note, however, the flexible metal conduit must be terminated in fittings that are listed for grounding.

"6. Listed liquidtight flexible metal conduit meeting all the following conditions:

"a. The conduit is terminated in listed fittings.

"b. For metric designators 12 through 16 (trade sizes 3/8 through ½), the circuit conductors contained in the conduit are protected by overcurrent devices rated at 20 amperes or less."

"c. For metric designators 21 through 35 (trade sizes ¾ through 1¼), the circuit conductors contained in the conduit are protected by overcurrent devices rated not more than 60 amperes and there is no flexible metal conduit, flexible metallic tubing, or liquidtight flexible metal conduit in trade sizes metric designators 12 through 16 (trade sizes 3/8 or ½) in the ground-fault current path."

"d. The combined length of flexible metal conduit and flexible metallic tubing and liquidtight flexible metal conduit in the same ground-fault current path does not exceed 1.8 m (6 ft).

"e. If used to connect equipment where flexibility is necessary to minimize the transmission of vibration from equipment or to provide flexibility for equipment that requires movement after installation, an equipment grounding conductor shall be installed" (see figure 9.5).

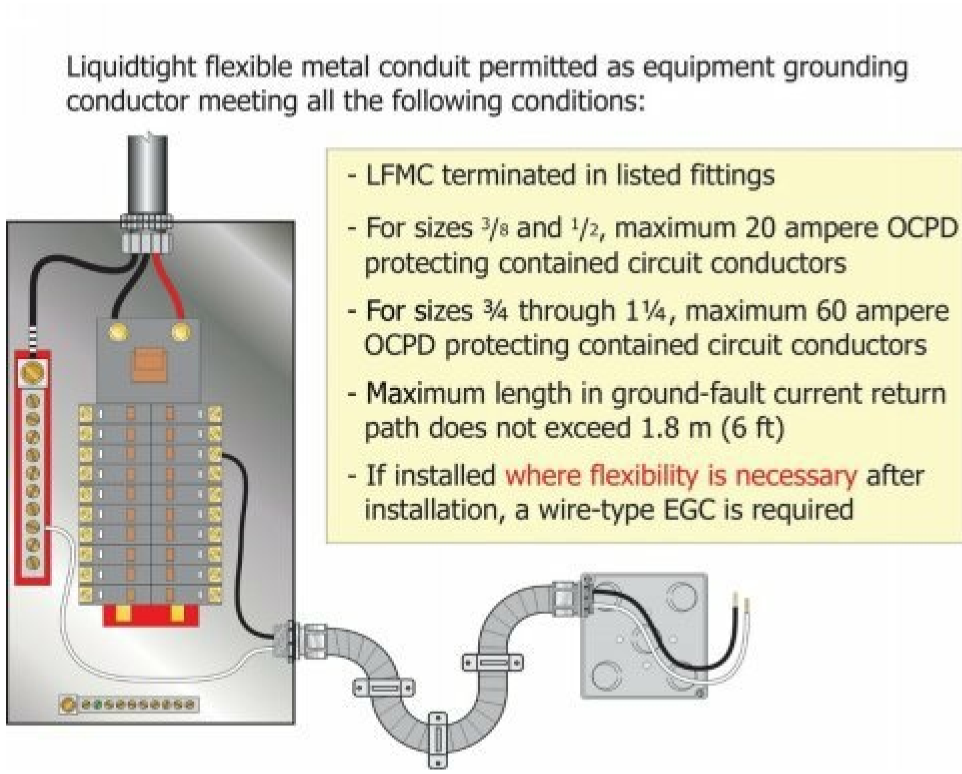


Figure 9.5 Liquidtight flexible metal conduit as equipment grounding conductor

"7. Flexible metallic tubing where the tubing is terminated in listed fittings and meeting all the following conditions:

"a. The circuit conductors contained in the tubing are protected by overcurrent devices rated at 20 amperes or less.

"b. The combined length of flexible metal conduit and flexible metallic tubing and liquidtight flexible metal conduit in the same ground return path does not exceed 1.8 m (6 ft)" (see figure 9.6).

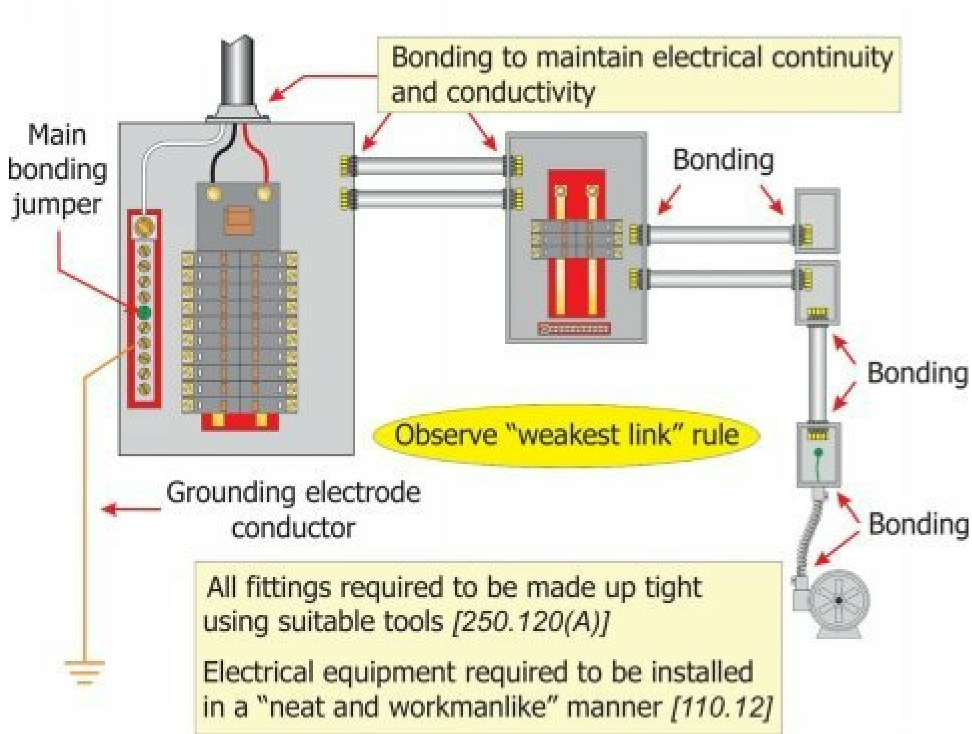


Figure 9.6 Equipment grounding conductor path back to grounding point

"8. Armor of Type AC cable as provided in 320.108.

"9. The copper sheath of mineral-insulated, metal-sheathed cable type MI.

"10. Type MC cable that provides an effective ground-fault current path in accordance with one or more of the following:

"a. It contains an insulated or uninsulated equipment grounding conductor in compliance with 250.118(1)

"b. The combined metallic sheath and uninsulated equipment grounding/bonding conductor of interlocked metal tape–type MC cable that is listed and identified as an equipment grounding conductor

"c. The metallic sheath or the combined metallic sheath and equipment grounding conductors

of the smooth or corrugated tube-type MC cable that is listed and identified as an equipment grounding conductor.

"11. Cable trays as permitted in 392.10 and 392.60.

"12. Cablebus framework as permitted in 370.60.

"13. Other listed electrically continuous metal raceways and auxiliary gutters listed for grounding.

"14. Surface metal raceways listed for grounding."

Included are auxiliary gutters (not specifically a raceway as defined in Article 100 but essentially the same equipment as wireways), wireways with associated fittings, busway enclosures, and in some cases an additional ground bus, surface metal raceways, and pull and junction boxes that are installed in the ground-fault path.

It should be noted here that these requirements or provisions in 250.118 are general in nature. Many sections of the *Code* contain specific requirements that must be complied with. A few examples follow:

Section 501.30 does not recognize the standard double locknut-type conduit connections for Class I hazardous (classified) locations.

Section 517.13(B) requires an additional insulated equipment grounding conductor installed in a metal raceway or flexible cable assembly that qualifies as an equipment grounding conductor in patient care areas of health care facilities.

Section 550.33(A) generally requires the equipment grounding conductor for the feeder to a mobile home to be insulated.

Several sections of Article 680 require an insulated equipment grounding conductor.

It is always best to carefully examine the specific requirements for the equipment grounding conductor for the type of installation being made.

Photo 9.2 Equipment grounding conductor is installed to ground and bond electrical equipment. Exhaust fan motor is shown and equipment grounding conductor is installed in flexible metal conduit.

Photo 9.3 Flexibility necessary after installation (for aiming heater)

Conductor Enclosures

Conduit runs of rigid or intermediate metal that are properly threaded and in which the couplings are made up tightly, preferably using a joint sealer that will not reduce continuity, can be expected to perform satisfactorily as an equipment grounding conductor for runs of limited length. Listed compounds to provide corrosion protection and are also electrically conductive aid in assuring an effective equipment grounding path. These compounds act as lubricants and permit the joint to be screwed up tighter and at the same time maintain electrical continuity. Under poor conditions, the conduit impedance with couplings should not show an increase of over 50 percent when compared with a straight run of conduit. The use of this higher impedance value would provide a factor of safety. In the case cited, there is no economic justification for using an additional equipment grounding conductor unless another factor such as overall length deems this necessary.

The *Code* further requires that where conduit is used as an equipment grounding conductor, all joints and fittings shall be made up tight using suitable tools [see 250.120(A) and figure 9.6]. This calls attention to the fact that conduit, where used as an equipment grounding means, is a current-carrying conductor under fault conditions and is required to be made electrically continuous by having joints made up tight.

Usually, large and often parallel conduits are installed from the utility transformer to the service equipment. Then, smaller and smaller conduits are installed for feeders and branch circuits. For instance, at one point the equipment grounding path may be three 102 mm (4-inch) conduits in parallel; at another point, two 4-inch conduits in parallel while down the line it may be only one 31.8 mm (1¼-inch) conduit, all being connected together to form a permanent and continuous path. As the circuit changes from large overcurrent protective means to smaller ones, the conductivity of the equipment grounding path becomes lower. The conduit or tubing at the end of the circuit may be no larger than 12.7 mm (½ -inch) electrical metallic tubing or 10 mm (⅜-inch) flexible metal conduit.

The *NEC* does not dictate any particular size of conduit or tubing to serve as the equipment grounding conductor for an upstream overcurrent device, other than as mentioned in the previous section. It is generally expected that a metallic raceway that is sized properly for the conductor fill will provide an adequate equipment ground-fault return path. The one consideration for raceways used as equipment grounding conductors is limits on circuit length. As shown, Tables 22.10 to 22.16 in the back of this text provide some guidance on the maximum length of metal raceway that can be effectively used as an equipment grounding conductor. Exceeding these lengths may not provide the low impedance path required by 250.4(A)(5) and (B)(4). This information is also available using the GEMI software [See note before Table 22.13 in Chapter-two for more information and how to obtain the GEMI software]. Where long circuit lengths are encountered, other alternatives may need to be implemented to provide the required low impedance path.

The informational note to 250.120(A) provides an important reference to the UL Guide Information (FHIT) for equipment grounding conductors (wire types) that are part of an electrical circuit protective system or fire-rated cable listed to maintain circuit integrity for a duration of time under fire conditions. For these particular installations the type of insulation is specified so the integrity of the fire-rated circuit integrity cable insulation is maintained during a fire event.

Cables as Equipment Grounding Conductors

Several cables used as wiring methods are suitable for use as an equipment grounding conductor or contain an equipment grounding conductor. These include:

Type AC Cable

Armored cable (Article 320) is manufactured with conductors in sizes from 14 AWG through 1 AWG copper and from 12 AWG through 1 AWG aluminum (see photo 9.4). Type AC cable is required to have an armor of flexible metal tape.

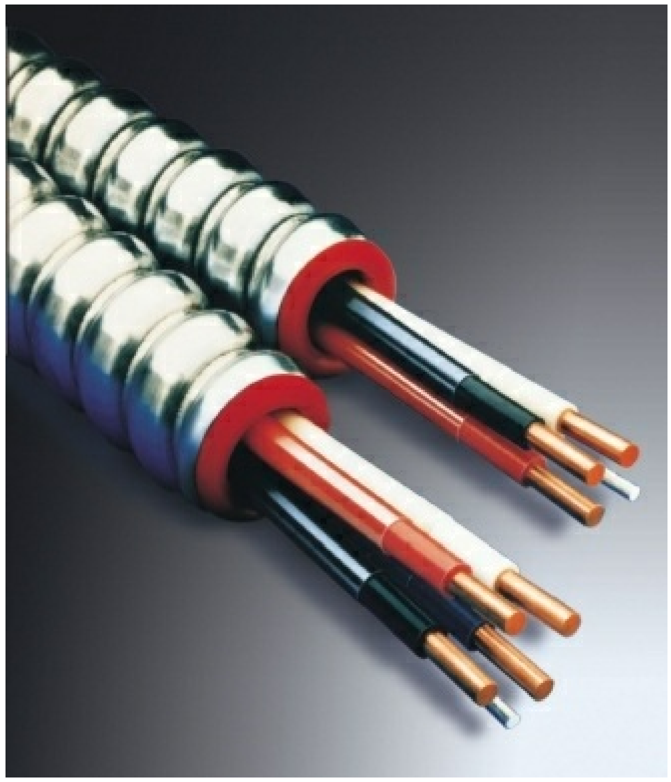


Photo 9.4 Standard AC cable where armor is the only equipment grounding conductor path [250.118(8)]. Courtesy of AFC Cable Systems.

The insulated conductors are required to be in accordance with 320.104. Cables of the AC type are required to have an internal bonding strip of copper or aluminum in intimate contact with the armor for its entire length. It is suitable as an equipment grounding conductor in accordance with 250.118(8). Additionally, AC cable conductors are required to have an overall moisture-resistant and fire-retardant fibrous (paper) covering. Another type of AC cable construction includes an insulated equipment grounding conductor and is acceptable for use as the branch circuits serving patient care areas as provided in 517.13 and for use in branch circuits for isolated grounding receptacles as permitted in 250.146(D) and 408.40 Exception (see photo 9.5).

Photo 9.5 Installation of AC cable that is acceptable for use in patient care areas because it provides two equipment grounding conductor paths (sheath and conductor)

Type MC Cable

Type MC cable is covered in Article 330 (see photo 9.6). Type MC cable is produced in three configurations: spiral interlocking metal tape, corrugated metal tube, and a smooth metal tube.

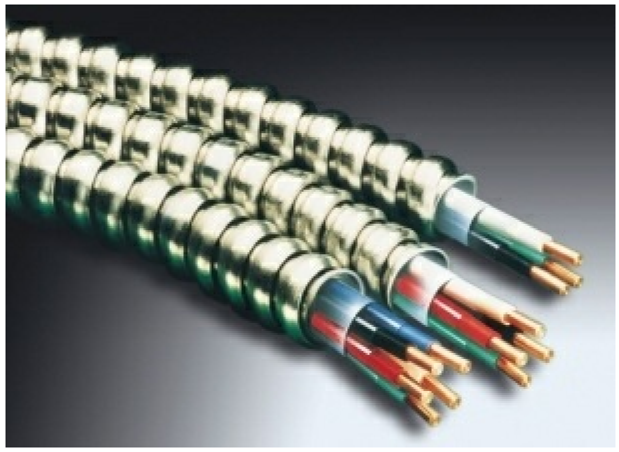


Photo 9.6 Metal Clad cable (interlocking metal tape-type shown). Courtesy of AFC Cable Systems.

1. Except for the MC Cable that is listed and identified as being suitable as an equipment grounding conductor, the spiral interlocking metal tape Type MC cable must always have a wire type equipment grounding conductor which may be insulated or bare. The jacket itself is not suitable as an equipment grounding conductor. The principal equipment grounding conductor may be divided (sectioned) into more than one conductor, often to facilitate spacing in the cable construction for larger sizes. Additional equipment grounding conductors may be included in the assembly and have green insulation and either a yellow stripe or other identification.

2. The sheath of the smooth or corrugated tube Type MC cable or a combination of the sheath and a supplemental bare conductor where the assembly is identified as suitable as an equipment grounding conductor may have a bare or green insulated conductor that is suitable for the required equipment grounding conductor. The principal equipment grounding conductor may be divided (sectioned) into more than one conductor, often to facilitate spacing in the cable construction for larger sizes. Additional equipment grounding conductors have green insulation and either a yellow stripe or other identification.

A specific type of metal-clad cable is manufactured that includes a bare conductor in the cable assembly in intimate contact with the armor that is recognized as an equipment grounding conductor. These MC cables have distinct markings indicating the suitability for the combination metal armor and internal conductor to act as an equipment grounding conductor, see figure 9.7.

Figure 9.7 MC cable that provides an equipment grounding conductor (wire-type) in the assembly, and the sheath is suitable as an equipment grounding conductor. Courtesy of Southwire Company

This MC cable is listed under UL standard 1569. As with any cable assembly, installation in accordance with the manufacturer's instructions is required to meet the requirements of *NEC* 110.3(B). One key is ensuring the selected connectors are listed for use on this type cable for equipment grounding. This type of MC cable with an additional insulated equipment grounding conductor provides two equipment grounding conductor paths which lends itself as suitable for use when installing isolated grounding circuits for sensitive electronic equipment as well as branch circuits serving patient care areas in health care facilities.

Nonmetallic-Sheathed Cable

NM cable is covered in Article 334. This cable is permitted to be produced in three styles: Type NM (commonly identified as “NMB”), Type NMC and Type NMS. The power conductors are permitted to be in sizes 14 AWG through 2 AWG copper and 12 AWG through 2 AWG aluminum and typically contain an equipment grounding conductor sized in compliance with Table 250.122. In addition to the power and equipment grounding conductor, type NMS is permitted to contain signaling conductors.

Service-Entrance Cable

Service-entrance cable (Type SE) is covered by Article 338. Type SE cable is produced in a variety of configurations. The type most commonly used for internal wiring is Type SE style U and Type SE style R. Specific rules for Type SE cables are contained in 338.10.

Type SE cables are permitted in interior wiring systems where all of the circuit conductors including the neutral or grounded circuit conductor of the cable are of the rubber-covered or thermoplastic type.

Type SE cables without individual insulation on the grounded circuit conductor are not to be used for branch circuits or as a feeder within a building. An exception allows a cable that has a final nonmetallic outer covering and is supplied by alternating current at not over 150 volts to ground to be used as a feeder to supply only other buildings on the same premises. Type SE cables are permitted for use where the fully insulated conductors are used for circuit wiring and the uninsulated conductor is used for equipment grounding purposes.

Underground Feeder and Branch-Circuit Cable

Underground feeder and branch-circuit cable is covered by Article 340. Type UF cable is permitted to be produced in sizes 14 AWG copper or 12 AWG aluminum through 4/0 AWG. Multiconductor cables are permitted to be installed in accordance with Article 340. In addition to the insulated conductors, the cable is permitted to have an insulated or bare conductor for equipment grounding purposes only. As such, it is required to comply with Table 250.122.

Equipment Grounding Conductor Not to Serve as Grounding Electrode Conductor

Equipment grounding conductors generally cannot be used in a duel role as a grounding electrode conductor. This probation is found at 250.121 and will clarify that grounding electrode conductors and equipment grounding conductors serve two different purposes in the electrical grounding system, are sized differently and have different installation requirements. In addition, all the identified equipment grounding conductors in 250.118 except the wire type are not of a construction and material required for grounding electrode conductors as specified in 250.62. Equipment grounding conductors do not normally carry current while a grounding electrode conductor may carry current under normal conditions since it is often in parallel with the grounded (neutral) conductor. A new exception has been added in the 2014 *NEC* to allow wire type equipment grounding conductors to also serve as the grounding electrode conductor where all the applicable requirements in Article 250 Parts II, III, and VI are followed. This means the dual purpose conductor would have to be continuous from the equipment to the grounding electrode (no independent terminations on equipment grounding bars), all ferrous metal raceways and enclosures would have to be bonded at each end and in between to the dual use conductor, as well as connectors used may have to be listed for grounding and bonding as opposed to standard connectors. These are some of the considerations and there are many more that will make this installation very difficult to be compliant.

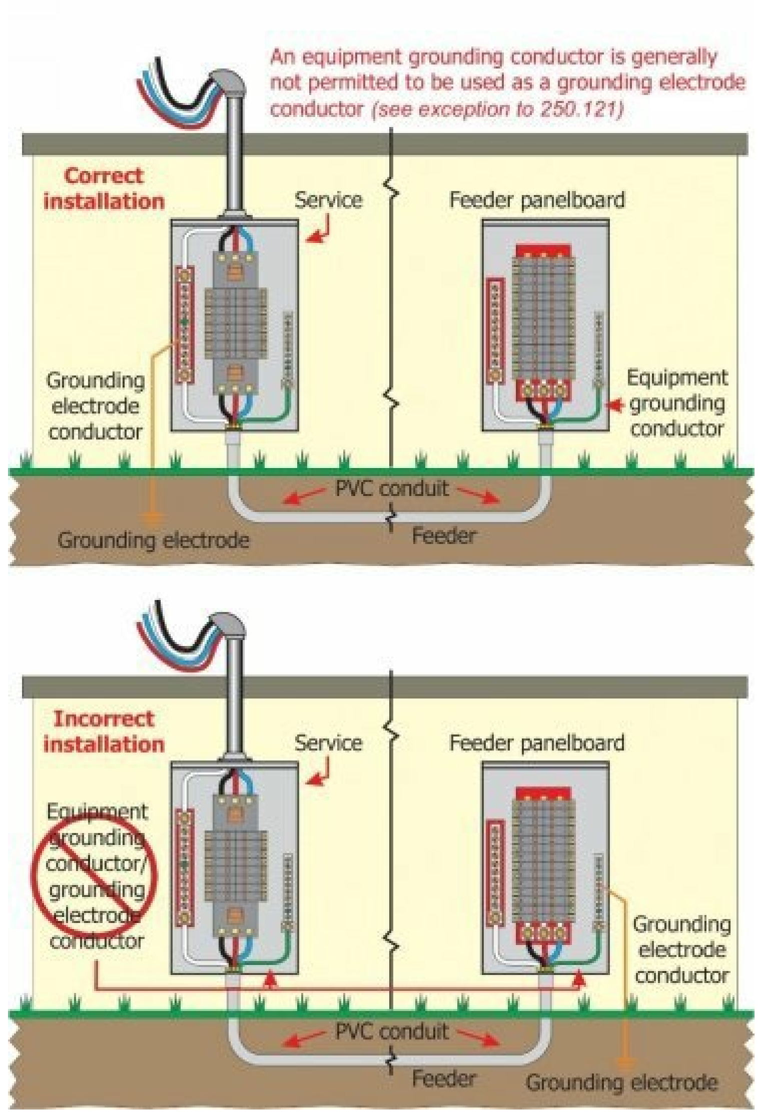


Figure 9.8 Equipment Grounding conductor generally not to be used as a grounding electrode conductor.

Size of Equipment Grounding Conductor

The entire equipment grounding conductor or path of any raceway system will be as shown in figure 9.9. Starting at the service, we have a large overcurrent protective device that is in series with other, and usually smaller, feeder or branch overcurrent protection devices. The ungrounded (phase or hot) conductor usually decreases in size as it progresses through smaller and smaller overcurrent devices.

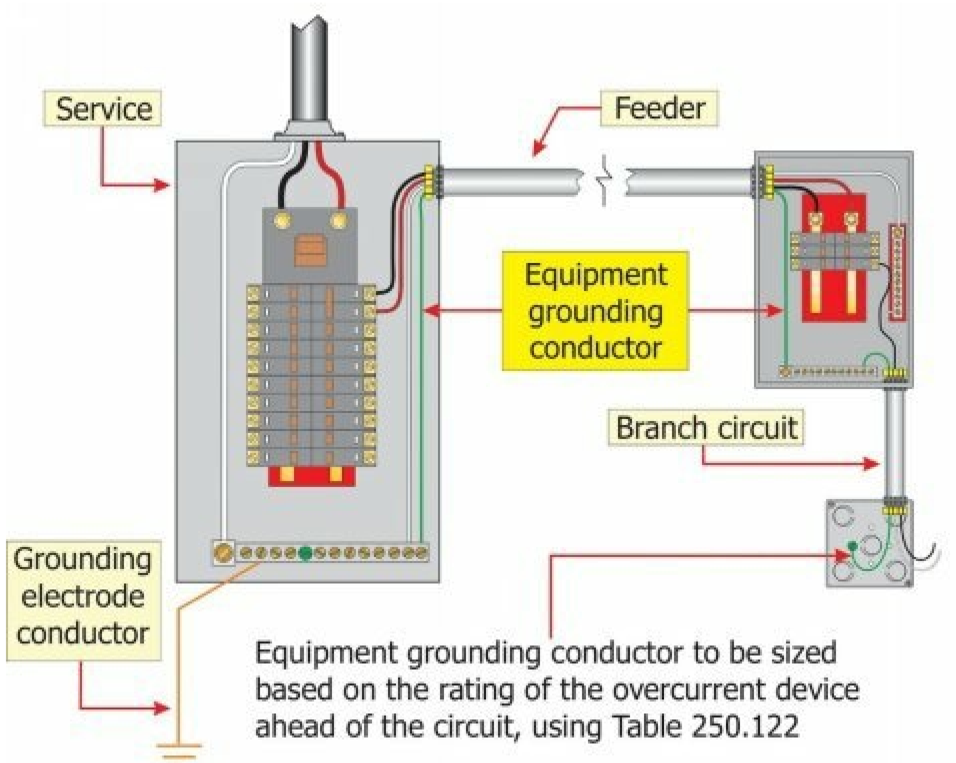


Figure 9.9 Minimum size of equipment grounding conductor [Table 250.122]

Section 250.122(A) provides the general rules for sizing the equipment grounding conductor. It refers to Table 250.122 for determining the minimum size of conductor that is required to be used as an equipment grounding conductor. The size is based on the ampere rating of the overcurrent protective device ahead of the conductor. [Table 250.122 is reprinted as table 22.7 in chapter twenty-two].

For example, if the overcurrent protection ahead of the circuit or feeder is 225 amperes, the minimum size equipment grounding conductor is found as follows:

In Table 250.122, follow the first column, which gives the rating of the overcurrent device, down to find the rating that equals or exceeds 225 amperes. Since 225 amperes is not found, go to the next larger size, which is 300 amperes. Follow that line across to find the minimum size copper wire to be 4 AWG and for aluminum, a 2 AWG minimum size conductor.

Table 250.122 *(in part)*

Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding *(Amperes)*	Size *(AWG or kcmil)*	
	Copper	Aluminum or Copper-Clad Aluminum
15	14	12
20	12	10
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0

Note: Where necessary to comply with 250.4(A)(5) or 250.4(B)(4), the equipment grounding conductor shall be sized larger than given in this table.

*See installation restrictions in 250.120

Table 250.122 Minimum size equipment grounding conductors

Follow a similar process to determine the minimum size conductor for any installation. In addition, the note below Table 250.122 requires that, "Where necessary to comply with 250.4(A)(5) or 250.4(B)(4), the equipment grounding conductor shall be sized larger than given in this table." Notes that are part of tables in the *NEC* are mandatory. The two main reasons this note needs to be applied are 1) very high fault current that can damage or melt the equipment grounding conductor and 2) due to long lengths that have to be compensated for to provide the low impedance path to operate the overcurrent device. A comprehensive analysis of the withstand rating of these equipment grounding conductors can be found in chapter eleven.

Specific requirements are provided for: Equipment grounding conductors that are increased in size for any reason, as provided in 250.122(B); for multiple circuits in 250.122(C); for motor circuits in 250.122(D); for flexible cord and fixture wire in 250.122(E); and for conductors in parallel in 250.122(F).

Increasing the Size of Equipment Grounding Conductor

Section 250.122(B) requires that, "Where conductors are increased in size from the minimum size that has sufficient ampacity for the intended installation," (for example to compensate for voltage drop or for any other reason), "wire type equipment grounding conductors, where installed, shall be increased in size proportionately according to circular mil area of the ungrounded conductors" (see figure 9.10). This means that where a feeder or branch-circuit conductor is increased in size, the wire type equipment grounding conductor, where run, is required to be increased at not less than the same ratio the feeder or circuit conductors are increased. For example, a 200-ampere feeder is to be installed. It is determined that the voltage drop would be excessive. A 250-kcmil conductor is selected for the feeder rather than installing the 3/0 copper conductor as is permitted by Table 310.15(B)(16). Table 250.122 requires a 6 AWG equipment grounding conductor for the 200-ampere overcurrent device.

Determine the minimum size equipment grounding conductor required for the feeder by the following formula: (Use Table 8 of *NEC* chapter 9 to determine the area in circular mils where the conductor size is given by a non-circular mil designation).

Selected Feeder Conductor Area ÷ Required Feeder Conductor Area = Ratio.

Table 250.122 Equipment Grounding Conductor X Ratio = Required EGC

250,000 kcmil ÷ 167, 800 kcmil = 1.49.

26240 (Circular mil area of 6 AWG) x 1.49 = 39098 circular mils

Next larger size = 4 AWG copper required equipment grounding conductor

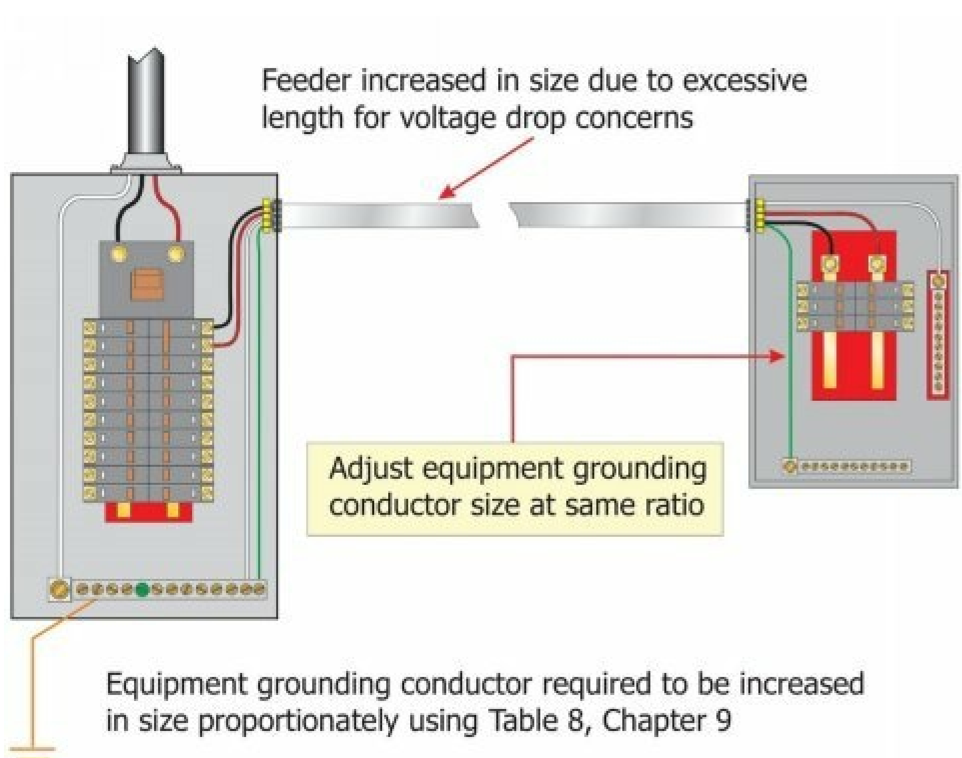


Figure 9.10 Increasing the size of the equipment grounding conductor for long circuits or

feeders

Equipment Grounding Conductors for Multiple Circuits

The *Code* permits a single equipment grounding conductor to serve several circuits that are in the same raceway, cable, or cable tray. To use this concept, the equipment grounding conductor is required to be sized for the rating of the largest overcurrent device of the group.

For example, a conduit contains multiple branch circuit conductors that have overcurrent protection rated: 20-amperes, 30-amperes, 50-amperes and 60-amperes. A single 10 AWG equipment grounding conductor is permitted to serve all the branch circuits in the raceway. The minimum size is determined from Table 250.122 based on the rating of the 60-ampere overcurrent device (see figure 9.11).

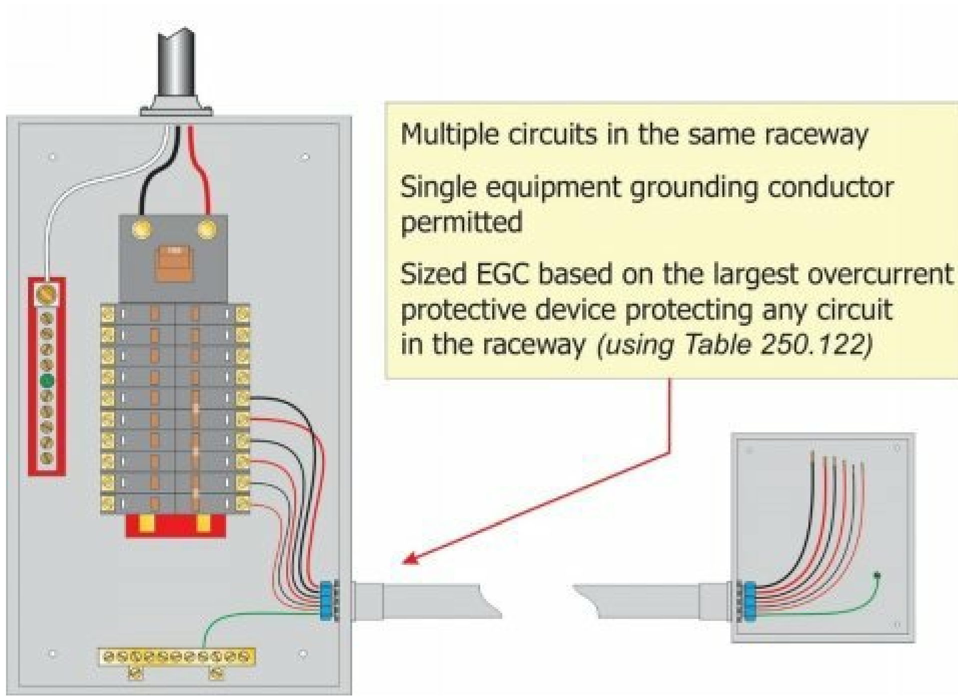


Figure 9.11 Sizing equipment grounding conductor where multiple circuits are installed in the same raceway

Equipment Grounding Conductors for Motor Circuits

The general rule for sizing the equipment grounding conductor for motor circuits is contained in 250.122(D) [see figure 9-13]. Determine the minimum size conductor from Table 250.122 based on the rating of the motor short circuit and ground-fault protective device. In some cases, this could result in an equipment grounding conductor that is the same size as the branch-circuit conductors. This is illustrated as follows: a 30-hp, 460-volt motor is being installed. From Table 430.250, the full-load amperes of the motor is 40 amperes. The minimum size branch-circuit conductors can be determined from Table 310.15(B)(16) by calculating 40 amperes x 1.25 = 50 amperes, which is 8 AWG copper conductors (75°C insulation and terminations). Maximum rating of the motor short circuit and ground-fault device of a circuit breaker type is 250 percent of the motor full-load amperes = 40 A x 250% = 100 amperes (Table 430.52), unless one of the exceptions to 430.52(C) applies. From Table 250.122, the minimum size of equipment grounding conductor based on a 100-ampere motor short circuit and ground-fault device is 8 AWG copper, which is the same size as the branch-circuit conductors. Note that 250.122(A) provides that the size of the equipment grounding conductor is not required to be larger than the branch-circuit conductors.

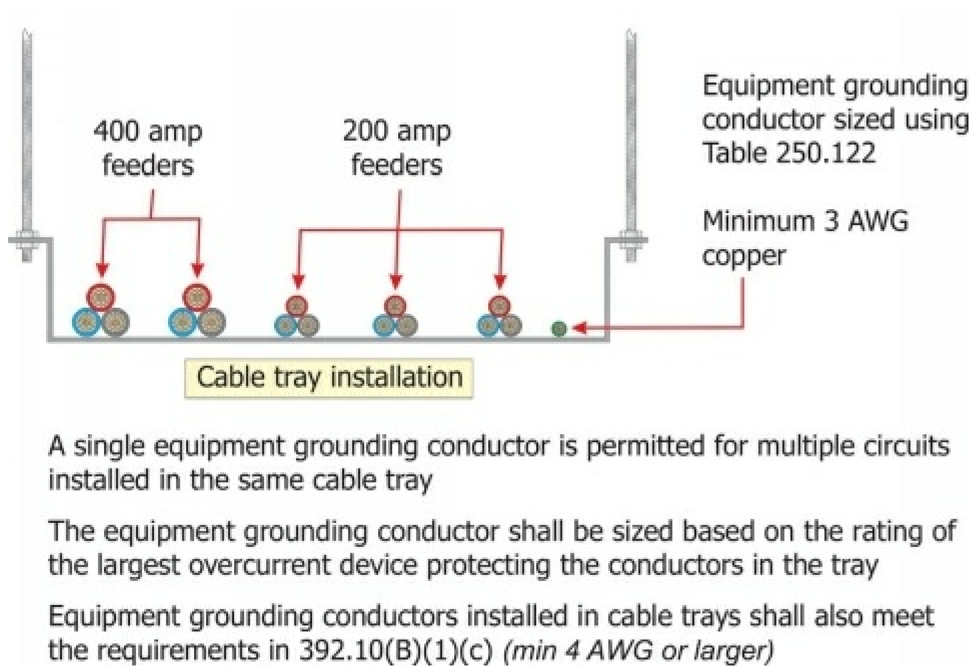


Figure 9.12 Single equipment grounding conductor for multiple circuits in same

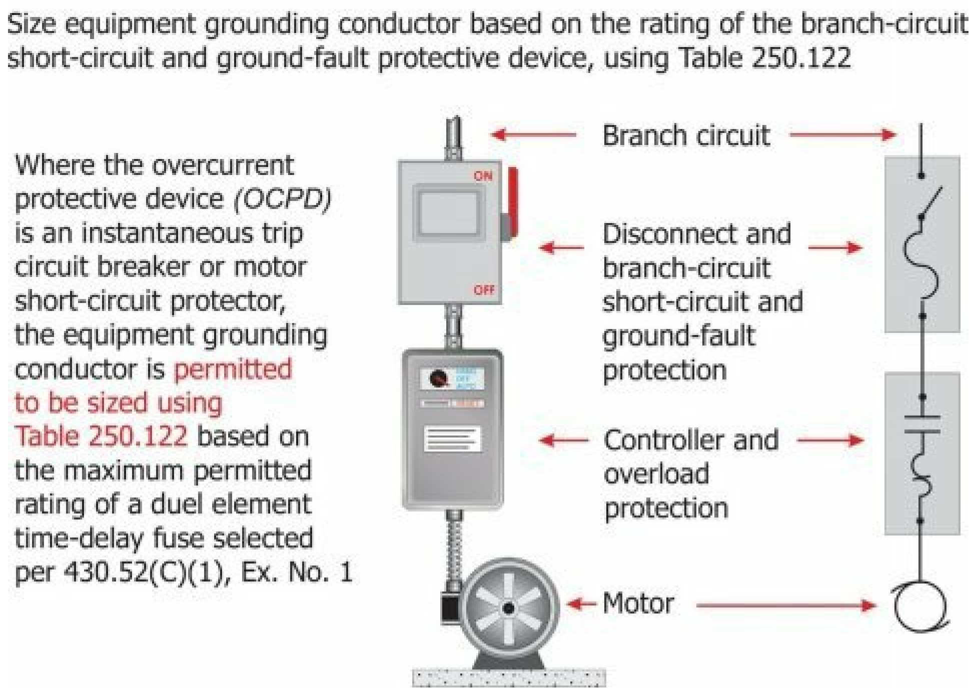


Figure 9.13 Sizing equipment grounding conductors for motor circuits

If the overcurrent device for the motor consists of an instantaneous-trip circuit breaker (rather than a more standard inverse-time circuit breaker) or a motor short-circuit protector, the equipment grounding conductor size is permitted to be sized per 250.122(A) using the maximum permitted rating of a dual element time-delay fuse selected for the short-circuit and ground-fault protection in accordance with 430.52(C)(1), Ex. No. 1. Note that the instantaneous-trip circuit breaker is permitted to be used only if it is a part of a listed combination motor controller having coordinated motor overload protection.

Using the above example, the instantaneous-trip circuit breaker that serves as the branch-circuit, short-circuit and ground-fault protective device is permitted to be up to 800 percent of the motor full-load current. The minimum size of branch-circuit conductors is determined as 40 amperes x 1.25 = 50 amperes. The minimum conductor from Table 310.16 is an 8 AWG copper conductor with 75°C insulation and terminations. The maximum rating of a motor short circuit and ground-fault protective device of an instantaneous circuit breaker type is 800 percent of the motor full-load amperes = 40 x 8 = 320 amperes, unless one of the exceptions following 430.52(C)(3) applies. However, using the dual element time delay fuse at 175% (Table 250.52) of the code FLA for the motor, this becomes 40 x 1.75 = 70 Amps. So from Table 250.122, the equipment grounding conductor would be 8 AWG copper or 6 AWG aluminum.

Equipment Grounding Conductors for Flexible Cord and Fixture Wire

The use of an equipment grounding conductor in a cord is permitted providing the cord is used as specified in 400.7. The method of grounding non-current-carrying metal parts of portable equipment may be by means of the equipment grounding conductors in the flexible cord supplying such equipment. The proper type attachment plug is required to be used to terminate the conductors, and the attachment plug must have provision to make contact with a grounding terminal in the receptacle.

For the grounding of portable or pendant equipment, where the conductors that are protected by fuses or circuit breakers rated or set at not exceeding 20 amperes, 240.5 permits the use of an 18 AWG copper wire as an equipment grounding circuit conductor. This is permitted provided the 18 AWG equipment grounding conductor is a part of a listed flexible cord assembly [see 250.122(E)].

Equipment Grounding Conductors in Parallel

Special rules apply where more than one raceway or cable is installed with parallel conductors and an equipment grounding conductor is installed in the raceway. (Parallel conductors consist of two or more conductors that comply with 310.10(H), and are connected together at each end to form a single conducting path.) In this case, 250.122(F) requires that an equipment grounding conductor be installed in each raceway or cable. Generally, each equipment grounding conductor is required to be sized in compliance with the ampere rating of the overcurrent device protecting the conductors in the raceway or cable (see photo 9.7).

Photo 9.7 Equipment grounding conductors in each raceway of parallel feeder

The 2017 *NEC* made significant revisions to 250.122(F) to separate raceway installations from cable installations. For the raceway installations, there are two conditions. One is a single raceway, like a wireway, with all the parallel conductors installed together. The second condition is each set of parallel conductors installed in separate raceways. The last modification clarified that cable tray meeting the requirements of 250.118 and Article 392 can be the equipment grounding conductor with or without an additional wire type equipment grounding conductor installed.

> **250.122(F) Conductors in Parallel.** For circuits of parallel conductors as permitted in 310.10(H), the equipment grounding conductor shall be installed in accordance with (1) or (2).
>
> **(1) Conductor Installations in Raceways, Auxiliary Gutters, or Cable Trays.**
>
> (a) *Single Raceway or Cable Tray*. If conductors are installed in parallel in the same raceway or cable tray, a single wire-type conductor shall be permitted as the equipment grounding conductor. The wire-type equipment grounding conductor shall be sized in accordance with 250.122, based on the overcurrent protective device for the feeder or branch circuit. Wire-type equipment grounding conductors installed in cable trays shall meet the minimum requirements of 392.10(B)(1)(c). Metal raceways or auxiliary gutters in

accordance with 250.118 or cable trays complying with 392.60(B) shall be permitted as the equipment grounding conductor.

(b) *Multiple Raceways*. If conductors are installed in parallel in multiple raceways, wire-type equipment grounding conductors, where used, shall be installed in parallel in each raceway. The equipment grounding conductor installed in each raceway shall be sized in compliance with 250.122 based on the overcurrent protective device for the feeder or branch circuit. Metal raceways or auxiliary gutters in accordance with 250.118 or cable trays complying with 392.60(B) shall be permitted as the equipment grounding conductor.

Section 310.10(H) permits equipment grounding conductors to be smaller than 1/0 AWG, and to be sized in compliance with Table 250.122. However, all other requirements for installing conductors in parallel must be met. These rules require that each set: (1) be the same length; (2) be of the same conductor material [all copper or all aluminum]; (3) be the same size in circular mil area; (4) have the same insulation type; (5) be terminated in the same manner; and (6) the raceways or cables must have the same physical properties. However, the sets of conductors are not required to be identical (see figure 9-14). Where installed in multiple raceways the equipment grounding conductor is not required to be larger than the largest ungrounded conductor in the raceway as stated at 250.122(A).

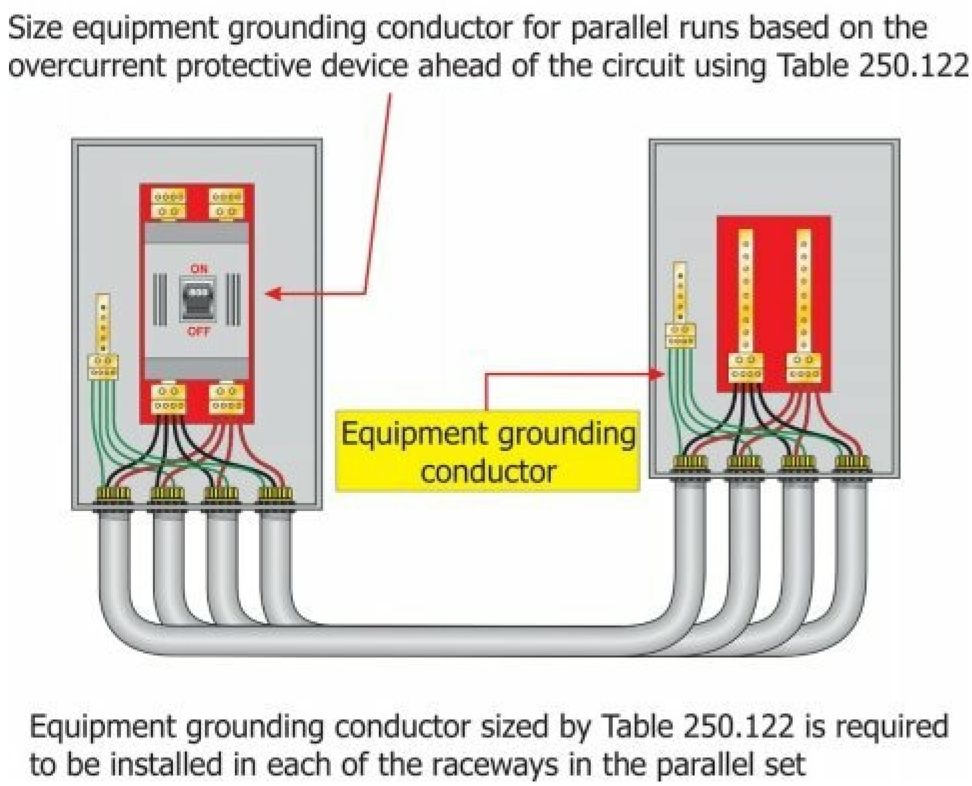


Figure 9.14 Equipment grounding conductors for feeders installed as parallel

One reason for this requirement for installing equipment grounding conductors in parallel is shown in figures 9.14 and 9.15. In the event of a line-to-ground fault in the equipment supplied by the circuit, the fault current should divide equally between the equipment grounding conductors. However, if a line-to-ground fault occurs in the raceway or cable, current will be fed to the fault from both directions. The equipment grounding conductor will thus be called upon to carry the entire amount of fault current until the overcurrent protective device ahead of the fault opens.

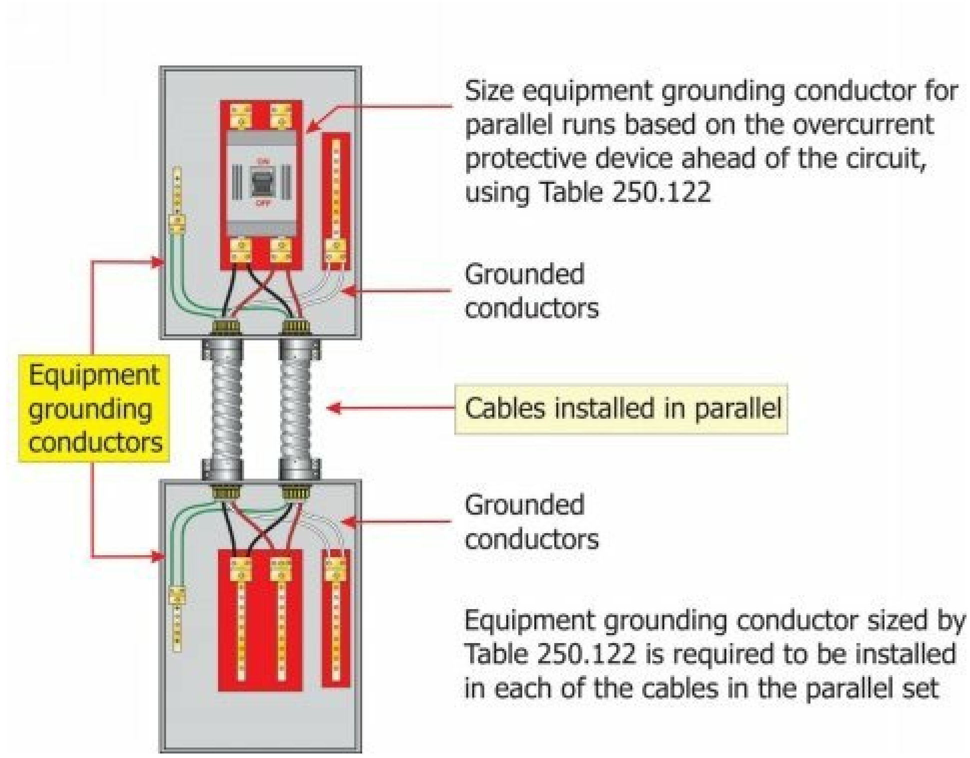


Figure 9.15 Sizing equipment grounding conductors in parallel circuits

Equipment Grounding Conductors in Cables in Parallel

In some cases, where cables are installed in parallel, special constructions will be required to comply with *Code* rules on the equipment grounding conductor in the cable. Listed cables are generally produced with the equipment grounding conductors sized in compliance with a construction standard that complies with Table 250.122. For example, a copper cable construction suitable for a 300-ampere overcurrent device will have a 4-AWG copper equipment grounding conductor placed within the cable by the manufacturer. If two of these cables are installed in parallel and connected to a 600-ampere overcurrent protective device, a 1-AWG copper equipment grounding conductor would be required in each cable to comply with Table 250.122. These "special" cables can be ordered from the manufacturer although conditions such as minimum length requirements may apply. In addition, a significant amount of time may be required to produce these special cables (see figure 9.15).

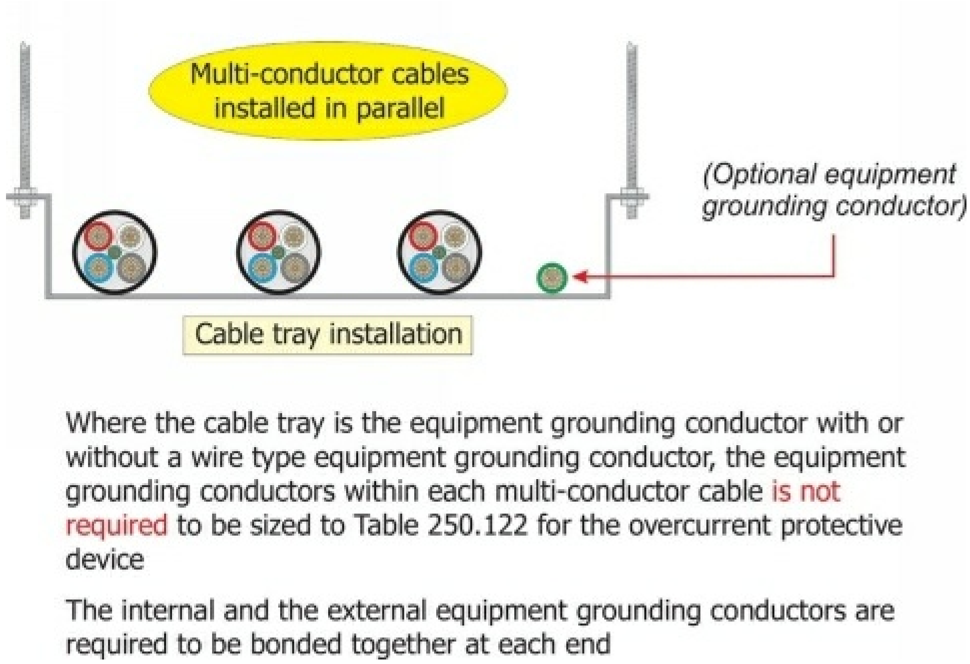


Figure 9.16 Internal and external equipment grounding conductors are required to be bonded together at each end.

Revisions in the 2017 *NEC* separate cables installed in parallel as the sole wiring method and another part where the cables are installed in a raceway, gutter or cable tray that qualifies as an equipment grounding conductor. Where cables are installed in parallel, for example in cable tray meeting the requirements of 250.18 and Article 392, the cables are permitted to just have the standard equipment grounding conductor. The cable tray or raceway is accepted as the main equipment grounding conductor but the wire type equipment grounding conductors within the cable are still required to be connected to the main equipment grounding conductor at each end. (see figure 9.16)

250.122(F)(2) Multiconductor Cables.

(a) If multiconductor cables are installed in parallel, the equipment grounding conductor(s) in each cable shall be connected in parallel.

(b) If multiconductor cables are installed in parallel in the same raceway, auxiliary gutter, or cable tray, a single equipment grounding conductor that is sized in accordance with 250.122 shall be permitted in combination with the equipment grounding conductors provided within the multiconductor cables and shall all be connected together.

(c) Equipment grounding conductors installed in cable trays shall meet the minimum requirements of 392.10(B)(1)(c). Cable trays complying with 392.60(B), metal raceways in accordance with 250.118, or auxiliary gutters shall be permitted as the equipment grounding conductor.

(d) Except as provided in 250.122(F)(2)(b) for raceway or cable tray installations, the equipment grounding conductor in each multiconductor cable shall be sized in accordance with 250.122 based on the overcurrent protective device for the feeder or branch circuit.

Auxiliary Grounding Electrode

Engineers often specify that ground rods or another electrode be installed to ground metal lighting standards or poles and at metal poles for electric signs (see figure 9.17). Some manufacturers of computer-
controlled machine tools specify that a ground rod be used to locally ground their equipment (see figures 9.18).

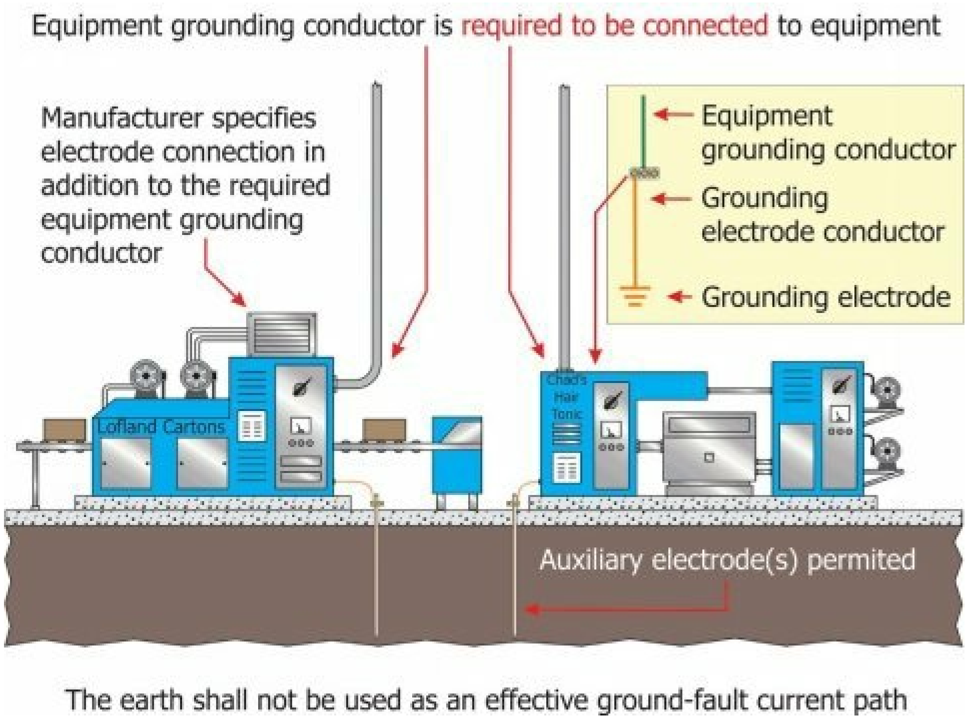


Figure 9.17 Auxiliary grounding electrodes are permitted (light pole is a common example)

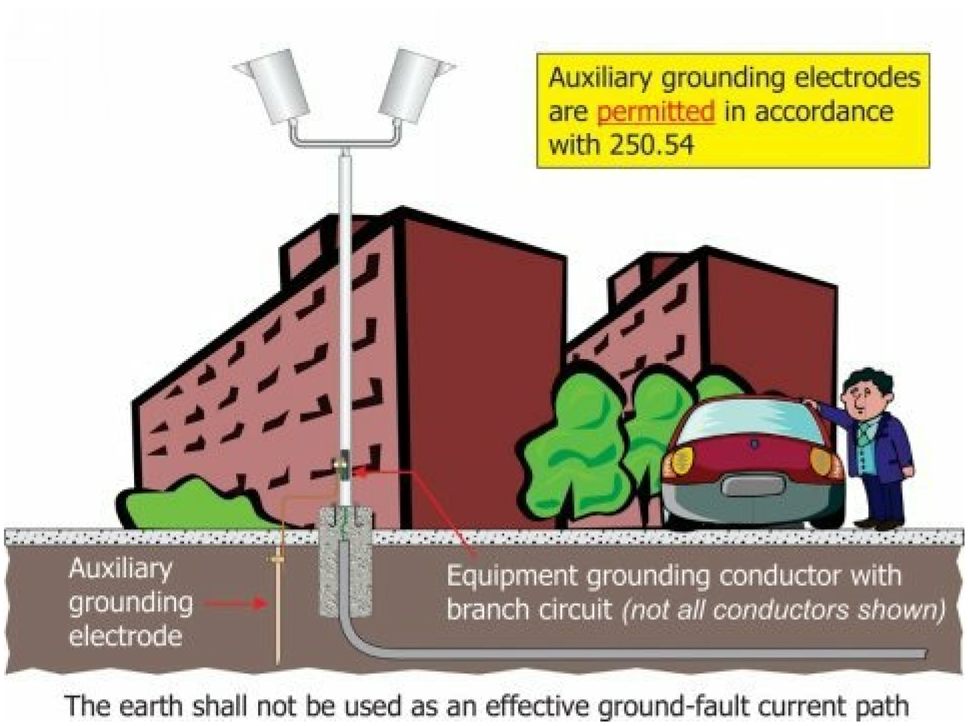


Figure 9.18 Auxiliary grounding electrodes are permitted but must meet 250.54 requirements where installed. The earth shall not be used as an effective ground-fault current path

These rods are permitted to be used but are required to be considered auxiliary grounding electrodes. They can supplement the equipment grounding conductor that is run with the branch circuit but cannot be the only means of grounding this or similar equipment (see 250.54). To use these ground rods as the only means of grounding would constitute an earth return which is unsafe and prohibited by *Code*. The concept of the earth being used for a circuit conductor should never be considered. The *NEC* strictly prohibits this in multiple sections. The earth is a poor conductor.

Equipment Grounding Conductor with Circuit Conductors

A very important requirement for installing equipment grounding conductors is contained in 250.134(B). This requirement is that the equipment grounding conductor is generally required to be installed in the same raceway, cable or cord, or otherwise be run with the circuit conductors. This requirement is repeated in 300.3(B) where, in addition to the requirement for raceways, equipment grounding conductors are required to be contained in the same trench with other circuit conductors. This requirement is critical for the installation of alternating-current systems.

It has been proven that separating the equipment grounding conductor from the circuit conductors greatly increases the impedance of the circuit. Separation of these conductors will increase the inductive reactance of an ac circuit, which in turn increases equipment grounding conductor circuit impedance values. The impedance of the equipment grounding conductor of a circuit should be kept as low as practicable.

This excessive separation can render an adequately sized equipment grounding conductor ineffective in carrying enough current to operate the circuit protective device and clear the faulted equipment. In this case, providing properly sized equipment grounding conductor but installing it improperly results in an ineffective and possibly unsafe installation (see chapter 11 for additional information on this subject).

Nonmetallic Raceway

Where the wiring method or means is nonmetallic or is open conductors, it is necessary to install a wire-type equipment grounding conductor along with the circuit conductors. Do not separate them at any point in the circuit by any metallic material regardless of whether the metallic material is magnetic or not. It is true that if the material is nonmagnetic, the increase in impedance of the circuit will not be as great as if the material was magnetic. In any case, such separation is to be avoided.

Use of Building Steel for Grounding

Section 250.136(A) permits a metal rack or structure to ground electric equipment that is secured to it and in electrical contact, provided the support means is grounded by an equipment grounding conductor as specified by 250.134. However, the structural metal frame of a building is not permitted to serve as an equipment grounding conductor to ground equipment. That is due to the uncertain path that ground-fault current must take in an effort to clear a fault (see figure 9.19).

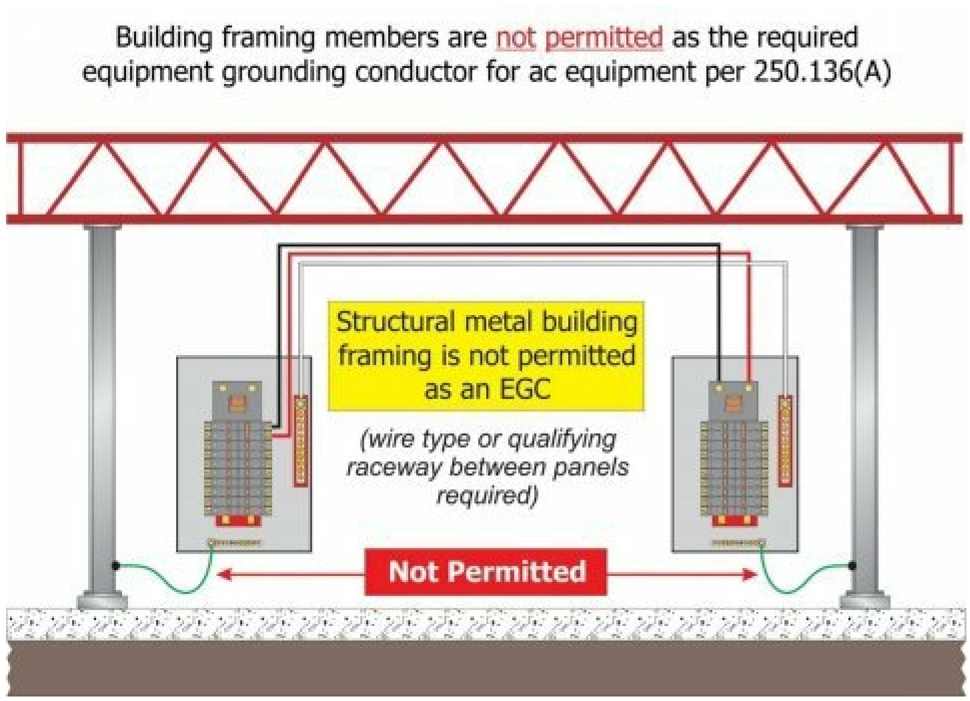


Figure 9.19 Structural metal building framing is not permitted as an equipment grounding conductor

This section emphasizes the requirement in 250.134(B) and 300.3(B) that the equipment grounding conductor must be in the same raceway, cable or cord, or otherwise be run with the circuit conductors. Again, this is so the grounding circuit impedance will be as low as possible to allow adequate ground-fault current so the circuit protective device will clear the fault. Separating the equipment grounding conductors from the circuit conductors increases the inductive reactance of the circuit in ground-fault conditions and thus increases the impedance on the equipment grounding circuit, which is required to be kept at a minimum.

In the same manner, and on the same basis, metal car frames, supported by metal hoisting cables attached to or running over sheaves or drums of elevator machines, are considered grounded when the machine is grounded as required by the *Code* [see 250.136(B)].

Grounding for Direct-Current Circuits

All of the previous text applies to the grounding of alternating-current systems where reactance of the circuit plays a large part in the impedance of the ground-return path. In the case of direct-current circuits the concern is with ohmic resistance only. Owing to that fact, the current-carrying capacity of the equipment grounding conductor for a direct-current supply system is required to be equal to that of the largest conductor of the system. However, if the grounded circuit conductor is a neutral conductor derived from a balancer winding or a balancer set which has overcurrent protection as required under 445.12(D), then the equipment grounding conductor size shall be not less than the size of the neutral conductor.

The requirement for overcurrent protective devices in 445.12(D) states that the two-wire direct-current generators used in conjunction with balancer sets shall be equipped with overcurrent protective devices that will disconnect the 3-wire system in the case of excessive unbalancing of voltages or currents.

Long Term Reliability of Metal Raceways

In the above discussions, it is assumed that a conductor enclosure (conduit or other raceway) has been properly installed with good tight joints that will provide a permanent and continuous electrical circuit when it is first installed. However, time and corrosion will affect the continuity of the conduit (see photo 9.8).

Photo 9.8 Metal raceway that has been severely damaged due to corrosion

The safety of an electrical system will therefore depend on how long we can expect conduit acting as the equipment grounding conductor to remain permanent and continuous. The answer will vary depending on the type of metal raceway, the environment it is installed in, and the quality of the installation (see table 9.1).

For design purposes, two categories can be created:

1. Where little corrosion will exist and where it can be reasonably expected that the equipment grounding conductor, in the form of a metal raceway, will remain permanent and continuous for a period of fifty years or more.

2. Where corrosion in varying degrees will exist and where the permanency of the equipment grounding conductor provided by the metal raceway can be questioned.

Most commercial and residential buildings are in the first category. That being the case, conductor enclosures, which are approved for the purpose can be used as part of the equipment grounding conductor (with the use of bonding jumpers where required).

Some industrial and most areas of petrochemical plants are in the second category where a wire type equipment grounding conductor, sized per Table 250.122, is usually specified to be run in parallel with and within the conductor enclosure so as to ensure continuity if the conduit circuit is broken owing to eventual corrosion (see table 9.1).

Metal Conduit Corrosion Protection Required

In Concrete:	Required	Optional
Rigid Steel		X
Intermediate Steel		X
Aluminum Rigid	X	
Steel EMT	Below grade may be needed	On or above grade
Aluminum EMT	X	
In Soil:	**Required**	**Optional**
Rigid Steel		X
Intermediate Steel		X
Aluminum Rigid	X	
Steel EMT	Generally Required	
Aluminum EMT	X	

Table 9.1 Corrosion protection for metal raceway is required.

Some electrical design engineers and local electrical inspection agencies require that a wire type equipment grounding conductor be installed in each metal conduit or tubing to help ensure the reliability of the equipment grounding conductor path.

Metal Conduit Underground

Care must be taken when installing metallic conduit and electrical metallic tubing in the earth, in concrete on or below grade, or where exposed to moisture (344.10 and 300.6). The Underwriters Laboratories' ProductSpec guide card information for Rigid Ferrous Metal Conduit (DYIX) and Intermediate Ferrous Metal Conduit (DYBY) contains the following information regarding corrosion protection:

> "Galvanized rigid (and intermediate) steel conduit installed in concrete does not require supplementary corrosion protection. Galvanized rigid (and intermediate) steel conduit installed in contact with soil does not generally require supplementary corrosion protection.
>
> "In the absence of specific local experience, soils producing severe corrosive effects are generally characterized by low resistivity (less than 2000 ohm-centimeters).
>
> "Wherever ferrous metal conduit runs directly from concrete encasement to soil burial, severe corrosive effects are likely to occur on the metal in contact with the soil.
>
> "Conduit that is provided with a metallic or nonmetallic coating, or a combination of both, has been evaluated for resistance to atmospheric corrosion. Nonmetallic outer coatings that are part of the required resistance to corrosion have been additionally evaluated for resistance to the effects of sunlight.
>
> "Rigid metal conduit with or without a nonmetallic coating has not been evaluated for severely corrosive conditions." [6]

In addition, experience has shown that steel conduit fails rapidly where exposed to corrosive environments found at some seacoast marinas, boatyards and plants as well as at some chemical plants. Experience has also shown that metal conduit systems are particularly vulnerable to failure from corrosion where they pass from concrete that is on or below grade to exposure to an atmosphere containing corrosive elements, particularly in combination with atmospheres containing oxygen.

For electrical metallic tubing [see 358.10(B)], the following instructions are given in the UL ProductSpec guide card (FJMX):

> "Galvanized steel electrical metallic tubing installed in concrete on grade or above generally requires no supplementary corrosion protection. Galvanized steel electrical metallic tubing in concrete slab below grade level may require supplementary corrosion protection.
>
> "In general, galvanized steel electrical metallic tubing in contact with soil requires supplementary corrosion protection. Where galvanized steel electrical metallic tubing without supplementary corrosion protection extends directly from concrete encasement to soil burial, severe corrosive effects are likely to occur on the metal in contact with the soil.
>
> "Aluminum electrical metallic tubing used in concrete or in contact with soil requires supplementary corrosion protection. Supplementary nonmetallic coatings presently used

> have not been investigated for resistance to corrosion." [7]

As a result, the authority having jurisdiction is required to make a decision regarding the suitability of these raceways for these applications. This, of course, affects the reliability of the raceway serving as an equipment grounding conductor. Several reports have been made where electrical metallic tubing installed to provide an equipment grounding means has failed due to corrosion.

To maintain the integrity of the equipment grounding means, some inspection agencies require that a copper equipment grounding conductor be installed in parallel with the electrical metallic tubing.

In addition, the authority having jurisdiction must make a decision regarding the suitability of supplementary nonmetallic coatings intended for resistance to corrosion.

Grounding of Equipment by Using the Grounded Circuit Conductor

The *Code* does not generally permit the grounded circuit conductor (often a neutral) to be grounded more than once on the load side of the service disconnecting means [see 250.24(A)(5), 250.30(A), and 250.142(B)]. Three exceptions to this rule exist for services or separately derived systems 250.142(A) applies and allows the grounded conductor (neutral) to ground the following:

1. The service supply side raceways and enclosures
2. Grounding the grounded circuit conductor at a remote building or structure (existing installations only).
3. Grounding the supply side of separately derived systems.

Where the electrical system produced by a separately derived system meets the conditions of 250.20(A) or (B), the system is required to be grounded according to 250.30(A). A system that falls within the parameters that require it to be grounded is required to have a grounding electrode conductor connected to the grounded conductor of the separately derived system (see chapter eight for additional information on this subject).

Under the specific conditions given in 250.32(B) Exception, a grounded circuit conductor is permitted to be grounded again at a separate building or structure. This is allowed only for existing installations where the initial installation complied with the *Code* in effect at the time of the installation. Feeders and branch circuits that supply separate buildings or structures in accordance with Part II of Article 225 are now required to include an equipment grounding conductor. Where the exception is applied, the grounded conductor serves as both a grounded conductor and an equipment grounding conductor between the buildings or structures [see chapter thirteen for additional information on this subject].

Section 250.142(B) covers rules on the use of the grounded circuit conductor for grounding equipment on the load side of the service equipment. As stated previously, such practice is generally prohibited. Four exceptions to the general rule are provided.

'Exception No. 1: The frames of ranges, wall-mounted ovens, counter-mounted cooking units, and clothes dryers under the conditions permitted for existing installations by 250.140 shall be permitted to be grounded by a grounded circuit conductor." [See chapter ten for additional information on this subject.]

"Exception No. 2: It shall be permissible to ground meter enclosures by connection to the grounded circuit conductor on the load side of the service disconnect if: (see figures 9-20, 9-21 and photo 9-9)

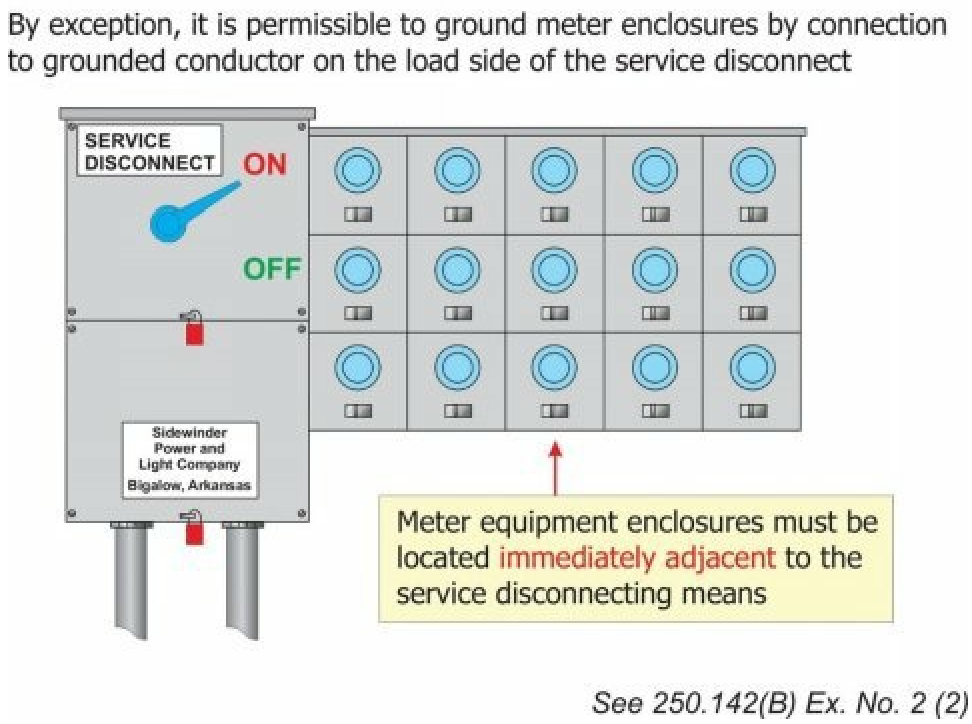


Figure 9.20 Grounded conductor is permitted for grounding meters on load side of service disconnect

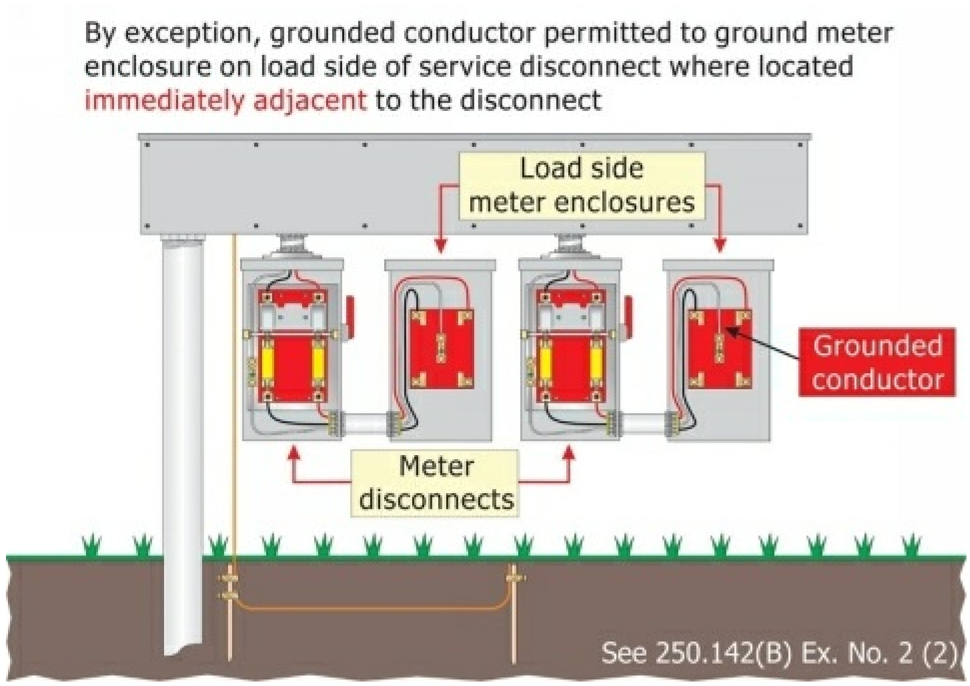


Figure 9.21 Grounded conductor is permitted for grounding where the meter equipment enclosure is located on the load side of the service disconnect, but immediately adjacent to the disconnect.

Photo 9.9 Meter equipment enclosures installed immediately adjacent to disconnecting means

"(a) No service ground-fault protection is installed. [This condition is important, as grounding the grounded circuit conductor downstream from the service will desensitize the equipment ground-fault protection system.]

"(b) All meter enclosures are located immediately adjacent to the service disconnecting means.

"(c) The size of the grounded circuit conductor is not smaller than the size specified in Table 250.122 for equipment grounding conductors.

"Exception No. 3: Direct-current systems shall be permitted to be grounded on the load side of the disconnecting means or overcurrent device in accordance with 250.164." [Rules are different depending on whether the direct-current supply is from an off-premises or on-premises source.]

"Exception No. 4: Electrode-type boilers operating at over 600 volts shall be grounded as required in 490.72(E)(1) and 490.74." [8]

1,2,3,4, 5 and 8 NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA 2016)

6 *UL Productspec* .

7 *UL Productspec*.

Review Questions

1. The conductive path(s) that provides a ground-fault current path and connects normally non–current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor, or both, best defines which of the following?

    1. equipment grounding conductor
    2. main bonding jumper
    3. grounding systems conductor
    4. circuit bonding jumper

2. An equipment grounding conductor is intended to prevent an objectionable voltage above ground on conductor and equipment enclosures and to provide a low-impedance path for fault-currents. This path must also ____.

    1. be electrically continuous
    2. have ample capacity to conduct safely any currents likely to be imposed on it
    3. be of the lowest practical impedance
    4. all of the above

3. The equipment grounding conductor or effective ground-fault current path must extend from the ____ point on the circuit to the service equipment or source of separately derived system where it is connected to the grounded conductor.

    1. closest
    2. service
    3. furthermost
    4. bonding

4. Where the overcurrent protection ahead of a branch circuit or feeder is sized at 225 amperes, the minimum size of the equipment grounding conductor is to be a ____ copper conductor.

    1. 4 AWG
    2. 6 AWG
    3. 8 AWG
    4. 10 AWG

5. Which of the following is recognized as a conductor or raceway for use as an equipment grounding conductor ____?

    1. a conductor of copper or other corrosion-resistant material such as aluminum
    2. rigid or intermediate metal conduit
    3. electrical metallic tubing

4. all of the above

6. Listed flexible metal conduit and listed flexible metallic tubing are permitted to be used for equipment grounding purposes. Which of the following statements is NOT true ____?

    1. The total combined ground return in the same path cannot exceed 1.8 m (6 ft)
    2. They must be terminated with listed fittings
    3. They cannot be used on a circuit exceeding 15 amperes

2. They cannot be used on a circuit exceeding 20 amperes

7. Listed liquidtight flexible metal conduit in sizes metric designator 21 through 35 (¾-in. through 1 ¼-in.) trade size is to be used as an equipment grounding conductor. Which of the following statements is NOT true ____?

1. The total length of the combined ground return in the same path cannot exceed 1.8 m (6 ft).
2. Listed fittings must be used
3. The circuit is permitted to be protected by a 100 ampere or less overcurrent device.
4. The circuit is permitted to be protected by a 60 ampere or less overcurrent device.

8. Where rigid metal conduit is used as an equipment grounding conductor, all joints and fittings are required to be ____.

1. readily accessible
2. tested
3. made up tight using suitable tools
4. sealed

9. For the grounding of portable or pendant equipment and where protected by fuses or circuit breakers rated or set at not over ____ amperes, the *Code* permits the use of a 18 AWG copper wire as an equipment grounding conductor provided it is a part of a listed flexible cord assembly.

1. 25
2. 20
3. 30
4. 35

10. Under what conditions may the structural metal frame of a building serve as an equipment grounding conductor to ground equipment?

1. Where it is effectively grounded
2. Never
3. Where approved

4. By special permission

11. Where equipment grounding conductors are installed in parallel in separate nonmetallic raceways, which of the following statements is true?

1. A full-size equipment grounding conductor is required in only one of the conduits.
2. A smaller equipment grounding conductor than required by Table 250.122 is permitted if the total area is not less than given in the table.
3. A full size equipment grounding conductor is required in each of the conduits.
4. Various size copper and aluminum conductors can be used together so long as they are not smaller than given in Table 250.122.

12. Equipment grounding conductors in parallel listed cables are permitted to be smaller than given in Table 250.122 if ____.

1. they are protected by an equipment ground fault protection device that is listed for the purpose of protecting the equipment grounding conductor
2. the total area of the conductors is not less than the area required divided by the number for conductors
3. they do not leave the building or structure they originate in
4. they are installed in cable tray, raceway or other enclosure as allowed in 250.118

13. Metal equipment supplied from ungrounded systems _____.

1. must be isolated from the supply source
2. is not required to be grounded by connection to an equipment grounding conductor
3. is required to be grounded by connection to an equipment grounding conductor
4. is not permitted to be grounded by an equipment grounding conductor

14. Flexible metal conduit that is listed ____.

1. is permitted to be used without restriction
2. is suitable for equipment grounding if the circuit conductors are protected at not over 20 amperes
3. is suitable for equipment grounding if the circuit conductors are protected at not over 60 amperes
4. is permitted when the total length of the combined equipment ground return in the same path exceeds 1.8 m (6 ft).

15. Flexible metal conduit and liquidtight flexible metal conduit that is used where flexibility is necessary after installation_______.

1. must have an equipment grounding conductor installed

2. is suitable for grounding if the circuit conductors are protected at not over 20 amperes
3. is suitable for grounding if the circuit conductors are protected at not over 60 amperes
4. is not permitted

16. Auxiliary grounding electrodes are permitted to connect to equipment grounding conductors as long as ____.

1. the earth is not used as an effective ground-fault current path
2. a green insulated conductor is used
3. the resistance to ground does not exceed 25 ohms
4. the electrode is not less than 3.0 m (10 ft) in length

17. The minimum size equipment grounding conductor for a 2500-ampere feeder shall not be less than _____.

1. 350 kcmil aluminum
2. 400 kcmil copper
3. 350 kcmil copper
4. 2 AWG copper in each raceway

18. The equipment grounding conductor for a switch-leg of a 20-ampere lighting circuit shall not be smaller than ____.

1. 14 AWG copper
2. 12 AWG aluminum
3. 10 AWG copper
4. 12 AWG copper

19. Where the ungrounded conductors of 300 m (1000 ft) long feeder are increased in size from the minimum size that has sufficient ampacity for the intended installation, the wire-type equipment grounding conductors of the feeder shall ____.

1. be increased proportionately
2. be permitted to be sized per Table 250.122
3. must be sized per Table 250.66
4. permitted to be reduced in size

⏚ Chapter 10
Enclosure and Equipment Grounding

Objectives to understand

- General requirements and definitions for enclosure and equipment grounding
- Grounding of fixed and specific equipment
- Grounding of cord- and plug-connected equipment
- Grounding of nonelectrical equipment
- Special provisions for grounding certain appliances
- Grounding of metal enclosures and panelboards
- Installation of grounding-type receptacles
- Installation of isolated grounding-type receptacles equipment

Both enclosures for service conductors and other conductor enclosures, where of metal, are required to be grounded (see 250.80 and 250.86). This requirement does not mean that simply connecting equipment to a grounding electrode is acceptable or permitted. The installation must comply with the requirements of 250.4 where the concept of the effective path for fault current is carefully outlined.

It is important to realize that wherever the *Code* states “shall be grounded”, it means effectively grounded as spelled out in 250.4. Note that nothing in the *Code* permits equipment that is supplied by an electrical system to be grounded only by connection to a grounding electrode. An effective ground-fault path always includes providing a low-impedance path consisting of an equipment grounding conductor that has adequate capacity to conduct the maximum fault current it is likely to carry. It also must be electrically continuous.

While the system grounding methods are different, electrical equipment associated with both grounded and ungrounded systems must be effectively connected (bonded) together and ultimately connected to ground. Where grounding is not effectively accomplished, the situation, while bad in an ungrounded system, becomes worse in a grounded system.

Definitions

Bonding Conductor or jumper: "A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected." [1]

Bonding jumper, equipment: "The connection between two or more portions of the equipment grounding conductor." [2]

Grounded (Grounding): "Connected (connecting to ground or to a conductive body that extends the ground connection." [3]

Grounding Conductor, Equipment (EGC): "The conductive path(s) that provides a ground-fault current path and connects normally non-current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor, or both." [4]

Informational Note No. 1: It is recognized that the equipment grounding conductor also performs bonding.

Informational Note No. 2: See 250.118 for a list of acceptable equipment grounding conductors.

Equipment Grounding Conductor

It is important to recall that an equipment grounding conductor is required to be used for grounding equipment. The equipment grounding conductor performs bonding functions and serves as an effective ground-fault current path to facilitate overcurrent device operation. The equipment grounding conductor is permitted to consist of any of the conductors or wiring methods identified in 250.118.

Installing only a grounding electrode conductor to ground equipment without having an equipment grounding conductor connected to the grounded service conductor is unsafe and not permitted (see 250.4 and 250.54).

By referring to figure 10.1, it can be seen that the grounding as shown literally meets the wording of the *Code* in that the enclosures are grounded which means "connected to ground …." But the installation does not comply with 250.4(A)(5) because an effective ground-fault current return path has not been provided. In addition, the grounding shown in this figure violates 250.4(A)(5) and 250.54 as an earth return grounding circuit is indicated.

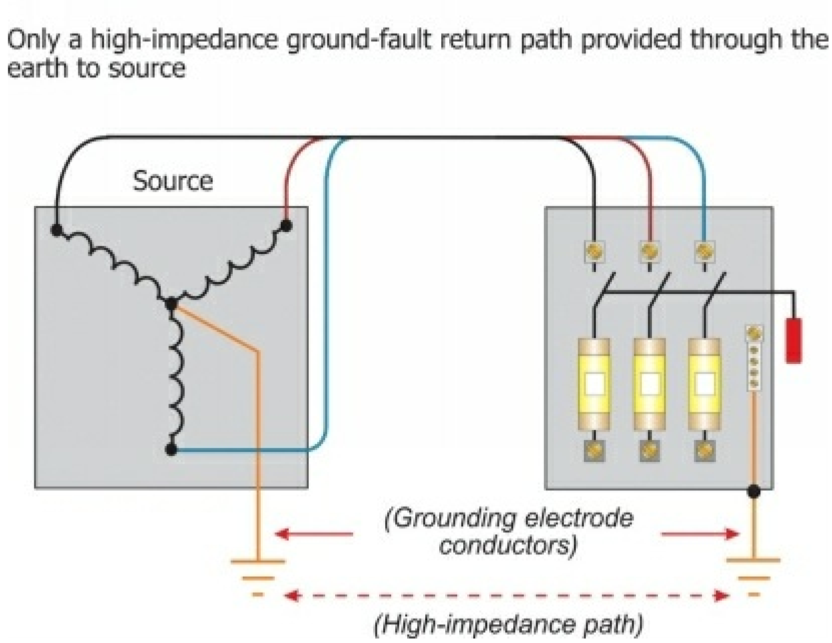


Figure 10.1 Grounded improperly (only a high-impedance return path through the earth to source)

The wiring in figure 10.2 complies literally with 250.80 and 250.86 and also complies with 250.4(A)(5) as a grounded system (neutral) conductor is installed completing the effective ground-fault current path.

It is obvious that only a high-impedance fault-current return path is indicated in figure 10.1, while in figure 10.2 there is a path having sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit.

In figure 10.2 there are two paths for current to return to the source. The primary and low-impedance path is over the equipment grounding conductor to the system grounded conductor (often a neutral conductor); while a second, high-impedance path in parallel with the first is through the grounding electrodes and the earth.

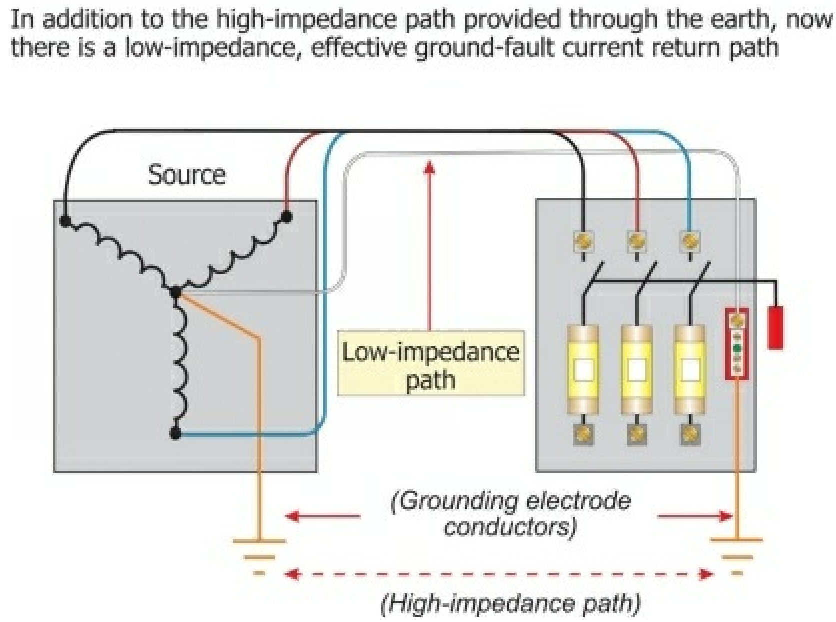


Figure 10.2 Grounded properly (in addition to the path through the earth, there is a low-impedance, effective ground-fault current path)

Photo 10.1 Equipment bonding jumper installed outside of flexible metal conduit [less than 1.83 m (6 ft)]

Service Raceways and Enclosures

We have dealt in earlier chapters with the requirement for bonding service raceways and equipment. By connecting (bonding) the service equipment to the grounded service and grounding electrode, we have complied with the requirements of 250.80.

An exception to 250.80 exempts metal raceway component(s) from the requirement that it be grounded where it is installed in an underground nonmetallic raceway(s) and is isolated from possible contact by a minimum cover of 450 mm (18 inches) to all parts of the metal components. These are typically metal elbows that are often referred to as pulling elbows and are commonly installed in duct banks or other underground runs of nonmetallic raceways because they are more durable than PVC elbows during the cable-pulling process.

A similar exception regarding metal components used in underground runs of nonmetallic raceways (Exception No. 3) for other than service raceways has been added to 250.86. This exception is discussed in the next section. There are additional requirements for bonding of isolated sections of metallic raceways or enclosures installed at pole locations. Section 250.102(E) permits an equipment bonding jumper to be installed either inside or outside the raceway or enclosure. Where installed on the outside of the raceway or enclosure, it is required to be routed with the raceway and not exceed 1.83 m (6 ft) in length (see photo 10.1). The exception to this rule allows a bonding jumper to exceed the length of 1.8 m (6 ft) at pole locations for the purposes of bonding isolated portions of metallic raceways or enclosures or elbows in a run of nonmetallic raceways.[5]

Other Than Service Conductor Enclosures. For other than service conductor enclosures, three exceptions are provided from the requirement that metallic conductor enclosures be connected to the equipment grounding conductor and not the grounded (neutral) conductor as provided in 250.24(A)(5) (see 250.86).

Exception No. 1 covers "metal enclosures and raceways for conductors added to existing installations of open wire, knob-and-tube wiring, and nonmetallic-sheathed cable." Conditions that must be met are as follows:

- An equipment grounding conductor is not provided by the wiring method.
- The metal enclosure or raceway must be less than 7.5 m (25 ft) long.
- The metal enclosure or raceway must be free of probable contact with ground or a grounded object.
- The metal enclosure or raceway is guarded against contact by persons.

Exception No. 2 exempts short sections of metal enclosures from the requirement to be connected to an equipment grounding conductor of the circuit where used to protect cable assemblies from physical damage. No explanation is given for the meaning of short sections of metal enclosures. Since the standard length is 3 m (10 feet), short sections are often considered to be less than 3 m (10 feet) long but in some cases a longer section may be acceptable.

Exception No. 3 permits metal component, for example a metal elbow, to not be connected to the equipment grounding conductor or the supply-side bonding jumper of the circuit where it is installed in an underground run of nonmetallic raceway and is isolated from possible contact by a minimum cover of 450 mm (18 in.) to any part of the metallic component(s) or is encased in not less than 50 mm (2 in.) of concrete. These provisions are similar to that for services as provided in 250.80 Exception but include the isolated metal elbows that may be installed in runs of nonmetallic conduit such as in deck slabs (see figure 10.3). [6] The exception for concrete encasement applies at any location below grade, at grade, or above grade.

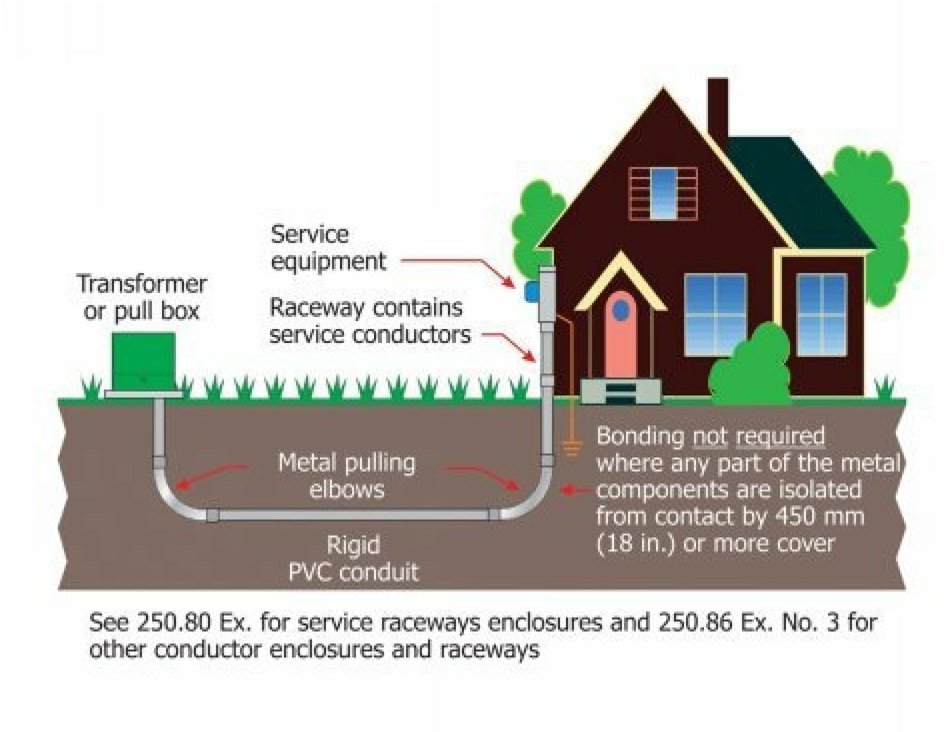


Figure 10.3 Metal components (elbows) installed in underground nonmetallic raceway

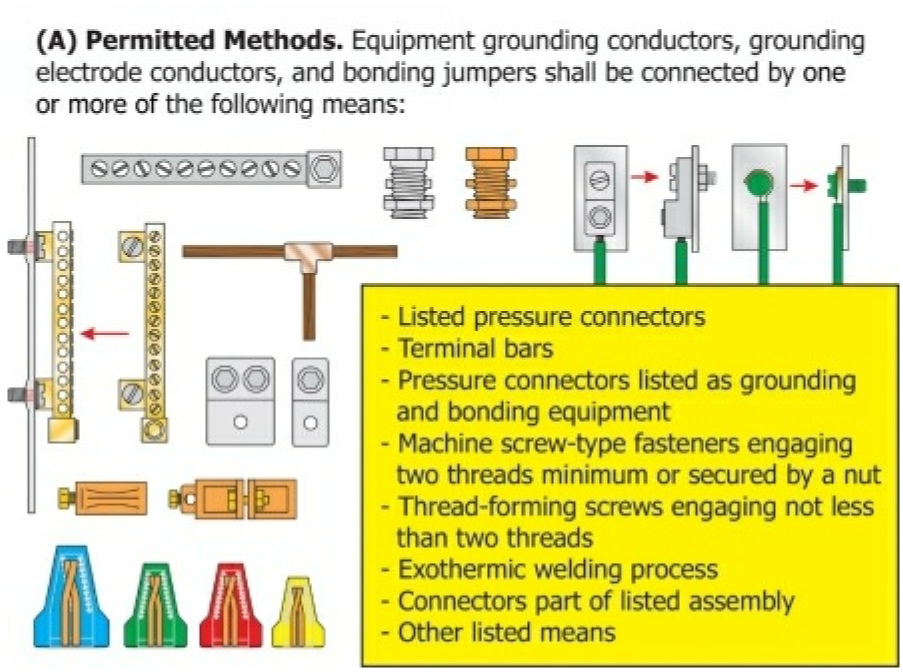


Figure 10.4. Methods of connecting EGCs described at 250.8(A)

Grounding of Fixed Equipment

It is mandatory that non-current-carrying metal parts of fixed equipment that are likely to become energized be connected to the equipment grounding conductor of the circuit under the six conditions cited in 250.110. Here, again, the term *shall be grounded* must not be interpreted literally to mean "connect to a grounding electrode" but must be interpreted in the light of all of Article 250 where providing an effective fault-current path is outlined in 250.4(A)(5). The *Code* does not define what is meant by *likely to become energized*. Generally, if the equipment has exposed non-current-carrying metal parts and is supplied by electric current it should be grounded by connection to an equipment grounding conductor of the supply circuit where any of the following six conditions exist at the equipment.

The six conditions are as follows:

1. Where within 2.5 m (8 ft) vertically or 1.5 m (5 ft) horizontally of ground or grounded metal objects and subject to contact by persons

2. Where located in a wet or damp location and not isolated

3. Where in electrical contact with metal

4. Where in hazardous (classified) locations as covered by Articles 500 through 517

5. Where supplied by a metal-clad, metal-sheathed, metal raceway, or other wiring method that provides an equipment ground, except as permitted by 250.86, Exception No. 2, for short sections of metal enclosures.

6. Where equipment operates with any terminal at more than 150 volts to ground.[7] The three exceptions from this equipment grounding requirement are as follows:

Exception No. 1. Metal frames of electrically heated devices, exempted by special permission [Written approval of the authority having jurisdiction], in which case the frames are required to be permanently and effectively insulated from ground.

Exception No. 2. Distribution apparatus, such as transformers and capacitor cases, mounted on wooden poles, at a height exceeding 2.5 m (8 ft) above ground or grade level.

Exception No. 3. Listed equipment that is protected by a system of double insulation or its equivalent shall not be required to be connected to the equipment grounding conductor. Where such a system is employed, the equipment shall be distinctively marked. [8]

Grounding Specific Equipment

The *Code* requires that exposed, non-current-carrying metal parts of certain specific equipment, regardless of voltage, shall be connected to the equipment grounding conductor of the supply circuit. Those items are spelled out in 250.112 and include:

Switchgear and Switchboard Frames and Structures [250.112(A)]

Switchgear and switchboard frames and structures supporting switching equipment, except frames of 2-wire dc switch-boards where effectively insulated from ground.

Pipe Organs [250.112(B)]

Generator and motor frames in an electrically operated pipe organ, unless effectively insulated from ground and the motor driving it.

Motor Frames [250.112(C)]

Motor frames, as provided by 430.242.

- Where supplied by a metal-enclosed wiring method
- Where in a wet location and not isolated or guarded
- If in a hazardous (classified) location as covered in Articles 500 through 517
- If the motor operates with any terminal at over 150 volts to ground.

Where the frame of the motor is not grounded, it shall be permanently and effectively insulated from ground.

Enclosures for Motor Controllers [250.112(D)]

Enclosures for motor controllers unless attached to ungrounded portable equipment.

Elevators and Cranes [250.112(E)]

Electrical equipment for elevators and cranes.

Garages, Theaters, and Motion Picture Studios [250.112(F)]

Electric equipment in commercial garages, theaters, and motion picture studios, except pendant lampholders supplied by circuits not over 150 volts to ground.

Electric Signs [250.112(G)]

Electric signs, outline lighting, and associated equipment as provided in 600.7 [see chapter 16 for additional information on this subject].

Motion Picture Projection Equipment [250.112(H)]

Motion picture projection equipment.

Remote-Control, Signaling, and Fire Alarm Circuits [250.112(I)]

Equipment supplied by Class 1 circuits shall be grounded unless operating at less than 50 volts. Equipment supplied by Class 1 power-limited circuits and by Class 1, Class 2, and Class 3 remote-control and signaling circuits, and by fire alarm circuits, shall be grounded where system is required by Part II or Part VIII of this article.

Luminaires [250.112(J)]

Luminaires as required by Part V of Article 410.

Exposed Conductive Parts. Exposed metal parts shall be grounded or insulated from ground and other conductive surfaces or be inaccessible to unqualified personnel. Lamp tie wires, mounting screws, clips, and decorative bands on glass spaced at least 38 mm (1½ in.) from lamp terminals shall not be required to be grounded [see 410.42(A)].

Made of Insulating Material. Luminaires made of insulating material that is directly wired or attached to outlets supplied by a wiring method that does not provide a ready means for grounding shall be made of insulating material and shall have no exposed conductive parts [see 410.44 exception no. 1].

Luminaires with exposed metal parts shall be provided with a means for connecting an equipment grounding conductor for such luminaires (see 410.46).

Skid-Mounted Equipment [250.112(K)]

Permanently mounted electrical equipment and skids shall be connected to the equipment grounding conductor jumper sized as required in 250.122.

Motor-Operated Water Pumps [250.112(L)]

Motor-operated water pumps, including the submersible type. [See 547.5(F) and 547.9 for specific requirements for grounding in agricultural buildings.]

Metal Well Casings [250.112(M)]

Where a submersible pump is used in a metal well casing, the well casing shall be connected to the pump circuit equipment grounding conductor.

Grounding of Cord- and Plug-Connected Equipment

Section 250.114 covers grounding of equipment connected by cord and plug. It is mandatory under certain conditions that non-current-carrying metal parts of cord- and plug-connected equipment which are liable to become energized be connected to the equipment grounding conductor. Listed tools, listed appliances, and listed equipment that are protected by a system of double-insulation are not required to be connected to the equipment grounding conductor. This double-insulated equipment is required to be distinctively marked (See 250.114 exception no. 1).

Specifically, cord- and plug-connected equipment is required to be grounded where located in:

- hazardous (classified) locations, [250.114(1)]
- if the equipment operates at more than 150 volts to ground [250.114(2)]. Exempted from this requirement are:
- motors, where guarded, and
- metal frames of electrically-heated appliances exempted by special permission, in which case the frames shall be permanently and effectively insulated from ground. [250.114(2) exception nos. 1 and 2]

The *Code* cites in 250.114(3) specific equipment of the cord- and plug-connected type that must be connected to the equipment grounding conductor in residential occupancies. In addition, 250.114(4) lists specific cord- and plug-connected equipment in other than residential occupancies that must be connected to an equipment grounding conductor. For tools and portable handlamps in other than residential occupancies, an exception from the requirement for grounding is provided for cord- and plug-connected equipment that is supplied through an isolating transformer with an ungrounded secondary of not over 50 volts. [250.114(4) exception]

Nonelectric Equipment

The grounding of nonelectric equipment is covered in 250.116. The equipment mentioned is considered as being likely to become energized and is thus required to be grounded by connection to the equipment grounding conductor as a safety measure. Included are:

- Frames and tracks of electrically operated cranes and hoists
- Frames of nonelectrically driven elevator cars to which electric conductors are attached
- Hand-operated metal shifting ropes or cables of electric elevators

The informational note following this section recommends that, “where extensive metal in or on buildings or structures may become energized and is subject to personal contact, adequate bonding and grounding will provide additional safety.”

Methods of Equipment Grounding

To provide the reliable and effective ground-fault return path required, it is important to connect the equipment grounding conductor recognized in 250.118 to the equipment in such a manner that the requirements for having an effective ground-fault current path are met.

For equipment that is fastened in place or connected by permanent wiring methods, the equipment grounding conductor must be connected to the enclosure in a proper manner.

Equipment grounding conductors and bonding jumpers must be connected to equipment that is required to be grounded by any of the methods provided in 250.8 (see photo 10.2). It should be noted that the connection means specified in 250.8 applies to the means of connecting to the conductor as well as the mean to attach the connector to the equipment. All means of connection are required to comply with the requirements of 250.8

Photo 10.2 Equipment grounding conductors connected to enclosure by listed irreversible compression connectors

One connecting means that is not required to be listed is the exothermic welding method. It is most important that equipment to be welded be clean and dry and that manufacturer's instructions are followed to ensure a satisfactory connection.

These welds must be examined and tested after completion to be certain that a reliable connection has been made. It is common to test the welds in the field by x-ray where required by the job specifications or by striking the weld with a hammer after it has cooled for less demanding installations.

In the case of a metallic raceway being used as the equipment grounding conductor, the raceway must be connected to the enclosure by using listed fittings designed for the purpose. The fittings for various wiring methods covered in Chapter 3 of the *NEC* are required to be listed. All connections must be made up tight using proper tools. This includes locknuts, bushings, conduit, and electrical metallic tubing couplings and connectors [see 250.120(A)].

Solder Connections

Connections that depend solely upon solder cannot be used for grounding connections [see 250.8 and 250.148].

The reason for this prohibition is that when equipment grounding conductors carry fault current, they can get very hot. This elevated temperature can exceed the melting point of the solder and weaken or destroy the connection. This can create a hazard by opening the effective ground-fault current path and leaving equipment at a dangerous potential above ground, creating a shock hazard to those who could contact the equipment.

It is permissible to secure the connections mechanically and then apply solder to the joint to make the electrical connection.

Special Provisions for Grounding Certain Appliances

Special requirements are set forth in the exception to 250.140 for the grounding of frames of electric ranges, electric clothes dryers and similar appliances. These provisions apply only to existing branch-circuit installations. New installations must comply with the requirements for an insulated neutral conductor as well as an insulated or bare equipment grounding conductor given in 250.134 and 250.138.

Appliances or equipment to which 250.140 Exception applies include:

- Electric ranges
- Wall-mounted ovens
- Counter-mounted cooking units
- Clothes dryers
- Outlet or junction boxes that are part of the circuit for these appliances

These appliances and equipment, such as the junction boxes in the circuit, are permitted to be grounded in two ways: either by use of an equipment grounding conductor; or, except for mobile homes and recreational vehicles, by the use of the grounded circuit (neutral) conductor, provided all the conditions of this section are complied with (see figures 10.5 and 10.6). If a 3-wire with equipment grounding conductor circuit is installed, simply use the equipment grounding conductor for grounding metal equipment and install a grounding type receptacle (3-wire plus equipment grounding terminal) (see figure 10.7).

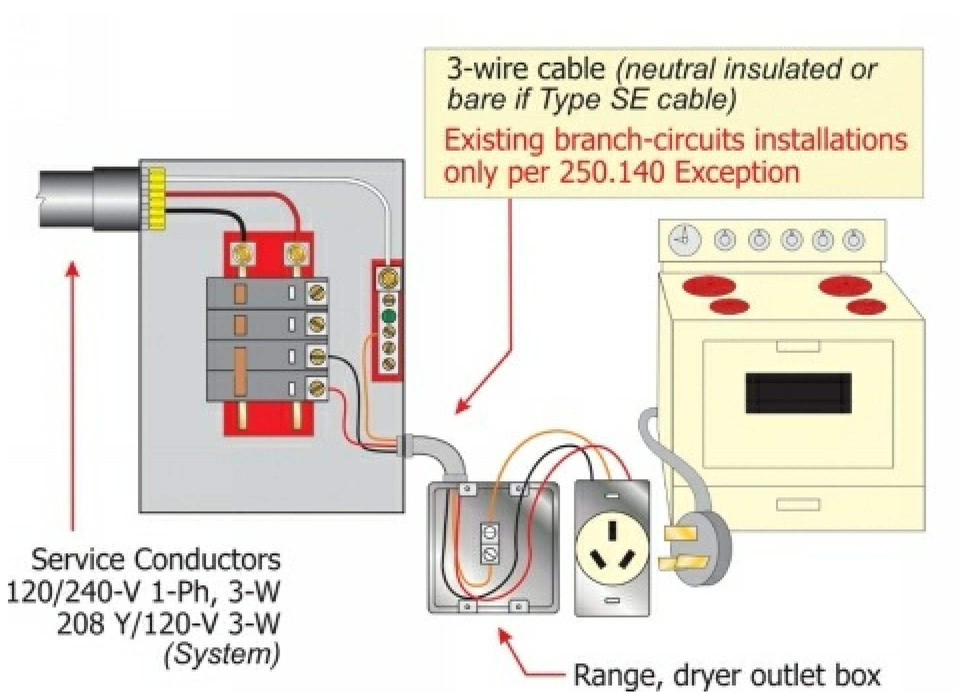


Figure 10.5 Wiring methods for appliances permitted to be grounded using the bare grounded (neutral) circuit conductor

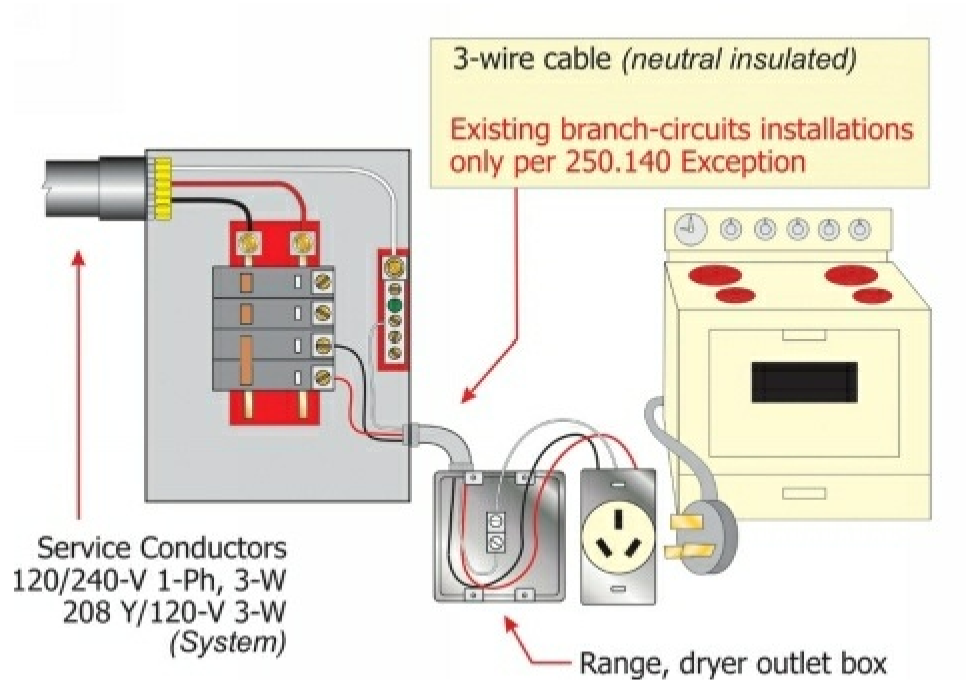


Figure 10.6 Wiring methods for appliances permitted to be grounded using the insulated grounded (neutral) circuit conductor

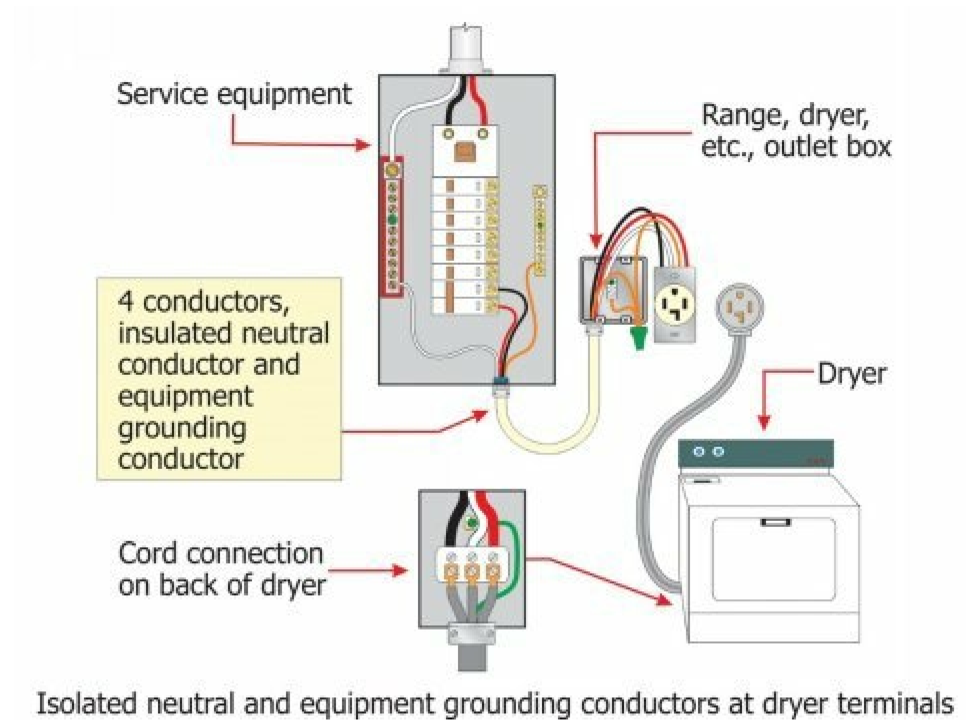


Figure 10.7 Grounding requirements for new electric range and electric dryer circuits

The conditions that must be met for grounding the above equipment using grounded circuit conductor in existing installations are as follows:

- The appliances are supplied by a 120/240-volt, single-phase, 3-wire circuit or by a 3-wire circuit derived from a 208Y/120-volt, 3-phase, 4-wire, wye-connected system.
- The grounded (neutral) conductor is 10 AWG copper or 8 AWG aluminum or larger.
- The grounded (neutral) conductor is insulated. The grounded (neutral) conductor is permitted to be uninsulated if it is part of a Type SE cable and it originates at the service equipment, and

- Grounding contacts of receptacles furnished as part of the equipment are bonded to the equipment.

It is important to note that all of these special conditions must be met before the appliances, and outlet and junction boxes that are a part of the circuit to the appliances, are permitted to be grounded using the grounded (neutral) conduct of the circuit. Note that the supply cable must have an insulated neutral conductor where supplied from a panelboard on the load side of the service disconnect.

Use caution when applying the provisions of 250.140 Exception No. 3, which permits the use of a Type SE cable having a bare neutral for wiring these appliances only when the circuit originates at service equipment. Also, use caution if the service panel is ever relocated. A service panel relocation will require these circuits that were acceptable under the exception to now require rewiring to the present *NEC* requirements.

Wiring for New Ranges and Dryers

New installations for ranges, dryers, and similar appliances require a three-wire with equipment grounding conductor (total four conductors) circuit having an insulated neutral conductor and an equipment grounding conductor (see figure 10.7). The equipment grounding conductor is permitted to be any of those included in 250.118 including conduit and cables. Receptacles, where installed, must be of the 3-pole, 4-wire grounding type. Supply cords, where used, must be of the 3-wire with equipment grounding conductor type.

Neither the frame of the appliances nor the outlets or junction boxes that are a part of the supply to the appliances are permitted to be connected to the grounded (neutral) circuit conductor. The frame of the appliances and junction boxes must be grounded by means of an equipment grounding conductor run with the branch circuit.

Care must be taken when these appliances are moved from a location employing one grounding scheme to a location having a different one. In the case where a 3-wire cable is used, the bonding jumper in the appliance junction box must be connected between the frame of the appliance and the neutral. Where a four-wire supply is used, the bonding jumper must be removed or disconnected, the neutral conductor is isolated from the appliance frame and the equipment grounding conductor connected to the frame.

Outlet, Device, Pull and Junction Boxes

Metal outlet, device, pull and junction boxes are required to be grounded and bonded in accordance with Parts I, IV, V, VI, VII and X of Article 250 [see 314.4]. It is important that the grounding of these enclosures be accomplished by the wiring method that supplies the enclosure [see 250.134].

Under no circumstances can a metal enclosure be connected to a local grounding electrode in lieu of grounding it by means of the suitable wiring method or equipment grounding conductor unless specifically permitted by *Code* rules. The metal raceway containing circuit conductors is permitted to be used as an equipment grounding conductor for these enclosures if installed properly with all connections made up wrenchtight. In addition, where fittings are used for connecting cables or raceways being used for grounding, the fittings used for connecting the wiring methods must be listed. Some wiring methods have restrictions on their use as an equipment grounding conductor. These include flexible metal conduit, liquidtight flexible metal conduit and flexible metallic tubing.

Wire type equipment grounding conductors that are supplied for grounding metallic enclosures must be sized in accordance with Table 250.122 based upon the rating of the overcurrent device protecting the circuit conductors in the raceway.

Section 314.40(D) requires that "a means be provided (by the manufacturer) in each metal box for the connection of the equipment grounding conductor. This means shall be permitted to be a tapped hole or equivalent."

Grounding of Panelboards

Section 215.6 requires that "where a feeder supplies branch circuits in which equipment grounding conductors are required, the feeder shall include or provide an equipment grounding conductor in accordance with the provisions of 250.134 to which the equipment grounding conductors of the branch circuit shall be connected (see figures 10.8 and 10.9)."

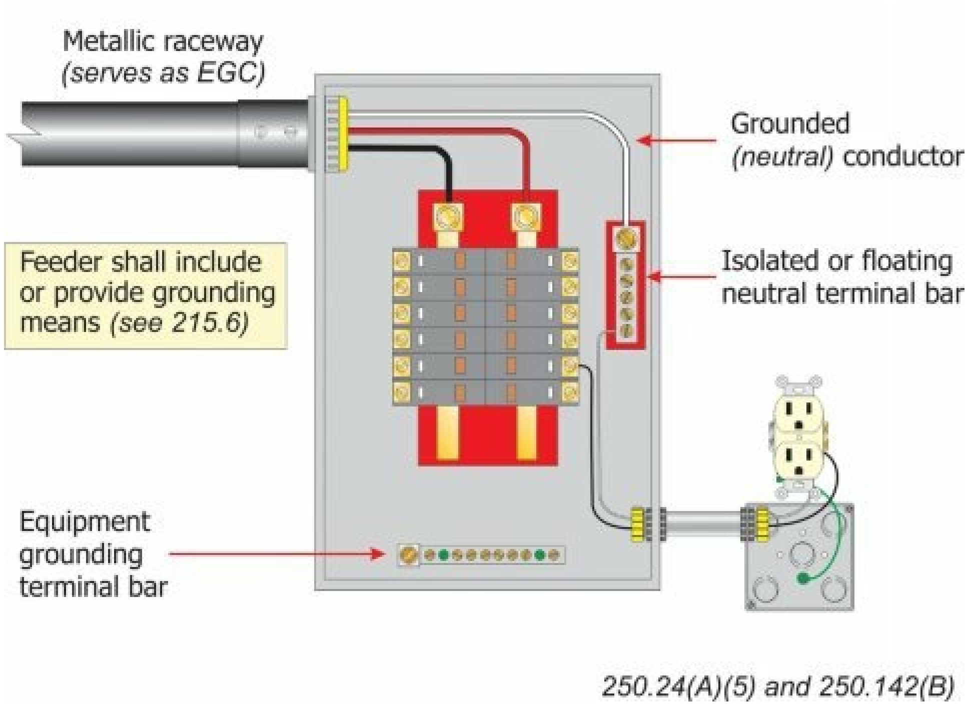


Figure 10.8 Separate equipment grounding terminal bar required in panelboard [408.40]

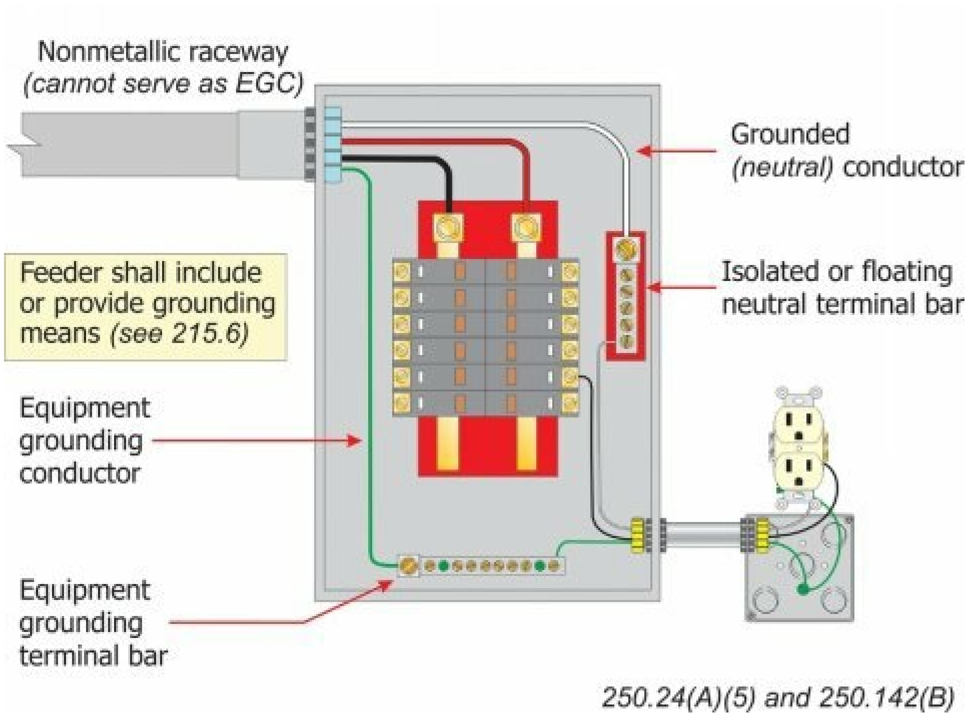


Figure 10.9 Separate the grounded (neutral) conductors and the equipment grounding conductors [250.24(A)(5) and 250.142(B)]

Specific requirements for grounding panelboards are contained in 408.40. All panelboard cabinets and panelboard frames if of metal are required to be in physical contact with each other and must be grounded by connection to an equipment grounding conductor. Section 408.3(C) requires that where used as service equipment, the panelboard must be provided with a main bonding jumper located inside the cabinet for the purpose of bonding the enclosure to the grounded service conductor.

Section 215.6 goes on to require, “where the panelboard is used with nonmetallic raceway or cable or where separate equipment grounding conductors are provided, a terminal bar for the equipment grounding conductors shall be secured inside the cabinet. The terminal bar shall be bonded to the cabinet and panelboard frame if of metal; otherwise, it shall be connected to the equipment grounding conductor that is run with the conductors feeding the panelboard.” Usually, the manufacturer provides matching and tapped holes along with appropriate screws or bolts for attaching the bar to the enclosure (see photo 10-3).

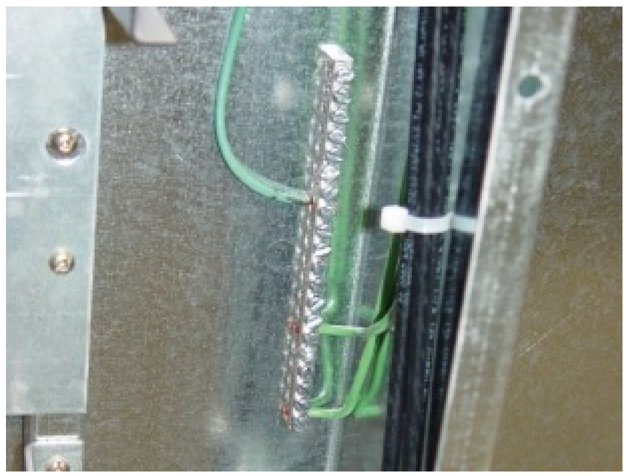


Photo 10.3 Equipment grounding terminal bar fastened to enclosure with thread-forming screws provided by the manufacturer.

Grounding electrode, equipment grounding and equipment bonding conductors are not permitted to be connected to the terminal bar for the grounded (may be neutral) conductors unless the terminal bar is identified for the purpose. This is typically only in equipment identified as “Suitable for Use as Service Equipment.” The allowance to terminate equipment grounding conductors will usually be on the manufacturer’s label that is located within the cabinet. Section 408.41 requires that each grounded conductor (may be a neutral) be terminated in an individual terminal that is not also used for another conductor. This prohibits grounded conductors and equipment grounding conductors from being terminated in the same “hole” of a terminal bar, even if it is identified for more than one conductor (see photo 10.4).

Photo 10.4 Grounded conductor terminal bar showing only one wire per terminal connected

Another allowance where grounding and bonding conductors are permitted to terminate on the grounded (neutral) terminal or bus is where the panelboard is used at a location where the grounded conductor terminal (neutral conductor) bar is connected to a grounding electrode, as permitted or required by Article 250. These locations include: at services, at the building disconnecting means for separate buildings or structures served by a feeder(s) or branch circuit(s) [see 225.32, 250.32 exception], and for separately derived systems [see 250.30(A)].

An exception permits an insulated equipment grounding conductor for an isolated grounding scheme to pass through a panelboard, box, wireway, or other enclosure without being connected to the equipment grounding terminal bar in compliance with 250.146(D).

Section 250.24(A)(5) generally prohibits a grounding connection to a grounded conductor (may be a neutral) on the load side of the service disconnecting means. Often, the term *floating neutral conductor* is used to describe the grounded conductor's relationship to the enclosure as it is insulated electrically from the enclosure. As previously discussed, exceptions to the general rule are provided for separately derived systems, at separate buildings for existing installations only, and for certain appliances such as electric ranges and clothes dryers on existing branch circuits.

See chapter twelve for additional information on separately derived systems and chapter thirteen for grounding at more than one building on the premises.

Grounding-Type Receptacles

Where grounding-type receptacles are installed, the equipment grounding terminal of the receptacle must be connected to an equipment grounding conductor of the circuit supplying the receptacle [see 406.4(C)]. Where more than one equipment grounding conductor enters a box, even from different circuits, they must be connected together using a suitable and listed connector. In addition, it is permitted to connect each of the equipment grounding conductors to the metal box individually using a listed clip or screw. An equipment bonding jumper must be connected to the receptacle so grounding continuity is not disturbed if the device is removed.

An equipment bonding jumper from the receptacle to the box is not required where a device with listed grounding means is installed in a metal box that is properly grounded. These devices are often referred to as self-grounding receptacles and are specially designed so one or more of the mounting screws are maintained in contact with the device's metal yoke (see the requirements in chapter eight for additional information on this subject). It is never permissible to ground the box by the use of these self-grounding receptacles.

Isolated Grounding Receptacles

Receptacles that have the equipment grounding terminal isolated from the mounting strap, and therefore from the box, are commonly installed at computer terminals and cash registers (see figure 10.10). This is permitted by 250.146(D) for the purpose of reducing electrical noise (electromagnetic interference). The grounding terminal of the receptacle must be grounded by means of an insulated equipment grounding conductor that is run with the circuit conductors. Note, that this "isolated grounding" receptacle does not mean the green terminal just goes to a grounding electrode. This is the ground-fault current carrying conductor back to the source for and ground faults of connected equipment.

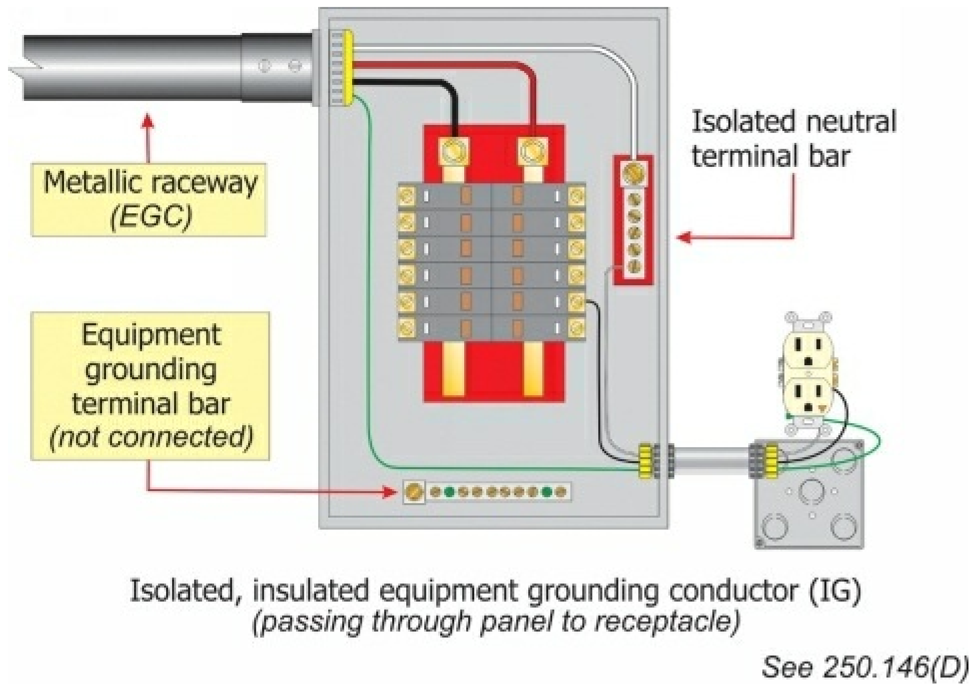


Figure 10.10 Isolated grounding receptacles [250.146(D)]

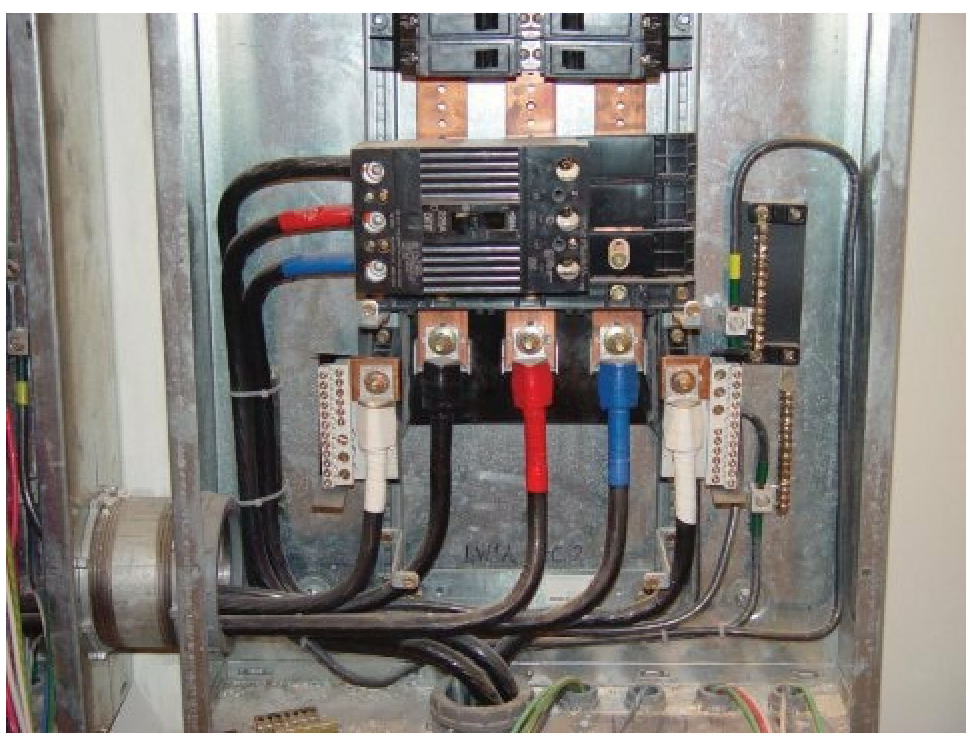


Photo 10.5 Panelboard with isolated grounding terminal bar (insulated) and equipment

grounding terminal bar fastened to the enclosure

This insulated equipment grounding conductor is *permitted* to pass through one or more panelboards, boxes, wireways, or other enclosures without connection to the box or the terminal bar within the panelboard on its way back to, usually, the service disconnecting means [see 250.146(D) and 408.40, Exception and photo 10-5]. However, the insulated equipment grounding conductor must terminate within the same building at the building or structure disconnecting means or source of a separately derived system where the circuit originates from that separately derived system (see chapter twelve for additional information on the subject of grounding separately derived systems). Note that the isolated equipment grounding conductor is permitted (not required) to pass through panelboards, boxes, etc., but is also permitted to be terminated to the safety equipment grounding conductor at any point up to these limits.

Isolated Equipment Grounding

Section 250.96(B) permits an equipment enclosure supplied by a branch circuit to have the metal raceway isolated separating that equipment grounding path as long as the equipment is grounded by connection to an insulated equipment grounding conductor contained within the raceway for the branch circuit that supplies the equipment. A listed nonmetallic raceway fitting at the point of connection to the equipment must be installed (see figure 10.11) to complete the isolation of the metallic raceway. This provision typically applies to listed data processing (information technology) equipment. See chapter eighteen for additional information on this subject.

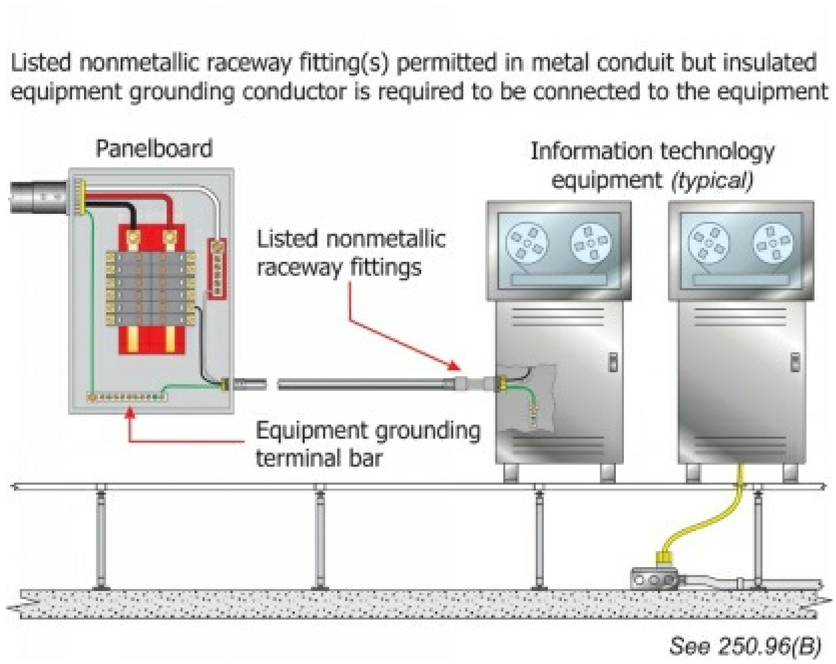


Figure 10.11 Listed nonmetallic raceway fitting is permitted at point of connection to equipment.

Underwriters Laboratories performed tests of a similar grounding scheme to determine whether isolating the metal conduit from the equipment had an adverse effect on the grounding circuit impedance. They found no appreciable increase in impedance with the metal conduit isolated from the equipment and being grounded by means of the insulated equipment grounding conductor.

Short Sections of Raceway

Where isolated sections of metal raceway or cable armor are required to be grounded, the *Code* requires in 250.132 that grounding of such sections be performed in accordance with the requirements of fixed equipment found in 250.134; in other words, they are required to be connected to the equipment grounding conductor. While the *Code* does not identify what is meant by a short section, perhaps this is a length less than the standard length of 3 m (10 ft). These short sections of raceways are often installed as physical protection of cables.

As mentioned previously, short sections of metal enclosures or raceways used to provide support or protection of cable assemblies from physical damage are not required to be connected to the equipment grounding conductor due to Exception No. 2 to 250.86 (see figure 10.12).

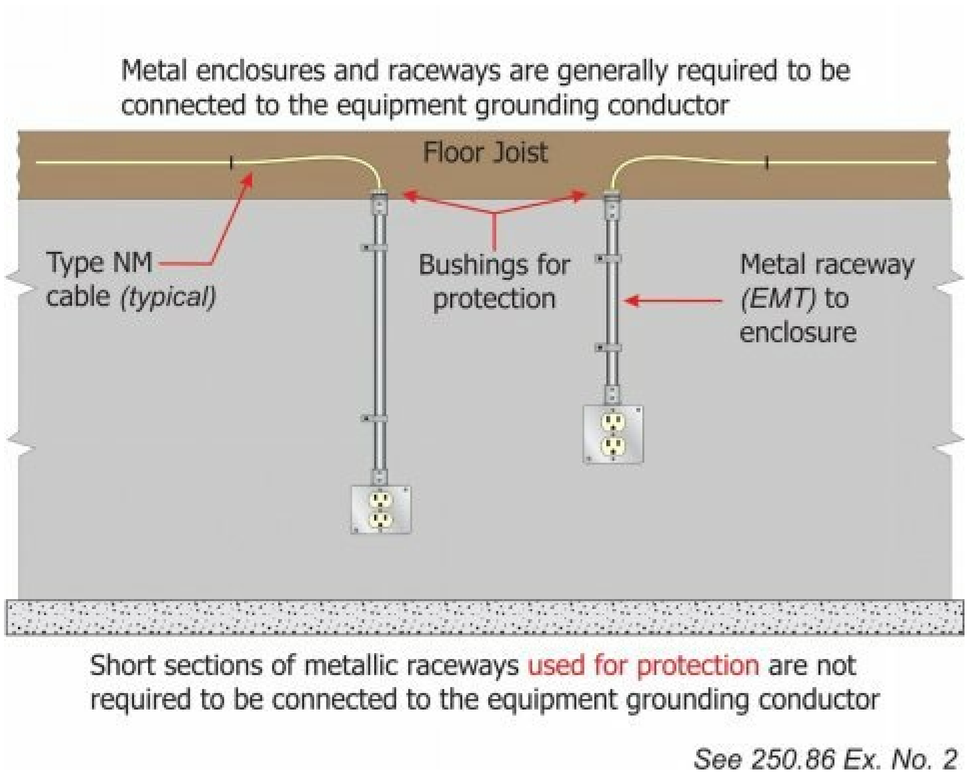


Figure 10.12 Short sections of metallic raceways

Where these short sections of raceways or cable armor are required to be grounded, 250.134 generally requires that they be grounded by connection to one of the equipment grounding conductors recognized by 250.118.

1– 8. NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA, 2016)

Review Questions

1. A reliable conductor to assure the required electrical conductivity between metal parts required to be electrically connected is defined as a ____.

1. grounding electrode conductor
2. grounded conductor
3. bonding conductor or jumper
4. identified conductor

2. The connection between two or more portions of the equipment grounding conductor is defined as ____.

1. equipment bonding jumper
2. grounded
3. neutral
4. main bonding jumper

3. Exposed normally non-current-carrying metal parts of fixed equipment supplied by or enclosing conductors or components that are likely to become energized must be connected to an equipment grounding conductor where within ____ vertically or ____ horizontally of ground or grounded metal objects, and subject to contact by persons.

1. 2.7 m (9 ft) - 1.8 m (6 ft)
2. 2.5 m (8 ft) - 1.5 m (5 ft)
3. 2.5 m (8 ft) - 2.5 m (8 ft)
4. 2.7 m (9 ft) - 2.7 m (9 ft)

4. Exposed non-current-carrying metal parts of equipment are required to be connected to the equipment grounding conductor where located in wet or damp locations and are not ____.

1. guarded
2. identified
3. shielded
4. isolated

5. Where other than short sections of metal enclosures are installed as per Section 250.86, exposed non-current-carrying metal parts of equipment added to existing installations are required to be connected to the equipment grounding conductor where supplied by any of the following wiring methods EXCEPT ____.

1. metal-clad, metal-sheathed cables
2. knob-and-tube wiring

3. other wiring methods that provide an equipment ground
4. approved metal wireways

6. Exposed non-current-carrying metal parts of equipment not required to be connected to the equipment grounding conductor include metal frames of electrically heated devices unless exempted by ____ in which case the frames must be permanently and effectively insulated from ground.

1. the product instructions
2. the local government
3. special permission
4. the code

7. Exposed non-current-carrying metal parts of equipment not required to be connected to the equipment grounding conductor include distribution apparatus, such as transformers and capacitor cases, that are mounted on wooden poles at a height of more than ____ from the ground or grade level.

1. a. 1.8 m (6 ft)
2. b. 2.5 m (8 ft)
3. c. 1.5 m (5 ft)
4. d. 2.1 m (7 ft)

8. Exposed non-current-carrying metal parts of equipment not required to be connected to the equipment grounding conductor include ____ equipment that is distinctively marked.

1. hospital
2. triple insulated
3. single insulated
4. double insulated

9. Where added to existing installations of open wire, knob-and-tube wiring, and nonmetallic-sheathed cable without an equipment grounding conductor, a metal enclosure for conductors run in lengths not to exceed 7.5 m (25 ft), free from probable contact with ground, grounded metal, metal lath, or other conductive material, and if guarded against contact by persons are ____.

1. required to be grounded to a grounded electrode
2. not required to be connected to the equipment grounding conductor
3. required to be protected by a GFCI
4. not permitted unless approved

10. Motor-operated water pumps including the submersible type are required to be connected to an equipment grounding conductor when they operate at ____.

1. any voltage
2. 120 volts
3. 240 volts
4. 208 volts

11. Of the connecting means included below, which is not a permitted method for connection of an equipment grounding conductor?

1. pressure connectors
2. lugs
3. clamps
4. soldered joints

12. Grounding connections for direct soil burial or concrete encasement____.

1. are only permitted when approved
2. shall be listed
3. are permitted on the load side of the service
4. are permitted on the line side of the service

13. Metal raceways that enclose service conductors are required to be connected to the grounded system conductor if the electrical system is grounded or to the grounding electrode conductor if the electrical system is not grounded unless it is ____.

1. installed on a pole
2. more than 2.5 m (8 ft) above the ground
3. a metal elbow in a PVC run covered by not less than 450 mm (18 in.) of earth
4. buried at a depth given in Table 300.5

14. All the following statements about grounding the frame of ranges and dryers are true EXCEPT_______.

1. A three-wire (insulated) wiring method with equipment grounding conductor is required for new installations.
2. The frame of the appliances is permitted to be grounded to the neutral conductor of the circuit in new installations.
3. A two-wire (insulated) wiring method with bare neutral conductor is permitted for existing installations.
4. New installations must be grounded to comply with Sections 250.138 and 250.140.

15. All the following statements about grounding of panelboards supplied by a feeder in the same building as the service are true EXCEPT_______.

1. The feeder must supply or provide an equipment grounding conductor.

2. The neutral conductor is permitted for grounding the enclosure.
3. The neutral conductor must connect to a neutral bar that is isolated from the enclosure.
4. An equipment grounding conductor must be connected to an equipment grounding terminal bar.

16. Generally, an equipment grounding conductor _______ in the same hole of a terminal bar, with a grounded (neutral) conductor.

1. is prohibited from terminating
2. is permitted to terminate
3. is required to be terminated
4. should be terminated

17. Isolated metal electrical equipment enclosures of grounded systems are _______to be grounded solely by connecting to a grounding electrode system.

1. permitted
2. recommended
3. not permitted
4. permitted if not greater than 25 ohms of resistance

18. Metal elbows are not required to be connected to the equipment grounding conductor where installed in nonmetallic raceways and isolated from possible contact by_______.

1. a minimum cover of 450 mm (18 in.)
2. encased in not less than 50 mm (2 in.) of concrete
3. neither a nor b
4. either a or b

Chapter 11
Clearing Ground Faults and Short Circuits

Objectives to understand

- Ground faults and circuit impedance
- Fundamentals of equipment grounding, circuit design, and test procedures
- Common elements in clearing ground faults and short circuits
- Sizing of equipment grounding conductors
- Purposes served by grounded conductor on grounding systems
- Conductor withstand ratings

Section 310.106(D) generally requires that conductors be insulated, but permits covered or bare conductors to be installed where specifically allowed in the Code. Ungrounded (phase or hot) conductors must be insulated for the applied voltage.

Typical voltage ratings of conductors are 300, 600, 1000, 2000, 5000 15,000, 25,000, and 35,000 volts. Conductors are also available with much higher rated insulations, although these are most often used for primary distribution of electrical energy rather than for premises wiring.

Definitions

Overcurrent: **"**Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault."[1]

Informational Note: **"**A current in excess of rating may be accommodated by certain equipment and conductors for a given set of conditions. Therefore, the rules for overcurrent protection are specific for particular situations."

Short Circuit: "An abnormal connection (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential. Note: The term *fault* or *short-circuit fault* is used to describe a short circuit." [2]

Ground Fault: "An unintentional, electrically conductive connection between an ungrounded conductor of an electrical circuit and the normally non–current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth." [3]

Overload: "Operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload." [4]

As can be seen by the above definitions, using the term *overcurrent* is inclusive of all three elements that make up overcurrent namely, short circuits, ground faults, and overloads. It is also important to note that short circuits and ground fault are due to a failure in the insulation system, either accidental or intentional that provide a relatively low-impedance path and therefore can have significant current flow. On the other hand, an *overload* is a function of the load or current being drawn by the load. An overload for a sustained time can lead to insulation failure which results in a ground fault or short circuits. Also what may start as a ground fault may propagate rapidly into a short circuit or what starts as a short circuit can rapidly include a ground fault. From the above it can be seen that when speaking of *overcurrent protective devices* the device provides a protection level for each of the elements of overcurrent. Conversely, such as with motor *short-circuit and ground-fault protection* the device is only intended to provide protection for these two elements, and overload protection must be provided by another device.

Table 310.104 provides conductor applications and insulations. It provides the trade name, type letter such as MI, maximum operating temperature and application provisions. It also gives the conductor insulation, size in American Wire Gage (AWG), thickness in mils and outer covering, if any.

Bare or covered conductors are permitted to be used in certain cases. Grounded service conductors are permitted to be uninsulated under the conditions given in 230.30 Exception. Service-entrance conductors are generally required to be insulated and used as provided in 230.41, but grounded conductors are permitted to be uninsulated in accordance with any of the exceptions to 230.41. On the other hand, wire type equipment grounding conductors are permitted to be insulated, covered or bare by 250.118(1) and 250.119. Some *Code* rules require insulated equipment grounding conductors for specific applications such as for certain electrical equipment associated with swimming pools and in patient care areas of certain health care facilities.

No hazard such as from a short circuit or a ground fault can exist on a distribution system unless there is an insulation failure of the ungrounded (hot) conductor; it follows that every precaution should be taken to provide the best possible insulation consistent with an economical installation. Good installation practices should be followed carefully to ensure that conductor insulation is not damaged during the installation process. Damage includes cuts, abrasions, or stretching of the insulation. Conductor insulation can be easily damaged by pulling operations, if raceways are not cleaned prior to the installation of conductors, if excessive bends are in the run, or where long or heavy pulls require the use of heavy-duty pulling equipment.

Further, if the conductor insulation breaks down, the hazard can exist only as long as the circuit remains energized. Every effort should be made to de-energize, as quickly as is practical, any circuit on which a short circuit or fault to ground has developed.

When first considered, the use of a copper or aluminum equipment grounding conductor, by itself, can seem to be an ideal method of getting a low-impedance path. It will in most cases, but that is not always the best choice. Each individual circuit must be studied in relation to the size and length of the circuit, the magnitude of the ground-fault current, the rating of its overcurrent device, and the size of the conductor enclosure(s) before any design or engineering conclusion can be reached.

Fundamentals of Equipment Grounding Circuit Design

To get low impedance of the equipment grounding system in an ac system, the circuit conductors and the equipment grounding conductor must generally be kept together at all times [see figure 11.1, 250.134(B) and 300.3(B)]. The equipment grounding conductor may, of course, be a copper or aluminum conductor. The equipment grounding conductor may also be the metal enclosure of the conductors such as conduit, cable armor or wireways, where the conduit, or cable armor, or wireway qualifies as an equipment grounding conductor in accordance with 250.118 for such use.

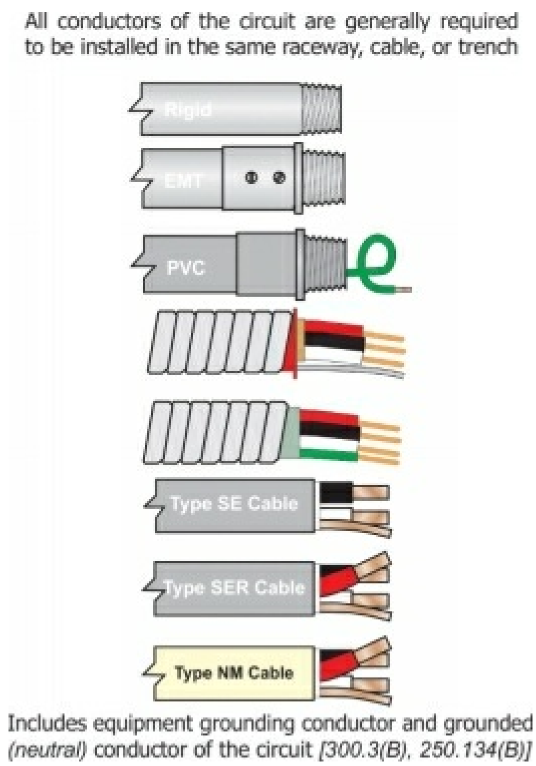


Figure 11.1 All circuit conductors generally are required to be installed together.

In an ac electrical distribution system, whether grounded or ungrounded, the inductive reactance is a key influence in directing the return current to a path closely paralleling the outgoing power conductor. In addition to resistance, an inductive reactance value is associated with every conductor in an acsystem. The inductive reactance (expressed in ohms) increases as the spacing between the conductors or the circuit is increased. This indicates that the inductive reactance of a current path closely paralleling the phase conductors offers lower total impedance to the ground-fault current than any other current path regardless of the other current path(s) having a lower resistance. Inductive reactance will be the predominate factor in determining current division in parallel ground return paths in high capacity or larger circuit constructions. This has been proven by actual tests where it is shown that the greater portion of the ground return currents take a path physically close to the outgoing current power conductor. [5]

Usually, the conduit or metallic raceway that encloses the conductors provides an excellent fault return path. The presence of magnetic material (iron or steel) in the power conductor enclosure (conduit or raceway) introduces additional inductive effects tending to confine the return ground currents within the magnetic enclosure. Installation of an external equipment grounding conductor for any significant length is generally not acceptable and in reality is quite ineffective. Where external bonding conductors are used, they are generally limited to a length of 2 m (6 ft.) Connections to nearby structural building steel members, in an effort to serve as an equipment grounding means, are equally ineffective as well as being prohibited by 250.136(A).

The intentional or accidental omission of using the metallic conductor enclosure as an equipment grounding conductor can lead to large induced voltages in nearby metallic structures, which can appear as a dangerous shock hazard or unwanted circulating currents. Only by the installation of an internal equipment grounding conductor, in parallel with the raceway, can the current carried by the raceway be reduced. Joints in conduit and raceways must be connected in a workmanlike manner and made wrenchtight, using proper tools, for the raceway to function effectively as an equipment grounding conductor and as an effective path for fault current.

Fault-Current Test Procedure

As illustrated in figure 11.2, a special installation of 65 mm (2½-inch) rigid steel conduit and 4/0 AWG copper conductors was made for this investigation. It was installed in a building previously used for short-circuit testing because the building had heavy steel column construction, and all columns were tied to an extensive grounding mat composed of 250-kcmil bare copper conductors. The conduit was supported on insulators throughout the 30 m (100 ft) length. The conduit was about 1.5 m (5 ft) from a line of building columns. The external 4/0 AWG conductor was spaced about 300 mm (1 ft) from the conduit on the side opposite the building columns.

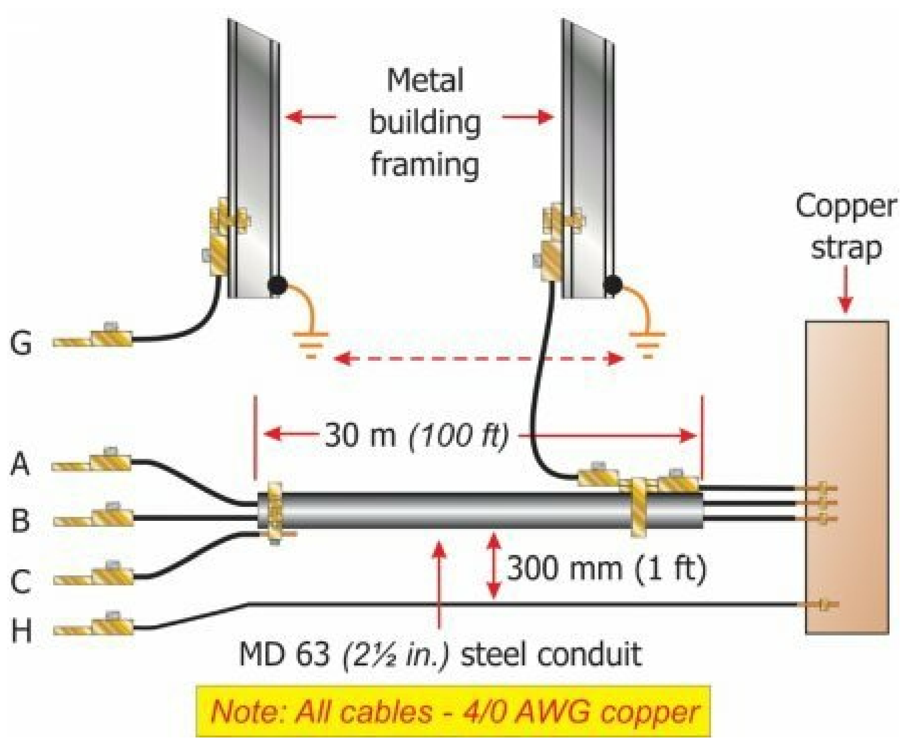


Figure 11.2 Ground current test procedure model diagram

The setup was intended to simulate a typical electrical feeder circuit, which can be found in many commercial and industrial plants. It allowed a study of a wide variety of equipment grounding arrangements. In every case the supply current was through the "A" conductor run through the conduit. The "B" conductor served as an internal equipment grounding conductor. The "C" conductor was connected to the run of steel metal conduit, the "G" conductor was connected to the steel building columns, and the "H" conductor was the external equipment grounding conductor spaced about 300 mm (1 ft) away from and parallel to the conduit. A copper shorting bar was used at the far end of the conduit. With this arrangement it was possible to simulate various fault conditions at the right end and to verify various fault-current return paths.

Tests Performed, Low-Current

One series of tests was made at low current of 200 and 350 amperes using an AC welding transformer as a source of 60-hertz power. At these low-current magnitudes, the current could be maintained for extended periods. Voltage measurements were made with high quality indicating meters. Current measurements were made with a clip-on ammeter.

Tests Performed, High Current

A second series of tests was made at high current, approximately 10,000 amperes using a 450 kVA, 3-phase, 60-hertz transformer with a 600-volt secondary as a source of power. Switching was done at the 13,800 primary voltage. An induction relay was used to control the duration of current to about ¼ second. An oscilloscope was used for all measurements of current and voltage.

Fault-Current Test Results

The results of the tests performed are shown in Table 11.1. The test number (for example, A2) is for reference purposes. The next two columns show the conductor connections used to determine the current path (for example, out on A and return on C). Next, the current values are shown, first the total input current through conductor A (350), and next the return current through the conduit (350) and its percentage of the total (100). The other columns with an “I” heading, along with a subscript indicating the circuit, show the amount of current returning over other possible paths.

Current Magnitudes

Current Flow				Ic					Voltage Magnitudes					
Test No.	Out On	Return On	IA Total	Amperes	Percent of Total	I_B	I_H	I_G	E_{AC}	E_{CG}	E_{AB}	E_{AH}	E_{AG}	E_{GB}
						Low-Current Tests								
A1	A	B	350	0	0	350	0	0	2.47	0	4.85	0	0	0
A2	A	C	350	350	100	0	0	0	15.9	0.45	2.50	0	0	0
A3	A	C	200	200	100	0	0	0	9.05	0.15	1.51	0	0	0
A4	A	CH	350	340	97	0	12	0	16.0	0.05	2.55	0	0	0
A5	A	CH	200	190	95	0	8	0	9.13	nil	1.55	0	0	0
A6	A	CG	350	340	97	0	0	12	14.6	0	2.54	14.4	0	0
A7	A	CG	200	180	90	0	0	8	9.5	0	1.50	9.4	0	0
A8	A	CB	350	62	18	290	0	0	4.55	nil	4.55	0	0	0
A9	A	CB	200	40	20	150	0	0	2.68	nil	2.68	0	0	0
A10	A	GH	350	0	0	0	160	160	14.0	12.5	2.50	26.4	26.4	24.6
A11	A	GH	200	0	0	0	98	98	9.2	8.1	1.50	17.1	17.1	15.1
						High-Current Tests								
B2	A	C	11,200	11,200	100	0	0	0	168	36*	0	0	0	0
B3	A	C	11,070	11,070	100	0	0	0	173	38*	0	0	0	0
B4	A	CH	11,070	11,200	101	0	1,140	0	173	18*	0	0	0	0
B5	A	CH	11,080	11,090	100	0	1,220	0	173	17*	0	0	0	0
B6	A	CG	10,830	10,770	99	0	0	1,080	168	0	71	0	0	0
B7	A	CG	10,910	10,780	99	0	0	1,145	173	9*	0	0	0	0
B8	A	CB	11,620	5,810	50	5,660	0	0	0	27*	0	0	155	0
B9	A	CB	11,380	6,070	53	5,620	0	0	146	25*	0	0	0	0
B10	A	GH	8,710	0	0	0	4,300	4,500	0	146	0	0	268	0

*Distorted wave shape. Tabulated values are crest / $\sqrt{2}$

Table 11.1 Measured Electrical Current Quantities

The analysis conclusively confirms that only by the use of an internal equipment grounding conductor can any sizable fraction of the return current be diverted from the raceway. In spite of the extremely low resistance of the building structural frame, it was ineffective in reducing the magnitude of the return current in the conduit (see tests A6, A7, B6 and B7).

Some interesting secondary effects were observed in the course of the tests. The first high-current test produced a shower of sparks from about half of the couplings in the conduit run. From one came a “blowtorch” stream of sparks that burned out many of the threads. Several small fires ignited nearby combustible material, which would have caused a serious fire hazard if not promptly extinguished.

The conduit run had been installed by a crew regularly engaged in such work, and they gave assurance that the joints had been tightened per normal practice and perhaps a little more. A short 4/0 copper (wire) jumper was bridged around this joint but, even so, some sparks continued to be expelled from this coupling on subsequent tests. The other couplings threw no more sparks during subsequent tests. Apparently, small tack welds had occurred on the first test.

In one high-current test, the conduit termination was altered to simulate a connection to a steel cabinet or junction box (see figure 11.3). The bushing was applied finger-tight. In one test, with about 11,000 amperes for about ¼ second, a fan-shaped shower of sparks occurred parallel to the plate. In the process, a weld resulted and the parts were separated only with considerable difficulty, with the use of wrenches and a hammer. This suggested that a repeat shot (of current) would have produced no disturbance (shower of sparks).

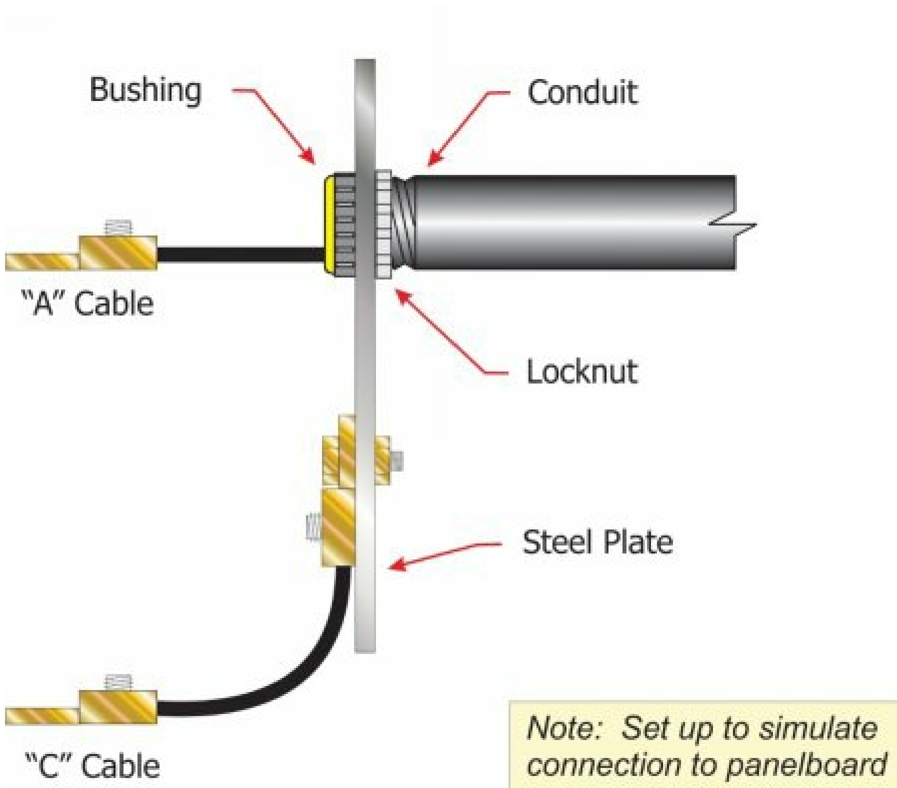


Figure 11.3 Alternate termination of "C" cable

"During high-current test B10 (conduit circuit open), a shower of sparks was observed at an intermediate building column. Careful inspection disclosed that the origin was at a spot at which a water pipe passed through an opening cut in the web of the steel beam involved. Here is evidence of the objectionable effects of forcing the short-circuit current to seek return paths remote from the outgoing conductor. The large spacing between outgoing and returning current creates a powerful magnetic field which extends far out in space around the current-carrying conductors." [6]

Fault-Current Study Circuit Analysis

"The reactance of the circuit including the B conductor will be the lowest. Next will be the innermost tube of the conduit, followed by others in successive order until the outer tube is reached. The inductance of these tubular elements of the steel conduit assumes unusual importance because of the high magnetic permeability. Next in spacing (impedance) is the external [equipment] grounding conductor (H conductor) and last, the structural members of the building frame and their interconnecting grounding conductors buried below floor level." [7]

"In test B10, both the exterior [equipment] grounding conductor (H conductor) and the building frame (G terminal) were connected to provide parallel paths for the return current, but the conduit circuit was left open (C terminal not connected). The test results clearly evidence the powerful forces tending to maintain current in the conduit circuit. Note that across the open connections at the C terminal, a voltage of 146 volts (or, more significantly, over 50 percent of the impressed driving voltage) is required to force the current to return via the H conductor and the building frame in parallel. Such a voltage could be a serious shock hazard.

"Furthermore, unless the conduit was well insulated throughout its entire length (which is usually impossible or impractical in typical commercial or industrial installations), there would be a significant number of sparks at various points to constitute a serious fire hazard. It was during this test that a shower of sparks occurred between magnetic members in the building system that was caused simply by the strong magnetic field extending far out from the power conductors." [8]

Maximum Impedance of Ground-Fault Circuit

Overcurrent Device *(Amps)*	Maximum Z of Ground-Fault Circuit in Ohms Includes Fault Impedance
60	0.4
100	0.24
200	1.12
400	0.06
600	0.04
800	0.03
1200	0.02
1600	0.015
2000	0.012
2500	0.0096
3000	0.008
4000	0.006

Values based on the maximum impedance for the full ground-fault circuit assuming a 120 volts to ground system and a trip level 5 times the over-current device rating

Table 11.2 Maximum impedance of ground-fault circuit

Conclusions on Fault-Current Path Study

The significance of this investigation clearly points to the conclusions presented earlier. Effective use of the conduit or raceway in the equipment-grounding system is paramount. Additional work is needed to develop joints which will not “throw fire” during faults. Improving effectiveness requires greater conductivity in the conductor enclosure or the use of an internal (equipment) grounding conductor. Grounding electrode conductors connecting the building structure to grounding electrodes (connection to earth) are needed to convey lightning currents or similar currents seeking a path to earth, but these conductors will play a negligible part in the performance of the equipment grounding system. Of course, the importance of proper equipment grounding becomes greater with the larger size feeder circuits and the availability of higher short circuit currents.

Common Elements of Fault-Current Path

Clearing faults involves one or two parts, depending on whether the supply system is grounded or ungrounded. In a grounded distribution system, there are two parts: (a) the grounded system conductor and (b) the equipment and circuit conductor enclosure grounding system. In an ungrounded system, the grounding system covers only (b) the equipment and circuit conductor enclosure grounding system.

Effective Path for Fault Current

To have an effective path for fault current for both grounded systems and ungrounded systems, the fault-current path must: (1) be electrically continuous; (2) must have ample capacity to conduct safely any fault currents likely to be imposed on it; and (3) have lowest possible impedance to limit the voltage to ground and (4) to facilitate the operation of overcurrent protective devices in the circuit [see 250.4(A)(5) and 250.4(B)(4)]. The definition of *effective ground-fault current path* also provides this same information relative to the function of this path [see 250.2 Definition].

"Impedance sufficiently low" means, for all practical purposes, that the equipment grounding path and the circuit conductors for an ac system must always be within the same metallic enclosure such as a conduit, wireway or armored cable. The metallic enclosure (such as a conduit or cable) under certain conditions may be used to provide the equipment grounding path for the circuit conductors within it. In addition, where a nonmetallic raceway wiring method is used for an ac system, all the circuit conductors, including the equipment grounding conductor, must be in the same raceway.

The *Code* gives no prescriptive maximum impedance of the ground-fault circuit for grounded or ungrounded systems but states in 250.4(A)(5) a performance requirement that it shall be sufficiently low to facilitate the operation of the circuit-protective devices. This path should have impedance no greater than the level which allows the circuit breaker or fuse to reach its instantaneous pickup operating range. Table 11.2 provides some examples for the maximum impedance for the full ground-fault circuit assuming a 120 volts to ground system and a trip level five times the overcurrent device rating. This will cause the overcurrent device to operate quickly to remove the fault from the system. Any fault current less than the instantaneous operating value will extend or delay, by some value, the opening time of the overcurrent device.

Every manufacturer of circuit breakers and fuses publishes operating characteristic or time-current curves for their products (for example, see figures 11.4 and 11.5). These trip curves should be carefully reviewed to be certain the ground-fault path has an impedance low enough to allow the overcurrent device to operate quickly to reduce thermal damage to the circuit and equipment. As can be seen by reviewing these trip curves, circuit breakers have the same trip curve for single-, double- or three-pole configurations. In addition, the same family of circuit breakers will have slightly different trip curves for different ampere-rated circuit breakers. To determine the current needed for best fault protection look for the multiple of the circuit breaker rating at which it reaches its instantaneous pickup rating. At this trip level there is no intentional time delay in the operation of the circuit breaker. The instantaneous pickup trip level is where the trip curve is a vertical line.

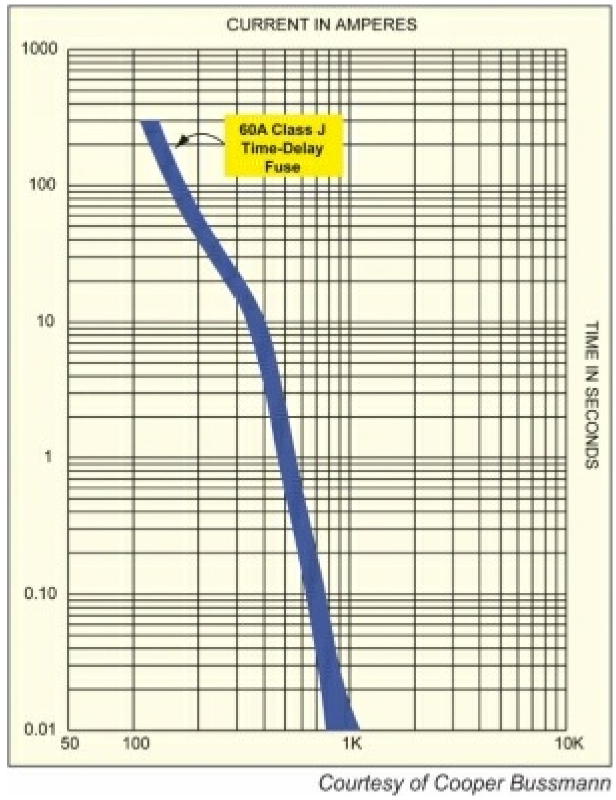


Figure 11.4 Fuse Curve Graph. Courtesy of Eaton Cooper Bussmann

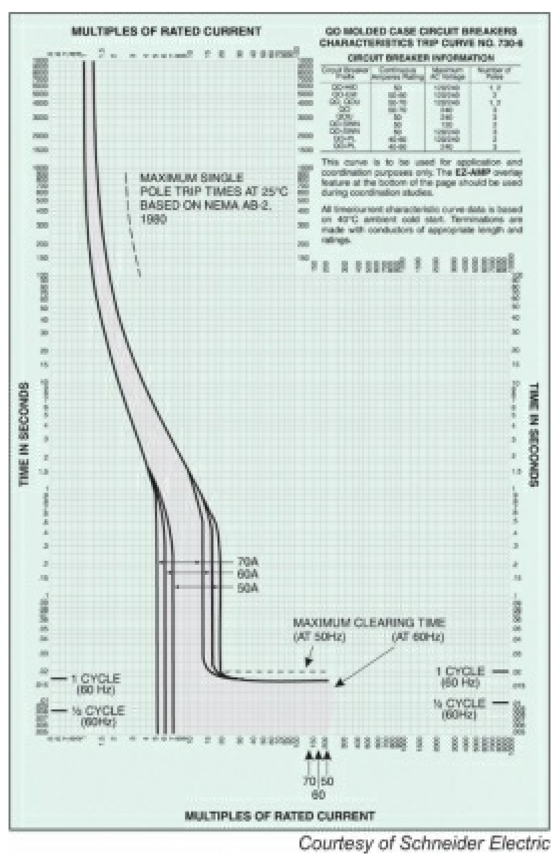


Figure 11.5 Circuit Breaker Trip Curves Graph
Courtesy of Schneider Electric (Square D)

A similar review of the fuse operating characteristics chart should be performed to select a ground-fault circuit that will result in instantaneous operation of the fuse. The time-current characteristic curve of such fuses starting from a value of from five to six times the rating of the fuse indicates a clearing time of about one second and a time of well below one cycle for values of 50 times fuse rating. A further study indicates that such high-interrupting capacity current-limiting fuses have a pronounced current-limiting effect at values as high as fifty times the fuse rating.

Some engineering designs may incorporate the concept of a maximum impedance so the ground-fault current is at least five times the rating of the overcurrent device to provide device operation near the instantaneous trip values. For example, referring to figure 11-5, if the overcurrent device is 70 amperes, there needs to be not less than 350 amperes (5 on the "X" axis of the time-current curve) of current in the circuit for it to open the faulted circuit in a reasonable time. For some overcurrent devices, a current of five times the device rating might not reach the instantaneous trip range of the device. See figure 11-4 where five times the 60-amp fuse rating, or 300 amps, has a fuse clearing time of approximately 15 to 25 seconds. For this fuse a ground-fault current level of thirteen times the fuse rating, 800 amps, is needed for instantaneous tripping. In most ground fault situations this level of current is easily achieved. Generally, the longer the excessive current exists in the circuit, the greater the thermal and mechanical stress to the conductor insulation.

Clearing Short Circuits

The method employed for clearing a short circuit is the same regardless of whether the system is grounded or ungrounded. Essentially, it involves placing an overcurrent device in series with each ungrounded circuit conductor (see figure 11.6).

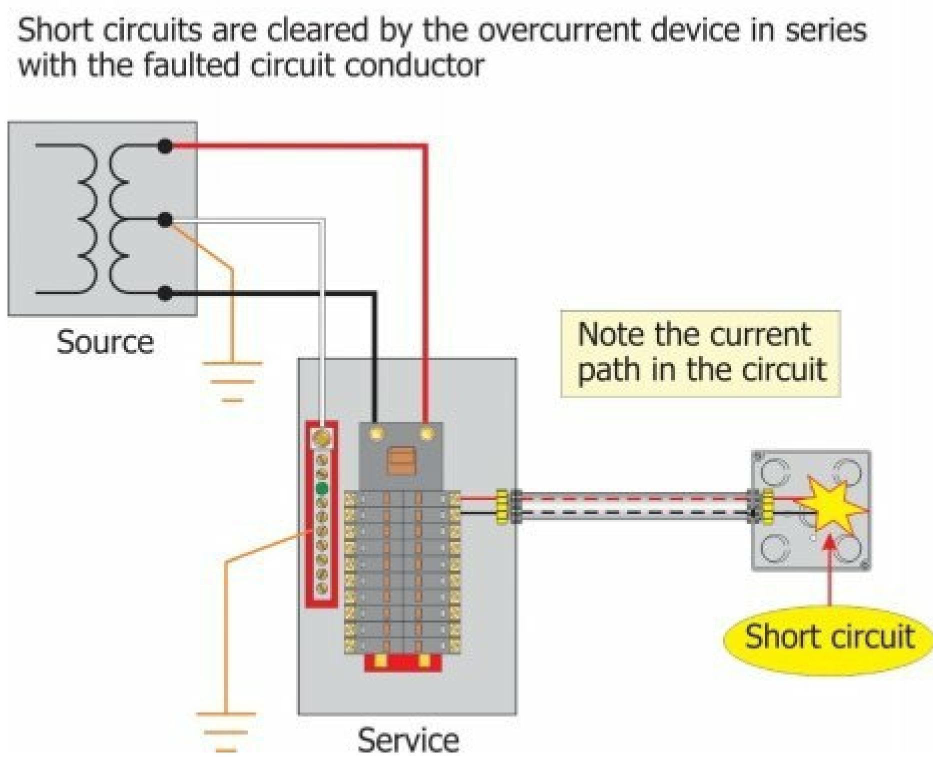


Figure 11.6 Clearing short circuits

In the event of a *short circuit*, which is a fault from conductor to conductor, the words “as quickly as is practical” means a very short period of time down to as low as a fraction of a cycle (4 to 8 milliseconds) depending on the amount of short-circuit current and the characteristics of the overcurrent device. Short circuits typically have fault paths with very low impedance. The high-interrupting capacity current-limiting fuse does that automatically within virtually all ranges of short-circuit current values. In addition, current-limiting circuit breakers and circuit breaker current limiters are available from a wide variety of manufacturers. Where properly applied, these current-limiting devices significantly reduce the thermal and mechanical damage to electrical equipment in the event of a short circuit.

Information for current-limiting fuses and their correct application are covered in Underwriters Laboratories’ *Productspec* under the category code of JCQR. This section reads in part: “The term *current limiting* indicates that a fuse, when tested on a circuit capable of delivering a specific short-circuit current (RMS amperes symmetrical) at rated voltage, will start to melt within 90 electrical degrees and will clear the circuit within 180 electrical degrees (½ cycle).

“Because the time required for a fuse to melt is dependent on the available current of the circuit, a fuse that may be current-limiting when subjected to a specific short-circuit current (rms amperes symmetrical) may not be current-limiting on a circuit of lower maximum available current.” [9]

A current-limiting circuit breaker is defined in the Underwriters Laboratories' *Productspec* under the category code of DIVQ information as, "A current-limiting circuit breaker is one that does not employ a fusible element and that when operating within its current-limiting range, limits the let-through I^2t (current squared time) to a value less than the I^2t of a ½ cycle wave of the symmetrical prospective current…. Current-limiting circuit breakers are marked 'current-limiting' and are marked either to indicate the let-through characteristics or to indicate where such information may be obtained." [10]

Circuit breaker current limiters are covered in Underwriters Laboratories' *Productspec*) under the category code of DIRW. They are described as "Circuit breaker current limiters are designed to be used in conjunction with specific circuit breakers and to be directly connected to the load terminals of the circuit breakers. They contain fusible elements which function only to increase the fault current interrupting ability of the combination which is intended for use in the same manner as circuit breakers when installed at the service and as branch circuit protection. The limiters are rated 600 V or less." [11]

It is vital to carefully follow manufacturers' instructions when applying current-limiting fuses or circuit breakers.

In some cases, depending on the available fault current at the point of the fault, this equipment might not provide current limitation. This is due to the inverse time nature of these overcurrent devices. Inverse time means that as the amount of current through the device increases, the operating time of the device reduces. Overcurrent devices see fault current at lower operating ranges as a load and react much slower than at their current-limiting range.

Series Combination Ratings

Some installations of fuses or circuit breakers are installed in a series combination configuration, that is, two or more fuses or circuit breakers are in series for the circuit that open together under short circuit conditions. These devices that have been tested for their operating compatibility may be marked by the manufacturers with a series-combination rating. In this case, usually the downstream overcurrent device interrupt rating is below the fault current that is available at its line terminals, while the overcurrent device closest to the source has an interrupting rating at or above the fault current that is available at its line terminals.

Where a series-rated system is installed, only the equipment that has been tested to determine its suitability can be installed in this manner. Suitability is determined by reference to manufacturer's identification of components on decals located on the equipment. For additional information, see "Interplay of Energies in Circuit Breaker and Fuse Combinations." [12] Whether a fault current is a short circuit or a ground fault, the overcurrent devices ahead of the point of fault will see the entire fault current. Placing an overcurrent protective device at the point the conductor receives its supply, as required by 240.21, will provide the short-circuit protection that is necessary. The rating of the overcurrent device is based upon 240.4 and the ratings of standard overcurrent protective devices given in 240.6. The basic requirement is that conductors be protected in accordance with their rated ampacity in accordance with 310.15.

Clearing Ground Faults

A ground-fault circuit is different than a short circuit. In a ground fault, there can be such a high impedance of the faulted circuit that the controlling factor of current is the impedance of the ground-fault circuit. This can be because the ground fault is an arcing fault with a high impedance in the arc itself or for circuits of larger ampacity, for example above 100 amps, the biggest part of the impedance may be the ground fault return path(s). For the circuits with larger ampacities, this is because the equipment grounding conductor is smaller than the ungrounded conductors supplying the ground fault. In this case, the only part the available short-circuit capacity plays is in its ability to maintain voltage. In some circuits, the amount of current in a ground-fault circuit is not dependent on the available capacity of the system, other than its ability to maintain full voltage during a ground fault (see figure 11.7).

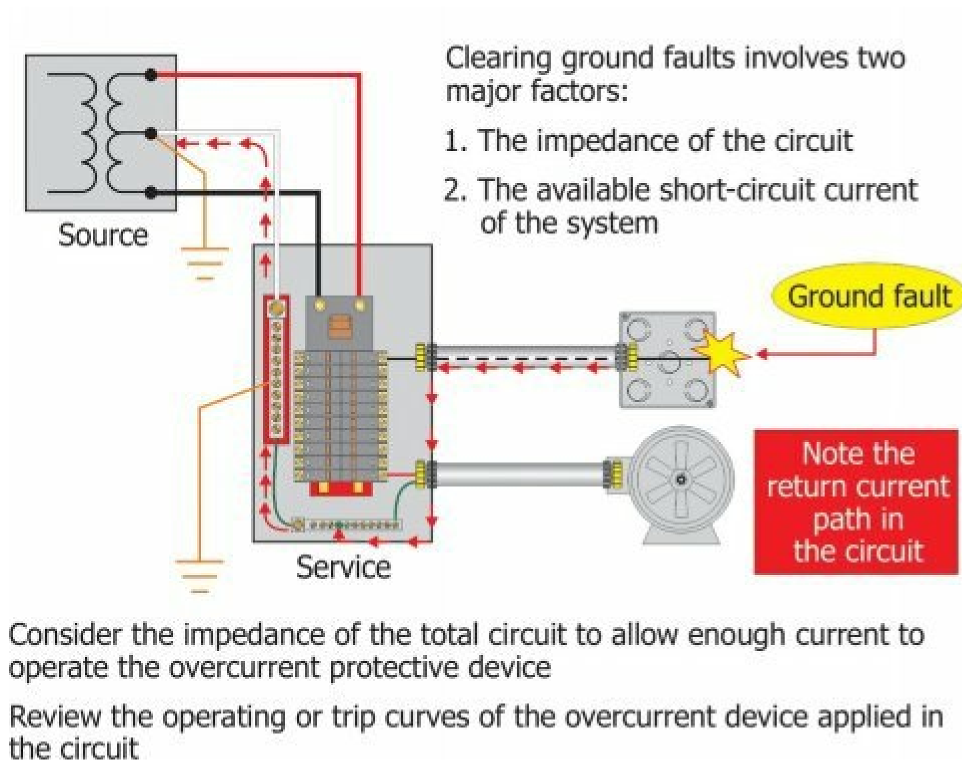


Figure 11.7 Clearing ground faults

When it comes to clearing a ground fault, two things control the current, these are: (1) the impedance of the circuit, and (2) the available short-circuit current of the system.

A relatively large voltage drop can be tolerated in the equipment grounding conductor. The impedance of the complete ground-fault circuit, from the source to the point of fault and back to the source, should never be higher than what would permit the minimum amount of current necessary for the overcurrent device to operate within its instantaneous range [review the operating characteristics time-current curve for the overcurrent device to determine the correct value] (see figures 11.4 and 11.5).

This will provide a factor of safety to allow for the variable impedance at the point of the fault. Some overcurrent devices operate at their instantaneous current range at about five times the rating of the overcurrent device. For example, some 50-ampere overcurrent devices have an instantaneous trip rating of about 250 amperes. In other cases, a 50-ampere device may have an instantaneous rating from six to ten times the rating of the overcurrent device. This is one reason to always check the time-current characteristic curve and when doing replacements to use devices matching the original.

Selective Coordination

Good electrical system designs generally involve good coordination between all levels of overcurrent protection to localize overcurrent or ground-fault conditions to the offending circuit. There are cases where the *Code* specifically requires selective coordination of the overcurrent devices. A definition, as modified in the 2014 *NEC*, of the term *selective coordination* is provided in Article 100 and reads as follows:

Coordination (selective). "Localization of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the selection and installation of overcurrent protective devices and their ratings or settings for the full range of available overcurrents, from overload to the maximum available fault current, and for the full range of overcurrent protective device opening times associated with those overcurrents."

Section 240.12 specifically requires electrical system coordination where an orderly shutdown is required to minimize hazard(s) to personnel and equipment. This system of coordination can be accomplished by either coordinated short-circuit protection or by overload indication or monitoring systems. Another requirement for selective coordination for the overcurrent devices of a system is provided in Article 700, which covers the requirements for emergency systems. Emergency system overcurrent protective devices are required to be selectively coordinated with all supply side over-current devices [see 700.32]. There are other requirements for selective coordination found in Articles 620, 645, 695, 701 and 708.

As indicated earlier in this chapter, good system design meeting the applicable requirements of the *Code* requires a careful study and selection of the overcurrent protective devices and ensuring an effective ground-fault current path is provided to facilitate overcurrent device operation at the local offending circuit level. An example of a system that has not been coordinated properly would be where a ground fault on a 30-ampere branch circuit causes a 2000-ampere ground-fault protective equipment (GFPE) device in a main switchboard to operate before the 30-ampere circuit breaker can open.

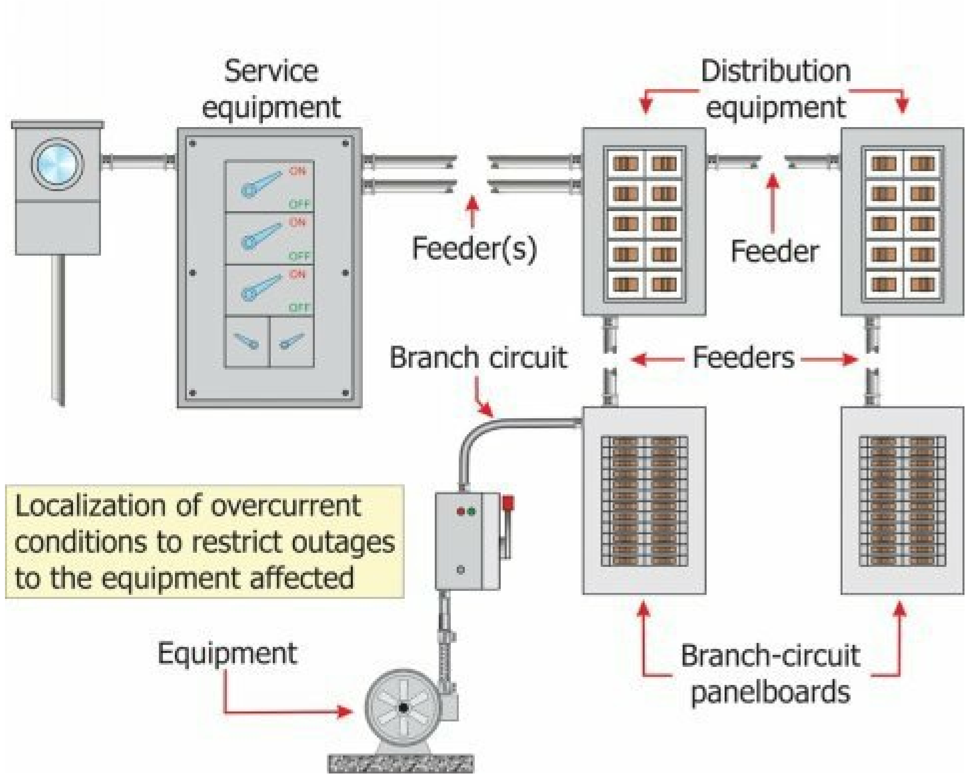


Figure 11.8 Selective coordination of overcurrent devices

Clearing Faults in Service Equipment

The service equipment enclosure is probably one of the most vulnerable locations for ground faults to occur. There is no *Code*-controlled overcurrent protection for the service conductors on the line side of the service disconnect and overcurrent device, only short-circuit levels of protection are provided by the serving utility's transformer primary overcurrent protection. Overload protection is provided by the service overcurrent device in series with the service-entrance conductors. This is one of the main reasons the *Code* requires the service disconnecting means to be located outside of the building, or, if installed inside, nearest the point of entrance of the service conductors into the building. This limits the length of service conductors without typical overcurrent protection inside the building.

If a ground fault develops at a point on the line side of the service overcurrent device, then that fault can only be cleared by the primary overcurrent device on the supply side of the utility transformer. This protection is the primary fuses or cutouts for the transformer which can be many times the rating of the secondary conductors. In many cases, a ground fault on the line side of the service will not clear through the primary overcurrent devices and can only clear by developing into a short circuit or by burning itself clear. This can easily result in a main service switchboard burn down.

If the electrical equipment on the line side of the service is not properly bonded (as discussed in chapters 4 and 5 of this text) and a properly sized main bonding jumper installed, it is highly unlikely that there will be enough current in the path to clear the ground fault through the overcurrent devices on the line side of the utility transformer (see figure 11.9).

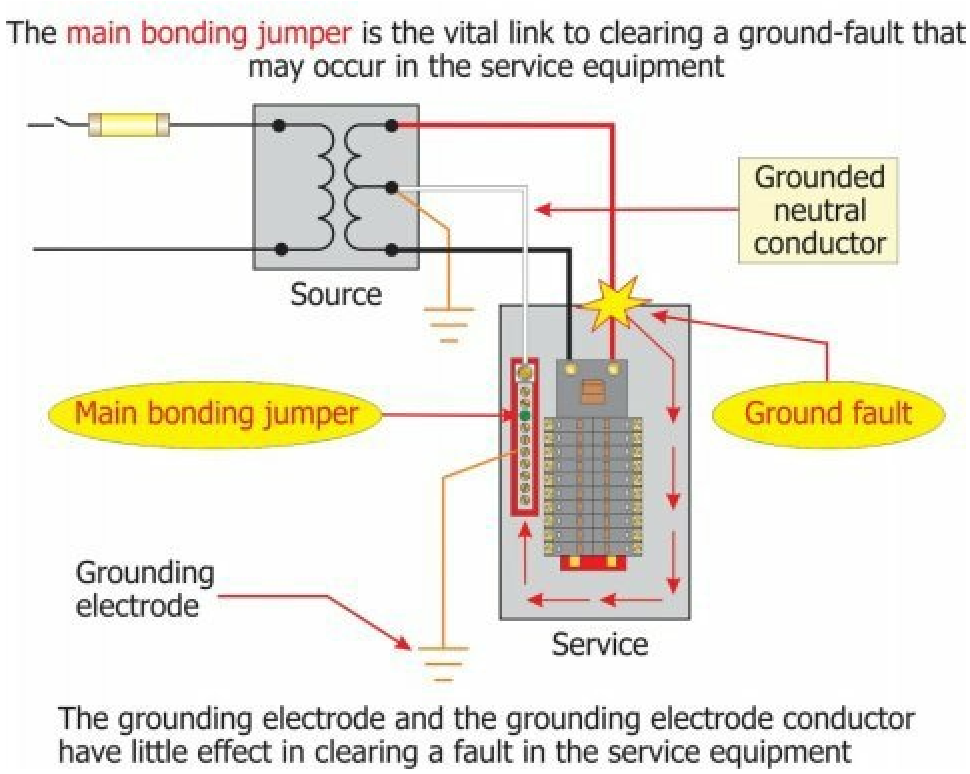


Figure 11.9 Clearing faults in service equipment

Purposes Served by the Grounded Conductor (Often the Neutral Conductor) on a Grounded System

For maximum safety and to comply with 250.24(C) and 250.186, the neutral conductor or grounded conductor must be installed from a grounded system power supply source (transformer) to all services and be bonded to each service disconnecting means enclosure (see figure 11.10). This is required even though the service might supply only line-to-line loads [see 250.24(C) and 250.28].

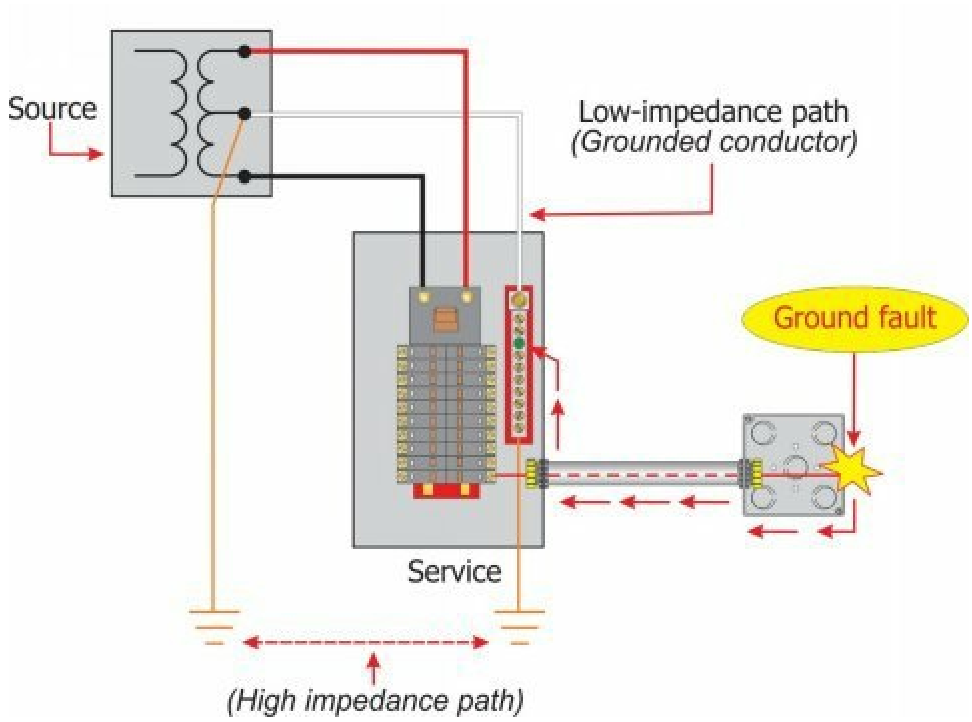


Figure 11.10 Grounded conductor run to service equipment as required by 250.24(C)

The grounded conductor of any grounded system serves two main purposes. First, it permits utilization of power at line-to-neutral voltage, and therefore serves as a current-carrying conductor to carry any unbalanced current back to the source. Second, it plays a vital part in providing a low-impedance path for ground-fault currents to facilitate the operation of the overcurrent devices in the circuit, as required by 250.4(A)(5).

The grounded conductor (neutral conductor) provides the lowest impedance return path for fault currents to the power supply source neutral point as can be traced in figure 11-10. If the neutral is not needed for voltage requirements, it still must be run to the service, bonded to the service disconnecting means enclosure, and connected to the equipment grounding conductor at the service. In this application, the neutral conductor no longer serves as a neutral conductor but as a grounded conductor and ground-fault return path. If this is not done, it is difficult, if not impossible, to clear a ground fault on the system.

Analysis of Clearing Ground Faults

The following examples illustrate a simple electrical system and help analyze the conditions existing in the event of a ground fault. In the first case, the neutral is installed from a grounded system where it is connected to the service equipment. In the second example, the grounded system (service) conductor has not been installed from the system to the service disconnecting means.

Grounded (Neutral) Conductor Installed

In figure 11.10, the neutral of the system serving as the grounded conductor is carried to the service equipment and bonded to the enclosure and equipment grounding conductor to provide a low-impedance path directly to the transformer. Here it can be seen that ground-fault current does not have to go through the earth to complete the circuit, but will go through the grounded service conductor, which is a low impedance path. This will very likely permit sufficient current to operate the overcurrent device. The parallel path through the grounding electrode conductors and the grounding electrodes and the earth still exists. The grounded service conductor, forming a relatively low impedance path, will carry most of the fault current, generally 90 percent or more in most cases.

It is obvious, then, that to get all the protection afforded by a grounded system, the grounded system conductor must be run to the service and must be bonded to the disconnect enclosure and equipment grounding conductor even though the neutral conductor is not needed for serving any load. For the same reason, where the neutral is used for voltage requirements, the neutral size should be based not only on the neutral load demands [220.61] but also on the basis of the service-entrance conductor size and the amount of fault current necessary to operate the overcurrent devices. [250.24(C)]

Figure 11.11 shows a 120/240-volt single-phase grounded system where the entire load is supplied at 240 volts. A grounding electrode conductor is properly connected to a low-resistance grounding electrode, for example, the metal water supply system, and bonded to the equipment grounding conductors, all in accordance with the requirements of the *Code* (prior to the 1962 *Code*). However, the neutral conductor is not run to the service equipment since all power utilization is at 240 volts only. For serving the load, the neutral has no useful purpose, and it would at first appear as if it could be omitted.

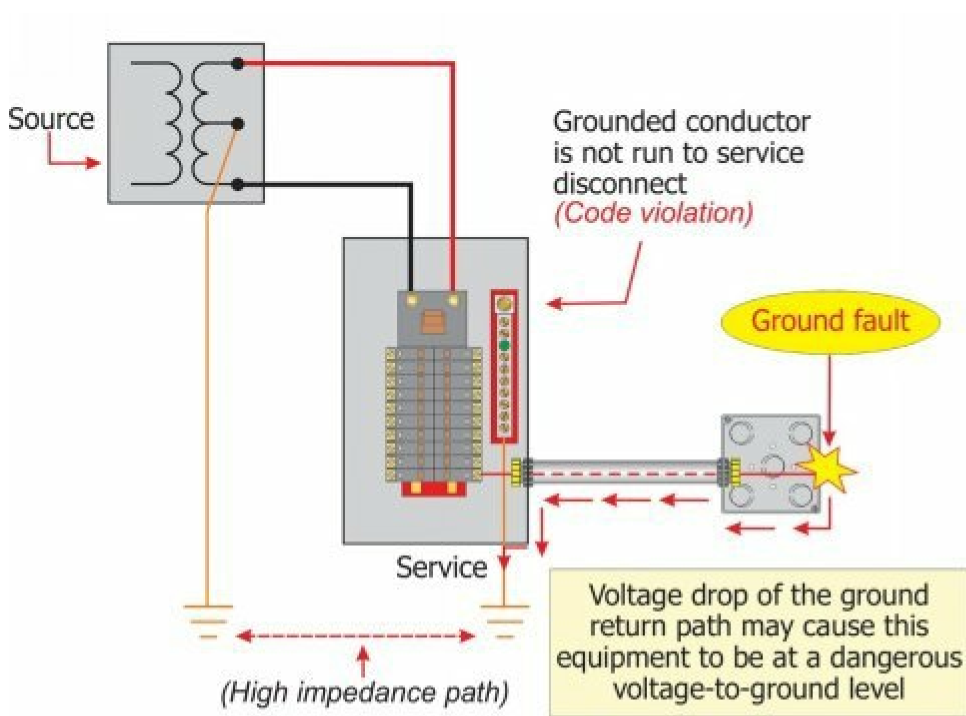


Figure 11.11 Grounded service conductor is not run to service equipment.

From the standpoint of limiting the voltage between equipment and ground under normal conditions and from the standpoint of utilization of power at 240 volts, the circuit, as shown in figure 11.11, will function correctly, provided that the insulation remains intact and no ground faults occur on the system.

If, however, a ground fault occurs in the equipment, as illustrated in figure 11.11, due to insulation failure, the voltage between equipment and ground will rise considerably. Starting at the point of the ground-fault, first is the impedance of the fault, then the conduit itself becomes a conductor in the fault-current circuit, then the grounding electrode conductor and the grounding electrode at the service. However, the ground-fault current must then travel from the grounding electrode through the earth itself to the point where the neutral is grounded at the transformer by its separate grounding electrode and grounding electrode conductor. Finally, the ground-fault current travels through the transformer and back to the service, through the overcurrent device to the point of the ground-fault.

A study of the fault circuit as diagrammatically represented in figure 11.11 shows that it would be unlikely to have an impedance of less than 22 ohms as the sum of all the impedances shown.

That is an optimistically low value at best. The maximum current in this circuit is 5.5 amperes for the 120/240-volt circuit shown (120 volts ÷ 22 ohms = 5.5 amperes). With a 100-ampere service and 20-ampere overcurrent device, it is obvious that neither of the overcurrent devices would operate. A serious shock hazard, as well as fire hazard, will exist until the circuit is manually opened. If the circuit was opened because of being properly grounded, then the only period of time a shock hazard would exist would be for the duration of the fault. The fire hazard, as well as shock hazard, would be reduced to a relatively short period of time.

When a fault occurs on a system, it is only during the period while the fault exists that a potential hazard is present. It is of the utmost safety importance that the fault clearing time be held to the shortest practical period of time.

For the installation as shown in figure 11.11, the fault will not clear and can exist for minutes, hours or even days before it is recognized. Further, that recognition can be from observing a fire, or from noting that a victim has received a shock, which sometimes can even be fatal. It is a matter of record that many serious, and sometimes fatal, accidents have resulted from faults that were not cleared promptly because the system was not properly grounded.

If the neutral at the utility transformer were grounded to the same water pipe system as the service (may not be too likely), then the resistance of the fault path would be appreciably decreased. But because of the wide separation between the service conductors and the water pipe, the reactance and, therefore, the impedance of the fault circuit would remain high. The probabilities are that the fault current would not reach a high enough value to operate the overcurrent device. Again, fire and damage to equipment would continue until the circuit was manually opened. To improve the safety of such a system, a low-impedance path must be provided to carry enough current to clear the circuit by the overcurrent devices.

Three-Phase Services

Identical reasoning to that used for single-phase systems may be applied to any multi-wire, multi-phase grounded system. Any 3-phase power supply taken from such a grounded transformer bank must have the neutral or grounded conductor brought into each service to satisfy the requirements of 250.24(C). A change in the 2014 *NEC* added a new section 250.186 that now provides the requirements to provide the grounded conductor (neutral) or a supply side bonding jumper from the utility to the service equipment for services over 1000 volts. This is true regardless of whether or not there is neutral load at the service. The grounded conductor provides a low-impedance path for fault current to return to the source.

Open System

The above statements applying to maximum ground-fault currents would not apply to an open system. If there were no metallic enclosures, the impedance of the ground-fault circuit would be much lower. Accordingly, greater ground-fault currents can be expected in actual practice in an open or nonmetallic installation. However, since most systems of 600 volts or less are metal enclosed, there would not be such high ground-fault currents in those systems. For open systems, it is vital that the equipment grounding conductor be run with the circuit conductors to maintain a low impedance ground-fault path.

Recommended Length of Conduit for Use as Equipment Grounding Means

In Eustace Soares' original work, he calculated by hand the limitations on length of metal conduit and tubing. Part of the results from this work is contained in the tables located in chapter 22 of this text. In 1993, this work was validated by modern computer modeling techniques and actual testing. The *Code* currently places no restriction on the size or length of rigid metal, intermediate metal conduit or electrical metallic tubing where used as an equipment grounding conductor. Independent tests have shown that consideration must be given to both size and length of conduit.

Extensive work to determine the maximum safe length of conduit or tubing to serve as an equipment grounding conductor has been done by the School of Electrical and Computer Engineering at the Georgia Institute of Technology in Atlanta, Georgia.[13] Computer software has been developed which will allow the calculation of just metallic conduit or tubing and almost any combination of metallic conduit or tubing with wire type equipment grounding conductors for use in the ground-return path. This software can also be used for calculating the maximum length of just wire type equipment grounding conductors that are safe to use where not installed in metallic conduits, such as PVC conduit and other nonmetallic raceways.

Where a metallic conductor enclosure is used as an equipment grounding conductor, it must have continuity and the conductivity to carry enough current to facilitate the operation of the overcurrent devices. Some electrical inspection authorities and engineering specifications require that a wire type equipment grounding conductor be installed inside the conduit to account for poor workmanship of the raceway installation or to maintain continuity where fittings can be broken during use. This is a requirement above and beyond the minimum requirement of the *NEC* except in parts, such as hazardous (classified) locations or health care facilities where the wire type equipment grounding conductor is required in addition to the metal raceway system.

The engineer, installer or inspector should examine the equipment grounding conductor (the metal enclosure) to assure it will function properly in the event of a ground fault. Where wireways, auxiliary gutters and busways have steel enclosures, there can be enough material cross section to serve as an equipment grounding conductor. When it is questionable whether the electrical connections between lengths are adequate for carrying enough fault current to clear the fault, these raceways may also require a supplemental wire type equipment grounding conductor.

The conductor enclosure, conduit, raceway, and so forth, also may be acceptable as the equipment grounding conductor in lieu of the copper or aluminum conductors given in Table 250.122. Generally, if a conduit, electrical metallic tubing or wireway meets the *Code* requirements for conductor fill, the enclosure will provide an acceptable equipment grounding conductor.

In an average busway up to 1500 amperes rating, there is enough steel in the enclosure to provide an acceptable equipment grounding conductor if proper conductivity is assured at the joints. For busways of higher rating, it is doubtful if the steel enclosure is heavy enough. For all sizes of busways, the electrical connection at the joints must be checked carefully. Many busways have aluminum enclosures. In such busways, the enclosure has sufficient conductivity. Good electrical connections at the joints also must be checked.

Long Conduit Run Designs

Consider an installation where a metric designator (MD) 78 (3-inch) conduit run is 300 m (1000 ft) long and has a 400-ampere overcurrent protective device protecting the contained conductors. Assume that the minimum fault current for instantaneous tripping would be 600 percent of the overcurrent device rating, or, in this case, 2400 amperes. The impedance of MD 78 (3-inch) conduit at 2400 amperes is approximately 0.0875 ohms/300 m (1000 ft). For a 208Y/120-volt system with zero impedance at the point of the fault, the maximum current will be about 1400 amperes. That value of current would operate a 400-ampere high-interrupting capacity current-limiting fuse in about two seconds. However, such ground faults are nearly always arcing faults. This adds additional impedance to the circuit and reduces the fault current in the circuit. Moreover, since conduit impedance increases with a decrease in fault current, the conduit impedance would now be 0.129 ohms/300 m (1000 ft) at a current of 1,400 amperes.

Allowing for the arc impedance in the circuit described and the increase in conduit impedance at 1400 amps (about 50 percent) and other variable factors including a further increase of conduit impedance at the still lower current, the ground-fault current is more likely to be closer to 300 amperes. With a 300-ampere fault current, the 400-ampere high-interrupting capacity current-limiting fuse obviously would not ever clear the fault.

For a long feeder such as this, it can be necessary to increase conductor sizes to account for voltage drop. Section 250.122(B) requires that the wire type equipment grounding conductor also be increased in size in proportion to the size of the ungrounded conductors. For example, if the MD 78 (3-inch) conduit run was only 30 m (100 ft) long, the anticipated fault current would be about 3000 amperes, which would satisfactorily operate the overcurrent device. Both fault-current values were based on the impedance of only that part of the circuit that would be within the conduit, not the impedance of the entire circuit. The fault-current values met in practice would likely be less than those given here.

What can be done to achieve maximum safety? The system must be designed to ensure that performance of the grounding and bonding in the system fulfills all the requirements as set forth in 250.4(A)(5) and 250.4(B)(4) to obtain proper or effective grounding, bonding, and an effective path for fault current. This can mean adding a supplementary wire type equipment grounding conductor within the conduit in parallel with the conduit if the calculations indicate its need.

If the impedance of the ground-fault circuit is higher than what will allow enough ground-fault current to properly operate the overcurrent devices in a reasonable time, then a lower impedance can be obtained by adding a wire type equipment grounding conductor within the conduit in parallel with the conduit. That conductor must be installed within the conduit (installed with the circuit conductors). The wire type equipment grounding conductor should never be installed outside the conduit or raceway through which the conductors serving the equipment are installed. Where installed external to the conduit, it becomes quite ineffective in the equipment grounding circuit, for virtually all the ground-fault current will return on the conduit. Further, the wire type equipment grounding conductor must be run as close to the phase conductors as is practical, right to the point where it connects to the neutral conductor at the service (see figure 11.12).

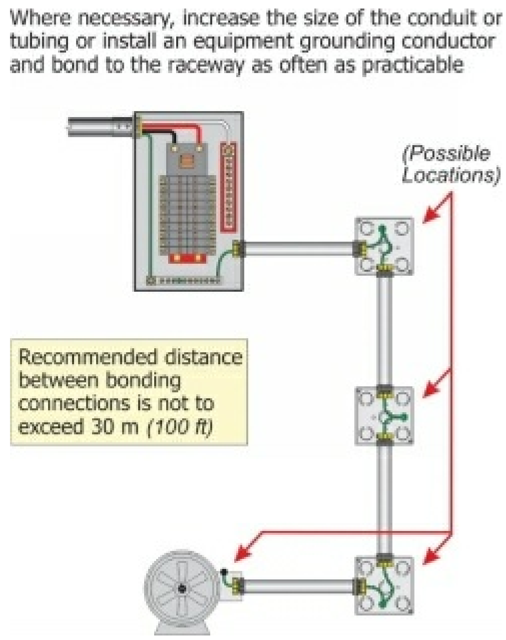


Figure 11.12 Long conduit runs can necessitate installing a wire type equipment grounding conductor in the raceway in some cases.

It would be neither practical nor desirable to substitute a copper or aluminum conductor for the conduit. Rather, add the copper or aluminum conductor, and connect it in parallel with the conduit to form an equipment grounding conductor of two conductors in parallel. The copper or aluminum conductor and the conduit should be connected together at convenient practical intervals, about every 30 m (100 ft) or less. That will reduce the length of circuit through which the ground-fault current will be through the conduit alone.

By determining the impedance of the circuit involved when a ground fault occurs, it can be determined whether the metallic enclosure will make an acceptable equipment grounding conductor or whether it will be necessary to supplement the enclosure with a wire type equipment grounding conductor. Where a steel conduit is a part of the electric circuit, as it will be where a ground fault occurs, there will be a large increase in both the resistance and reactance of the circuit, which will vary considerably with the amount of fault current.

Laboratory tests have shown that for a single-phase current through a conductor within a steel conduit, the impedance of the circuit is approximately equal to the impedance of the conduit itself. The size of the conductor within the conduit has relatively little effect on the circuit impedance. Also, despite the fact that there are many parallel paths external to the conduit, the current in all the other parallel paths will be very small, and under normal conditions would be less than 10 percent of the total fault current.

Two other factors need to be taken into account in estimating the ground-fault current. They are the effects of the conduit couplings in increasing the impedance of the circuit and the voltage drop across the point of fault. If conduit couplings are installed wrenchtight, as required by *Code*, the increase in impedance of the conduit with couplings is about 50 percent more than the impedance for a straight run without couplings. This is where the value and importance of installing a properly sized wire type equipment grounding conductor inside the conduit and bonding it to the conduit at frequent intervals is proven for ensuring low impedance and safety.

Impedance values for conduit can be obtained from manufacturers. By using these impedance values, adjusting for the couplings and estimating a 50-volt drop across the fault, a reasonable value for the amount of fault current in the circuit can be determined.

Assume a 60 m (200 ft) run of MD 78 (3-inch trade size) conduit with 500-kcmil conductors on a 208Y/120-volt circuit protected by 400-ampere overcurrent devices. During a ground fault, the amount of current will therefore be:

$$E \text{ (voltage)} \div Z \text{ (impedance)} = I \text{ (current)}$$

With a 50-volt drop at the fault and Z (impedance) = 0.02970, the current will be about 2350 amperes. The use of a MD 78 (3-inch trade size) conduit as the equipment grounding conductor where 400-ampere overcurrent devices are used is, thus, satisfactory for this run.

A simpler method of determining if the conduit or metallic enclosure will perform satisfactorily is to first calculate the minimum desired fault-current (5 times the overcurrent device rating or more to reach the instantaneous portion of the time/current curve), which, in this case, is 5 x 400 or 2000 amperes. Then, on the basis of 70 volts available for a 120-volts-to-ground circuit (120 - 50 voltage drop), calculate Z (impedance), which will be found to be 0.035. A straight run of MD 78 (trade size 3) conduit has about 0.099 ohms impedance per thousand feet at 2000 amperes. To that value add 50 percent to include a factor of safety. That will give an impedance of 0.01485 ohms per 30 m (100 ft). The impedance value that will allow 2000 amperes in that circuit was found to be 0.035. Since 71 m (235 ft) of conduit carrying 2000 amperes will have an impedance of 0.035, it has been determined that to have a minimum current of 2000 amperes in a ground fault, up to 71 m (235 ft) of MD 78 (trade size 3) conduit can be installed for a circuit protected by a 400-ampere overcurrent device.

Table 22.10 in chapter twenty-two provides supporting data by the Georgia Institute of Technology relative to the maximum lengths of steel conduit or tubing that may safely be used as an equipment grounding conductor (see also tables 20-13 through 20-16).

If a MD 103 (trade size 4) conduit was used instead of metric designator 78 (trade size 3), and the overcurrent device rating did not change but remained at 400 amperes, the maximum length of conduit can be determined by reference to table 20-10. With some interpolation and using the same calculations, it is found that 78 m (260 ft) of MD 103 (trade size 4) conduit could be installed and provide a satisfactory equipment grounding conductor for this circuit.

It can be determined for any circuit and any size conduit, for any size overcurrent device, the maximum safe length of conduit that will allow a fault current which will be sufficient to facilitate the operation of the overcurrent device. Should the circuit length exceed the maximum safe length as calculated, and then it will be necessary to add a metallic (copper or aluminum) equipment grounding conductor in parallel with the conduit or increase the size of the conduit. Minimum equipment grounding conductor sizes are provided in Table 250.122. It should be noted this analysis needs to be completed considering the conduit and the included wire type equipment grounding conductor since even that combination may not be sufficient to provide the required low impedance path. For example, if the actual installation using the conditions above with 4 inch steel conduit with a 3 AWG equipment grounding conductor was 450 feet, this would exceed the maximum length calculated of 403 feet for the conduit and wire combination.

The *Code* permits a wire type equipment grounding conductor to be bare or insulated. However, if the conductor is bare, there can be some arcing between the bare conductor and the interior of the conduit at points other than the point at which the ground fault occurs. This is due to slight differences in impedance between the raceway and wire, resulting in potential differences that can result in arcing. Such arcing can damage the phase conductors without adding to the proper functioning of the ground-fault circuit. This makes a strong case for the use of insulated wire type equipment grounding conductors where installed in a metallic enclosure.

If aluminum conduit was used instead of steel conduit for the same conditions cited above [500-kcmil copper conductors, MD 78 (trade size 3) conduit and a 400-ampere overcurrent device], the circuit run could be about 270 m (900 ft) long, and the aluminum conduit would provide a satisfactory equipment grounding conductor. A MD 78 (trade size 3) aluminum conduit has a dc resistance of about 0.0088 ohms/300 m (1000 ft) and 500-kcmil copper cable has a dc resistance of 0.0222 ohms/300 m (1000 ft).

Flexible metal conduit is suitable as an equipment grounding conductor for not more than 1.8 m (6 ft) lengths in the entire ground-fault return path and with not more than 20-ampere overcurrent protection of the contained conductors and meeting the other conditions stipulated in 250.118(5). As such, flexible metal conduit should generally include an internal equipment grounding conductor. The *Code* requires that the various metal raceways shall be so constructed that adequate electrical and mechanical continuity of the complete system be secured. However, because of the various joints involved, it is important for the engineer, installer and inspector to investigate such conductor enclosures to determine that their impedance is sufficiently low to provide an effective ground-fault current path.

Adequate Size of Wire Type Equipment Grounding Conductor

In general, the minimum size of wire type equipment grounding conductors is provided in Table 250.122 and is based on the rating of the overcurrent device ahead of the conductors. (An analysis of Table 250.122 is provided in table 22.8 of chapter twenty-two.) The rule of thumb may be applied, but it should be verified by calculation that the equipment grounding conductor should not be less than 25 percent of the capacity of the phase conductors or the overcurrent device that supplies the circuit. A note has been added to the table indicating that the size of equipment grounding conductor given in the table must be increased if necessary to comply with 250.4(A)(5). This adds emphasis to the heading of Table 250.122 because it indicates that equipment grounding conductors given in the table are the minimum size.

An analysis of Table 250.122 shows the relation of the equipment grounding conductor to the size of the overcurrent device (based on the continuous rating of 75°C-rated wire). It is from 50 to 125 percent of the phase conductor for overcurrent devices up to 100-ampere rating. The rating varies from 33 to 25 percent for overcurrent devices rated up to 400 amperes and is from 22 percent for 600-ampere overcurrent devices to a low of only 8 percent for an overcurrent device of 6000 amperes.

Obviously, the equipment grounding conductor must be large enough to carry that amount of current, for the amount of time necessary to clear the overcurrent device with which it is associated, and not result in extensive damage. This was covered extensively in chapter nine.

Conductor Withstand Rating

Section 110.9 states, "Equipment intended to interrupt current at fault levels shall have an interrupting rating sufficient for the nominal circuit voltage and the current which is available at the line terminals of the equipment."[11] This includes fuses, circuit breakers, disconnect switches and similar equipment.

Section 110.10 reads in part, "The overcurrent protective devices, the total impedance, the equipment short-circuit current ratings, and other characteristics of the circuit to be protected shall be selected and coordinated to permit the circuit protective devices used to clear a fault to do so without extensive damage to the electrical equipment of the circuit. This fault shall be assumed to be either between two or more of the circuit conductors or between any circuit conductor and the equipment grounding conductor(s) permitted in 250.118. Listed equipment applied in accordance with their listing shall be considered to meet the requirements of this section."

Equipment grounding conductors, circuit conductors, busbars, bonding jumpers, and so forth, are not intended to break current. These conductors must be large enough to safely carry any short-circuit and ground-fault current for the time it takes the overcurrent protective device to clear the fault. This is clearly stated in 110.10, 240.1 Informational Note, 250.4, 250.90 and 250.96. Section 310.10 also provides details for the temperature limitations of conductors.

The integrity of equipment grounding conductors, grounding electrode conductors, main and system bonding jumpers and other circuit conductors must be ensured by sizing them properly. Equipment grounding conductors that are too small are of little value in clearing a fault and can, in fact, give one a false sense of security. Equipment grounding conductors must not burn off during ground-fault conditions, leaving the equipment enclosure energized, in many cases, creating a shock hazard that can cause serious injury or even be fatal. Safety should not be compromised. In fact, the first sentence of the *Code* states that, "the purpose of this *Code* is the practical safeguarding of persons and property from hazards arising from the use of electricity."

Bolted Connections

It can be calculated, using values from the Insulated Cable Engineers Association publication P32-382 (1994), that an insulated copper conductor with a bolted connection can safely carry one ampere for every 42.25 circular mils for five seconds without destroying its insulation validity (see figures 11.13 and 11.14). That will be the short-time rating or I^2t (amperes x amperes x time) value of the conductor. Then, from the time-current characteristic curves of various approved overcurrent devices, the amount of current necessary to clear the overcurrent device in five seconds can be determined.

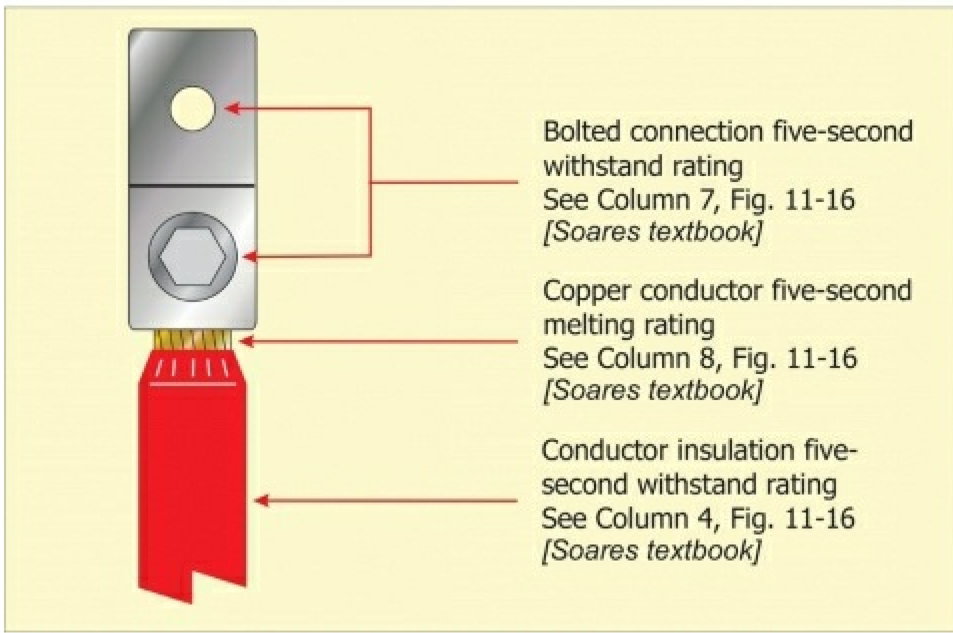


Figure 11.13 Wire, insulation, and connection withstand ratings

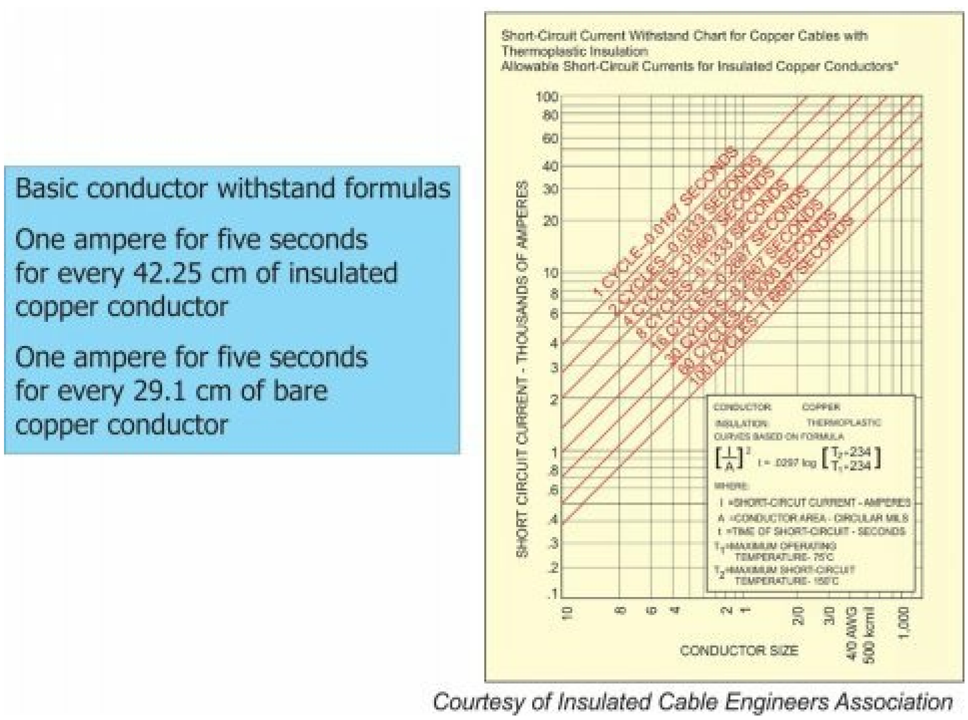


Figure 11.14 Short-circuit current withstand chart Courtesy of the Insulated Cable Engineers Association

Using that formula, the size of the equipment grounding conductors that will be proportional to those given in Table 250.122, as analyzed in table 20.8 of chapter twenty can be determined. Equipment grounding conductors are permitted to be bare, and, in most cases, are pulled into the same raceway as the insulated phase conductors. This presents a potential problem. When an equipment grounding conductor is carrying ground-fault current, an extreme rise in its temperature can cause the insulation on the adjacent phase conductors to melt, causing further damage. Again, the potential for equipment damage and electrical shock hazard to personnel is increased. It is desirable to limit the heat of the faulted circuit to reduce damage to adjacent insulated conductors.

Thus, as discussed in this chapter, for copper conductors, the clearing time and short-circuit current must be limited to:

- One ampere...
- for five seconds...
- for every 42.25 circular mils.

This can be expressed by the formula ampere squared seconds (I^2t).

For example, from Table 8 of *NEC* chapter nine, an 8 AWG conductor has a cross-sectional area of 16,510 circular mils. By dividing the circular mil area of the conductor by 42.25, the conductor's five-second withstand rating can be calculated (16,510 ÷ 42.25 = 391).

Stated another way, this conductor has an I^2t five-second withstand rating of:

391 x 391 x 5 = 764,405 ampere squared seconds.

From this five-second withstand rating value, it is easy to calculate the conductor's withstand rating for other values of time and/or for other values of current.

Example 1: How many amperes will the 8 AWG copper conductor be able to safely carry if the impedance of the circuit along with the operating characteristics of the overcurrent device protecting the circuit results in a 2-cycle (0.0333 seconds) opening time? See example 11.1.

Example 1 - 2 Cycles (0.0333 seconds)

I^2t = 764,405 ampere squared seconds

$$I^2 = \frac{764{,}405}{t}$$

$$I = \sqrt{\frac{764{,}405}{0.0333}}$$

$$I = 4{,}791 \text{ amperes}$$

The 8 AWG copper conductor could carry 4,791 amperes for 2 cycles

Quicker clearing times allow for higher conductor withstand rating

Example 11.1

Example 2: How many amperes will the 8 AWG copper conductor be able to safely carry if the impedance of the circuit along with the operating characteristics of the overcurrent device protecting the circuit results in a ¼ cycle (0.0042) opening time? See example 11.2.

Example 2 - ¼ Cycles (0.0042 seconds)

I^2t = 764,405 ampere squared seconds

$$I^2 = \frac{764{,}405}{t}$$

$$I = \sqrt{\frac{764{,}405}{0.0042}}$$

$$I = 13{,}491 \text{ amperes}$$

The 8 AWG copper conductor could carry 13,491 amperes for a ¼ cycle

Quicker clearing times allow for higher conductor withstand rating

Example 11.2

Note that in the example above, because a much faster total clearing time is achieved, the allowable fault current that the conductor will be subjected to can be increased. This is a result of substituting different time values in the I^2t formula.

Generally, where current-limiting overcurrent devices are protecting the circuit, the equipment grounding conductor sizes are determined directly from Table 250.122. Where available fault currents are high and the overcurrent protective device takes longer than 0.25 cycle to clear the fault, it is suggested that the equipment grounding conductor be sized per figure 11.14, to be on the safe side.

Figure 11.16 provides information to assist the installer in the proper selection of equipment grounding conductors. Among other information, it includes:

- safe values for 75°C thermoplastic insulated conductors,
- safe values for bolted connections,
- unsafe (melting) values for the copper conductor itself.

Because the weakest link in any system is the insulation short-circuit withstand rating as found in columns 4, 5, and 6 of figure 11.16, it is recommended that column 4 be the deciding factor where selecting equipment grounding conductors. The Insulated Cable Engineers Association data, figure 11-16, column 4 calculates out to the previously discussed: *Do not exceed one ampere… for five seconds… for every 42.25 circular mils of copper conductor.*

This chart also shows the 8 AWG conductor used in the above text examples. Where you are absolutely certain that the equipment grounding conductor will not come into contact with any of the current-carrying insulated circuit conductors, the withstand rating of a bare equipment grounding conductor, for every 29.1 circular mils of copper conductor, cannot exceed one ampere for five seconds (see column seven, figure 11.16).

This is the standard previously referred to in this text as the "Do not exceed one ampere for five seconds for every 29.1 circular mils of conductor area."

This value is only to be used where bare equipment grounding conductors are used in such a manner that they will not come in contact with insulated conductors. In this application, the limiting element of the circuit is the bolted connection of the lug.

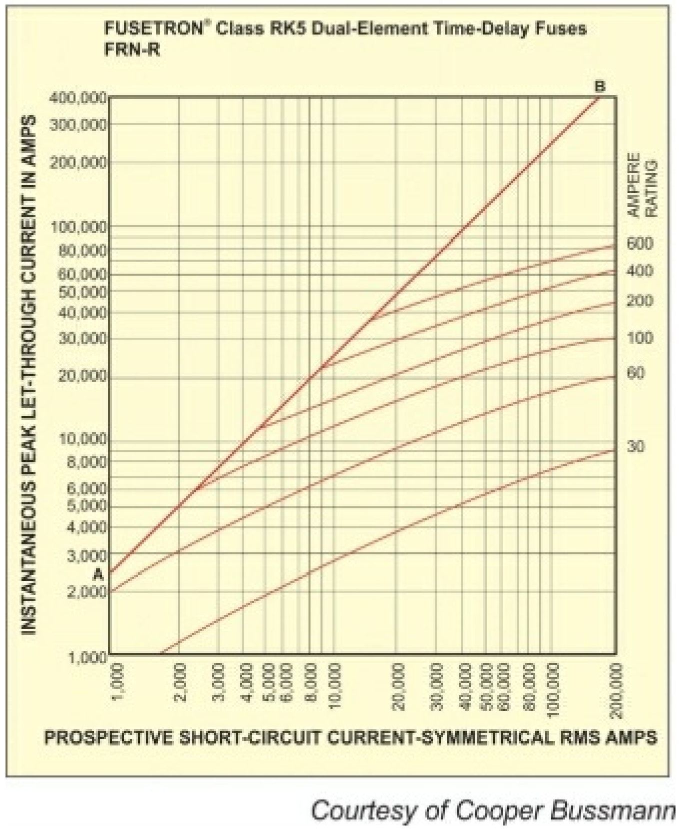


Figure 11.15 Typical time current curves for fuses.
Courtesy of Copper Bussmann, Cooper Industries

Column 8 of figure 11.16 gives the current in amperes at which the melting temperature of copper conductors is reached. Of course, you never want to reach the current shown because the equipment grounding conductor will burn off leaving the equipment ungrounded and a possible shock hazard.

Copper 75° C. Thermoplastic Insulated Conductors, Bare Conductors, Bolted Connection Five Second Withstand Rating in Amperes and Melting of Copper Wire

1 Wire Size	2 Area in circular mils	3 Area in square mm	4 ICEA Amperes	5 IEC Amperes	6 IEE Amperes	7 Bolted Connection 250° C. Amperes	8 Melting of Conductor 1,083° C. Amperes
14	4,110	2.080	97	107	107	141	254
12	6,530	3.310	155	170	170	224	403
10	10,380	5.261	246	271	271	357	641
8	16,510	8.367	391	430	430	567	1,020
6	26,240	13.300	621	684	684	902	1,621
4	41,740	21.150	988	1,088	1,088	1,435	2,578
3	52,620	26.670	1,245	1,372	1,372	1,808	3,251
2	66,360	33.620	1,571	1,729	1,729	2,281	4,099
1	83 690	42.410	1,981	2,181	2,181	2,876	5,170
1/0	105 600	53.490	2,499	2,751	2,751	3 629	6,523
2/0	133,100	67.430	3,150	3,468	3,468	4,574	8,222
3/0	167.800	85.010	3.972	4.372	4.372	5.767	10.366
4/0	211,600	107.200	5,009	5,513	5,513	7,272	13,071
250	250,000	126.700	5,918	6,516	6,516	8,592	15,443
300	300,000	152.000	7,101	7,818	7,818	10,310	18,532
350	350,000	177.300	8,285	9,119	9,119	12,029	21,621
400	400,000	202.700	9,467	10,425	10,425	13,747	24,709
500	500,000	253.300	11,834	13,027	13,027	17,184	30,887
600	600,000	304.000	14,201	15,636	15,636	20,621	37,064
700	700,000	354.700	16,568	18,243	18,243	24,057	43,241
750	750,000	380.000	17,752	19,544	19,544	25,776	46,330
800	800,000	405.400	18,935	20,850	20,850	27,494	49,419
900	900,000	456.000	21,302	23,453	23,453	30,931	55,596
1,000	1,000,000	506.700	23,669	26,060	26,060	34,368	61,773

Column 4 - Insulated Cable Engineers Association publication P32-382. One ampere for five seconds for every 42.25 circular mils of conductor area.
Column 5 - International Electrotechnical Commission publication 364-4-43.
Column 6 - Institute of Electrical Engineers publication 434-6.
Column 7 - Electrical Engineers Handbook (75° C ambient). One ampere for five seconds for every 29.1 circular mils of conductor area.
Column 8 - Electrical Engineers Handbook (75° C ambient). One ampere for five seconds for every 16.19 circular mils of conductor area.

Figure 11-16. Five-second withstand ratings for insulated conductors, bare conductors with bolted connections. *(Courtesy of the ICEA)*

Figure 11.16 Five-second withstand ratings for insulated conductors, bare conductors with bolted connections.
Courtesy of the ICEA

Conclusion on Equipment Grounding Conductor

For a grounded system, it is vital to safety that a low-impedance equipment grounding conductor path be provided in addition to a good grounding electrode system with as low of impedance as practical. This allows sufficient current to clear a ground fault automatically in a limited time, which would be as quickly as is practical, without undue interruption of service.

The I^2t values found in column 7 of figure 11-16 are based on the adequacy of a copper conductor and its bolted joints to carry the current values without destroying its validity. The values are obtained from an IEEE committee report in "A Guide to Safety in AC Substation Grounding." The value expressed in amperes per circular mil is one ampere for every 29.1 circular mils cross section. The time of five seconds was used to provide a safety factor and was considered a reasonable approach for distribution systems of 600 volts or less protected by high-interrupting-capacity current-limiting fuses and having equipment ground-fault protection.

As previously stated, where bare equipment grounding conductors might come into contact with insulated phase conductors, use the values found in column four of figure 11-16. This column is based on one ampere for every 42.25 circular mils of conductor for five seconds. Figure 11-16 has all the calculations done and is much easier to use than performing complicated calculations.

The short-time rating of the equipment grounding conductor bears an approximately constant relation to the size of the overcurrent device. The I^2t values of the conductors given in Table 250.122 are between about 13 and 28 times their nominal continuous rating based on one ampere for every 42.25 circular mils cross section.

[1, 3,] NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA, 2016.

[2] IEEE 100-1992, The *New IEEE Standard Dictionary of Electrical and Electronic Terms*, 5th Edition. Institute of Electrical and Electronics Engineers, Inc. 445 Hoes Lane, PO Box 1331, Piscataway, NJ, 08855.

[4] Kaufmann, ibid.

[5] *Electric Power Distribution for Industrial Plants.* The Institute of Electrical and Electronics Engineers, Inc., © 1954 AIEE, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331.

[6] "Some Fundamentals of Equipment-Grounding Circuit De-sign" by R. H. Kaufmann, Paper 54-244 presented at the AIEE Summer and Pacific General Meeting, Los Angeles, California, June 24-25, 1954, © 1954 AIEE, (now IEEE), 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

[7] Kaufmann, ibid.

[8] Kaufmann, ibid.

[9] Fuses (JCQR), *Guide Information for Electrical Equipment* - 2013, (Underwriters Laboratories, Northbrook, IL, 2004), p. 211.

[10] Circuit Breakers, Molded-Case and Circuit Breaker Enclosures (DIVQ), *Guide Information for Electrical Equipment* - 2013, (Underwriters Laboratories, Northbrook, IL, 2007), p 107.

[11] Circuit Breaker Current Limiters (DIRW), Guide Information for Electrical Equipment - 2013, (Underwriters Laboratories, Northbrook, IL, 2004), p.106.

[12] 1991 IEEE Industry Applications Society Annual Meeting, Volume II. The Institute of Electrical and Electronics Engineers, Inc., © 1954 AIEE (now IEEE), 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

[13] **"Modeling and Testing of Steel MT, IMC and Rigid (GRC) Conduit," School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332.**

Review Questions

1. A conducting connection, whether intentional or accidental, between any of the conductors of an electrical system whether it be from line-to-line or line-to the grounded conductor, is defined as a _____.

1. ground fault
2. phase fault
3. short circuit
4. unidentified fault

2. “An unintentional, electrically conductive connection between an ungrounded conductor of an electrical circuit and the normally non-current-carrying conductors, equipment, or the earth to the electrical supply source” best defines which of the following _____?

1. identified fault
2. ground fault
3. short circuit
4. failure of the system

3. A short circuit may be from one phase conductor to another phase conductor, or from one phase conductor to the grounded conductor or _____.

1. unidentified conductor
2. enclosure
3. neutral conductor
4. equipment grounding conductor

4. The grounding and bonding system must provide an electrically continuous path; must have ample carrying capacity to conduct safely any fault currents likely to be imposed on it; and must have impedance sufficiently low to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit. This is best described as being _____.

1. improved
2. effective
3. sufficient
4. required

5. In general, the rule of thumb may be applied, but should be checked by calculation, that the equipment grounding conductor should not be less than _____ percent of the capacity of the phase conductors that supply the circuit.

1. 25
2. 20
3. 15
4. 18

6. There generally is no overcurrent protection on the line side of service conductors; there is generally only _____ protection on the primary of the transformer.

1. ground-fault
2. short-circuit
3. overload
4. equipment ground fault

7. The grounded service (usually a neutral) conductor must be run to each service disconnecting means and connected (bonded) to the enclosure even if the service supplies only _____.

1. 240 volt loads
2. 208 volt loads
3. 480 volt loads
4. line-to-line loads

8. An 8 AWG THW copper conductor has an allowable ampacity of 50 amperes according to Table 310.15(B)(16). This conductor also has a safe five-second withstand rating of ____ amperes, but will melt if subjected to ____ amperes for five seconds.

1. 8367 10,000
2. 391 1020
3. 30 500
4. 4110 254

9. When Insulated Cable Engineers Association (ICEA) conductor short-circuit withstand rating tables are not available, it is possible to calculate the short-circuit current withstand ratings for a conductor. For example, to determine the safe withstand rating for copper conductors with 75°C insulation, use ____ ampere for every ____ seconds for every ____ circular mils of cross sectional area of the conductor.

1. one, five, 42.25
2. one, five, 16.9
3. one, five, 29.1
4. one, five, 10.2

10. Table 250.122 provides the minimum size equipment grounding conductors. Where high values of fault current are available, the equipment grounding conductors may have to be ____ in size to be capable of safely carrying the available fault current for the duration of time required to withstand such higher levels of current until the overcurrent device clears.

1. decreased
2. increased

11. Emergency system overcurrent devices are required to be ________________ with all supply side overcurrent protective devices.

1. rated at not less than 600%
2. installed in parallel
3. selectively coordinated
4. located

12. The primary purpose of selective coordination of overcurrent protective devices is to________________.

1. localize overcurrent conditions to restrict outages to the affected circuit or equipment
2. ensure that the circuit always remains functional even under ground fault or short circuits
3. enable fuses to open first
4. enable circuit breakers to operate first under ground fault or short circuit conditions

⏚ Chapter 12
Grounding Separately Derived Systems

Objectives to understand

- General requirements and definitions for separately derived systems
- Installation and sizing of system bonding jumper for separately derived systems
- Installation and sizing of supply-side bonding jumper for separately derived systems
- Grounding electrodes for separately derived systems
- Sizing and types of grounding electrode conductors for separately derived systems
- Transformer overcurrent protection
- Generator types of separately derived systems
- Ground-fault protection systems

In many distribution systems for commercial, institutional, or industrial occupancies, it is common to have separately derived systems at another voltage level lower or higher than the electrical system supplied by the service. Several Code requirements must be met when installing a separately derived system.

First, if there is a separately derived system, this means there will be a new "source" established producing a voltage and providing a capacity from which current would be drawn. This capacity is usually referred to as the kVA or kW rating of the system. The system itself must have a capacity to supply the load served. Overcurrent protection sizing and the protection of conductors connected to the point of supply of the separately derived system are also required. Another important element is determining which grounding and bonding rules must be applied to satisfy the requirements. This chapter focuses on those specific grounding and bonding requirements.

The first item that must be established is whether or not the system is separately derived. An example of a system or transformer that is not separately derived is an autotransformer. Another example that is clearly a separately derived system is a generator that provides power as a stand-alone system. If a generator source or system is installed on a premises wiring system with grounded conductors installed, it must be grounded as a separately derived system if there is a switching action in the grounded conductor through the transfer equipment. If there is no switching action in the grounded conductor through the transfer switch or equipment, then the grounded conductor remains grounded through the service grounding connection point located at the service. In this case, the generator produced system is not a separately derived system and is not grounded again as required in 250.30(A) for a system that is separately derived. The Code requires a sign at the service equipment when the grounding electrode system at the service is also used for the grounding electrode for a generator [700.7(B), 701.7(B) and 702.7(B)]. In this case, the generator grounding and bonding is established through the equipment grounding conductor and an insulated grounded (neutral) conductor that is isolated from grounded metal parts at that location (generator) to comply with 250.24(A)(5).

Definition

Separately derived system. "An electrical source other than a service, having no direct connection(s) to circuit conductors of any other electrical source other than those established by grounding and bonding connections.” [1]

Transformer-Type Separately Derived System

Figure 12.1 is a diagram of a transformer-type separately derived system (for simplicity, all of the grounding and bonding conductors are not shown.) The supply or primary of the transformer is at one voltage level, and the secondary is often at another voltage level, either lower or higher. As shown, there is no direct connection between the transformer primary and secondary circuit conductors, so the installation meets the definition of a separately derived system. Where 3-phase systems are installed, the primary is usually delta connected so a neutral conductor is not needed. The secondary may be connected delta or wye as desired (see photo 12.1).

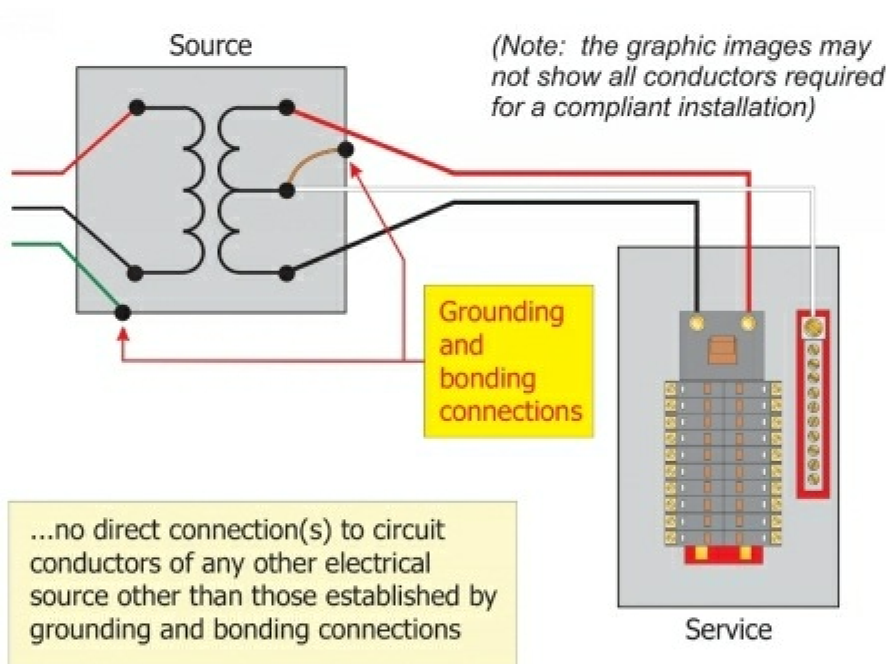


Figure 12.1 Transformer-type separately derived system

Photo 12.1 Transformer-type separately derived system

Grounding Primary Side Equipment

An equipment grounding conductor must be supplied with the primary circuit to provide a low-impedance fault-current path from the transformer case to the service or source of supply. The equipment grounding conductor can be any of the means included in 250.118 including wires and the wiring method, where appropriate. The overcurrent device on the primary of the transformer will then clear a short circuit or ground fault up to, and including, the transformer primary windings.

As stated in the definition, the equipment grounding conductor connection to the transformer enclosure, plus the system bonding jumper and supply-side bonding jumper from the secondary does not constitute a direct connection from the primary system to the secondary system. The equipment grounding conductor is not a circuit conductor intended to carry current as are the ungrounded and grounded (neutral) conductors.

A short circuit or ground fault on the secondary of the transformer is seen as a load by the transformer primary winding. The amount of fault current on the secondary side will determine whether or not the primary overcurrent device will open or operate owing to the turns ratio and possible phase shift between primary and secondary of the transformer.

Systems and Grounding Rules

The requirements found at the beginning of 250.30 make it clear that the requirements found in 250.20, 250.21, 250.22 and 250.26 also apply. Whether a separately derived system requires grounding in accordance with 250.30(A), is established in 250.20. Sometimes there is a choice as to whether the system is required to be grounded, or permitted to be grounded. Sometimes, as in those cases specified in 250.22, the separately derived system is not permitted to be grounded.

Photo 12.2 System bonding jumper in source enclosure

Sections 250.20(B)(1), (2), and (3) determine when the system produced must be grounded and there is no choice. For example, if the system can be grounded so that the voltage to ground from any of the system conductors does not exceed 150 volts, then generally it must be grounded [250.20(B)(1)]. If the system is required to be grounded, or if the system is grounded by choice, in other words, if it is not required by 250.20 but is grounded anyway as permitted by 250.21, then the separately derived system must still be grounded according to the applicable requirements of 250.30(A). Section 250.30(A) establishes the requirements in 230.30(A)(1) to 250.30(A)(8) to be complied with. This section goes on to state, "Except as otherwise permitted in this article, a grounded conductor shall not be connected to normally non–current-carrying metal parts of equipment, be connected to equipment grounding conductors, or be reconnected to ground on the load side of the system bonding jumper." This is the same requirement as found in 250.24(A)(5) for services.

The grounding requirements are as follows in the order they appear in the *NEC*:

1. System Bonding Jumper
2. Supply-Side Bonding Jumper Size
3. Grounded Conductor
4. Grounding Electrode

5. Grounding Electrode Conductor, Single Separately Derived System
6. Grounding Electrode Conductor, Multiple Separately Derived Systems
   a. Common Grounding Electrode Conductor Size
   b. Tap Conductor Size
   c. Connections
7. Installation
8. Bonding

These eight requirements can be reduced to five logical steps to complete the grounding and bonding of a separately derived system. These steps are:

- Install the system bonding jumper
- Install the supply-side bonding jumper
- Determine what is to be used for the grounding electrode
- Install the grounding electrode conductor using one option or the other, and
- Complete the bonding to the local metallic water piping system and the local structural metal building frame members.

System Bonding Jumper

The system bonding jumper is the first component addressed in 250.30(A)(1). The system bonding jumper is the vital link for the fault-current path at the source and is the connection between the grounded conductor and the supply-side bonding jumper at the source or between the equipment grounding conductors and the grounded conductor (neutral) conductor at the equipment containing the first overcurrent protective device. It functions in similar fashion to the main bonding jumper at the service location. A provision of 250.30(A)(1) requires the system bonding jumper to remain within the enclosure where it originates.

Those in the electrical field often refer to the system bonding jumper of a separately derived system as the main bonding jumper used at the service equipment. Its function is essentially the same, but the correct terms must be used to apply *Code* requirements properly. A system bonding jumper is used at separately derived systems. This term is used in Section 250.30(A)(1) and defined in Article 100.

Definition

Bonding jumper, system. "The connection between the grounded circuit conductor and the supply-side bonding jumper, or the equipment grounding conductor, or both, at a separately derived system."

The system bonding jumper must be installed in accordance with 250.30(A)(1)(a) and 250.30(A)(1)(b) and the requirements of 250.28(A) through (D). The sizing is to be based on the derived phase conductors supplied by the separately derived system. A brief look at the requirements in 250.28 identifies the material, construction, attachment, and sizing requirements for the system bonding jumper. It is required to be copper or other corrosion-resistant material, and is permitted to be in the form of a wire, bus, screw, or similar conductor. System bonding jumpers that are of the screw types must be identified by the color green that identifies the screw after installation. This type of system bonding jumper might be employed when the bonding jumper and grounding electrode conductor connection to the system are installed at the first system overcurrent protective device, such as a panelboard. The means of attachment of the system bonding jumper must be by the exothermic welding process, listed pressure connectors, listed clamps, or other listed means. The more common location for the system bonding jumper and grounding electrode conductor connection to the system is at the source enclosure (see photo 12.2).

However, the *Code* permits this connection at any single point from the source to the first system disconnecting means or overcurrent protective device, or it must be made at the source where there is no disconnecting means or overcurrent device located in the equipment supplied by the separately derived system (see figures 12.2 and 12.3). Section 250.28(D)(3) includes the sizing requirements for system bonding jumpers that are installed where there are multiple disconnects in separate enclosures, and sizing requirements for this same situation but with a single system bonding jumper installed at the source enclosure. Where the system supplies more than a single enclosure, the system bonding jumper in each enclosure is sized in accordance with 250.28(D)(1) based on the largest ungrounded feeder conductor serving each enclosure. Where a single system bonding jumper is installed at the source enclosure, it must be sized in accordance with 250.28(D)(1) based on the sum of the circular mil areas of all ungrounded derived phase conductors (see photo 12.2). The system bonding jumper is required to be connected to the separately derived system at the same location as the grounding electrode conductor connection to the system.

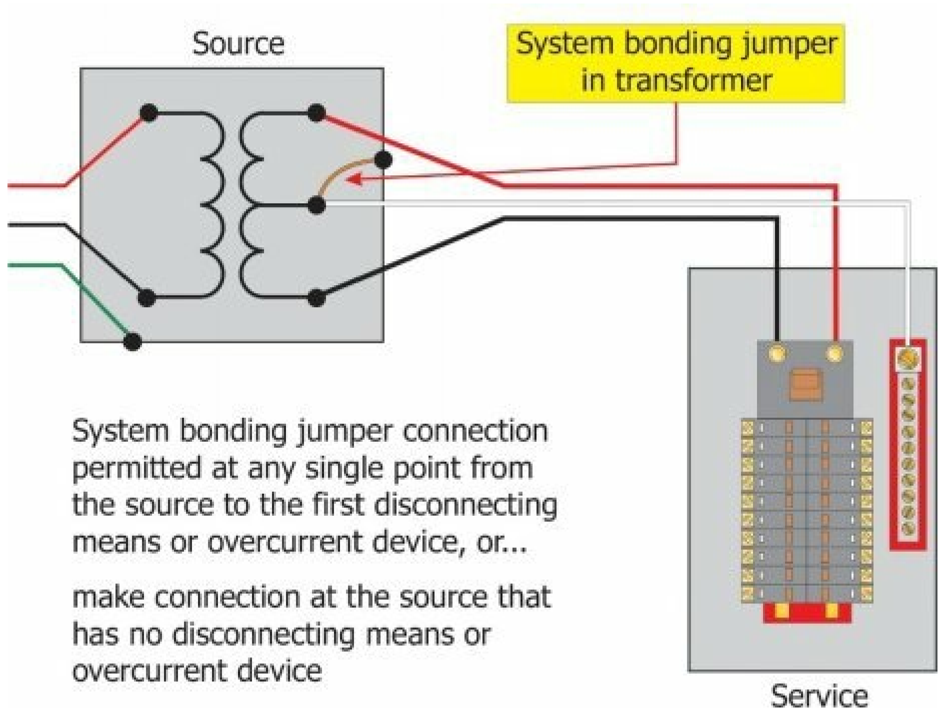


Figure 12.2 System bonding jumper located at the source enclosure

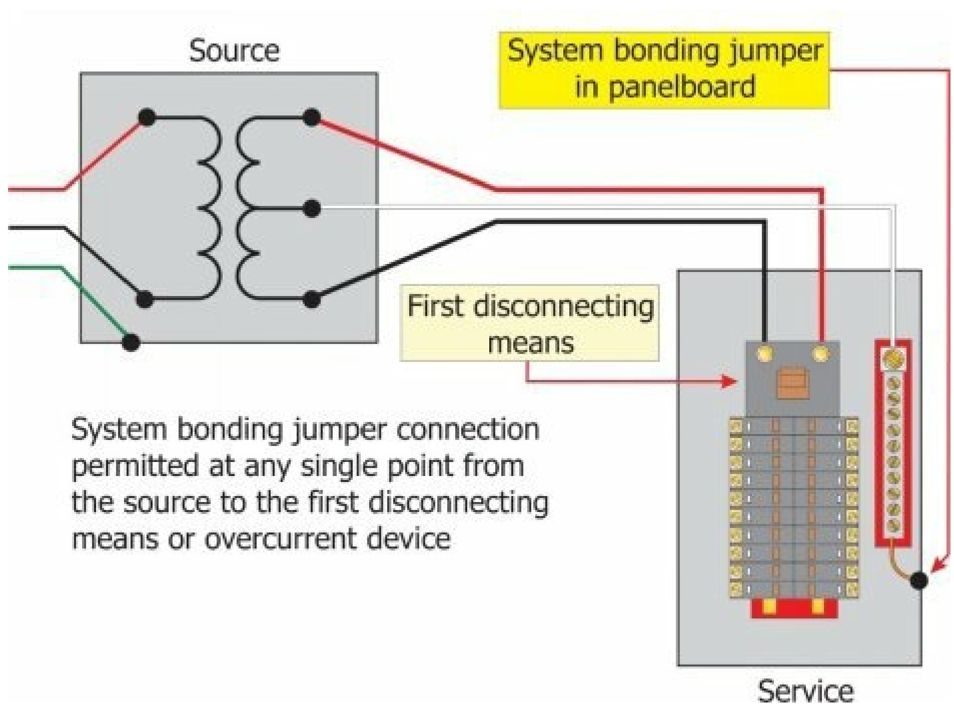


Figure 12.3 System bonding jumper located at the first disconnection means or overcurrent device enclosure

System Bonding Jumper Location Exceptions

Section 250.30(A) Exception recognizes provisions for connecting the system bonding jumper for a separately derived system according to the requirements for an impedance grounded system. These rules are given in 250.36 and 250.186. These systems are grounded only through an impedance device (often a resistor) usually located at the switchboard, panelboard, or motor control center and not at the source enclosure. These systems are designed to limit the fault current of the first ground fault to a predetermined value and often incorporate an indication or alarm system. Additional information on high-impedance grounded systems is provided in chapter four.

Exception No. 1 to 250.30(A)(5) and (A)(6) permits the grounding electrode connection to be made to an equipment grounding terminal bus, rather than to the neutral bar where the system bonding jumper is a wire or busbar connecting the equipment ground terminal or bus to the neutral bar or bus (see figure 12.4). This provides for residual-type equipment ground-fault protection systems where, often, a ground-fault current sensor is located in or on the system bonding jumper to measure ground-fault currents back to the source. Another common application of this exception is in switchboards where the main or system bonding jumper is a wire or busbar.

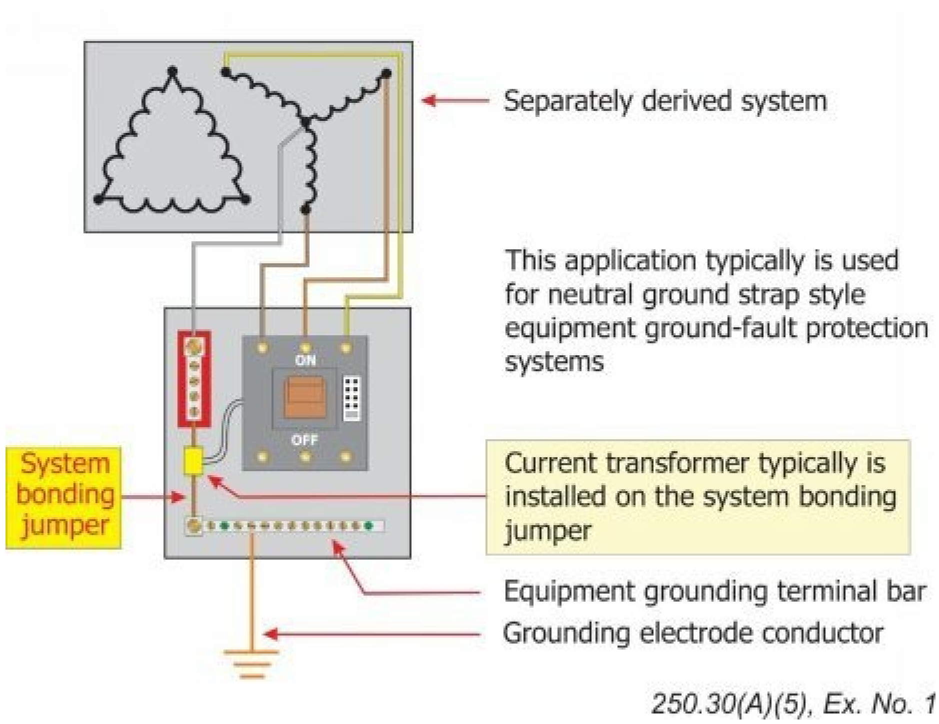


Figure 12.4 System bonding jumper exception

Supply-Side Bonding Jumper for Separately Derived Systems

The installation and sizing requirements for supply-side bonding jumpers of the wire type installed with the derived phase conductors from the source to the first disconnect or overcurrent protective are provided in 250.30(A)(2). Where the grounding and system bonding connections for separately derived systems in accordance with 250.30(A) are made at the source enclosure, most installations include routing of the derived phase conductors, the grounded (neutral) conductor of the system, and a supply-side bonding jumper for bonding the metal enclosure of the derived system source to the metal enclosure at the first disconnect or overcurrent protective device. This conductor is identified by the *Code* as a supply-side bonding jumper and if of the wire type must be sized in accordance with the requirements of 250.102(C) (see figure 12.5). If a nonflexible metal raceway is used as permitted by 250.30(A)(2), the sizing requirement does not apply but consideration should be given to ensure the supply-side bonding jumper provides an effective ground-fault path.

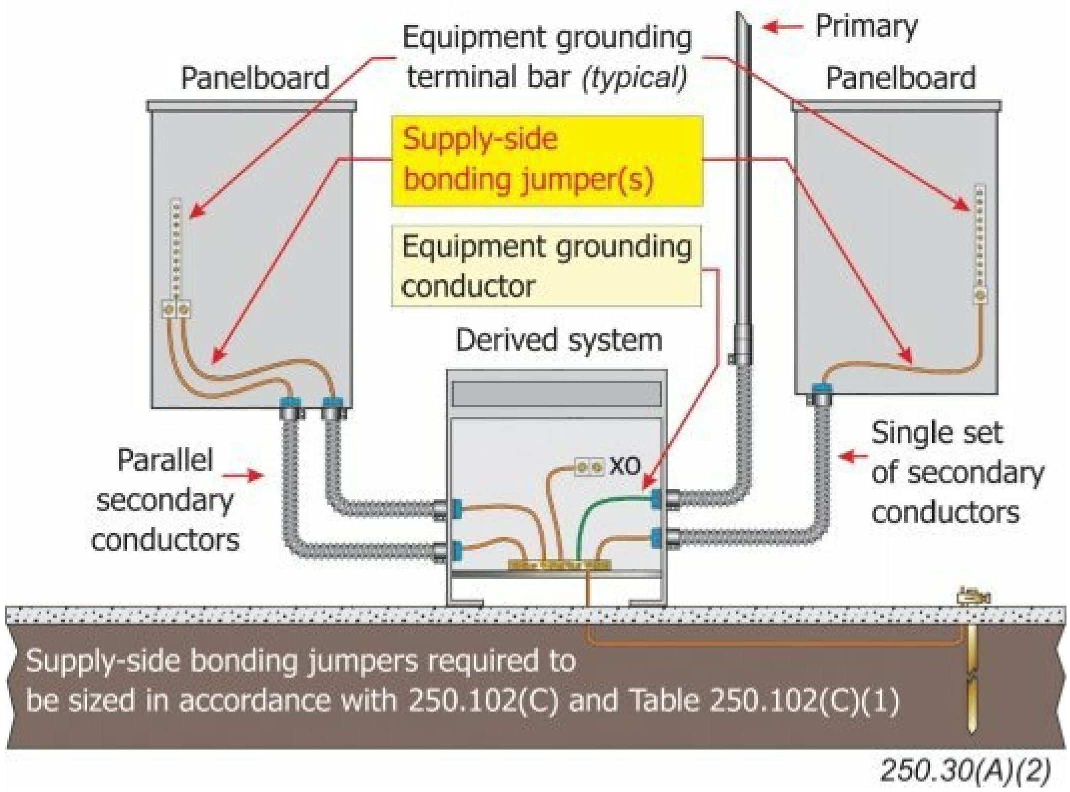


Figure 12.5 Supply-side bonding jumper size [250.30(A)(2)]

Conductors derived from the secondary of a transformer, generator or other separately derived systems are considered unprotected or unfused (line-side) conductors. They are often referred to as tap conductors. Tap conductors are defined in 240.2. Unless the secondary conductors are protected against overcurrent in a manner specified in 240.4(F) for transformer secondary conductors, they are not protected at their ampacity by the line-side overcurrent device, but obtain their overcurrent protection through proper application of the appropriate rules in 240.21.

The sizing requirements for the supply-side bonding jumper installed from the source enclosure to the first system disconnect or overcurrent device are similar to the supply-side bonding jumper sizing requirements on the supply side of service equipment disconnecting means. For separately derived systems, they must be sized based on the circular mil area of the derived phase conductors and the values in Table 250.102(C)(1) see figure 12.7. Where the size of the total circular mil area of the derived phase conductors exceeds the values given in Table 250.102(C)(1), the 12½ percentage rule that then must be applied per note 1 in Table 250.102(C)(1). An example would be a 750-kVA transformer supplying a 2500-ampere switchboard at 208/120 volts. If the derived secondary phase conductors were 10 sets of four 500-kcmil copper XHHW conductors per phase, the total circular mil area of one set would equal 5,000,000 circular mils. 5,000,000 x 12.5 percent = 625,000 circular mils. Take that value back to Table 8 in *NEC* Chapter 9 and the next higher size is required. The minimum size for the supply-side bonding jumper installed from the secondary of the derived system to the first disconnecting means or overcurrent device would be required to be not smaller than 700-kcmil copper. If the supply-side bonding jumpers and phase conductors are installed in parallel in separate raceways, the supply-side bonding jumper should be sized based on the size of the derived phase conductors installed in each raceway in accordance with 250.102(C), see figure 12.5.

Use of Derived Grounded (Neutral) Conductor

There is an alternative method of bonding that utilizes the grounded conductor and allows it to be bonded to the source enclosure and also at the first system disconnect or overcurrent device enclosure where doing so does not create a parallel path for current that would be returning to the source over the grounded conductor [see 250.30(A)(1) Exception No. 2, and figure 12.6]. Revisions to the 2014 *NEC* to 250.30(A)(1) exception 2, a new exception to 250.30(A)(2) clarified the use of the grounded (neutral) conductor as well as set new limits on this option only to separately derived systems that are installed outside the building or structure being served.

Section 250.142(A)(3) permits the grounded (neutral) circuit conductor to be used for grounding equipment "on the supply side or within the enclosure of the main disconnecting means or overcurrent devices of a separately derived system where permitted by 250.30(A)(1)." As used in 250.142(A)(3), the term, on the supply side means "up to or within the enclosure for the disconnecting means or overcurrent devices." It is widely accepted to make bonding connections of the neutral or grounded circuit conductor within the disconnecting means enclosure for the separately derived system and upstream to the transformer or generator.

As shown in figure 12.6, the grounded (neutral) circuit conductor serves two purposes. First, it allows line-to-neutral or grounded conductor loads to be supplied, and the conductor carries the unbalanced loads from ungrounded conductors. Secondly, it serves as the supply-side bonding jumper and will carry line-to-ground fault currents back to the source. This grounding scheme is similar to that used for services and by the exception to 250.32(B) for feeder(s) or branch circuit(s) to additional buildings on the premises.

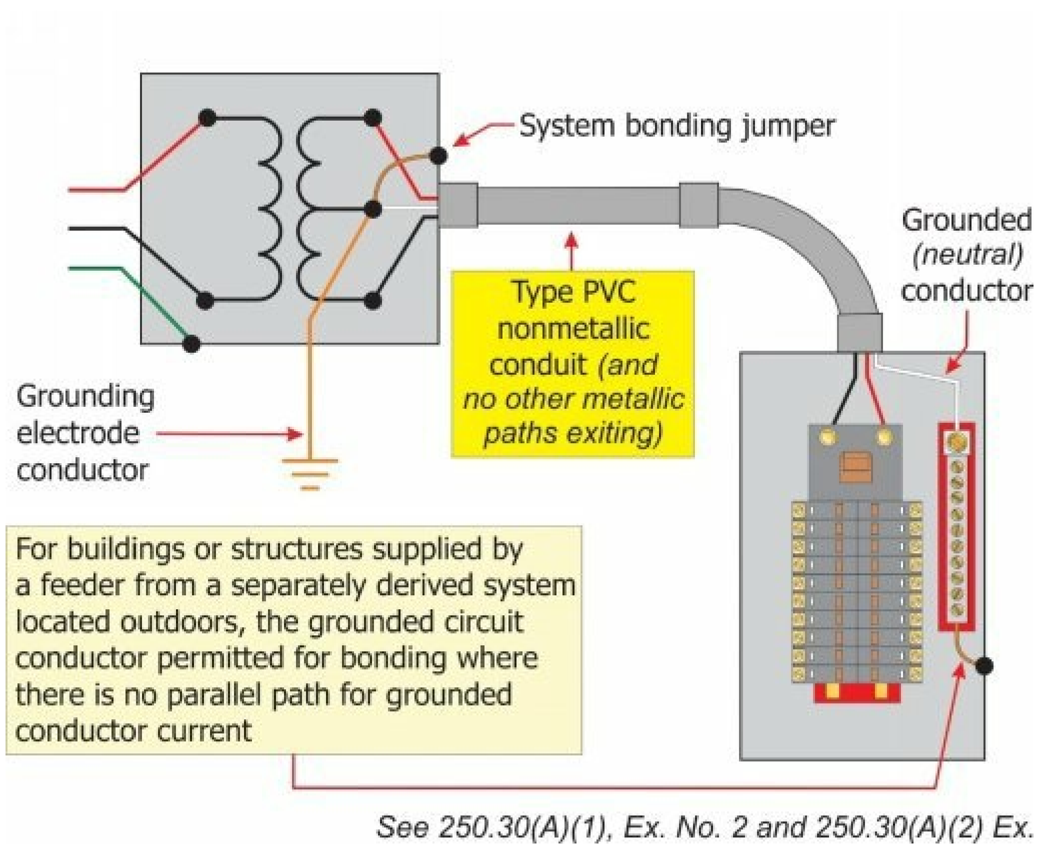


Figure 12.6 Use of derived grounded conductor (neutral) for bonding is permitted by exception

Where this scheme is used, it is not necessary to install another supply-side bonding jumper between the source and the disconnecting means or overcurrent protection enclosure. This requires nonmetallic raceways to be used. Where nonmetallic raceways are used, a parallel path for neutral current is not created by the wiring method.

Keep in mind that this method of bonding the grounded conductor at both ends is permitted only where doing so does not create a parallel path, the earth does not count, for grounded (neutral) conductor current. A parallel path for neutral current exists where a metal raceway or some other metallic conductor is installed between the source of the separately derived system and the metal enclosure for the disconnecting means or overcurrent device. A parallel path can also be established by other means such as through metal pipes, cable trays and structural metal framing members, etc. Another caution is to ensure the separately derived system enclosure and the first disconnecting means enclosure are not connected to a common grounding electrode system such as a buried ground grid. The neutral current will divide between the available paths depending upon the impedance of the paths. The lowest impedance path will obviously carry the most current.

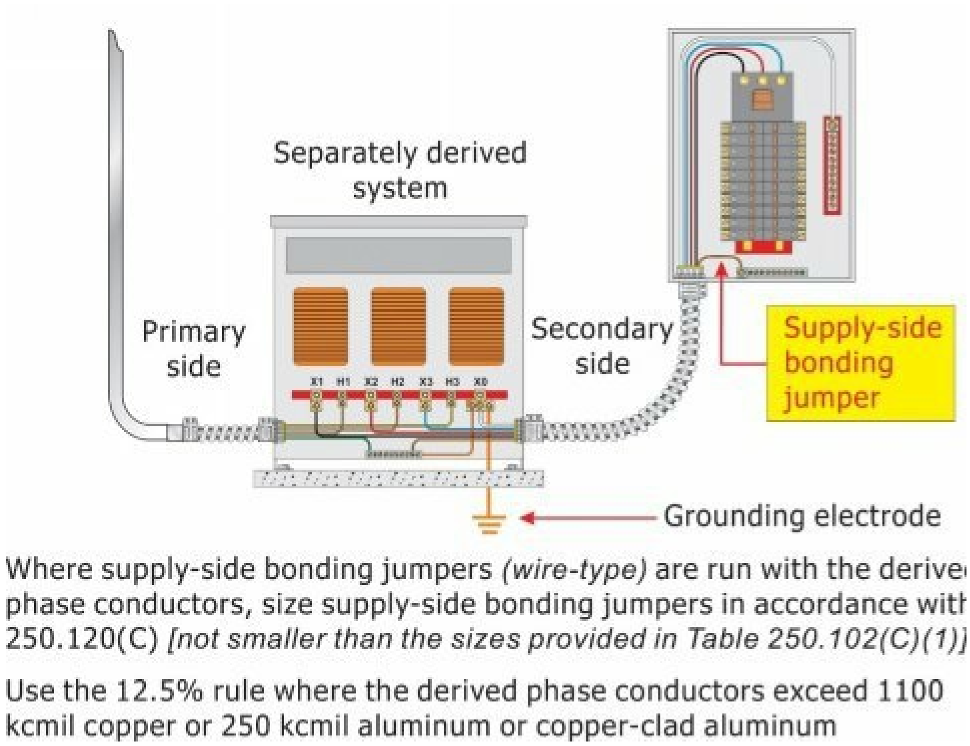


Figure 12.7 Minimum size for supply-side bonding jumpers of separately derived systems [250.30(A)(2)]

Where a system bonding jumper is installed at both the source location and the first disconnecting means as permitted in 250.30(A)(1) Exception 2 and 250.30(A)(2) exception, the grounded conductor must be adequately sized to carry any fault current likely to be imposed. Section 250.30(A)(3) covers the sizing and routing requirements for grounded conductors on the secondary of derived systems connected in this manner. Basically the sizing shall be no smaller than required by 250.102(C) and Table 250.102(C)(1) and where the derived phase conductors exceed 1100-kcmil copper or 1750-kcmil aluminum or copper-clad aluminum, the grounded conductor shall not be smaller than 12½ percent of the total kcmil of the largest derived phase conductor. The grounded conductor of a 3-phase, 3-wire delta-connected separately derived system shall have an ampacity not less than the ungrounded derived phase conductors.

The *NEC* in recent editions has continued to migrate away from the use of the grounded conductor for grounding non-current-carrying metal parts of equipment on the downstream side of the service grounding connection point or the grounding connection point for a separately derived system.

Use care when considering the use of the grounded (neutral) conductor to make grounding connections at points other than the service equipment or source of separately derived system. Current will always try to return to its source, both normal current through the grounded or neutral conductor and ground-fault current as reviewed in chapter one.

Parallel paths for this current can create additional shock hazards for persons and could also introduce additional impedance into the path for fault current.

Grounding Electrode for the Separately Derived System

Definition

Grounding Electrode. "A conducting object through which a direct connection to earth is established."

The rules regarding grounding electrodes permitted to be used for grounding a separately derived system are located and described in Part III of Article 250.

The evolution over several *Code* cycles was to better clarify the grounding electrode being in the earth [250.52(A)] and items above the earth are conductors [250.68(C)]. A change in the 2017 *NEC* completes a part of that evolution so that separately derived systems are now required to connect to the grounding electrode system for the building or structure and the specific electrodes identified as preferred have been eliminated. (see figure 12.8).

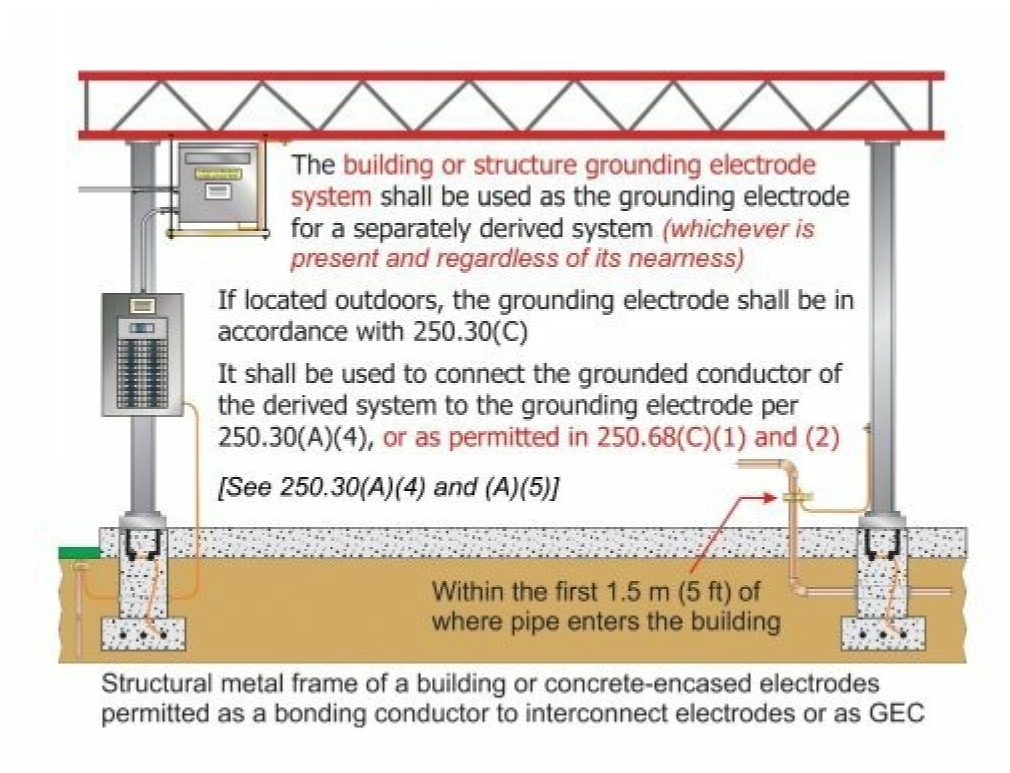


Figure 12.8 Grounding electrode(s) for separately derived systems

250.30(A)(4) Grounding Electrode. The building or structure grounding electrode system shall be used as the grounding electrode for the separately derived system. If located outdoors, the grounding electrode shall be in accordance with 250.30(C).

The next sections on the grounding electrode conductor will provide guidance on connection to the grounding electrode or grounding electrode system of the building or structure.

Where separately derived systems are an integral part of listed equipment such as in unit substations the grounding electrode used for the service equipment, or equipment that is suitable for use as service equipment installed in accordance with the requirements of Article 225 for feeders, shall be permitted to serve as the grounding electrode for the separately derived system. The internal equipment grounding bus in such equipment is permitted to serve as the grounding electrode conductor if it is large enough, and provided the grounding electrode conductor from the service or feeder to the grounding electrode is also large enough for the separately derived system (see figure 12.9).

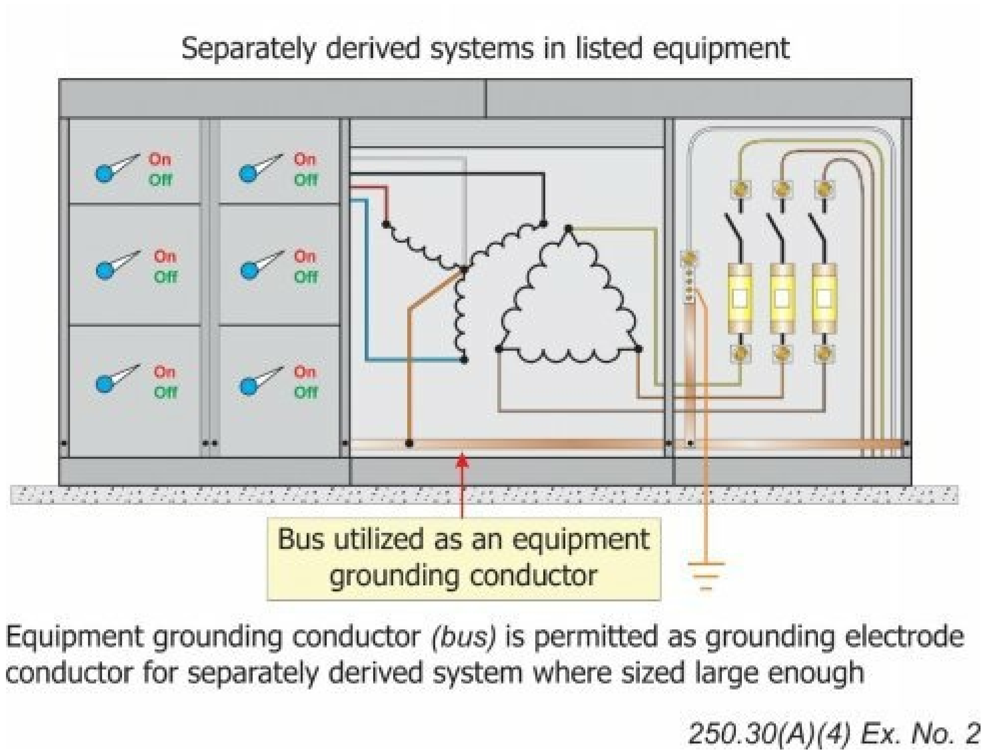


Figure 12.9 Separately derived systems contained within listed equipment such as unit substations

The Grounding Electrode Conductor(s)

Definition

Grounding electrode conductor. "A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system."

A separately derived system that is grounded must have a grounding electrode conductor to establish the connection of the grounded system conductor and metal equipment supplied by the derived system to ground (earth). Section 250.121 generally requires this to be a separate conductor and that the equipment grounding conductor cannot be used as the grounding electrode conductor. An exception to this restriction allows only a wire type conductor to be used for both an equipment grounding conductor and a grounding electrode conductor when all the applicable requirements in Parts II, III and VI, of Article 250 are met.

Separately derived systems are permitted to be grounded individually with an individual grounding electrode conductor, or, under certain conditions, multiple separately derived systems are permitted to be grounded by grounding electrode conductor tap connected to a single common grounding electrode conductor.

Grounding Electrode Conductor for Single Separately Derived System

The grounding electrode conductor for a single separately derived system in accordance with 250.30(A)(5) must be sized at a minimum in accordance with the sizes specified in Table 250.66 on the circular mil area of the derived phase conductors. This conductor must connect the grounded conductor of the derived system to the grounding electrode and must be installed in accordance with the requirements of 250.64(A), (B), (C), and (E), also see 250.30(A)(7) (see figures 12.10 and 12.11). This section includes all applicable installation requirements for grounding electrode conductors, including physical protection from damage and protection from magnetic fields.

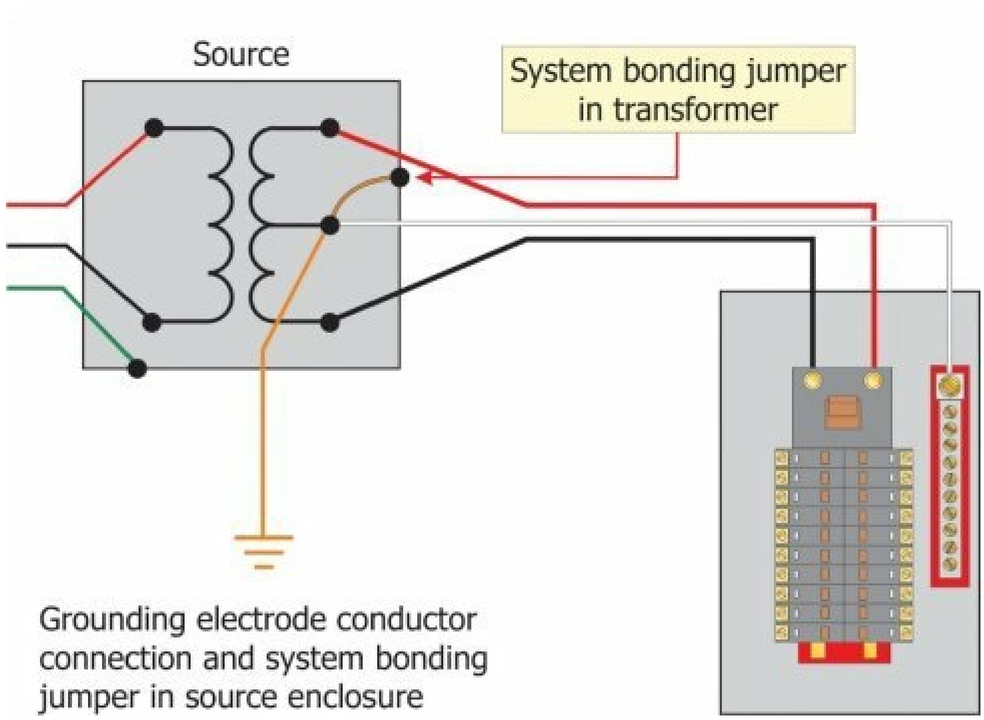


Figure 12.10 Grounding electrode conductor connections are to be made at the same location as the system bonding jumper (at source enclosure).

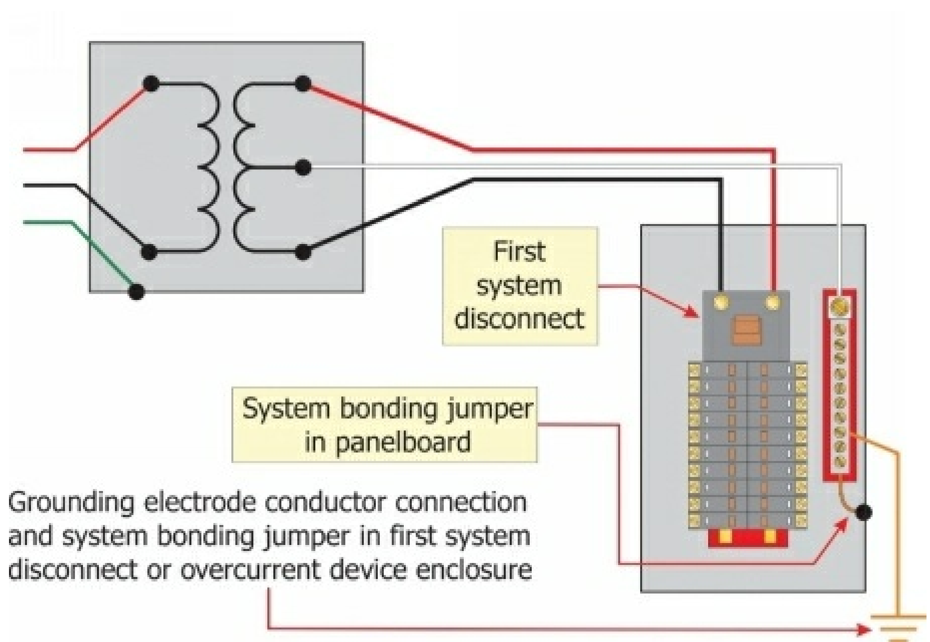


Figure 12.11 Grounding electrode conductor connections are to be made at the same location as the system bonding jumper (at first system disconnect or overcurrent device enclosure).

The connection of the grounding electrode conductor to the grounded (usually a neutral) conductor of the separately derived system is required to be made at the same location as the system bonding jumper connection unless the installation conforms to the requirements of 250.30(A)(5) Exception No. 1. In this case, the grounding electrode conductor is permitted to be connected to an equipment grounding terminal bar installed at the source or first system disconnect or overcurrent protective device and a busbar or wire type system bonding jumper sized in accordance with 250.28(D)(3) is installed from the grounded (neutral) conductor termination point to the equipment grounding terminal bus. This is typically done in a switchboard and where there is a residual or ground strap type of equipment ground-fault protection systems [see chapter fourteen for more information on ground-fault protection systems].

Grounding Electrode Conductors for Multiple Separately Derived Systems

An alternative method for establishing and installing grounding electrode conductors for multiple separately derived systems is provided in Section 250.30(A)(6) (see figure 12.12). It is permitted by the *NEC* to install a common grounding electrode conductor to which multiple separately derived systems shall be connected by individual grounding electrode (tap) conductors. The grounding electrode conductor connected to each separately derived system is sized based on the derived phase conductors of each separately derived system (see figure 12-13). An example of where this alternative method of grounding electrode conductor installation can be effective is a typical high-rise building. The common grounding electrode conductor can be a wire type as provided in 250.30(A)(6), metallic water pipe as provided in 250.68(C)(1) and exception, or structural metal as provided in 250.68(C)(2).

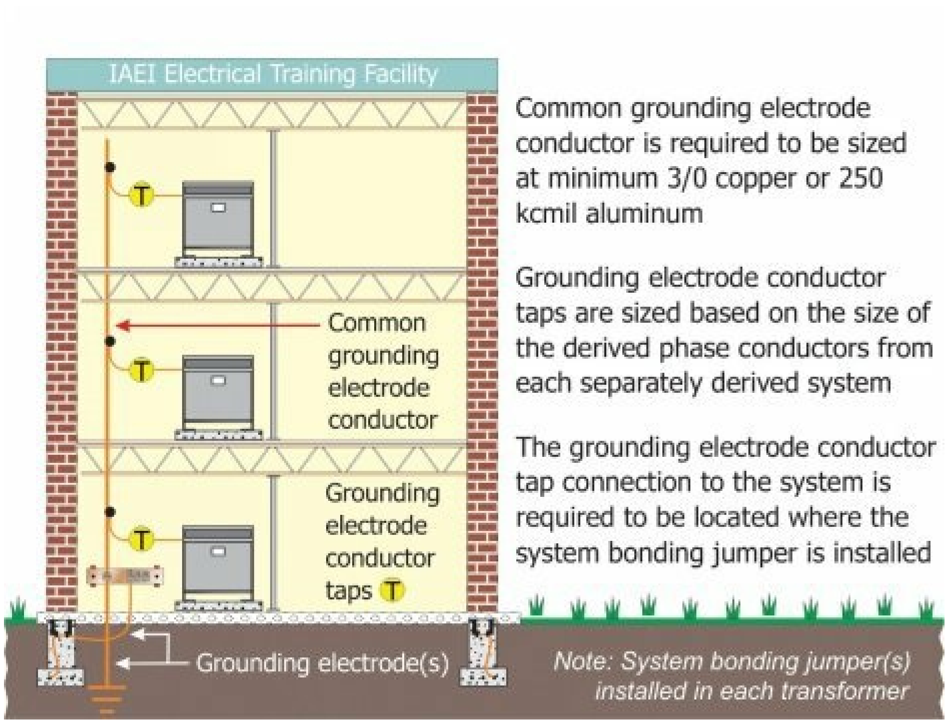


Figure 12.12 Multiple separately derived systems connected to a common grounding electrode conductor

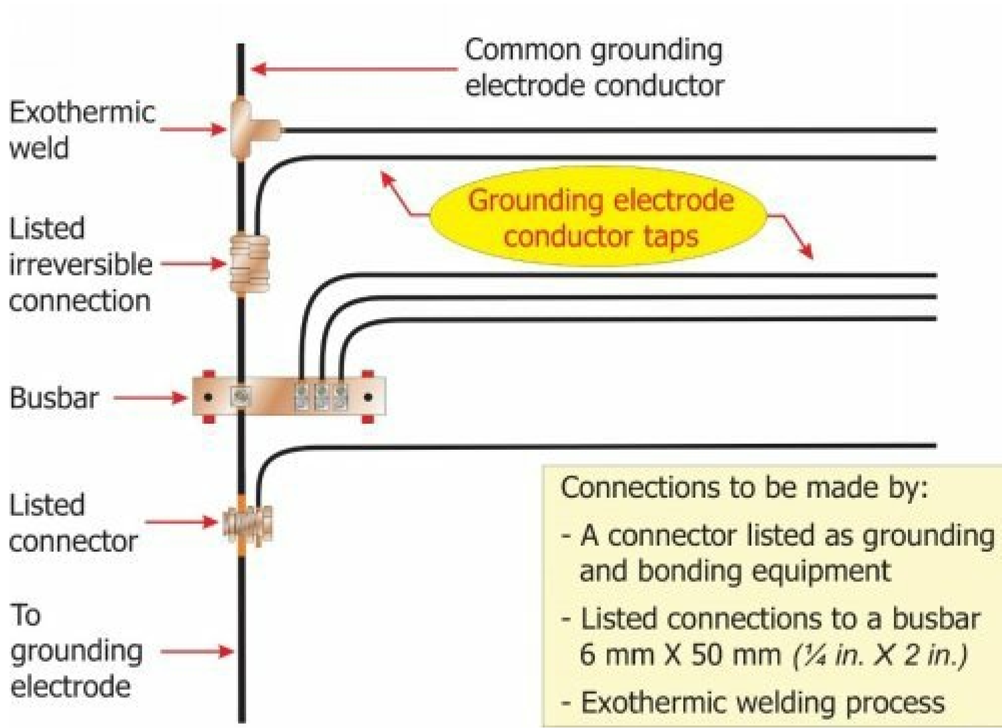


Figure 12.13 Grounding electrode conductor tap connections

The rules that must be followed when installing grounding electrode conductors for multiple separately derived systems in accordance with these alternative provisions are as follows:

Where more than one separately derived system is grounded to a common grounding electrode conductor, the common grounding electrode conductor shall be sized based at not less than 3/0 AWG copper or 250-kcmil aluminum [250.30(A)(6)(a)(1)]. If longer lengths for this common grounding electrode conductor are needed, which is often the case, the common grounding electrode conductor usually is increased in size based on the conditions and the design of the system but the *NEC* does not require an increase in size.

It is common to see high-rise buildings that have no structural metal frame that can act as extending the grounding electrode, but the building grounding electrode system established in the basement of the structure is used and a 500-kcmil conductor (common grounding electrode conductor) is run up through the core of the structure.

Individual grounding electrode conductor taps would then be installed from each derived system to this common grounding electrode conductor. This has been an industry practice for some time to accomplish the grounding for separately derived systems in high-rise buildings or in large single story buildings.

Once the common grounding electrode conductor is installed, then the installation of the grounding electrode conductor taps is required. Sizing the individual grounding electrode conductor taps is based on the derived phase conductors supplied by each separately derived system. The grounding electrode conductor tap connects the grounded conductor of the derived system to the common grounding electrode conductor, which is connected to the grounding electrode. The grounding electrode conductor tap is required to be connected to a separately derived system at the same enclosure where the system bonding jumper is located [250.30(A)(6)]. Installation for both the common grounding electrode conductor and the grounding electrode conductor taps must be in accordance with the installation requirements for grounding electrode conductors specified in

250.64(A), (B), (C), and (E), also see 250.30(A)(7). This alternative for grounding electrode conductor taps to a common grounding electrode conductor is similar in concept to the alternative methods for grounding electrode conductor taps for services in accordance with 250.64(D).

The common grounding electrode conductor must be installed in a continuous length without a splice or joint, unless splicing is accomplished by irreversible compression connectors or by the exothermic welding process [(250.64(C)]. The grounding electrode conductor taps must be connected to the common grounding electrode conductor at an accessible location by one of three methods:

- A listed connector listed as grounding and bonding equipment. This can be an irreversible crimp, or mechanical connector such as a split bolt. (see figure 12.13),
- Listed connections to aluminum or copper busbars not less than 6 mm thick x 50 mm wide) (¼in. thick x 2 in. wide). Where aluminum busbars are used, the installation must meet the requirements of 250.64(A).
- By the exothermic welding process.

The grounding electrode conductor taps must be connected to the common grounding electrode conductor in a manner that keeps it continuous without a splice or joint.

Bonding of Structural Steel and Water Piping

Where exposed structural steel that is interconnected to form the building frame or an interior metal piping system exists in the area served by the separately derived system, it is required to be bonded to the grounded conductor of the derived system. This effectively eliminates any possible differences of potential that can exist between the grounded conductor of the new derived source and either item, and also provides an effective path for ground-fault current directly to the source for any fault current likely to be imposed on either the steel or the water piping system. Bonding requirements for the metallic water piping system and metallic structural framing members that serve the same area as the separately derived system are provided in 250.104(D). Section 250.30(A)(8) provides a direct reference to 250.104(D) for these specific bonding rules (see figure 12.14).

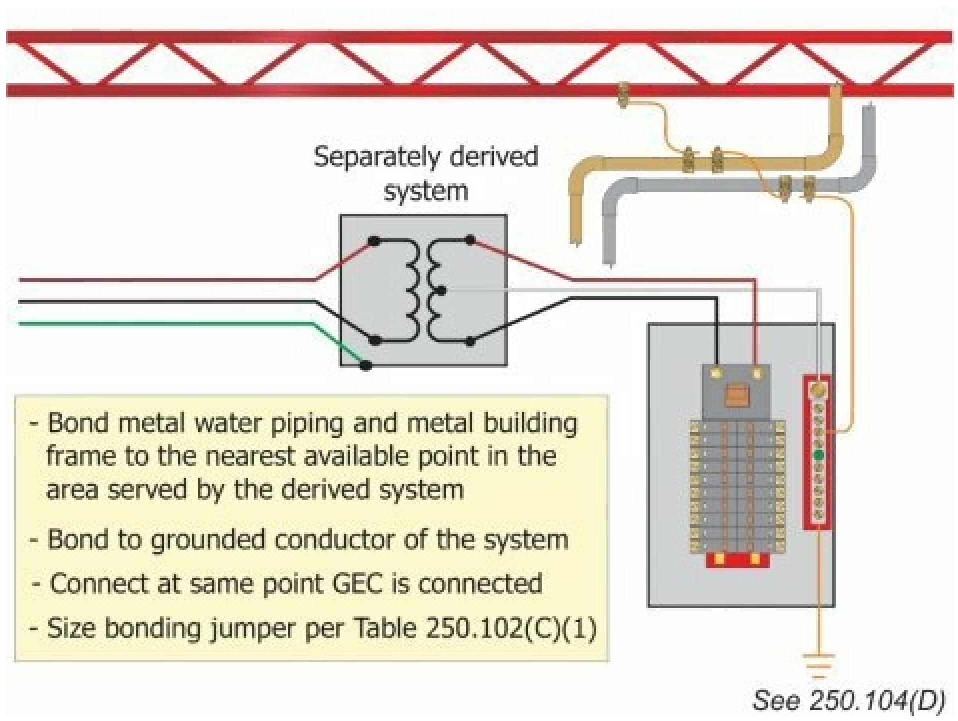


Figure 12.14 Bonding of metal water piping and structural framing members

Ungrounded Separately Derived Systems

Grounding rules are provided in 250.30(B) for ungrounded separately derived systems. Basically, a grounding electrode conductor connects the metal equipment (enclosure) of the separately derived system to a grounding electrode similar to the rules for grounded systems. However, the system itself is not grounded. Where the separately derived system itself is not grounded, the non-current-carrying metal parts of equipment and enclosures for conductors, metal raceways, etc., are required to be grounded. There must be a grounding electrode conductor installed from the metal enclosures or equipment supplied by the derived ungrounded system to a grounding electrode as specified in 250.30(B)(1). This grounding electrode conductor is permitted to be connected to the metal enclosures or equipment at any point on the separately derived system from the source to the first system disconnecting means. The grounding electrode for the ungrounded system is treated the same as for a grounded system and 250.30(B)(2) refers the user back to 250.30(A)(4). Lastly, 250.30(B)(3) requires a supply-side bonding jumper to be installed between the source enclosure and the enclosure containing the first disconnecting means.

Separately Derived Systems Located Outside of Buildings or Structures Served

Prior to the 2011 *NEC* there were no clear requirements for grounding and bonding a separately derived system when the source was located outside of the building or structure being served. For services, 250.24(A)(2) requires an additional grounding electrode at the transformer. Some authorities having jurisdiction treated the separately derived system situation as a building or structure falling under 250.32. Others have no requirements specific to establishing an earth reference at this location. The 2011 *NEC*, 250.30(C) establishes a similar requirement for another electrode and connection to the equipment enclosure as a minimum.

"Outdoors Source. If the source of the separately derived system is located outside the building or structure supplied, a grounding electrode connection shall be made at the source location to one or more grounding electrodes in compliance with 250.50. In addition, the installation shall comply with 250.30(A) for grounded systems or with 250.30(B) for ungrounded systems." The primary reason for this is the protection due to lightning and to provide the separately derived system enclosure is at the same potential as the area of the earth where it is installed.

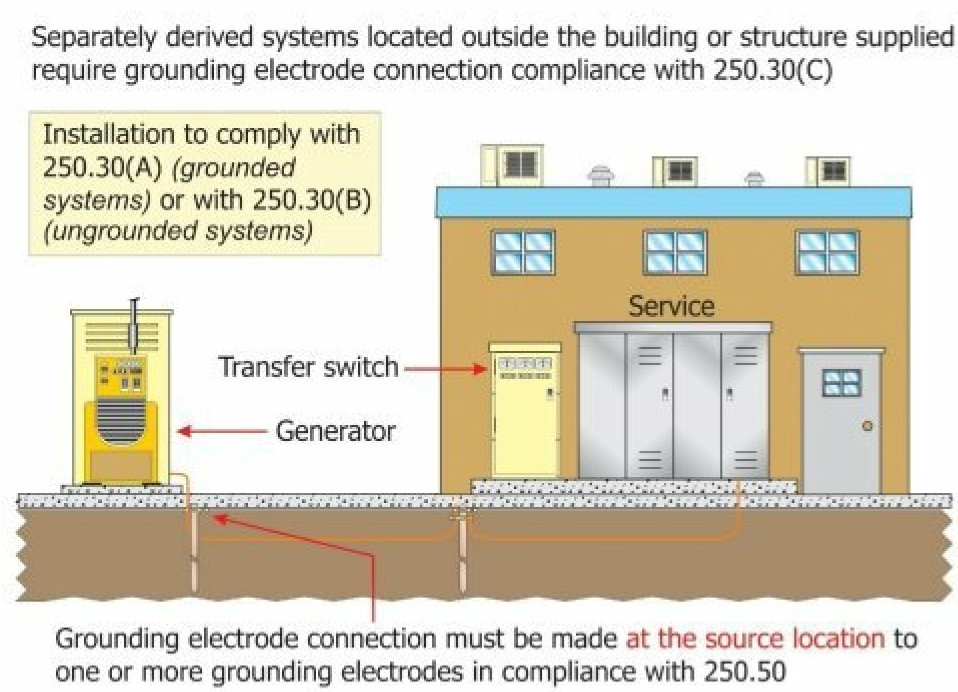


Figure 12.15 Grounding electrode connection for outdoor separately derived system

Effective Ground-Fault Return Path

As with all electrical systems, it is vital to be certain that, for separately derived systems, an effective ground-fault return path exists from the furthermost point on the electrical system back to the source. In this case, the source is the separately derived system.

Fault current downstream from the separately derived system follows the same laws of physics, as does the fault current on the line side. It will seek all possible paths to return to its source, which is the secondary windings of the transformer, generator or other source and primarily uses the lowest impedance path.

As can be seen in figure 12.16, fault current downstream from the separately derived system will return to the secondary windings of the transformer, not to the primary or to the service. The transformer primary sees the fault current on the secondary as a load, and the overcurrent protection devices on the line side of the transformer will respond according to their rating.

It is necessary that an effective path for ground-fault current be electrically continuous, of adequate capacity, and low impedance from the equipment supplied back to the separately derived system. Often, it is best to make a one-line diagram of the installed system to be certain a complete and low-impedance path is provided [see 250.4(A)(5)].

If the system bonding jumper for a separately derived system is installed in the panelboard or fusible switch rather than in the transformer, and flexible metal conduit is used as the wiring method, a supply-side bonding jumper must be installed between the transformer enclosure and the overcurrent device enclosure. In this case a parallel path for fault current will exist through the supply-side bonding jumper and the wiring method.

Equipment Grounding Conductors

The equipment grounding conductors of both the primary and the secondary of the separately derived system can be connected together, sometimes using the supply-side bonding jumper to complete the circuit, on the metal enclosure of the separately derived system. These equipment grounding conductors can be raceways such as conduit or electrical metallic tubing or any of the other equipment grounding conductors identified in 250.118. An equipment grounding conductor is used to be certain the circuit has low enough impedance to be effective. In both the feeder to the primary and the circuits from the separately derived system, a low-impedance path to the source grounded conductor (or neutral) of each system must be provided. This is vital to ensure that overcurrent devices will function to clear ground faults that can occur.

The important connections here require an equipment grounding conductor for the supply primary and supply-side bonding jumper on the secondary of the separately derived systems that function independently of each other and terminating at the respective points of supply at their grounded conductor or neutral. Both equipment grounding conductors and secondary system supply-side bonding jumpers will meet at some common point, such as the point where the system bonding jumper is connected, and they both may be connected to the common grounding electrode.

Interconnecting the equipment grounding conductor and the supply-side bonding jumper of the two systems does not defeat the definition of separately derived system. This is because the equipment grounding conductor on the primary side and the supply-side bonding jumpers on the secondary side are not system or power conductor(s) nor are they grounded conductor(s). In addition, the equipment grounding conductor usually does not make a direct electrical connection of the neutral to ground. By following the system bonding jumper and equipment grounding conductors of the two systems, on a one-line diagram, it can be seen that the systems are, in fact, connected together by these conductors (see figure 12.16).

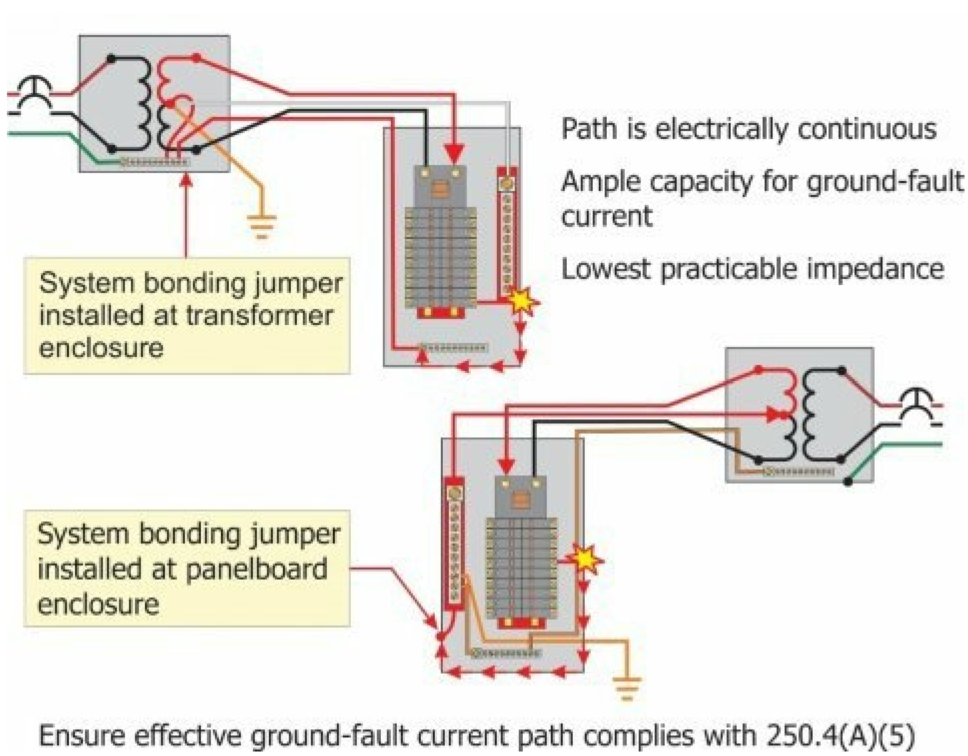


Figure 12.16 Effective ground-fault current path to source

Generator-Type Separately Derived System

Figure 12.17 illustrates a separately derived system supplied from a generator. Note that there is no system connection, including that of a solidly grounded neutral conductor, between the two systems. As stated before, the revised definition of a separately derived system indicates the interconnection of equipment grounding conductors and bonding does not apply as a direct electrical connection. An easy way to determine whether or not a generator must be grounded as a separately derived system in accordance with 250.30(A) is to examine the transfer equipment (see photos 12.3 and 12.4). If the grounded conductor (usually a neutral), in addition to the phase conductors, is switched at the transfer equipment, the generator is required to be grounded as a separately derived system (see figure 12.17).

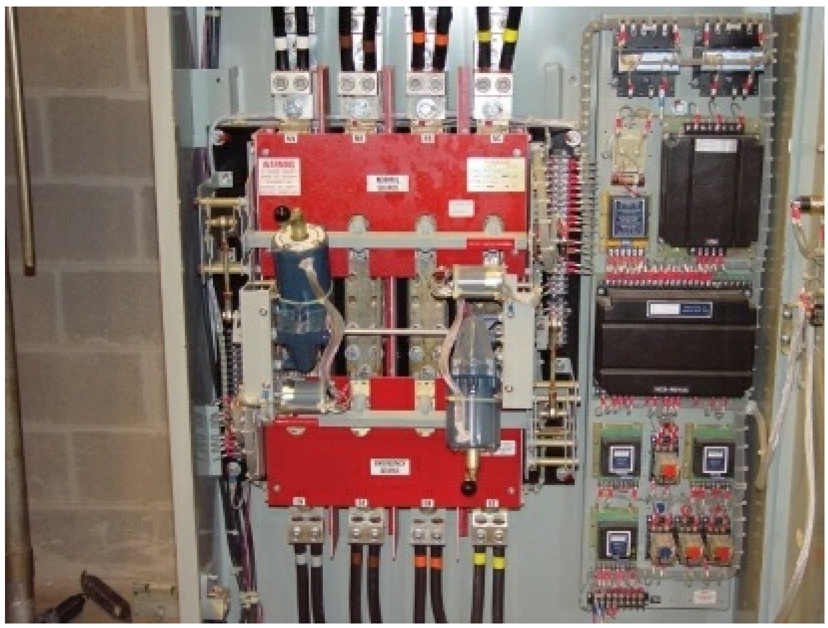


Photo 12.3 Transfer equipment that does switch the grounded (neutral) conductor

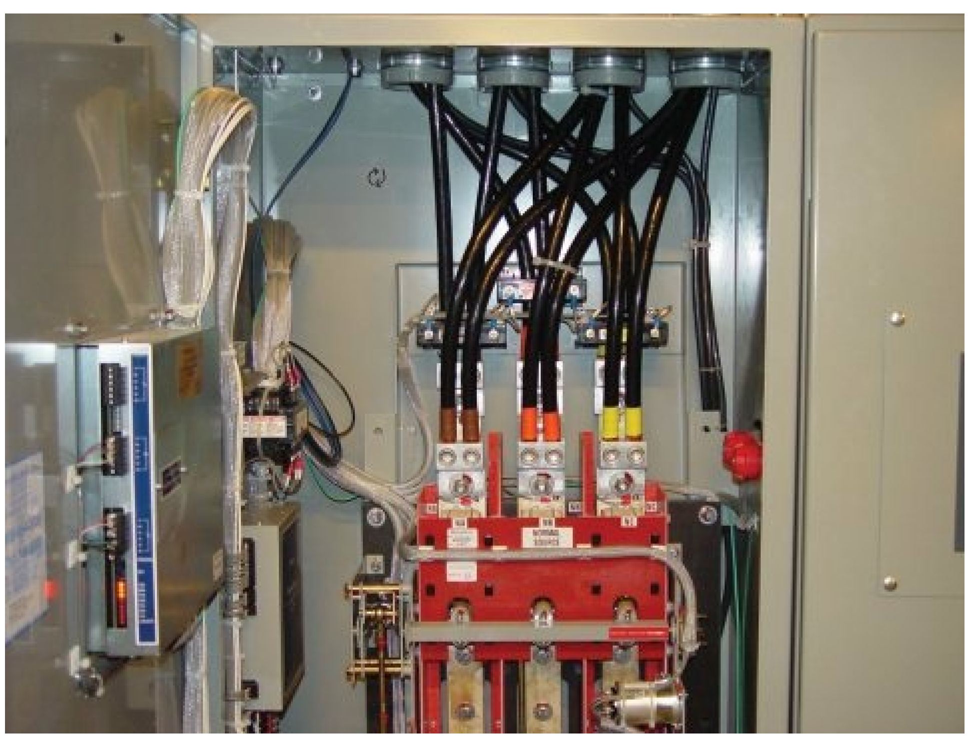


Photo 12.4 Transfer equipment that does not switch the grounded (neutral) conductor transfer equipment

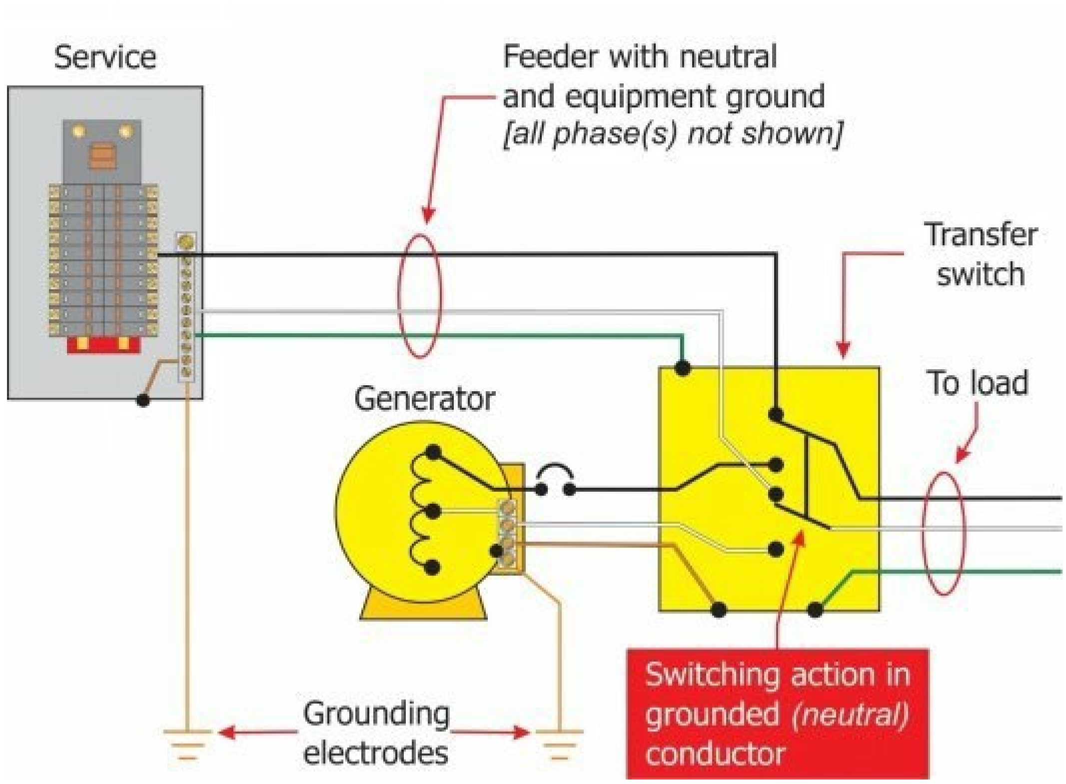


Figure 12.17 Generator-type separately derived system using transfer equipment that switches the grounded (neutral) conductor

If the neutral conductor is not switched by the switching action, but is solidly connected, then it is not a separately derived system (see figure 12.18). Where the generator or source is to be grounded as a separately derived system, the system bonding jumper must be installed, either at the generator or at the first disconnecting means or overcurrent device or any point between. In addition, a grounding electrode conductor must be installed from the system grounded (neutral) conductor to a grounding electrode. The grounding electrode conductor connection to the system must be located at the same point where the system bonding jumper is installed.

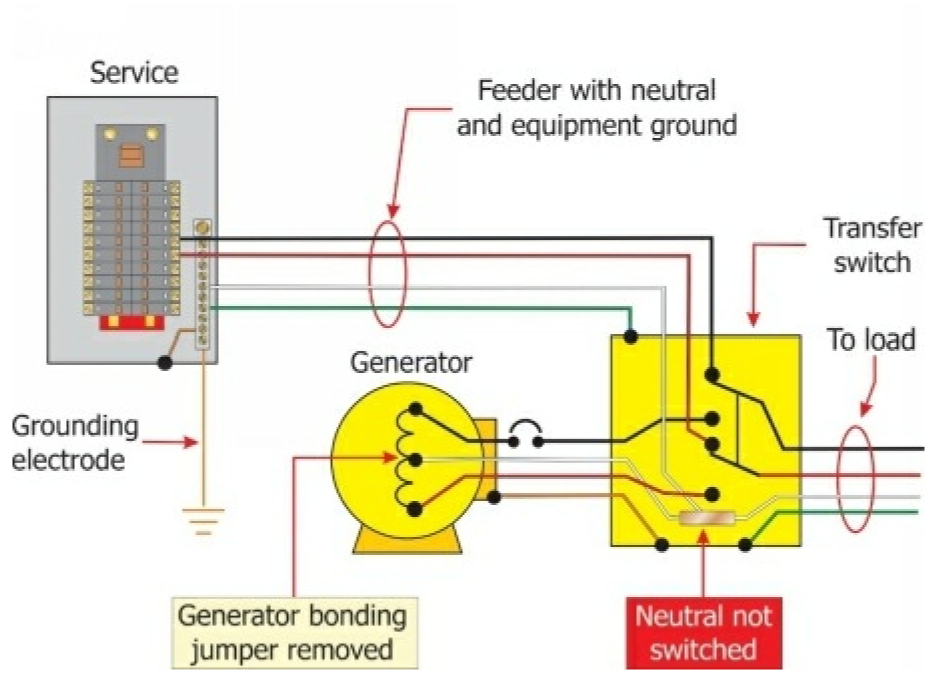


Figure 12.18 Generator system using transfer equipment that does not switch the grounded (neutral) conductor

Another possible installation is a solidly grounded service and wye type generator only serving 3-phase, 3-wire loads. A neutral is required to be installed to the service per 250.24(A)(5), but there is no "normal" power neutral conductor installed to the transfer switch. Also, there is no requirement for a neutral to be installed from the generator to the transfer switch. Therefore this arrangement is still a separately derived system and grounding and bonding of the generator is required in accordance with 250.30(A).

Section 700.7(B), regarding grounding of emergency systems, requires that where removal of a grounding or bonding connection in normal power source equipment interrupts the grounding electrode conductor connection to the alternate power source(s) grounded conductor, a warning sign shall be installed at the normal power source equipment stating:

WARNING

SHOCK HAZARD EXISTS

IF GROUNDING ELECTRODE CONDUCTOR OR

BONDING JUMPER CONNECTION IN THIS EQUIPMENT IS

REMOVED WHILE ALTERNATE SOURCE(S) IS ENERGIZED.

Identical requirements are in 701.7(B) for legally required standby systems and in 702.7(B) for optional standby systems (see figure 12.19).

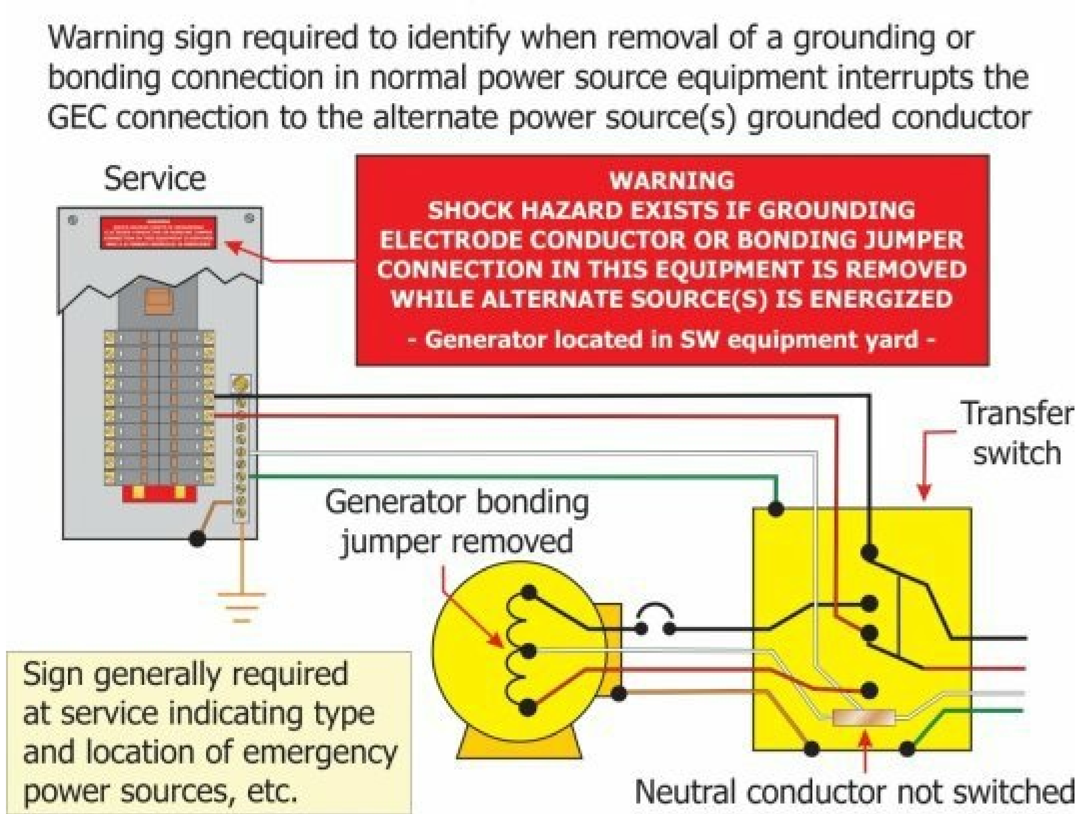


Figure 12.19 Signs are required for standby power source.

Alternate power supply systems that include grounded (neutral) conductors that are not switched through a transfer switch present a safety concern. Electricians that are unfamiliar with the system grounding scheme for that alternate source could inadvertently disconnect the grounded (neutral) conductor when working on the normal source. If the alternate or emergency system source is operating, the grounded (neutral) conductor from the transfer switch to the location where it is grounded is functioning as a grounding electrode conductor, and disconnecting it can present a serious shock hazard.

Section 250.35 includes requirements for providing an effective ground-fault current path between permanently installed generators and the first disconnecting means enclosure. This section addresses both separately derived systems and non-separately derived systems. Where the generator is a separately derived system, it is required to comply with all grounding and bonding rules in 250.30(A). Where the generator is not separately derived, the grounding and bonding connections are required to be in accordance with 250.35(B) depending on the location of the derived system overcurrent device. Supply-side bonding jumpers on the supply side (line side) of each generator overcurrent protective device must be sized according to 250.102(C) [see figure 12.20].

Equipment grounding conductors on the load side of each generator overcurrent protective device must be sized according to 250.122) [see figure 12.20].

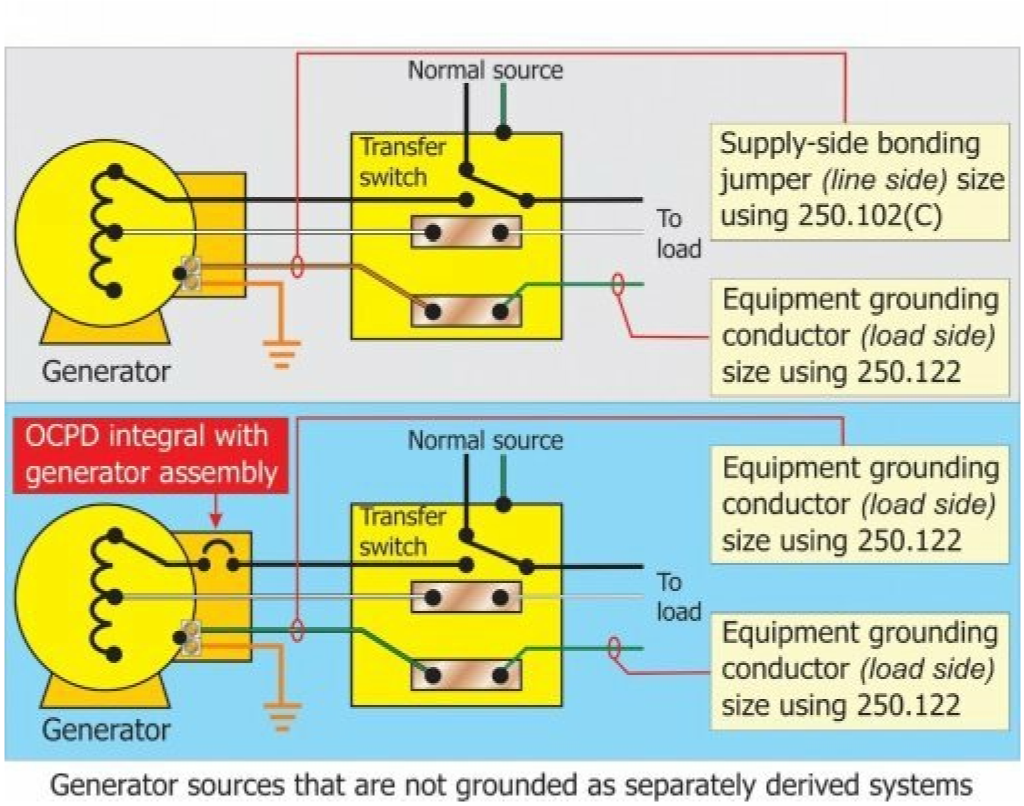


Figure 12.20 Generator is not a separately derived system

Generator Not Grounded as Separately Derived Systems

Where the generator is not a separately derived system, the neutral system bonding jumper must be removed from the generator, and the neutral must not be grounded at the generator or at any point between the generator up to the service.

In this case, the system is grounded by its solid connection to the neutral of the premises wiring system which is connected to earth by the grounding electrode conductor. The generator neutral is solidly connected from the generator to the terminal in the transfer switch completing the connection to earth. Equipment grounding conductors are installed throughout the system with the circuit conductors and to the supply-side bonding jumper between the generator and the generator disconnect thereby connecting all the non-current-carrying parts of the installation.

Equipment Ground-Fault Systems

There are situations where the location of the system bonding jumper is determined by the conditions of the installation and the type of equipment installed. For example, a large step-up transformer separately derived system with the voltage configuration of 240-volt 3-phase primary stepping up to 480Y/277-volt 3-phase, 4-wire secondary with a main disconnect rated at 1000 amperes or greater can require ground-fault protection for equipment [see 240.13 and 215.10].

Larger switchboards that include GFP equipment often require the system bonding jumper to be installed at the equipment and not at the source to ensure the performance of the GFP equipment and conform to the listing and installation instructions of the equipment [see 110.3(B)].

A word of caution is in order here. It is imperative that care be exercised where generators supply systems that have equipment ground-fault protection. In many cases, the designer or engineer will specify that the grounded (neutral) conductor be switched by the transfer equipment to avoid grounding connections to the grounded (neutral) conductor downstream from the ground-fault protection equipment. This is vital to prevent desensitizing the protection system. In this case, the generator is a separately derived system, and it must be grounded and bonded separately.

Section 700.26 provides that equipment ground-fault protection with automatic disconnecting means shall not be required for emergency systems. However, as a minimum indication of a ground fault on the emergency system must be provided in accordance with the rules of 700.6(D). It is required that, where practicable, audible and visual signal devices be provided that will indicate a ground fault in a solidly-grounded wye-connected emergency system of more than 150 volts to ground and circuit protective devices rated 1000 amperes or more. A similar exception from the requirement for ground-fault protection of equipment is provided in 701.26 for legally required standby systems. See chapter fourteen for a more complete discussion on the types of equipment ground-fault protection systems, how the function, and where they are required in premises wiring systems.

[1] **NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA, 2016).**

Review Questions

1. “An electrical source, other than a service, having no direct connection(s) to circuit conductors of any other electrical source other than those established by grounding and bonding connections” best describes ____.

1. medium voltage systems
2. utility supplied systems
3. separately derived systems
4. high voltage systems

2. Derived phase conductors supplied by a separately derived system sized at 500 kcmil aluminum generally require a grounding electrode conductor not smaller than ____.

1. 4 AWG copper or 2 AWG aluminum
2. 2 AWG copper or 1/0 AWG aluminum
3. 6 AWG copper or 4 AWG aluminum
4. 8 AWG copper or 6 AWG aluminum

3. The connection of the system bonding jumper is permitted to be made at the source, or the ____ disconnecting means or overcurrent device or any single point between.

1. first
2. second
3. any
4. line-side

4. The grounding electrode for a separately derived system is required to be _____ the grounding electrode installed for the building or structure.

1. in the same enclosure
2. same cabinet
3. the same as
4. separate and dedicated from

5. A grounding electrode conductor for a separately derived system is required to be connected to the _____ for the the building or structure where it is installed.

1. underground metal gas pipe
2. grounding electrode system for
3. service equipment enclosure
4. metal raceway

6 Where installed in or at the building, the same ____ is required to be used for the grounding of all ac systems.

1. grounding electrode system
2. grounded raceway
3. electrode enclosure
4. bonding jumper

7. The ____ grounding conductor(s) of the primary and the secondary of the separately derived system are permitted to be raceways or conductor enclosures, where permitted by *Code*.

1. isolated
2. identified
3. system
4. equipment

8. If the grounded (neutral) conductor and all phase (ungrounded) conductors are switched through transfer switching equipment associated with an on-site generator, then the generator ____ required to be grounded as a separately derived system according to 250.30 Informational Note No. 1.

1. is
2. is not
3. may be
4. cannot be

9. Where a generator is grounded as a separately derived system, the ____ bonding jumper must be installed, either at the generator or at the first disconnecting means or overcurrent device.

1. equipment
2. system
3. service
4. 10 AWG copper

10. Where the generator is not a separately derived system, the ____ bonding jumper must be removed from the generator and the neutral conductor must not be grounded. In this case, the system is grounded by its solid connection to the grounded (neutral) conductor of the premises wiring system.

1. 10 AWG
2. equipment
3. service
4. system

11. The supply-side bonding jumper installed between the separately derived system enclosure and the first overcurrent device enclosure is required to be sized in accordance with ________.

1. Section 250.102(C)
2. Table 250.122
3. Section 250.122
4. Section 220.22

12. The minimum size copper grounded (neutral) conductor required for a separately derived system where the derived phase conductors are 300 kcmil copper conductors (1 per phase) and there is very little or no neutral load on the system is________.

1. 6 AWG
2. 1/0 AWG
3. 2 AWG
4. 2/0 AWG

13. Where multiple separately derived systems are installed and connected to a common grounding electrode conductor, the minimum size of the copper common grounding electrode conductor must not be smaller than ________.

1. 6 AWG
2. 250 kcmil
3. 4 AWG
4. 3/0

14. Where a generator for an emergency system is provided with transfer equipment that does not switch the grounded (neutral) circuit conductor, a ____________ must be placed at the service equipment denoting the location of the generator and the grounding location and all emergency and normal sources connected at that location.

1. grounding electrode conductor
2. sign
3. bonding jumper
4. disconnect

15. Where a separately derived system is grounded by connection to a single ground rod and the derived phase conductors are sized at 750 kcmil copper, what is the minimum size grounding electrode conductor required?

1. 3/0 copper
2. 250 aluminum
3. 4 AWG copper

4. 6 AWG copper

16. The conductor used to connect the grounded circuit conductor and the supply-side bonding jumper, or the equipment grounding conductor, or both, at a separately derived system is defined as the __________.

1. main bonding jumper
2. system bonding jumper
3. equipment grounding conductor
4. bonding jumper

17. Where grounding electrode conductor taps are installed for multiple separately derived systems in accordance with 250.30(A)(6), they shall be connected to the system in which of the following locations?

1. at the service
2. within 1.5 m (5 ft) of the entry of the building
3. at the source enclosure
4. in the enclosure where the system bonding jumper is installed.

18. Where a generator is a nonseparately derived system, the supply-side bonding jumper between the generator and the equipment grounding terminal bus of the enclosure shall be sized in accordance with which of the following *Code* sections?

1. 250.102(D)
2. 250.102(C)
3. 250.122(A)
4. none of the above

19. What is the minimum copper size of the water piping system bonding jumper connected to the grounded conductor of a separately derived system if the derived secondary ungrounded phase conductors are sized at 500 kcmil copper?

1. 2 AWG copper
2. 3/0 copper
3. 6 AWG copper
4. 1/0 copper

20. Where the common grounding electrode conductor tap system is used for grounding multiple separately derived systems, the grounding electrode conductor taps shall be connected in a manner that the__________ remains without a splice or joint.

1. equipment grounding conductor

2. grounded conductor
3. common grounding electrode conductor
4. equipment bonding jumper

Chapter 13

Grounding and Bonding at Buildings or Structures Supplied by Feeders or Branch Circuits

Objectives to understand

- Grounding at more than one building
- or structure
- Sizing of grounding electrode conductors
- Requirements for bonding grounding electrodes together
- Disconnecting means requirements for separate buildings
- Objectionable currents over multiple paths
- Requirements for mobile homes, recreational vehicles, and agricultural buildings

Section 250.32 provides requirements for grounding of electrical systems and equipment at buildings or structures that are supplied from feeders or branch circuits. Included are rules for grounding electrodes, grounded systems, ungrounded systems, where supplied from separately derived systems, equipment grounding conductors, and grounding at buildings where the disconnecting means are located in a separate building or structure on the same premises.

Definition

Grounding electrode conductor. "A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system." [1]

This definition includes the grounding electrode conductors at services and separately derived systems as previously discussed in chapters seven and twelve of this text. The definition also applies to the conductor connecting the grounding electrode at a second or additional building or structure supplied by a feeder or branch circuit that is the topic of this chapter.

Grounding Electrode is Required

The general rule in 250.32(A) is that at each building or structure served by one or more feeders or branch circuits, a grounding electrode system or grounding electrode meeting the requirements of Article 250 Part III must be used or installed. The electrodes must be connected in a manner specified in 250.32(B) or (C). Where no grounding electrodes are already present from the construction of the building or structure, then a grounding electrode(s) as specified in Part III of Article 250 (specifically 250.50) must be installed and used. Section 250.50 indicates the following, "All grounding electrodes as described in 250.52(A)(1) through (A)(7) that are present at each building or structure served shall be bonded together to form the grounding electrode system. Where none of these grounding electrodes exist, one or more of the grounding electrodes specified in 250.52(A)(4) through (A)(8) shall be installed and used."

The grounding electrodes specified in 250.52 must be utilized where present. The electrodes required in 250.52(A), include the following:

(1) Metal Underground Water Pipe

(2) Metal Frame of the Building or Structure

(3) Concrete-Encased Electrode

(4) Ground Ring

(5) Rod and Pipe Electrodes

(6) Other Listed Electrodes

(7) Plate Electrodes

(8) Other Local Metal Underground Systems or Structures

Where none of the above electrodes is present at the building or structure, one or more of the following grounding electrodes specified in 250.52(A)(4) through (A)(8), as identified above, shall be installed and used[2].

As discussed in Chapter 6, section 250.52(B) identifies electrodes that shall not be used. "250.52(B) Not Permitted for Use as Grounding Electrodes. The following systems and materials shall not be used as grounding electrodes:

(1) Metal underground gas piping systems

(2) Aluminum"

(3) The structures and structural reinforcing steel described in 680.26(B)(1) and (B)(2) [3]

One of the main reasons for a grounding electrode system to be required at the additional building or structure is so the conductive non-current-carrying parts of equipment and enclosures in the building or structure reference the earth where the building or structure is located. This minimizes the possible difference in potential that could exist for a person standing on the ground in or at this building or structure and who could also be in contact with the electrical equipment enclosures or other non-current-carrying parts that are referenced to the earth connection as the source of the feeder or branch circuit serving the building.

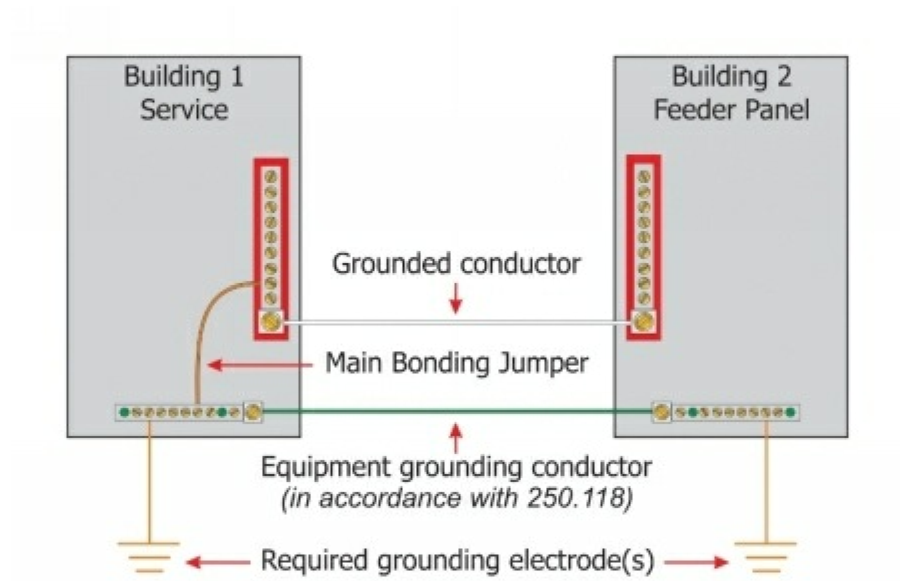
The exception to 250.32(A) indicates that a "grounding electrode at separate buildings or structures shall not be required where a single branch circuit supplies the building or structure and the single branch circuit including a multiwire branch circuit includes an equipment grounding conductor for grounding the conductive non-current-carrying parts of all equipment." [4] For the purposes of this section, a single branch circuit could be a multiwire branch circuit as indicated in the exception to 250.32(A). [See *NEC* 250.53 and chapter six for additional information on installing grounding electrodes].

Grounding Requirements for Grounded Systems

Rules are provided in 250.32(B)(1) for grounding electrical systems and equipment at additional buildings or structures on the premises. Buildings or structures supplied by a feeder(s) or more than one branch circuit shall include an equipment grounding conductor. Existing buildings or structures supplied by a feeder(s) or more than one branch circuit from a grounded system that does not have an equipment grounding conductor and were compliant with the *NEC* in effect at the time of installation must comply with the rules in 250.32(B)(1), Exception.

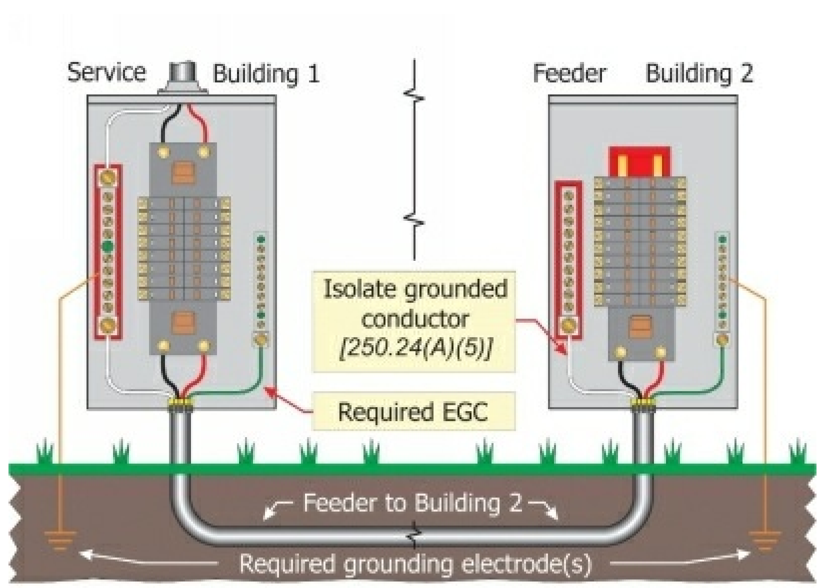
Grounding with an Equipment Grounding Conductor

In this method, that is required for all new construction, an equipment grounding conductor is installed with the feeder(s) or branch circuit(s), in addition to the ungrounded and grounded conductors to the building or structure. "Any installed grounded conductor shall not be connected to the equipment grounding conductor or to the grounding electrode(s)."[5] This would be in violation of 250.24(A)(5) and 250.142(B). This method is similar, or identical, to installing a feeder to a panelboard or distribution equipment that is located in the same building or service where the service is located (see figures 13.1 and 13.2).



Grounding at separate building or structure using the required equipment grounding conductor *[250.32(B)(1)]*

Figure 13.1 Grounding at separate buildings or structures using the equipment grounding conductor (insulate the grounded conductor from ground and grounded parts and equipment at building two).



Grounding and bonding at separate building or structure using required equipment grounding conductor *(EGC) [250.32(B)(1)]*

Figure 13.2 Insulate grounded (neutral) conductor from ground and grounded parts and equipment under this method.

The equipment grounding conductor (which could be any of those specified on 250.118) that is installed from the building or structure where the feeder or branch circuit(s) originates is connected to a terminal bar inside the building or structure disconnecting means enclosure. This disconnecting means (or equipment) is then locally grounded by connecting the required grounding electrode at the building or structure to the equipment grounding terminal bar of the disconnecting means enclosure. Equipment grounding conductors of the type included in 250.118 are acceptable and include wires as well as some conduits or other raceways.

The number of conductors for various systems that must be installed is summarized in a handy reference, Table 13.1.

Number of Conductors Installed
(Equipment Grounding Conductor Installed)

Table 13-1 - *(Soares G & B textbook)*

System	Grounded	Ungrounded	EGC	Total
120V	1	1	1	3
120/240V	1	2	1	4
208Y/120V	1	3	1	5
480Y/277V	1	3	1	5

Table 13.1 Equipment grounding conductor installed

The grounded (often a neutral) conductor, installed as a part of the feeder or branch circuit from the building or structure where the service is located to the second or additional building or structure, must be an insulated conductor [see 310.106(D)]. It should be noted that while an equipment grounding conductor is required, there is no requirement to install a grounded (neutral) conductor unless there are phase to grounded (neutral) conductor loads being served.

By using this method, the grounded (often a neutral) conductor(s) must be connected to the insulated terminal bar for the grounded conductors. There is not to be any connection between the equipment grounding conductors or the grounding electrode conductor to the grounded (neutral) conductor in the disconnecting means enclosure.

The equipment grounding conductor that is run to the additional building or structure must be sized from Table 250.122 based on the rating of the overcurrent device protecting the feeder or branch circuit.[6] (See figure 13.5).

Existing Installations by Exception

Exception No. 1 to 250.32(B)(1) applies only to existing installations where the installation was compliant with the *Code* in effect at the time of the installation and permits the grounded circuit conductor (often a neutral) to be grounded again at the disconnecting means for the building or structure only if all the specified conditions are complied with:

> *"Exception No. 1: For installations made in compliance with previous editions of this Code that permitted such connection, the grounded conductor run with the supply to the building or structure shall be permitted to serve as the ground-fault return path if all of the following requirements continue to be met:*
>
> *"(1) An equipment grounding conductor is not run with the supply to the building or structure.*
>
> *"(2) There are no continuous metallic paths bonded to the grounding system in each building or structure involved.*
>
> *"(3) Ground-fault protection of equipment has not been installed on the supply side of the feeder(s).*
>
> *"If the grounded conductor is used for grounding in accordance with the provision of this exception, the size of the grounded conductor shall not be smaller than the larger of either of the following:*
>
> *"(1) That required by 220.61*
>
> *"(2) That required by 250.122"* [7] (See figures 13.3 and 13.4).

In this case, the electrical system at the additional building or structure is treated like a service for grounding purposes, although the building or structure is actually supplied by a feeder or branch circuit. There are also some different requirements regarding bonding provisions and minimum conductor sizes. The grounded circuit conductor is bonded to the disconnecting means enclosure for the building or structure. The grounding electrode connection to the grounded (often a neutral) conductor must be made on the supply side of or within the building or structure disconnecting means.

In this method provided in Exception No. 1 to 250.32(B)(1), both the grounded circuit conductor (usually a neutral) and the non-current-carrying equipment are connected to a grounding electrode (system) at the additional building or structure. The number and type of conductors that must be taken, from the building or structure where the feeder or branch circuit originates, to the second building or structure is summarized in Table 13.2 (see also figures 13.3 and 13.4).

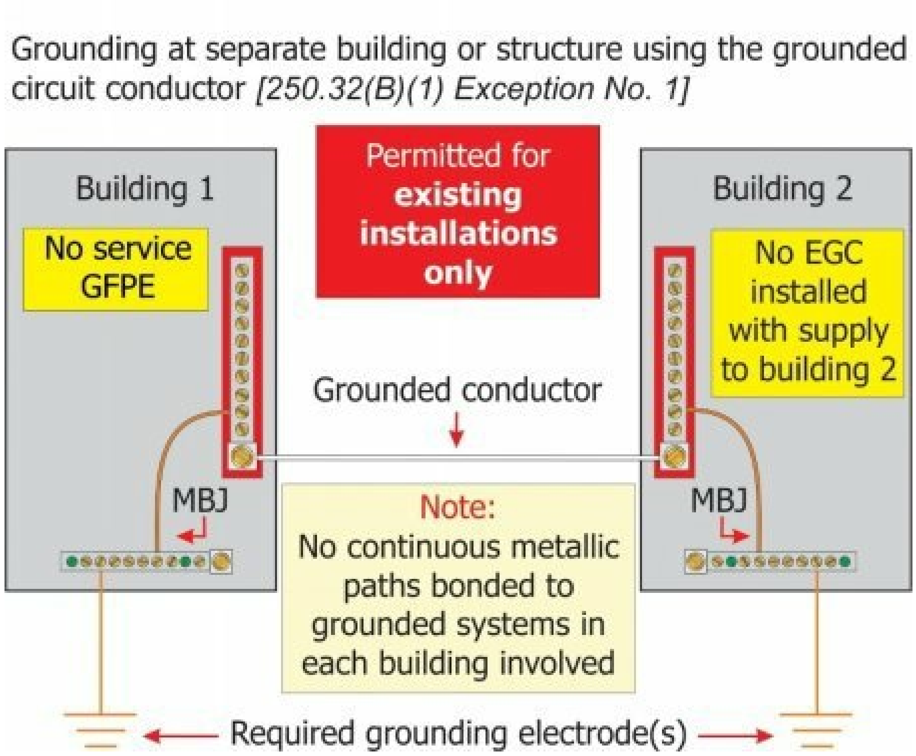


Figure 13.3 Grounding at separate buildings or structures using the grounded (neutral) conductor as allowed in 250.32(B)(1), Exception [Existing Installation]

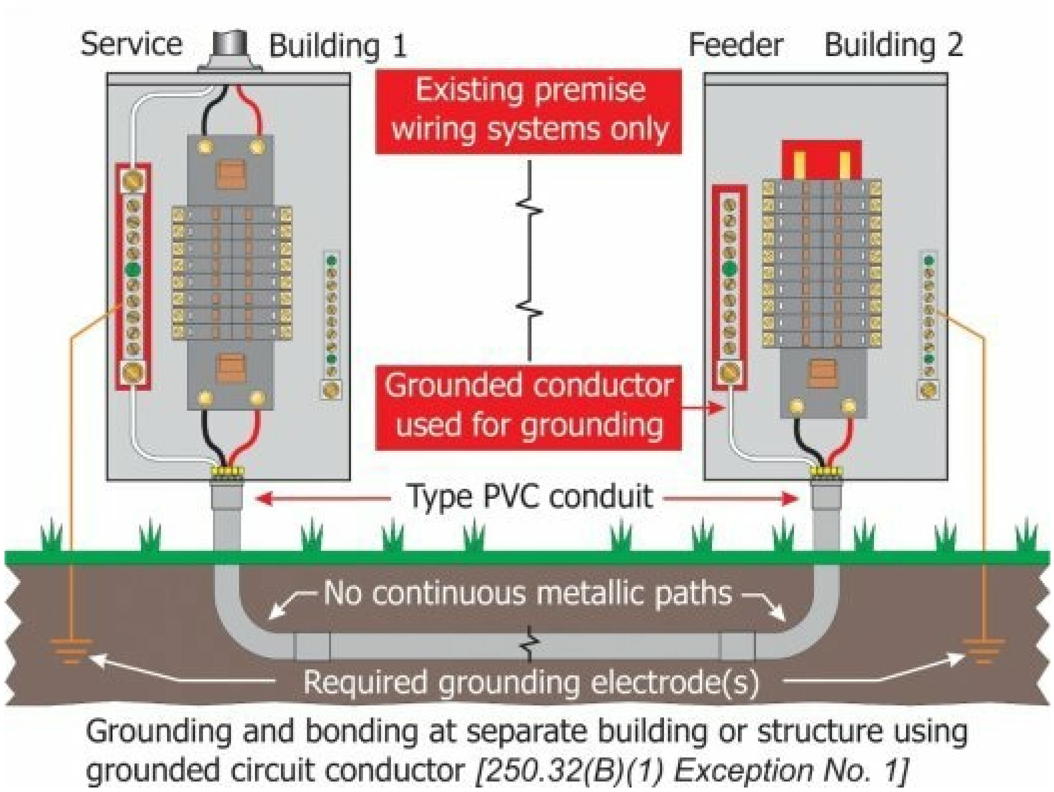


Figure 13.4 Grounding at separate buildings using the grounded (neutral) conductor by exception for existing premises wiring systems

Both the grounded — usually a neutral — conductor(s) and the equipment grounding conductor(s) are permitted to be connected to the terminal bar where the grounding electrode conductor connects to the grounded conductor.

Note that the grounded conductor supplied with the feeder or branch circuit(s) to the second or additional building or structure must generally be an insulated conductor [see 310.106(D)]. Section 338.10(B)(2) and exception permits the bare conductor of Type SE cable to be used only as an equipment grounding conductor for feeders or branch circuits but generally not as a grounded (neutral) conductor between buildings.

Size of Grounded Conductor

For existing installations where an equipment grounding conductor is not run to the additional building or structure in accordance with 250.32(B)(1) exception, the grounded circuit conductor must be sized no smaller than an equipment grounding conductor from Table 250.122. In this case, the grounded circuit conductor serves three purposes: first, to permit line-to-neutral loads to be utilized; second, to carry unbalanced loads back to the source; and, third, it must function as an equipment grounding conductor in the event of a ground-fault condition. As such, it must be sized for the calculated load according to 220.61 and not smaller than the minimum size equipment grounding conductor required from Table 250.122.

Keep in mind that feeders or branch circuit(s) that supply separate buildings or structures are often in extensive lengths, and voltage drop considerations can have an impact on the minimum sizes required for the equipment grounding conductor as well as for feeders and branch circuits [see 210.19(A) Informational Note No. 4 for branch circuits; 215.2(A) Informational Note No. 2 for feeders; 250.122(B) and the note to Table 250.122 for equipment grounding conductors].

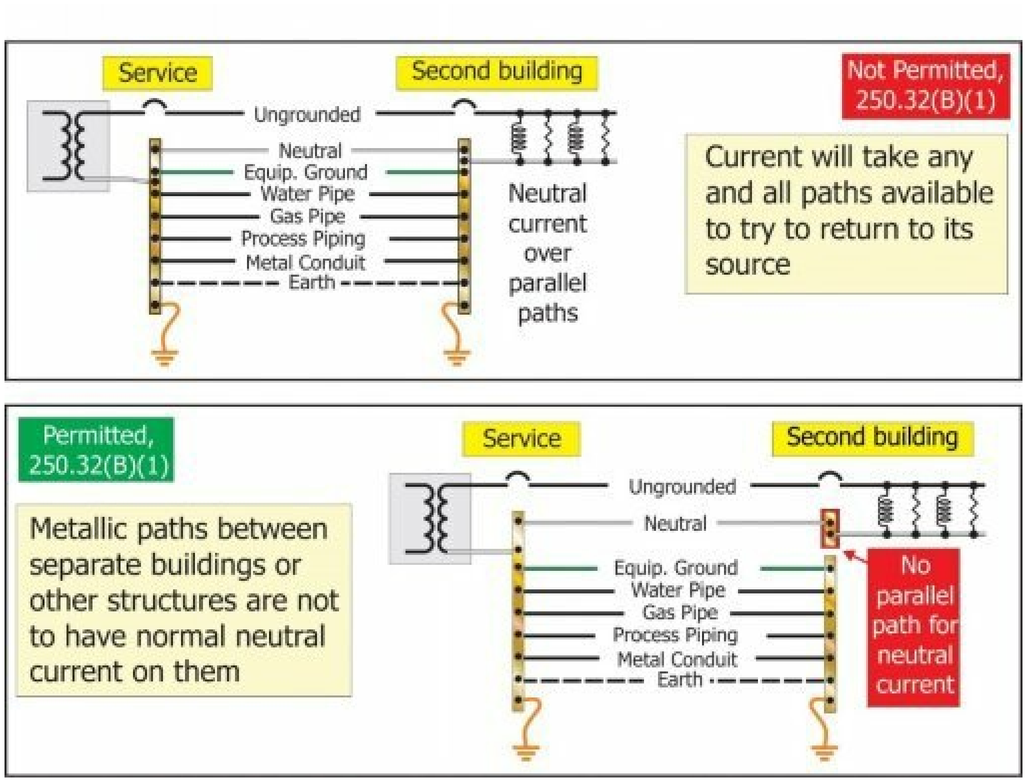


Figure 13.5 Objectionable currents—Paths

Number of Conductors Installed
(Equipment Grounding Conductor Not Installed)

Table 13-2 - *(Soares G & B textbook)*

System	Grounded	Ungrounded	EGC	Total
120V	1	1	0	2
120/240V	1	2	0	3
208Y/120V	1	3	0	4
480Y/277V	1	3	0	4

Table 13.2 Equipment grounding conductor not installed by exception for existing installations

Grounding Electrode Conductor Size and Connections

A grounding electrode conductor, sized in accordance with 250.66 based on the size of the largest ungrounded conductor supplying the building or structure, is used to connect the equipment grounding conductor and equipment, and for existing installations the grounded circuit conductor, to the grounding electrode system that exists or is installed at the additional building or structure (see figure 13.6). The installation shall comply with Part III of this article [see 250.32(E)].

This connection must be made inside the building or structure disconnecting means to the equipment grounding terminal bar or to the terminal bar for the grounded conductor as appropriate. The grounding electrode conductor connections are required to meet the requirements of 250.8.

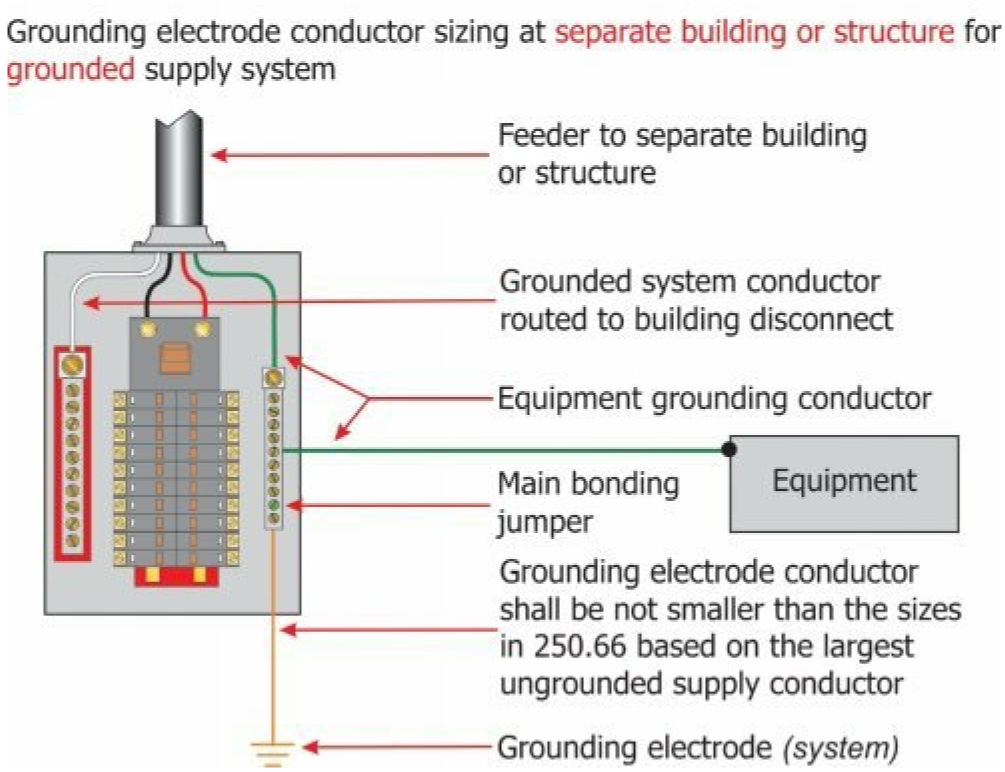


Figure 13.6 Sizing grounding electrode conductor(s) at separate buildings or structures

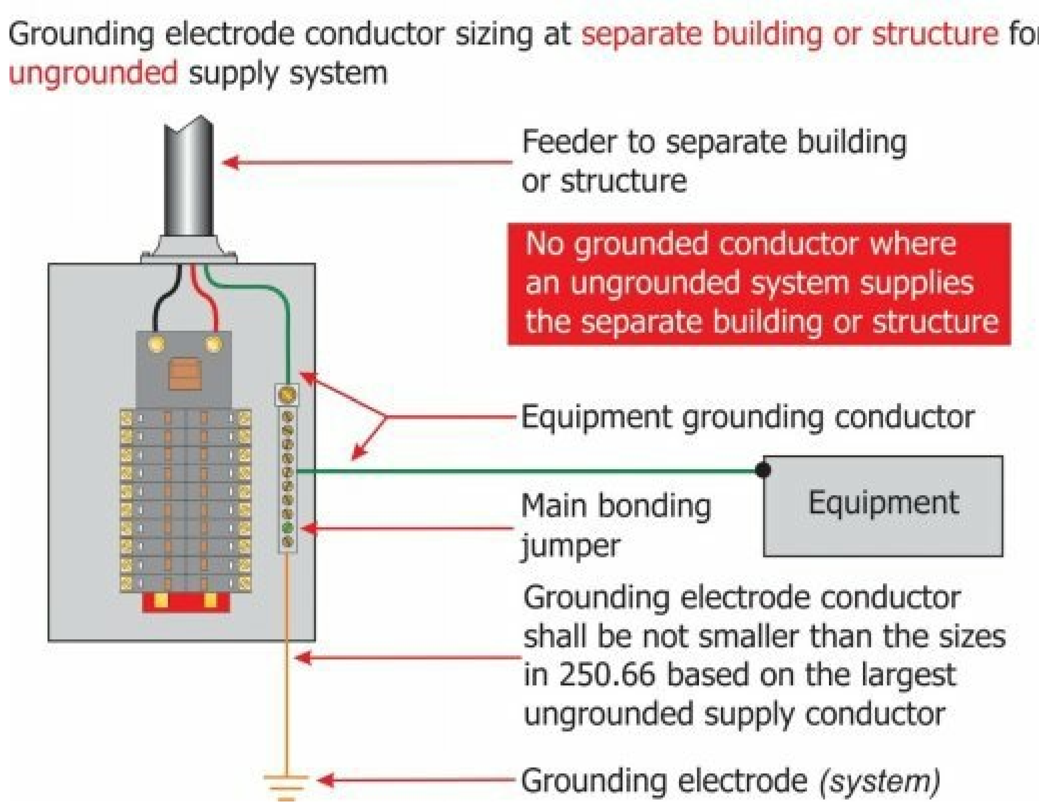


Figure 13.7 Sizing grounding electrode conductor at separate buildings that are supplied by an ungrounded system

Bonding Grounding Electrodes Together

Section 250.58 does not require that grounding electrodes at separate buildings or structures be bonded back to the service or the building where the feeder or branch circuit originated. Section 250.50 only requires the bonding together of the grounding electrodes that are present at each building or structure served. A study of the system will show that there is no real electrical separation between two separate grounding electrode systems. The grounding electrode system for the electrical system at the individual buildings or structures is connected together either by the equipment grounding conductor or by the grounded conductor routed with the feeder or branch circuit(s) to the additional building(s) or structure(s) (see figures 13.1 and 13.3).

Buildings or Structures Supplied by a Separately Derived System

Section 250.32(B)(2), addresses the grounding and bonding requirements where the building or structure is served by a feeder derived from a separately derived system. Section 250.32(B)(2)(a) set the requirements when the feeder has overcurrent protection as the source as follows:

"If overcurrent protection is provided where the conductors originate, the installation shall comply with 250.32(B)(1)." [8] This means a standard feeder with an equipment grounding conductor is installed.

Section 250.32(B)(2)(b) establishes the requirements for the condition where the overcurrent protection is not at the source.

"If overcurrent protection is not provided where the conductors originate, the installation shall comply with 250.30(A). If installed, the supply-side bonding jumper shall be connected to the building or structure disconnecting means and to the grounding electrode(s)." [9]

Exception 2 to 250.32(B)(1) allows the grounded (neutral) conductor to be used as the supply side bonding jumper as permitted by 250.30(A)(1) exception 2 and250.30(A)(2) exception. This provision can only be used where the separately derived system is installed outside the building or structure being served.

Ungrounded Electrical System(s)

Where ungrounded ac system equipment is connected to a grounding electrode in or at a building as specified in 250.24 and 250.32(C), the same grounding electrode shall be used to ground the conductor enclosures and equipment in or on that building.[10] A grounding electrode system in compliance with Part III of Article 250 must be installed and used at the building or structure where none exists (see figure 13.7). The size of the grounding electrode conductor is based on the size of the largest ungrounded phase conductor supplying the separate building or structure using Table 250.66.

Disconnecting Means Located in Separate Building or Structure on the Same Premises

Special rules have been provided for large capacity, multibuilding industrial installations under single management in 250.32(D) (see figure 13.8). These occupancies have trained and qualified personnel and have established procedures for safe switching of electrical feeders or circuits. As a result, the disconnecting means are permitted to be at other locations on the premises rather than at the building served. Often, the switching is managed by automatic or manual means from a control room or station.

The special rules for grounding the electrical system at these separate buildings or structures are as follows:

1. "The connection of the grounded conductor to the grounding electrode, to normally non-current-carrying metal parts of equipment, or to the equipment grounding conductor at a separate building or structure shall not be made.

2. "An equipment grounding conductor for grounding and bonding any normally non-current-carrying metal parts of equipment, interior metal piping systems, and building or structural metal frames is run with the circuit conductors to a separate building or structure and connected to existing grounding electrode(s) required in Part III of this article, or, where there are no existing electrodes, the grounding electrode(s) required in Part III of this article shall be installed where a separate building or structure is supplied by more than one branch circuit.

3. "The connection between the equipment grounding conductor and the grounding electrode at a separate building or structure shall be made in a junction box, panelboard, or similar enclosure located immediately inside or outside the separate building or structure." [11]

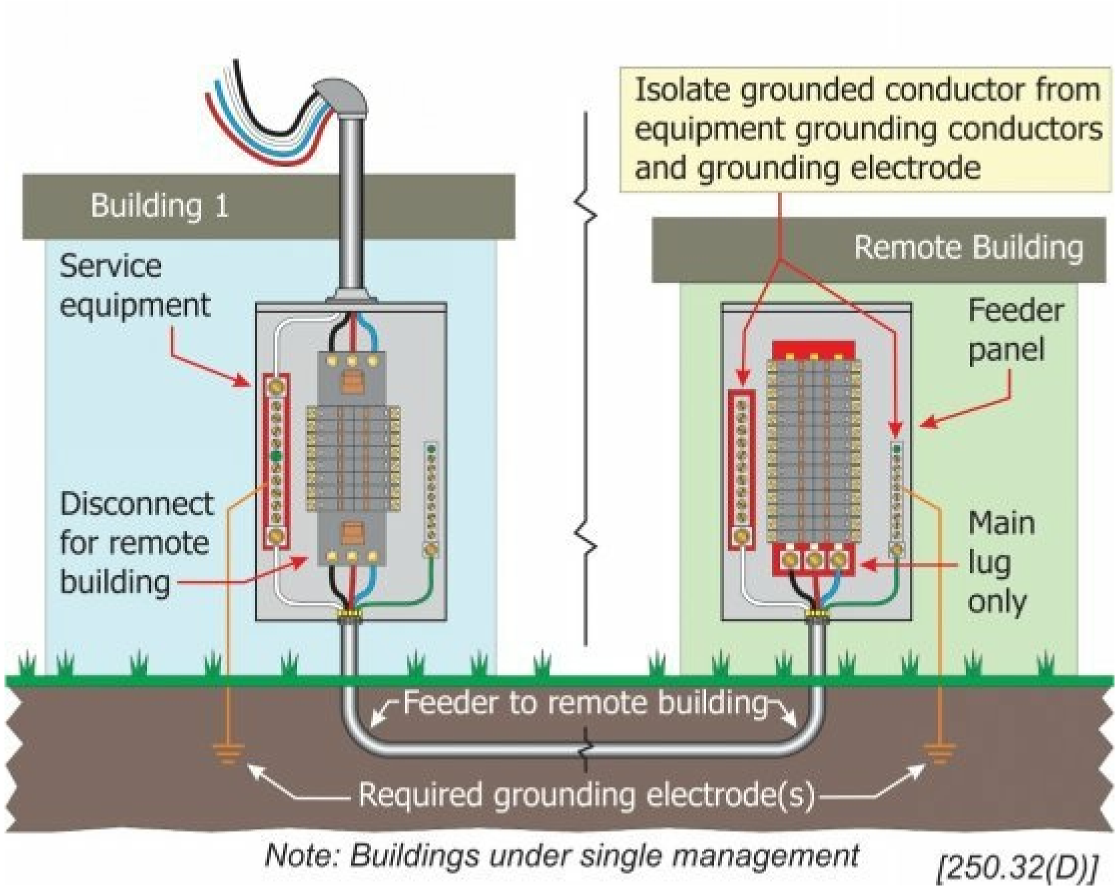


Figure 13.8 Disconnecting means located remote from separate buildings or structures according to 250.32(D)

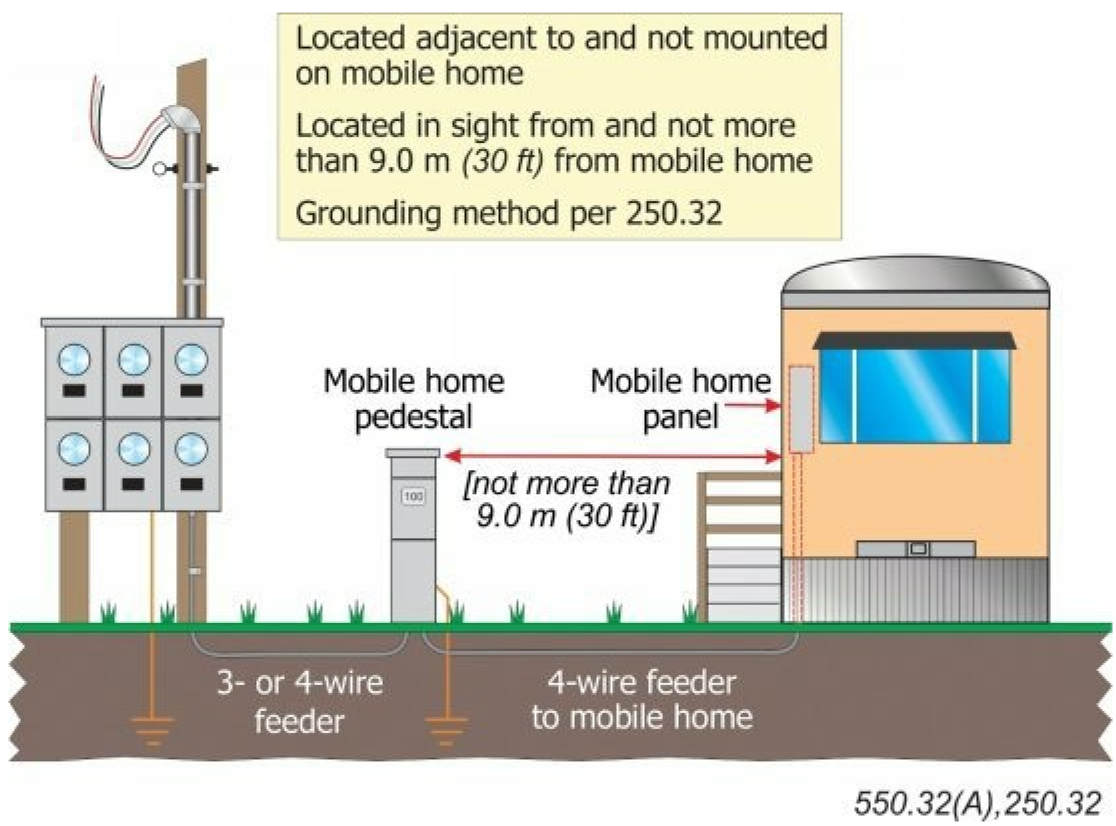


Figure 13.9 Service equipment located remote from mobile/manufactured home

Mobile Homes and Recreational Vehicles

The basic requirement in 550.32(A) is that mobile home service equipment be located remote from the structure but within sight from and not more than 9.0 m (30 ft) from the mobile home (see figure 13.9). There, the grounded (usually a neutral) conductor is connected to a grounding electrode(s). Feeders consisting of four insulated and color-coded conductors, one of which is an equipment grounding conductor, must be run to the mobile home distribution panelboard [see 550.33(A)].

"The service equipment shall be permitted to be located elsewhere on the premises, provided that a disconnecting means suitable for use as service equipment is located in sight from and not more than 9.0 m (30 ft) from the exterior wall of the mobile home it serves." [12] As such, this exception permits the two options for grounding to be used as described earlier in this chapter.

One option is a three-conductor feeder that is permitted to be installed between the service located remote from the mobile home disconnecting means where the neutral is grounded to the mobile home disconnecting means, and then a feeder consisting of four insulated conductors in compliance with 550.33(A) are then installed from the mobile home disconnecting means to the mobile home panelboard. Alternatively, the feeder between the service and the mobile home disconnecting means could be 4-wire in its entirety. This permits the mobile home service equipment to be located at a common location, such as a separate laundry or utility building as is required by some serving electric utilities. The grounding of the grounded (usually neutral) circuit conductor at the disconnecting means must comply with 250.32(B) as covered above.

Manufactured Home

Section 550.32(B) permits service equipment to be installed directly on the manufactured home (not mobile home — see the definitions in 550.2) under seven conditions.

1. "The manufacturer shall include in its written installation instructions information indicating that the home shall be secured in place by an anchoring system or installed on and secured to a permanent foundation.

2. "The installation of the service equipment shall comply with Part I through Part V of Article 230.

3. "Means shall be provided for the connection of a grounding electrode conductor to the service equipment and routing it outside the structure.

4. "Bonding and grounding of the service shall be in accordance with Part I through Part VII of Article 250.

5. "The manufacturer shall include in its written installation instructions one method of grounding the service equipment at the installation site. The instructions shall clearly state that other methods of grounding are found in Article 250.

6. "The minimum size grounding electrode conductor shall be specified in the instructions.

7. "A red warning label shall be mounted on or adjacent to the service equipment. The label shall state the following:

Warning

Do not provide electrical power until the grounding electrode(s) is installed and connected

(see installation instructions)." [13]

(See figure 13.10).

Where this concept is chosen, the service is grounded to the grounding electrode at the manufactured home, and no service disconnecting means remote from the manufactured home is required.

For additional information, see Part 3280, *Manufactured Home Construction and Safety Standards*, of the Federal Department of Housing and Urban Development for requirements related to manufactured homes.

If the service equipment is not installed in or on the unit, then the installation is required to meet the other provisions of Section 550.32.

Figure 13.10 Warning label at service equipment of manufactured home

Agricultural Buildings

The grounding of agricultural buildings is covered in Article 547. Sections 547.5(F), 547.9(A)(5), 547.9(B)(3), 547.9(C), and 547.10 all include grounding and bonding requirements that amend or add to the general requirements of Article 250. Where a building or structure houses livestock, an insulated conductor (copper, aluminum or copper-clad aluminum) must be installed where the equipment grounding conductor is installed underground from one building or structure to another. See chapter fifteen for additional information on this subject.

Two Buildings in One Structure

Figure 13.11 shows two buildings in one structure that are separated by a fire-rated wall. The two buildings, by definition (on the same slab or foundation), may be served by a single service or by multiple services in accordance with 230.2(A), (B), (C) or (D).

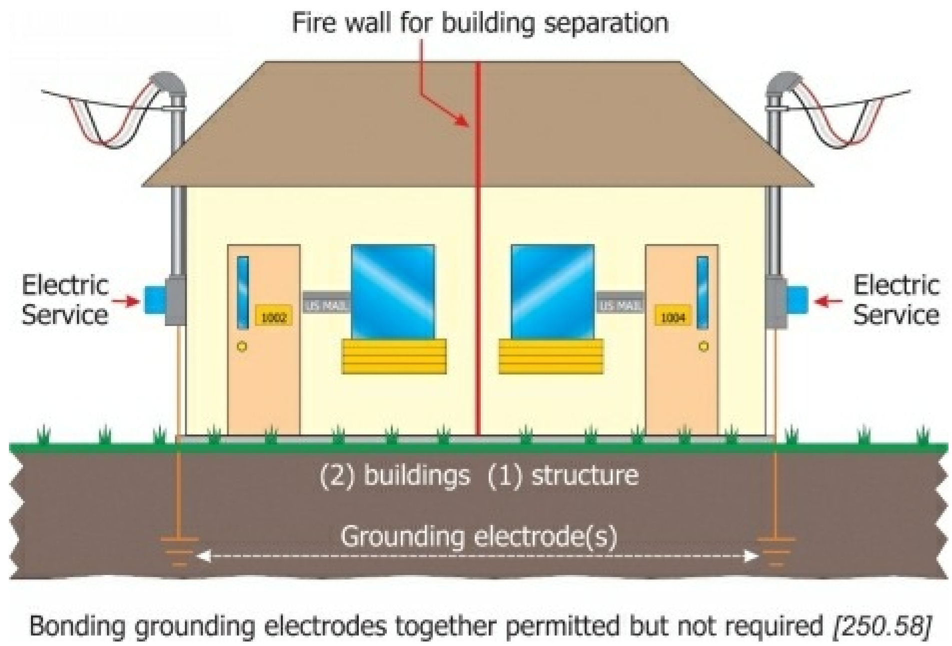


Figure 13.11 Two buildings (by definition) in one structure or on a common foundation or slab

As previously discussed, 250.58 generally requires that all grounding electrodes at a building or structure shall be bonded together. In figure 13.11, there are two buildings but there is only one structure. The applicable part of 250.58 states: "Where separate services … supply a building and are required to be connected to a grounding electrode(s), the same grounding electrode(s) shall be used. Two or more grounding electrodes that are effectively bonded together shall be considered as a single grounding electrode system in this sense."[14] The connecting conductor, or specifically, a bonding jumper in accordance with 250.53(C), must be properly sized according to 250.66.

Since the fire-rated wall creates two buildings by definition, bonding of the electrodes together is desirable but not required by *Code*. The key to the code requirement quoted above is that only the term *building* is used so multiple electrodes installed for each building would be required to be bonded together, but the electrodes for one building would not be required to be bonded to the electrodes of the other building even though it is a single structure. The *Code* only requires that multiple electrodes for multiple services that might be allowed in accordance with 230.2 on the same building or structure be bonded together to meet the requirements in 250.58. The electrodes between the buildings can be bonded together by connecting them together by a properly sized bonding jumper (see figure 13.11). When considering not bonding the electrodes from one building to the other, be sure to also consider other services that may provide an electrical connection between these electrodes such as telephone, cable, or other similar services that could be supplied to one side and then routed to the other through the first building.

[1–14] **NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA, 2016)**

Review Questions

1. “A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system” best defines which of the following ____?

1. main bonding jumper
2. grounding electrode conductor
3. grounded conductor
4. neutral conductor

2. A grounding electrode is required at a separate building or structure under which of the following conditions ____?

1. one grounded system feeder is installed
2. one ungrounded system feeder is installed
3. more than a single branch circuit is installed
4. all of the above

3. Which of the following methods is required for grounding at separate buildings or structures in new installations ____?

1. grounding using the grounded system conductor
2. grounding using the equipment grounding conductor
3. grounding using the ungrounded conductor
4. installing ground detectors

4. Where a grounding electrode(s) is not present at a building or structure supplied by a feeder(s) or branch circuit(s), ___.

1. one or more must be installed.
2. installing one or more is optional.
3. an equipment ground must be installed
4. a grounded conductor must be installed

5. The general rule for grounding at separate buildings requires the installation of an ____ where it is run with the feeder or circuit ungrounded (hot) conductors.

1. approved conductor
2. identified bonding jumper
3. equipment grounding conductor
4. acceptable conductor

6. All of the following are acceptable as a grounding electrode at a separate building or structure EXCEPT ____.

1. Metric designator 16 (trade size ½) conduit
2. 16 mm (5/8-in.) iron or steel not less than 2.5 m (8 ft) long
3. Metric designator 21 (¾-in.) galvanized conduit
4. plate electrode

7. Where an equipment grounding conductor is run with the feeder(s) or branch circuit(s) from a first building to a separate building, the minimum size of the equipment grounding conductor is based upon the ampere rating of the overcurrent protective device ____ the feeder or branch circuit.

1. on the load side of
2. in the transformer of
3. on the line side of
4. in the service disconnect of

8. A grounding electrode conductor can be used to connect the grounded circuit conductor, or equipment to the grounding electrode system at the separate building(s) or structure(s) only for _____.

1. new installations
2. new and existing installations
3. *existing installations made in compliance with previous editions of the Code*
4. installations where ground-fault protection of equipment has been installed on the supply side of the feeder(s)

9. For installations made in compliance with previous editions of this *Code* that permitted such connection, the grounded circuit conductor ____ to be used for grounding equipment on the line (supply) side of the disconnecting means for separate buildings.

1. is permitted
2. is not permitted
3. is permitted by special permission
4. is not required

10. Currents that introduce noise or data errors in electronic equipment, such as data processing equipment, are ____ considered the type of objectionable currents discussed in *NEC* 250.6.

1. not to be
2. considered to be
3. always to be

4. sometimes

11. Where the additional building or structure houses livestock, an insulated ____ conductor must be installed where run underground.

1. copper, aluminum or copper-clad aluminum
2. insulated or covered
3. aluminum type only
4. copper type only

12. Where a single branch circuit or multiwire branch circuit is installed to supply a separate structure, a grounding electrode is ______.

1. not required
2. not permitted
3. always required
4. never installed

13. Where a 400 ampere feeder containing 600 kcmil copper phase conductors is installed to supply a separate building on the premises, the minimum size equipment grounding conductor required for the feeder shall; not be less than _____.

1. 2 AWG copper
2. 4 AWG copper
3. 3/0 aluminum
4. 3 AWG copper

⏚ Chapter 14
Ground-Fault Protection

Objectives to understand

- Ground-fault circuit interrupter principles of operation
- Ratings of GFCI devices
- Markings for GFCI devices
- GFCI application and consideration
- Requirements for replacement of ungrounded receptacles
- Arc-fault circuit interrupters (AFCIs)
- Ground-fault protection for equipment (GFPE)
- Requirements for ground-fault protection of equipment
- Types of ground-fault protection systems
- Requirements for feeder and branch circuit ground-fault protection
- Ground faults in an ungrounded system
- Testing of equipment ground-fault protection

Considering the total number of faults (short circuit and ground-faults) that occur in power systems, ground-faults by far outnumber short circuits. The ratio is approximately 90 percent of all faults are or start as ground faults and the remainder are or start as short circuits. It should be noted that either one of these can be the result of an overload condition that is not cleared before insulation damage occurs.

With the more common use of elevated voltages, such as 480/277 volts, in power distribution systems ground-faults became even more destructive. About the same time in the evolution of electrical safety, the realization of shock hazards and the means to use what is now the ground-fault circuit interrupter was introduced to provide a higher level of protection from this hazard.

Definitions

The following definitions can be found in Article 100 of the NEC[1] with the exception of the definition of short circuit:

Overcurrent. "Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault.

> "**Informational Note**. A current in excess of rating may be accommodated by certain equipment and conductors for a given set of conditions. Therefore, the rules for overcurrent protection are specific for particular situations."

Short Circuit. "An abnormal connection (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential. Note: The term fault or short-circuit fault is used to describe a short circuit." (IEEE 100-1992, The New IEEE Standard Dictionary of Electrical and Electronic Terms, 5th Edition) [2]

Ground Fault. "An unintentional, electrically conductive connection between an ungrounded conductor of an electrical circuit and the normally non–current- carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth."

Overload. "Operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload."

Ground-Fault Circuit Interrupter (GFCI). "A device intended for the protection of personnel that functions to deenergize a circuit or portion thereof within an established period of time when a current to ground exceeds the values established for a Class A device."

> ***"Informational Note.*** Class A ground-fault circuit interrupters trip when the current to ground is 6 mA or higher and do not trip when the current to ground is less than 4 mA. For further information, see UL 943, Standard for Ground-Fault Circuit Interrupters."

Ground-Fault Protection of Equipment. "A system intended to provide protection of equipment from damaging line-to-ground fault currents by operating to cause a disconnecting means to open all ungrounded conductors of the faulted circuit. This protection is provided at current levels less than those required to protect conductors from damage through the operation of a supply circuit overcurrent device."

As was discussed in detail in chapter eleven and seen from the above definitions, using the term *overcurrent* is inclusive of all three elements that make up overcurrent namely, short circuits, ground faults, and overloads. Overcurrent is any level of current above the rating of the conductor or equipment. This chapter will concentrate on protection from ground-faults, how these ground-fault protective devices operate and what each of the types is intended to protect. Again, it is important to note that ground faults happen due to a failure in the insulation system, either accidental or intentional that provide a path for current to pass on or though normally non-current-carrying conductors. While the focus will be just on ground faults, in real situations what may start as a ground fault may propagate rapidly into a short circuit or what starts as a short circuit can rapidly include a ground fault. The devices covered in this chapter are specifically designed, or have an element in the design, just for protection from ground-fault conditions. These devices will include ground-fault circuit interrupters (GFCI), equipment ground-fault protective devices (EGFPD), arc-fault circuit interrupters (AFCI), and ground-fault protection for equipment (GFPE). Table 14.1 provides a quick visual of these devices and what they are intended to protect.

Protection	GFCI	EGFPD	AFCI	GFPE
Typical trip levels	4-6 milliamps [1]	20-50 milliamps	40-70 milliamps [2]	1 to 1200 amperes
Protect personnel from electric shock	Primary	Minimal	None	None
Protect equipment from arcing fault and or fire	Secondary	Primary	Primary	Primary

[1] *Class A GFCI protection*
[2] *Where ground-fault component is provided in AFCI device*

GFCI -	Ground-fault circuit-interrupter
EGFPD -	Equipment ground-fault protective device
AFCI -	Arc-fault current-interrupter
GFPE -	Ground-fault protection for equipment

Table 14.1 Ground-fault protective devices

To prevent confusion and misunderstandings it is very important to identify each of the above devices or systems by the correct name or acronym. Many times in the field the acronym "GFI" is used. Sometimes it is intended to mean "GFCI" and other times "GFPE" or "EGFCI." As with most aspects of grounding and bonding, the incorrect use of terminology is the main reason for misunderstanding what is being communicated.

Ground-Fault Circuit Interrupters (GFCI)

The primary function of GFCI is to protect persons from hazards relating to shock. As discussed in chapter one, perception is approximately 1 mA and paralysis can start as low as 10 to 15 mA. It is also known that the injury from shock is both from the magnitude of the current flowing through the body and also the duration of that current flow. These values are for healthy, dry, adults. The GFCI device is set to provide a level of protection from serious injury to a healthy person where the shock path is through unbroken outer (epidermis) skin. This is not to say that this level of shock will not be painful, it will be, but injury from the shock will be minimal.

The Underwriters Laboratories requirement for Class A ground-fault circuit interrupters (GFCIs) is that tripping shall occur when the continuous 60-hertz differential current exceeds 6 mA, but it shall not occur at less than 4 milliamperes (5 mA ± 1 mA) (see figure 14.1). Some people contend that 5 mA is too low and should be increased to 10 mA or higher but this will result in greater chances of serious injury or even death for more people, especially women and children.

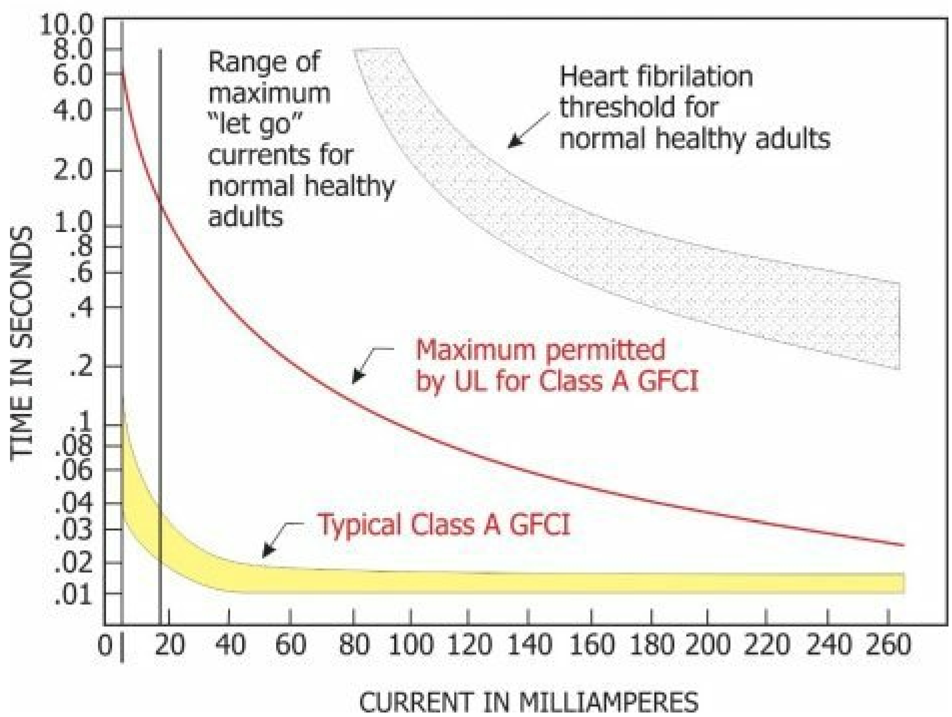


Figure 14.1 GFCI tripping characteristics graph

Several eminent investigators, including C. F. Dalziel, F. P. Kouwenhoven, O. R. Langworthy and others, have conducted extensive research and prepared papers on the dangers of electric shock hazards. They define *let-go current* as the maximum current at which a person is able to release a conductor by commanding those muscles directly stimulated by the shock. Currents over the let-go levels are said to freeze the victim to the circuit.[3]

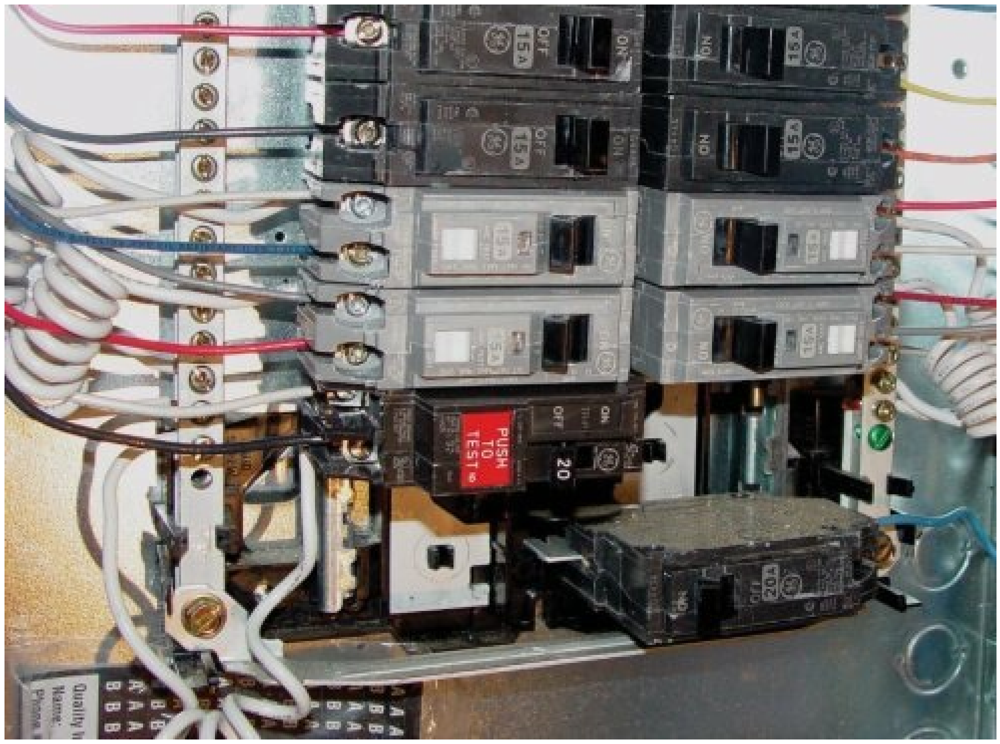


PHOTO 14.1 Ground-fault circuit interrupter (breaker type)

C. F. Dalziel's paper, titled "Electric Shock Hazard," published in the Institute of Electrical and Electronics Engineers (IEEE) *Spectrum*, Vol. 9, February 1972, summarizes the studies that estimate shock currents based on the effective impedance of the body under various conditions. According to Dalziel, the reasonably safe electric current for normal healthy adults is the let-go current from which 99.5 percent of the population can extricate themselves from the circuit by releasing the conductor. On page 44, Dalziel states, "so far, it has been impossible to obtain reliable [let-go] values for children; they just cry at the higher values." However, the IIT Research Institute report cites a value for children evidently based on engineering judgment by Dalziel and others. The following summarizes the let-go currents for 99.5 percent of the population for:

Children 4.5 mA

Women 6.0 mA

Men 9.0 mA

Based on information provided in the report by IIT Research Institute (IITRI), 4.5 milliamperes for children can be the appropriate GFCI trip level relative to the 6 mA and 9 mA thresholds for women and men, but the rationale for this selection is not very evident in Dalziel's or other publications.

Based on Dalziel's data, UL's estimates of the percentage of the population that would be protected against the inability to let-go at various current levels is shown in table 14.2.

Percentage of the Population Estimated to be Protected Against Inability to "Let-Go" Thresholds for Several Levels of Shock Current

Level of Shock Currents	6 mA (rms)	10 mA (rms)	20 mA (rms)	30 mA (rms)
Men	100%	98.5%	7.5%	0%
Women	99.5%	60%	0%	0%
Children*	92.5%	7.5%	0%	0%

* Half of the "let-go" threshold for men

Table 14.2 "Let-go" thresholds at various current levels

For general purposes, a let-go limit for GFCIs higher than 6 mA appears inappropriate because too large a fraction of the population would be left unprotected. UL has decided to continue to designate 5 mA (± 1 mA) as the limit based on tolerated reaction and physiological effects. Moreover, UL retains the 5 mA limit because the 4.5 mA level is only an estimate that is not based on data and because the 5 mA limit has withstood the test of time with no evidence of being inadequate and has appeared in a number of standards for many years.[4]

The first sensation of electricity can be felt by most people at currents considerably less than 0.5 mA, 60 Hz (frequency in Hertz). Current near 0.5 mA can produce an involuntary startled reaction such as to cause a person to drop a skillet of hot grease or cause a worker to fall from a ladder. As the current increases, involuntary muscular contractions increase, accompanied by current-generated heat.[5]

Higher currents of longer duration than one second can cause the heart to go into ventricular fibrillation, considered the most dangerous effect of electric shock. Once fibrillation begins, it practically never stops spontaneously. Death is almost certain within minutes. The rhythmic contractions of the heart become disordered, its pumping action stops, and the pulse soon ceases altogether. Fibrillation in adults can occur at 52 mA and in children at 23 mA. According to V. G. Biegelmeier, the onset of fibrillation in a 50-kilogram (110-pound) adult occurs within the range of 50 mA to 200 mA when the duration of the shock exceeds two seconds.[6] Table 14.3 shows implied safe voltages based on these values.

Implied Safe Voltage[4] Based on Several Published Values of Body Resistance and Selected Body Current Safety Criteria as Published by Dalzel

Criterion Ohms	Body Resistance			
	300	500	1500	3000
"Let-go" 4.5 mA for children	1.35 V	2.25 V	6.75 V	13.5 V
"Let-go" 9.0 mA for adult males	2.70 V	4.50 V	13.5 V	27.0 V
Fibrillation at 23 mA 5 sec.pulse of 60-Hz current for 40 lb. child	6.90 V	11.5 V	34.5 V	69.0 V
Fibrillation at 52 mA 5 sec. pulse of 60-Hz current for110 lb. adult	15.6 V	26.0 V	78.0 V	156.0 V

[4] According to V. G. Biegelmeier, the onset of fibrillation in a 50-kilogram (110-pound) adult occurs within the range of 50 mA to 200 mA when the duration of the shock exceeds two seconds.

Table 14.3 Implied safe voltages

The table's 3000-Ω (ohm) body resistance column, for example, indicates that 156 volts would result in a shock current of 52 milliamperes.

Extensive work on this subject has been reported in "Effects of Current on Human Beings and Livestock" IEC 479-1 by the International Electrotechnical Commission.[7] Several charts and graphs with background material are provided. Measurements were made on 50 living persons at a touch voltage of 15 volts and on 100 persons at a touch voltage of 25 volts. The total body impedance of one living person was measured with touch voltages of up to 200 volts. Measurements were also made on a large number of corpses.

Three-Wire Grounded System vs. GFCI

For many years, grounding and bonding were emphasized as the primary means for the protection of the electrical system, equipment and personnel from fires and injury, as well as for operating and maintenance advantages. The grounded neutral as a protective element was recognized more and more with each succeeding edition of the *NEC*. The *Code* has placed great emphasis on the importance of an effective ground-fault current path in order to ensure that wiring faults to ground became a sufficient overcurrent as required to activate the overcurrent device. The concept that wiring and equipment were designed to be protected, and the thought that the grounded system also provided adequate protection for people became ingrained and accepted.

The trend toward grounding equipment and appliances has been gradual, characterized as deliberate but cautious. The belief that grounding provided adequate protection against electric shock and fire hazards became so ingrained that consumers generally have not recognized its limitations, and they find it difficult to accept other more effective means of protection from electric shock and electric fire hazards.

Ground faults occur when an insulation failure causes electrical current in a circuit to return through:

- the equipment grounding conductor,
- conductive material other than the electrical system ground (metal, water, plumbing pipes, etc.),
- a person, or
- a combination of these ground return paths.

If a person becomes the, or part of the, path for electrical current to ground or a grounded object, the person will incur an electrical shock, and can be seriously injured or can be electrocuted depending on the

- amount of current,
- duration or time the current exists,
- size of the person,
- pathway the current follows through the body and the
- current frequency (DC, 60 Hz, 400 Hz, etc.).

On the other hand, arcing ground faults can occur just about anywhere on an electrical system, resulting in a fire. In either case, these ground faults can be of too low a magnitude to open or operate the overcurrent device and interrupt the circuit.

A person can become a path in an electrical circuit in one of two ways: in series contact or in parallel contact. In series contact, the person is the only current path to the ground fault return path(s). There are many ways in which contact can occur. One example of series contact was that of an infant that stuck a hairpin into a receptacle slot while sitting on a floor-heating vent. Unfortunately, in this actual case, the infant was electrocuted. Section 406.11 now requires all receptacles in areas specified in 210.52 to be listed tamper-resistant types. This should help minimize possibilities of electric shock or electrocution of unsuspecting infants and children. Another case involved a man operating a metal-encased electric drill that had a 3-wire grounded cord. He used a two-to-three wire adapter but did not connect the adapter pigtail to the wall plate grounding screw. Inadvertently, the pigtail touched the plug blade, thus energizing the drill case and electrocuting the man. In this incident, the equipment grounding conductor contributed to the electrocution by providing a current path to energize the drill case. In both cases, the 3-wire grounded system was totally ineffective since the equipment grounding conductor was not involved in the current path, and the current through the body was not large enough to trip the overcurrent protective device.

In parallel contact, the victim becomes a path to the ground-fault return path in parallel with the equipment grounding conductor. One scenario of parallel contact occurs when the metal case of an appliance becomes energized (charged electrically) by some internal fault condition resulting in current leakage to ground via the equipment grounding conductor but the equipment grounding conductor has a high impedance return path. The leakage to ground in this case might not be sufficient to activate the branch-circuit overcurrent protective device. A person who touches the charged case and, at the same time, contacts a grounded surface such as a water faucet or pipe will be subjected to an electric shock. In such parallel contact situations, the effectiveness of the equipment grounding conductor in preventing electrocution of the victim is dependent on several variables, including the following:

- whether or not the ground-fault current reaches the instantaneous trip level of the overcurrent protective device (which is relatively high—typically five times of the rating or over 75 amperes for a 15-ampere-rated molded-case circuit breaker or fuse);
- how fast the overcurrent device reacts;
- the voltage level from faulted enclosure to ground; and
- the impedance of the ground-fault return path(s) (composed of connections, contacts and the ground wire).

An effective ground-fault current path in the grounding and bonding system depends upon the integrity of many series connections, which must be properly made and maintained. Where good connections are not made or maintained, then the higher the resistance or impedance of the grounding (earth) path, the less effectual will be the protection provided by the 3-wire grounded system. Higher impedances can be due to long wire lengths, small wire sizes, loose and/or corroded equipment grounding wire connection devices and connections and other causes. A detailed analysis of the relationship of the impedance ratio of the line circuit to ground circuit to shock current levels is described in the previously cited Consumer Product Safety Commission paper titled “Three-Wire Grounding Systems vs. GFCI” and the cited IITRI report.[8]

A similar study by Mr. R. H. Lee of DuPont Company corroborates IITRI’s analysis of circuit impedances.[9] His paper deals with the hazard vs. safeguard of a 3-phase grounded power distribution system.

An assessment of the effectiveness of the 3-wire grounded system for providing protection against electric shock hazards was conducted by Mr. A. W. Smoot of Underwriters Laboratories.[10] He analyzed 164 fatal electric shock accidents occurring over a 3-¾ year period in and around homes. His study indicated the limitations of the 3-wire system and was submitted to the *National Electrical*

Code Committee to support proposed amendments to the 1971 *NEC*.

As can be seen from the above discussion, the required “effective ground-fault path” is a critical safety element and this remains true even with GFCI devices installed.

Principles of GFCI Operation

"The GFCI sensing system continuously monitors the current balance in the ungrounded (hot) conductor and the grounded (neutral) conductor. If the current in the grounded conductor becomes less than the current in the ungrounded conductor, a ground fault would exist. With this fault, a portion of the current returns to the supply source by some path other than the grounded conductor. With a current imbalance as low as 4 – 6 mA, the GFCI will interrupt the circuit and this will be shown by a trip or off indicator on the device (see figure 14.2).

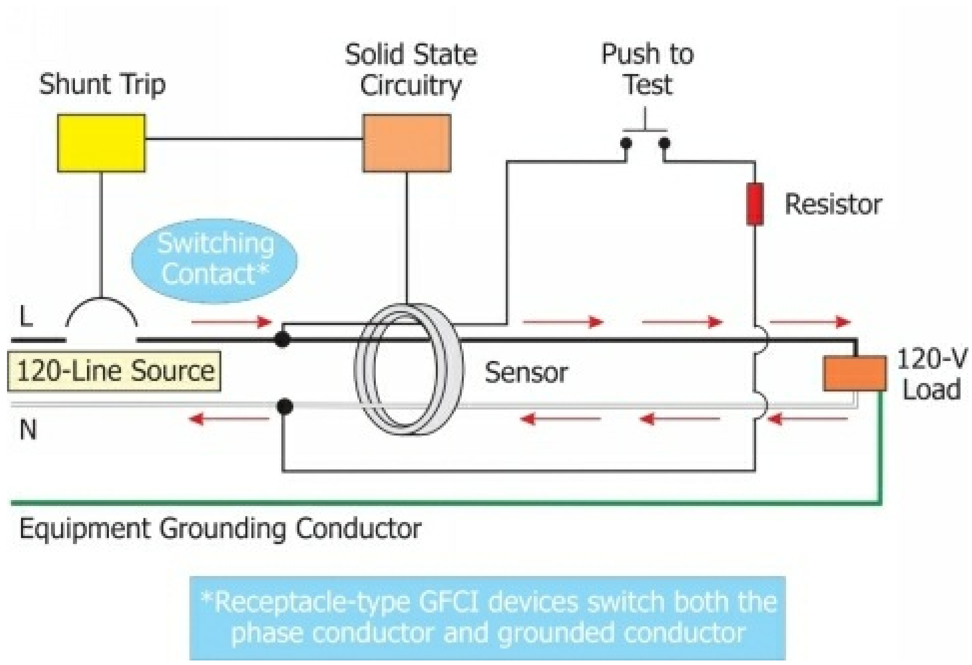


Figure 14.2 GFCI principles of operation

"The GFCI does not function to limit the magnitude of the ground-fault current but it does limit the time that a current of given magnitude exists. The trip level-time combinations allowed by the product standards are based on physiological data established for avoiding injury to normal healthy persons. These trip level-time combinations can be too high for persons with heart problems, such as those wearing a pacemaker or under treatment in health care facilities." [11]

The principle of operation of ground-fault circuit interrupters provides a significant advancement in safety for both equipment that is grounded by an equipment grounding conductor as well as for equipment that is ungrounded. Since the GFCI detects an imbalance of current in both the supply and return paths, it protects equipment supplied by both a 2-wire circuit and a 2-wire circuit with ground circuit. This is the reason some *NEC* sections will allow a grounding-type receptacle to be supplied on a 2-wire circuit that has GFCI protection.

Several kitchen appliances, as well as portable heaters, are manufactured with 2-wire supply cords and, therefore, do not have their housings or enclosures grounded. A significant advancement in safety is realized where these appliances are supplied from receptacle outlets that have GFCI protection.

Underwriters Laboratories Guide Card Information

The *UL Productspec website* has specific information on the use and application of GFCI devices. The information provided in the *UL Productspec* is part of the listing and in accordance with *NEC* 110.3(B), is mandatory to be followed. The two main category codes that apply are DIYA, Circuit Breakers and Ground Fault Circuit Interrupters, and KCXS, Ground Fault Circuit Interrupters. The following text from Category *Code* KCXS should be understood by installers and inspectors for application of GFCI devices.

> "A GFCI is a device whose function is to interrupt the electric circuit to the load when a fault current to ground exceeds some predetermined value that is less than that required to operate the overcurrent protective device of the circuit.
>
> "GFCIs are intended to be used only in circuits where one of the conductors is solidly grounded.
>
> "Class A GFCIs trip when the current to ground has a value in the range of 4 through 6 mA. Class A GFCIs are suitable for use in branch and feeder circuits, including swimming pool circuits. However, swimming pool circuits installed before local adoption of the 1965 *NEC* may include sufficient leakage current to cause a Class A GFCI to trip.
>
> "Class B GFCIs trip when the current to ground exceeds 20 mA. These devices are suitable for use with underwater swimming pool luminaires installed before the adoption of the 1965 *NEC*.
>
> "GFCIs of the enclosed type that have not been found suitable for use where they will be exposed to rain are so marked.
>
> "The 'TEST' and 'RESET' buttons on the GFCIs are only intended to check for the proper functioning of the GFCI. They are not intended to be used as 'ON/OFF' controls of motors or other loads unless the buttons are specifically marked 'ON' and 'OFF.' "[12]

GFCI Required for Replacement Receptacles

The general requirement in 406.4(A) is that "receptacles installed on 15- and 20-ampere branch circuits shall be of the grounding-type. Grounding-type receptacles shall be installed only on circuits of the voltage class and current for which they are rated, except as provided in Table 210.21(B)(2) and Table 210.21(B)(3)." [1] Section 406.4(D) sets the requirement for replacement receptacles such as where a 2-wire system was installed and non-grounding-type receptacles had been installed. There are several options for replacement receptacles summarized as follows from 406.4(D) and shown in figure 14.3:

- Replace with a grounding-type receptacle where an equipment grounding conductor exists in the enclosure or an equipment grounding conductor is installed in accordance with 250.130(C).
- Replace with a non-grounding-type receptacle.
- Replace with a GFCI-type receptacle and mark it with "No Equipment Ground."
- Replace with a grounding-type receptacle where the circuit is protected upstream by a GFCI device and mark it with both, "No Equipment Ground" and "GFCI Protected."

Specific marking requirements exist if non-grounding-type receptacles are replaced with grounding-type receptacles where an equipment grounding conductor does not exist at the outlet (see figure 14.3). These receptacles must be marked "No Equipment Ground" so the user will be informed that even though the receptacle has an equipment-ground slot, an equipment grounding conductor is not connected to the device. An equipment grounding conductor is not permitted to be connected from the GFCI-type receptacle to any outlet supplied from the GFCI receptacle.

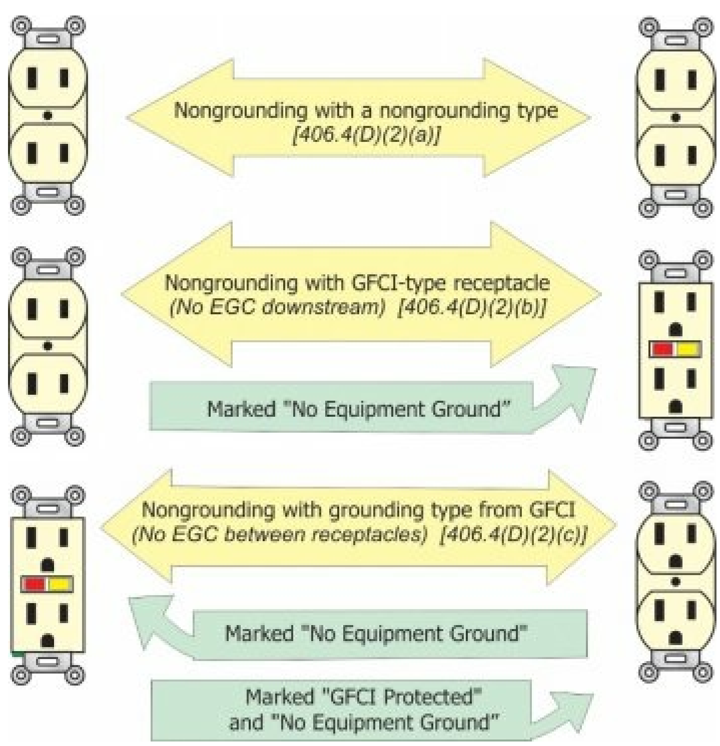


Figure 14.3 Replacement of non-grounding-type receptacles with GFCI receptacles and marking requirements

Where grounding-type receptacles are installed on a circuit that does not include an equipment grounding conductor but are protected on the line side by a ground-fault circuit-interrupter device, the receptacle(s) must be marked "GFCI Protected" and "No Equipment Ground." This will inform the user that even though the receptacle has a grounding terminal, it is not in fact grounded by a connection to an equipment grounding conductor, but is provided with GFCI protection. The grounding-type receptacle is protected by the GFCI device, but an equipment grounding conductor is not present as can be required for some sensitive electronic equipment such as computers. An equipment grounding conductor is not permitted to be connected between the grounding-type receptacles as this would present incorrect information to the users. As explained earlier, the GFCI device will protect the user from line-to-ground faults even though an equipment grounding conductor is not connected to the devices. It should be remembered that the equipment grounding conductor is intended to be that low impedance effective fault current path and when it is not present and an individual receives a shock, they are in series and will receive the full shock level until the GFCI operates.

Section 250.130(C) provides a method for installing an equipment grounding conductor for receptacles that are being replaced at a location where an equipment grounding conductor is desired but not present in the outlet box. The provisions are as follows:

> "The equipment grounding conductor of a grounding-type receptacle or a branch-circuit extension shall be permitted to be connected to any of the following:
>
> "Any accessible point on the grounding electrode system as described in 250.50
>
> "Any accessible point on the grounding electrode conductor
>
> "The equipment grounding terminal bar within the enclosure where the branch circuit for the receptacle or branch circuit originates

An equipment grounding conductor that is part of another branch circuit that originates from the enclosure where the branch circuit for the receptacle or branch circuit originates

> "For grounded systems, the grounded service conductor within the service equipment enclosure
>
> "For ungrounded systems, the grounding terminal bar within the service equipment enclosure."[13]

Section 406.4(D)(3) has some added provisions specific to where a non-GFCI receptacle (grounding or non-grounding) is being replaced in a location where the *Code* now requires GFCI protection. This section states that, "Ground-fault circuit-interrupter protected receptacles shall be provided where replacements are made at receptacle outlets that are required to be so protected elsewhere in this *Code*." [13] An exception to 406.4(D)(3) provides that a standard grounding type receptacle can be installed in these locations as long as the circuit ahead is protected by a GFCI. The receptacle would require the markings as required by 406.4(D)(2).

This requires that installers be aware of the rules that call for GFCI-protected receptacles in areas covered by 210.8(A) for dwellings, 210.8(B) for non-dwellings, as well as many other locations in the *Code* for other facilities. This includes 15- and 20-ampere, 125-volt receptacles installed in dwelling unit kitchens, bathrooms, garages, outdoor receptacles, and so forth. Also, receptacles that are replaced in locations where GFCI protection is required applies to other than dwelling units such as commercial repair garages, elevators and elevator pits, health care facilities and bathrooms in commercial and industrial facilities, as provided in 210.8(B).

Ground-fault circuit interrupters of various types, the most common of which are the circuit-breaker and receptacle-types, are permitted to be used to provide the protection required unless the particular type of device is specified. For example, 620.85 requires that the ground-fault circuit-interrupter protection in pits, on elevator car tops, and in escalator and moving walkways shall be of the receptacle-type.[1] So GFCIs of the circuit-breaker type would not be acceptable in those applications. The goal is to provide the service person the convenience of resetting the GFCI local to the elevator car or pit where the work is being performed.

Equipment Ground-Fault Protective Device (EGFPD)

Equipment ground-fault protective devices are very similar in construction and operation as Class A GFCI devices with the main difference being the trip level. As indicated by the name of the device, the primary function is to protect equipment. These devices are set to disconnect the electric circuit from the source of supply when ground-fault leakage current exceeds the ground-fault pick-up level marked on the device. The user must select the specific device for the voltage, full-load current and the trip level. To aid the user in making proper selection of this equipment, the EGFPDs are marked with a ground-fault pick-up level in milliamperes along with the voltage and current ratings. The ground-fault pick-up level is limited to the range above 6 mA to 50 mA by the listing of the device and typically has ground-fault trip levels of 20 or 30 milliamperes. These devices are intended to operate upon a condition of excessive ground-fault leakage current from equipment, rather than minimize damage due to arcing faults in services. EGFPDs are intended to be installed only on grounded alternating-current systems in accordance with the *NEC* and are required by 426.28, Fixed Outdoor Electric Deicing and Snow-Melting Equipment, and 427.22, Fixed Electric Heating Equipment for Pipelines and Vessels. These devices also have found wide usage in industrial process equipment. These devices have also been called earth leakage breaker or earth leakage relays by some manufacturers, especially from Asia, which does cause confusion.

From the listing information, UL Product spec Category *Code* FTTE, a two-wire device is not suitable for use in a multiwire branch circuit. These devices have not been evaluated to provide electric shock protection for personnel, and they are not intended to be used in place of a ground-fault circuit interrupter (GFCI) where a GFCI is required by the *NEC*. As stated above, in some applications from foreign manufacturers, this has caused confusion where the manufacturer believes the earth leakage breaker or relay they are installing is for personnel protection. In addition to the above, these devices are not intended to be used in electrical service-entrance equipment where ground-fault sensing and relaying equipment, required by Section 230-95 of the *NEC*, is used. When these devices are incorporated into a molded-case circuit breaker, the Category *Code* for additional listing information is DIYA.

When installing these devices, equipment grounding conductors and system grounding are still required to be installed in accordance with the *NEC*.

Arc-Fault Circuit Interrupters (AFCI)

Section 210.12 of the *National Electrical Code* sets the requirements for where AFCI is required to protect branch circuits in dwelling units. AFCI protection technology is different from how GFCI protection operates. As discussed above, GFCI functions based solely on current and that there is a balance of current going to the load and returning from the load under normal conditions. AFCI technology is based on monitoring the voltage waveform and identifying spikes or other distortions that are signatures of an electrical arc occurring. The arc sensing must also filter out those “arc” events, like a motor running or a snap switch operating, that are normal conditions and do not constitute an arcing fault requiring the AFCI device to open the circuit. Most manufacturers of AFCI circuit breakers, both the branch-circuit type and the combination type, do incorporate a form of GFCI function into the breaker but the trip levels range from 40 to 75 mA (see figure 14.4). With these trips levels, this is really more like the EGFPD device discussed in the last section. The purpose of the GFCI function is to assist in recognizing and clearing the parallel arcing fault from an ungrounded (hot) conductor to the equipment grounding conductor.

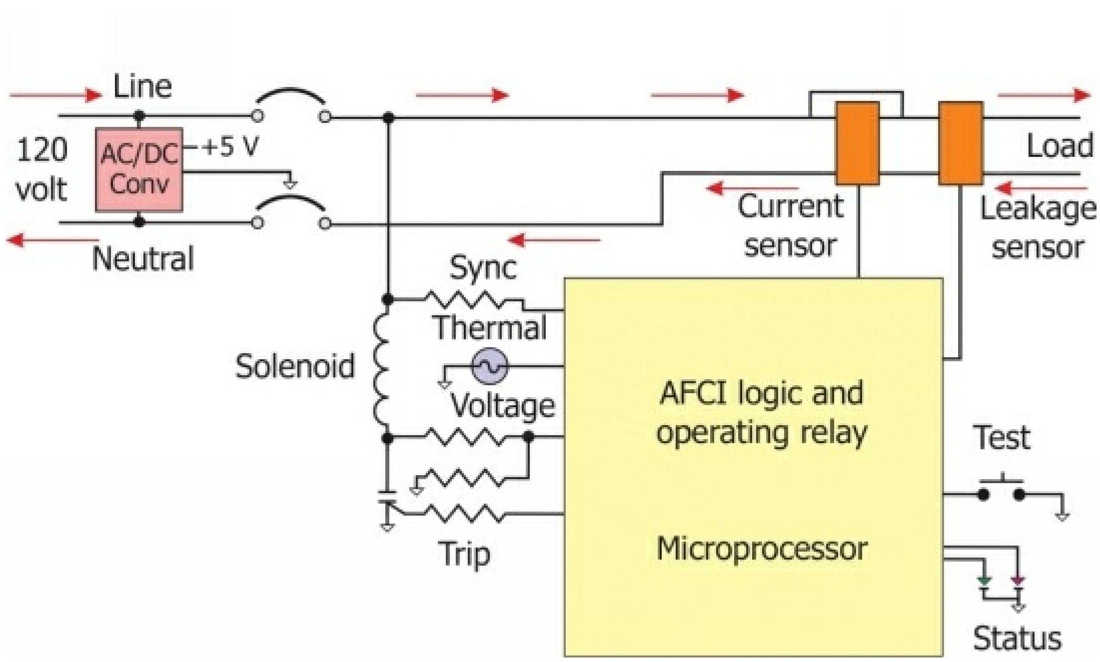


Figure 14.4 Arc-fault sensing diagram

It needs to be noted here that the term *combination-type* for AFCI is not for a combination of arc-fault protection and GFCI, but is the combination of parallel arcing protection (hot to neutral, hot to equipment ground) as well as the series arcing fault where a single current- carrying conductor (hot or neutral) has a poor connection or a break causing an arc to form to bridge that poor connection. Some manufacturers are now producing an AFCI circuit breaker that also incorporates Class A GFCI protection. These are identified as “dual function” or “dual purpose” AFCI/GFCI circuit breakers. It should be noted that GFCI receptacles can be installed on circuits protected by AFCI. There is no incompatibility with these devices due to the different technologies employed.

Ground-Fault Protection for Equipment (GFPE)

Ground-fault protection for equipment is required for solidly grounded wye electrical services of more than 150 volts to ground but not exceeding 1000 volts phase-to-phase for each service disconnect rated 1000 amperes or more [see 230.95 and figure 14.5]. Similar requirements for feeders exist in Sections 215.10 and 240.13 where ground-fault protection is not provided on the main overcurrent device ahead of the feeder in the same system. Lastly, 210.13 requires GFPE where such protection is not provided ahead of the branch circuit. As can be seen, this protection is required for nominal 480Y/277 or 600Y/347-volt, three-phase, 4-wire wye connected systems where the circuit breaker or fused switch rating is 1000 amperes or more.

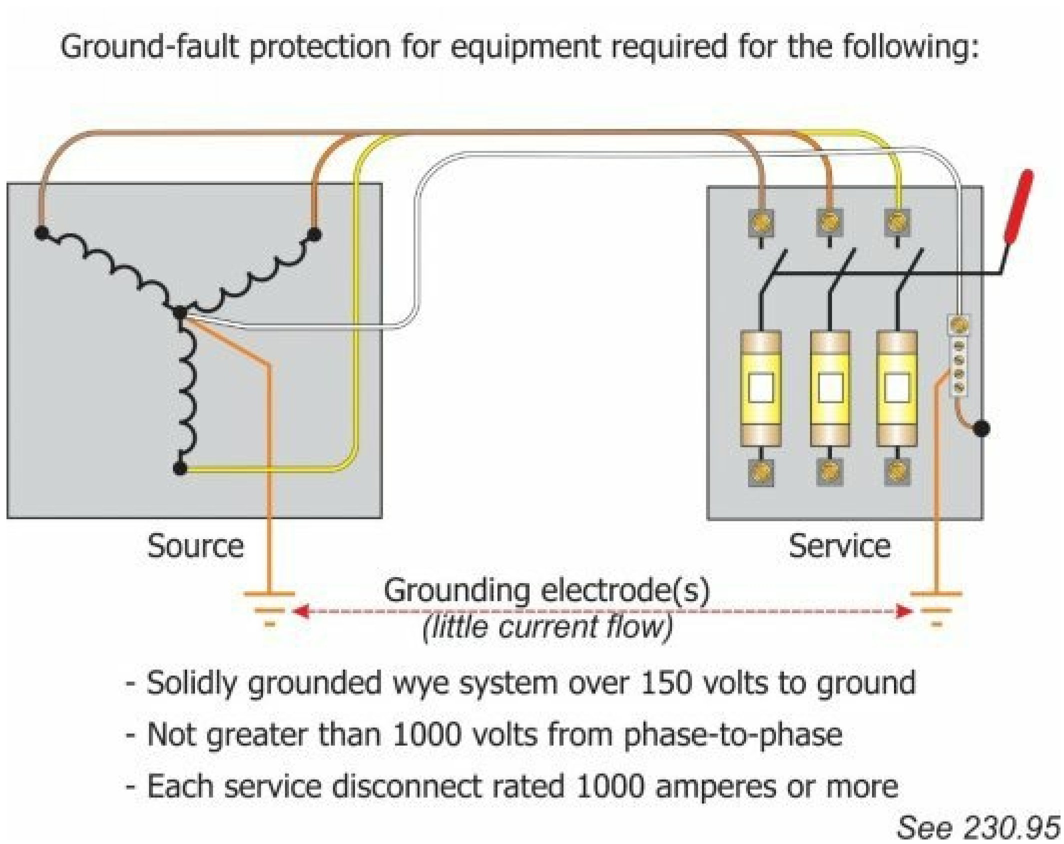


Figure 14.5 Ground-fault protection is required

These provisions do not apply to services or feeders for fire pumps or continuous industrial processes where a non-orderly shutdown would introduce additional or increased hazards. The exception to Section 230.95 states that ground-fault protection provisions of 230.95 "not apply to a service disconnect for a continuous industrial process where a non-orderly shutdown will introduce additional or increased hazards." This is a mandatory exception. Likewise, ground-fault protection of equipment is not permitted for fire pump services [see 695.6(G)]. For an emergency system, 700.26 excludes the alternate source of power from the requirement to have "ground-fault protection of equipment with automatic disconnection means." This applies to fire pumps that are classified as an emergency system in accordance with 700.1. Indication of a ground fault of the emergency source is required to indicate a ground fault in solidly grounded wye emergency systems of more than 150 volts to ground and circuit-protective devices rated 1000 amperes or more [700.6(D)]. The sensor for the ground-fault signal devices shall be located at, or ahead of, the main system disconnecting means for the emergency source, and the maximum setting of the signal devices shall be for a ground-fault current of 1200 amperes. Instructions on the course of action to be taken in event of indicated ground fault shall be located at or near the sensor location." [13]

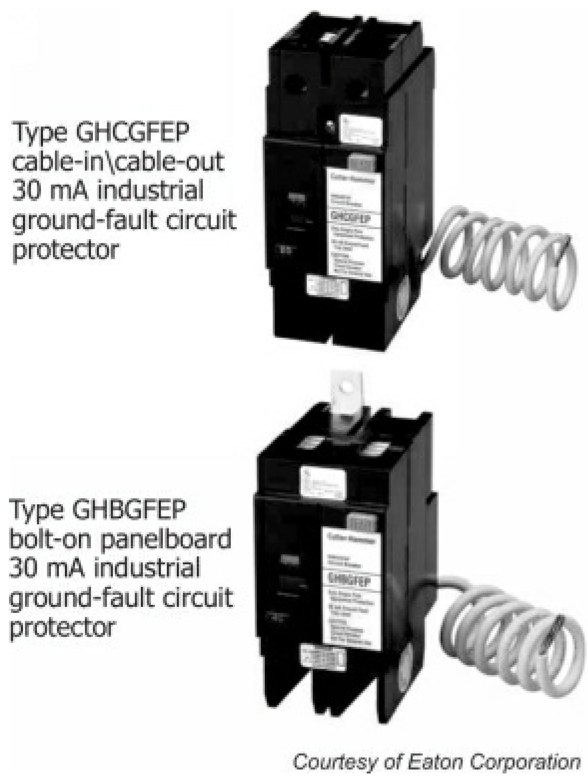


Photo 14.2 Molded-case circuit breaker with equipment ground-fault protection

Photo 14.3 Arc-fault circuit breakers and outlet branch-circuit (OBC) AFCI device

A similar exclusion from the ground-fault protection of equipment mandatory requirement is pro-vided for legally required standby systems in 701.17. No such exclusion is provided for optional standby systems installed in accordance with Article 702.

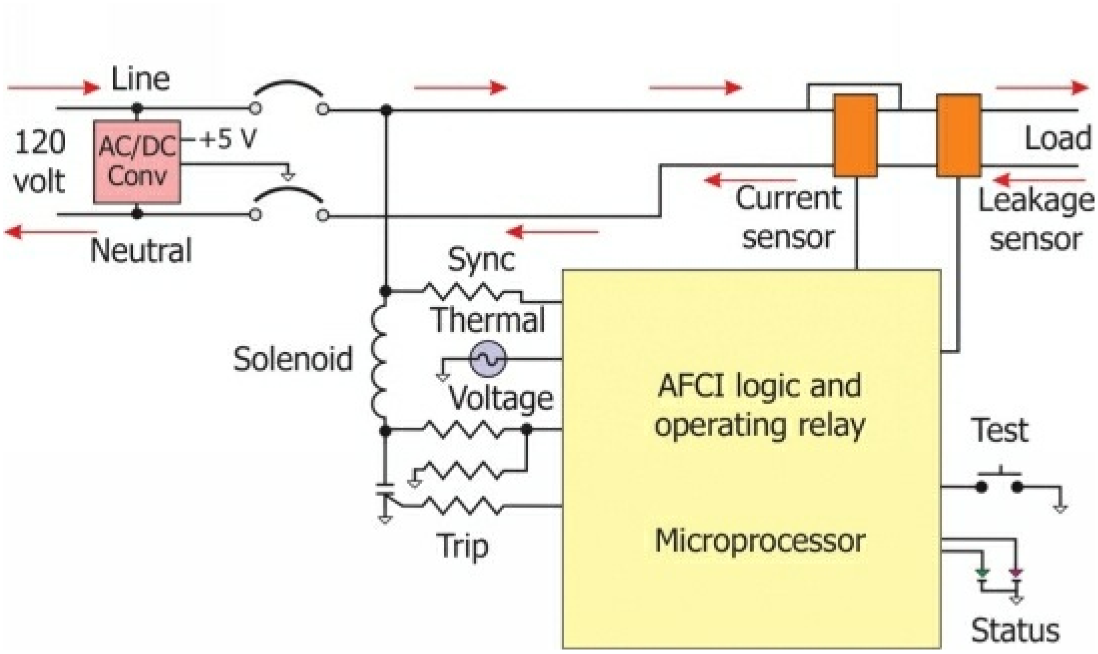


Figure 14.4

Also in accordance with 230.95, “The maximum setting of the ground-fault protection shall be 1200 amperes, and the maximum time delay shall be one second for ground-fault currents equal to or greater than 3000 amperes.” [1] The magnitude of the ground-fault current in the event of a line-to-ground fault on a grounded system is determined by the overall impedance of the circuit from the source to the point of the ground fault and back to the source. The major elements making up this impedance include the internal reactance of the grounded source, the resistance and reactance of the conductors leading to the fault and the resistance and reactance of the ground-fault return path(s) including any intentional grounding resistance or reactance. For interconnected systems, calculation of the current can be rather complicated. For simpler cases, the available ground-fault current can be calculated or a close approximation of the available fault current may be obtained.

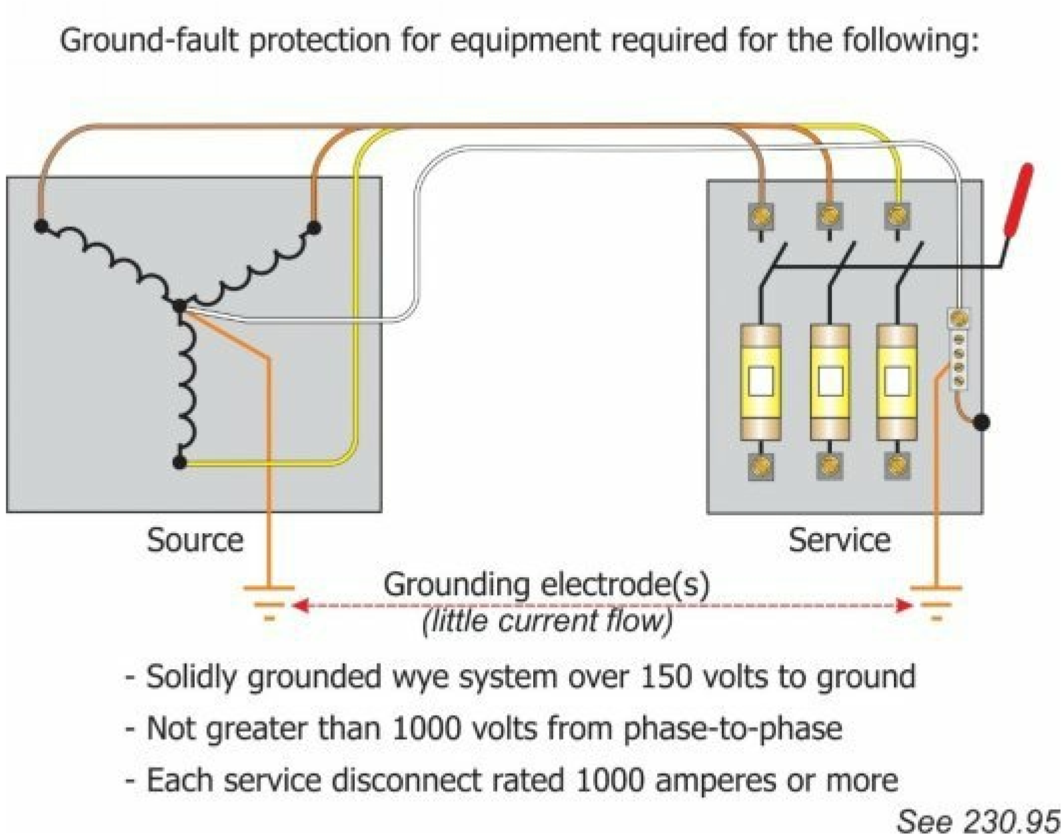


Figure 14.5 Ground-fault protection is required

The requirement to provide specific equipment ground-fault protection is due to a history of destructive burn downs of electrical equipment operating at this voltage level and the failure of standard overcurrent protection to prevent or mitigate the damage. The most destructive of these phase-to-ground faults are the arcing type faults as opposed to a bolted type fault. An electric arc, which generates a tremendous amount of heat and ionizes the surrounding air at the arc point, is readily maintained with a supply voltage of more than 150 volts or greater to ground. An arcing type ground-fault has the current additionally limited by the impedance of the arc itself. This often results in insufficient current in the circuit to cause the typical overcurrent device ahead of the fault to open or to open quickly. With a substantial amount of the fault energy concentrated at the point of the arc, a great deal of damage is done to the electrical equipment while the arc is burning (see photos 14.4 and 14.5). An analogy of this is an arc welder with 150 volts at the rod and capable of several thousands of amps. When the arc is struck, or stopped, there is residual splatter of the metallic materials. When this arc from the rod is struck 120 times a second, one can imagine the destructive energy and heat experiences by copper or aluminum bus and metallic enclosures.

Photos 14.4 and 14.5 This equipment endured an arcing event that resulted in extensive destruction (an arcing burn down) of the equipment. GFPE could have prevented, or at least limited, this amount of damage.

Case History

As can be seen in photos 14.4 and 14.5, this equipment was extensively damaged by a ground-fault event that at some point also became a phase-to-phase short circuit. This equipment was supplied by a utility source delivering considerably high levels of short-circuit current (approximately 42,000 amperes). This 2500-ampere 480Y/277-volt, 3-phase, 4-wire switch-board had a remote main service fused disconnect switch rated 3000 amperes with 2500 amperes current-limiting fuses, 200,000 amperes interrupting rating, installed. The main fused switch had ground-fault protection installed but due to a previous nuisance trip, the control power to the ground-fault protection system was turned off. The ground-fault event happened in the distribution switchboard when facility electricians were replacing a fuse that had opened for no apparent reason. The ground fault quickly escalated into an arcing short-circuit fault and the combination destroyed the equipment. The ground fault was finally stopped when two of the three fuses in the service fused switch opened under what they saw as an overload condition many minutes into the event. The photos clearly show the result of substantial electrical forces and heat due to this ground fault in the equipment. The obvious holes in the enclosures are where the arcing literally melted away the metal. This equipment had to be totally replaced and the building it served suffered considerable downtime as a result of this event. This actually happened in a hospital and due to the extensive damage and expected downtime, the hospital had to be evacuated and was out of business for five days. Ground-fault protection provides considerable protection for equipment from these types of events and could have helped prevent this damage. A properly installed and set ground-fault protection system would have cleared this ground fault in less than 30 cycles (½ second) instead of minutes. What happened to the workers? Both were severely burned and, unfortunately, one passed away from his injuries three days later; and the other eventually recovered. It is very important for the safety of electrical workers to understand the rules for electrical safety in the workplace. It is always the best plan to put electrical equipment into an electrically safe work condition, including verifying it through testing before working on it. See NFPA 70E – 2012 and OSHA 1910.331 to 1910.335 for additional information about this subject.

Ground-Fault Protection System Types

There are basically two types of equipment ground-fault protection systems in use, and one of them has two configurations, although these systems may have different names in the industry. The most common types are known as *zero-sequence system* and an alternate configuration is called the *residual system*, which may have more than one form. The other main type is the *neutral ground strap-type*, which is sometimes referred to as *ground-strap*, or *ground-return type* (see figure 14.6). All ground-fault protection systems are designed to protect equipment downstream of the ground-fault sensor from destructive arcing burn downs. Note that this equipment will not protect equipment or the system on the line side of the sensor from line-to-ground faults because the fault current will not pass through the ground-fault sensing equipment. The following will discuss each of these systems.

Neutral Ground Strap-Type System

The neutral ground-strap type of equipment ground-fault protection system consists of a current sensor, control power source, ground-fault relay, and a circuit breaker or fused disconnect switch equipped with a shunt-trip. The unique design feature of this type system is that the main bonding jumper, or for a separately derived system the system bonding jumper, passes through the current sensor as shown in figure 14.6.

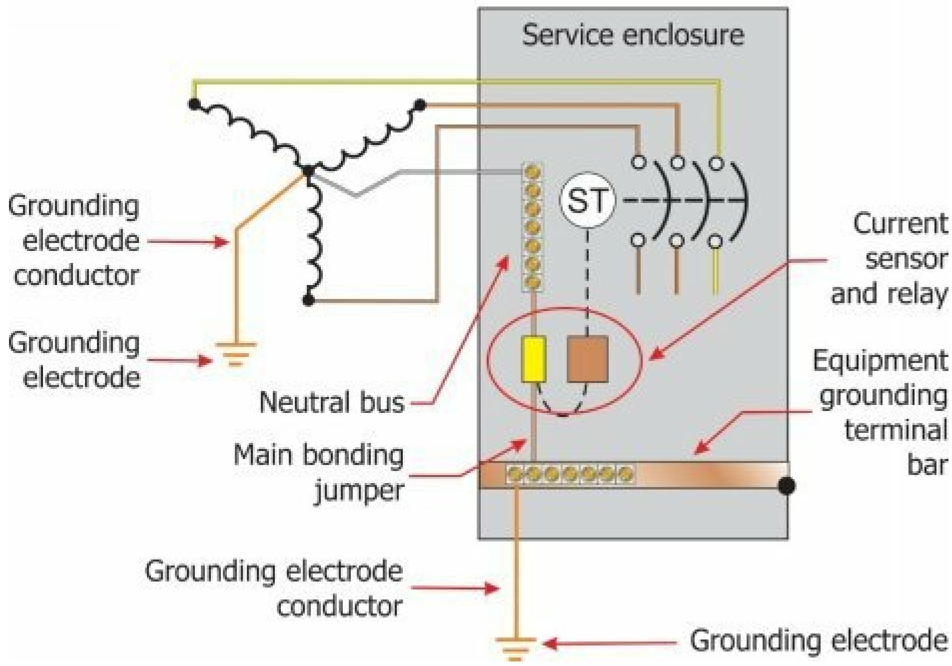


Figure 14.6 GFPE System – neutral ground strap-type

One advantage of this system is that it is the least expensive, but the big disadvantage is that it is limited to application only at the main service or separately derived system supply source. It cannot be used for downstream protection of feeders since the main bonding jumper at the service or system bonding jumper at a separately derived system are the only sensing path provided. Additionally, it is critical that all equipment grounding conductors and earth grounding electrode connections be to the equipment grounding bar so there is only one path provided for fault current—through the main bonding jumper or the system bonding jumper to return to the source. As was discussed in chapter one, the ground-fault current will return on any path that it can and the magnitude will depend on the relative impedance. To have this system function correctly, then all those possible parallel return paths must be consolidated at one point so there is one primary path for the current to flow back to the source. This system is shown in figure 14.7 under normal operation, no ground fault condition present.

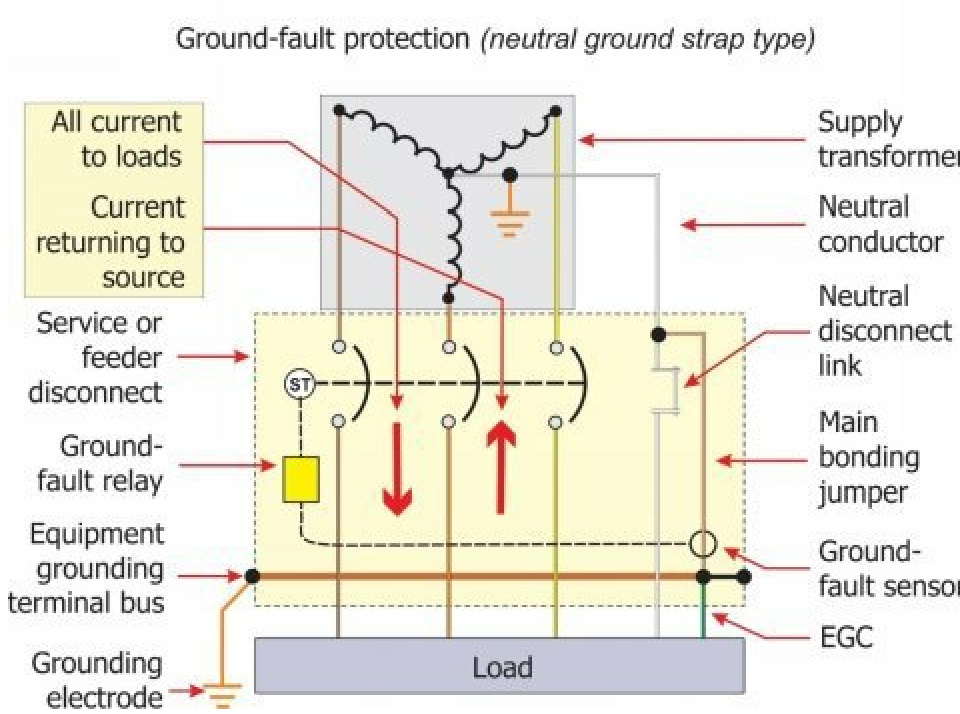


Figure 14.7 Neutral Ground Strap System – normal operation

With the connections as shown in figure 14.8 where a ground fault exists, the maximum ground-fault current will be through the main bonding jumper and will, therefore, be recognized by the ground-fault current sensor. When that current exceeds the pickup setting for the set time delay, then the relay will actuate the shunt-trip to open the circuit breaker or the fused switch disconnect. With a proper installation for the paths that can be controlled, the relative impedance of the main circuit is so low as compared to all the possible bypass circuits so that approximately 90 percent of the total ground-fault current will be through the and, therefore, be seen by the current sensor.

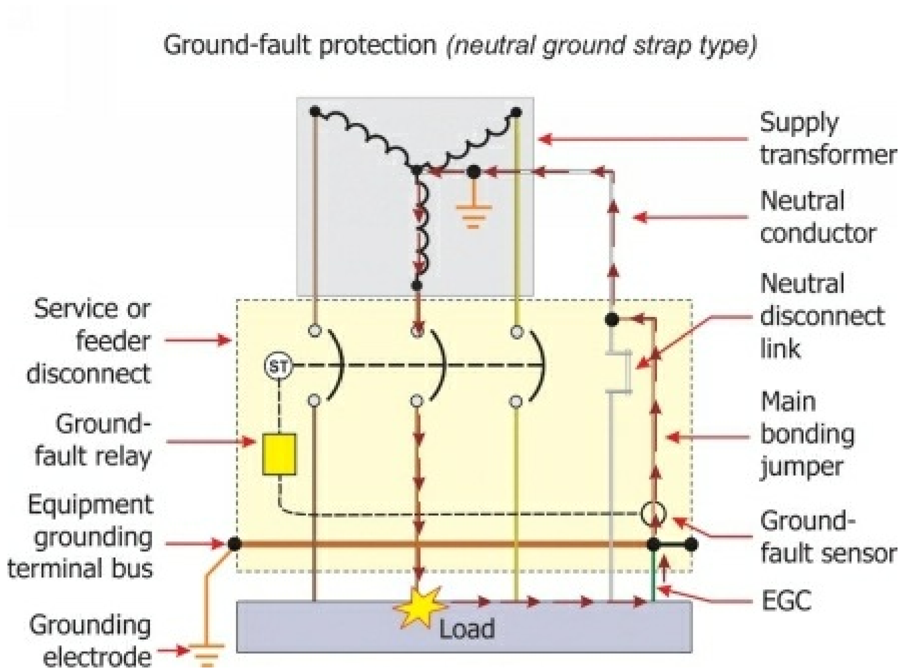


Figure 14.8 Neutral Ground Strap System – ground-fault condition

Examination of the diagram in figure 14.8, will show that the main ground-fault current path is from the transformer to the service, through the feeder to the fault, back to the service over the equipment grounding conductor, through the main bonding jumper where it returns to the transformer by the neutral conductor. The parallel circuit from the grounding electrode at the service to the grounding electrode at the transformer is both a high-resistance and a high-reactance circuit. As a result, little current on the order of less than 5 percent of available ground-fault current will return through the earth.

Some small amount of ground-fault current will be carried by the building structural metal framing if it is in the circuit. It is preferable to adequately bond the structural metal framing directly to the service equipment grounding bar or bus or to the same grounding electrode as used for the service. When this bonding is connected as indicated above, the possible fault return paths still capture the majority of the current through the ground-fault sensor. The bonding also prevents the building structural metal frame from rising to a dangerous potential above ground. Even though the building structural metal framing represents a possible parallel path for fault current, most of the current will still return to the transformer through the neutral because of the lower reactance of that path as compared to the reactance of the other available parallel paths.

Zero-Sequence Ground-Fault Sensing-Type System

Probably the most popular and common type of ground-fault protection system is the zero-sequence type. This system is shown in figure 14.9. It consists of one current sensor that is placed around all the current-carrying conductors of the circuit, including the grounded (neutral) conductor, a control power source, a ground-fault relay, and a shunt-trip circuit breaker or shunt-trip fused disconnect switch. Optionally, there may be one sensor around all the phase conductors and a second sensor for the grounded (neutral) conductor. As shown, the ground-fault current sensor must be placed around the neutral downstream from the main bonding jumper connection point. The equipment grounding conductors and the main bonding jumper or system bonding jumper do not pass through the window. Generally, the current sensor through which all conductors of the circuit pass, as shown in figure 14.9, is installed by the manufacturer of the switchboard. Where used for feeder circuits, the cables for the feeders are field-installed.

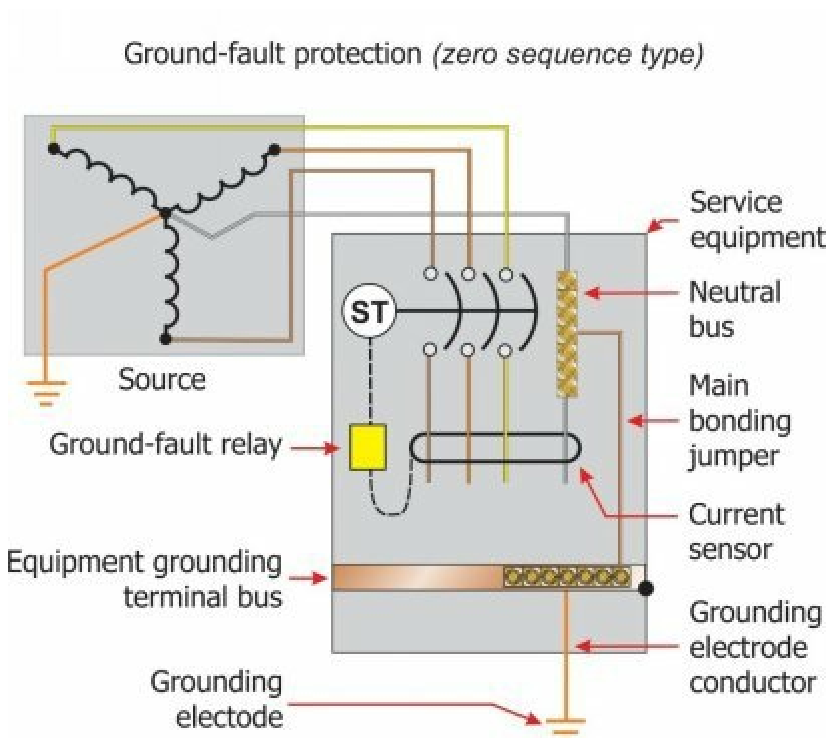


Figure 14.9 GFPE System – zero sequence system

As shown in figure 14.10, under normal operation, the vector summation of all phase and neutral (if used) currents approaches zero. This is due to the canceling effect of the currents in the conductors. It must be remembered that this is a vectorial summation and not a direct arithmetic sum because the three-phase and neutral currents are 120 degrees out of phase. Under ground-fault conditions, figure 14.11, not all the current going from the source to the fault location and loads returns on the phase and neutral conductors. The sensor around the phase and neutral conductors detects the current imbalance and sends the resultant current signal to the ground-fault relay. The imbalance happens because of the current passing outside the current sensor "window(s)" on the ground-fault current path.

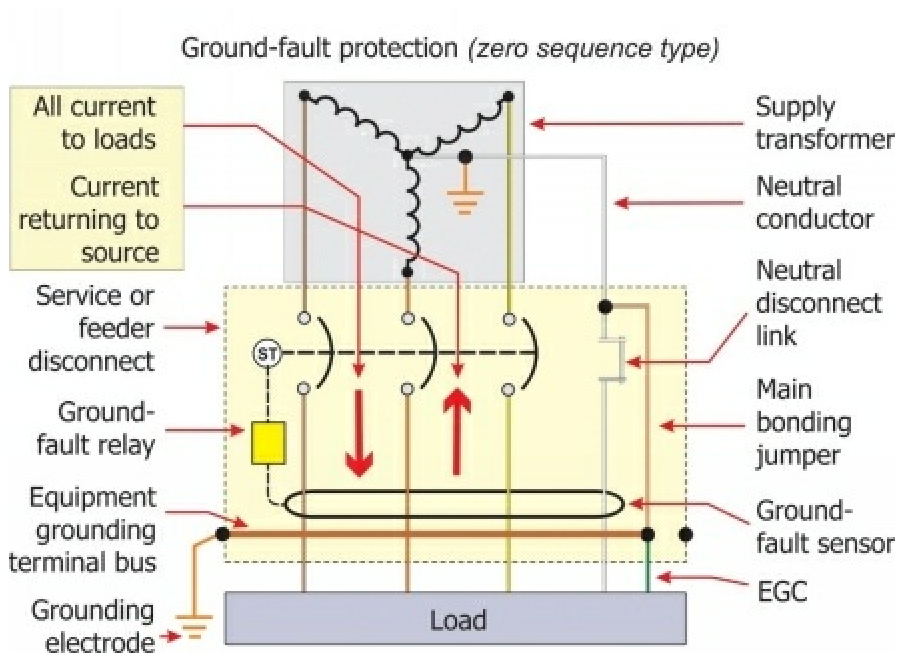


Figure 14.10 Zero-sequence GFPE system - normal operation

The output of the sensor is proportional to the magnitude of the ground-fault current. This output is sent to a ground-fault relay. The relays are usually field-adjustable with pickup ranges of from 4 to 1200 amperes depending on the relay selection. Typical ranges for service equipment ground-fault relays are 100 to 1200 amperes. Time-delay settings may be fixed or adjustable depending on ground-fault relay selections and are available from instantaneous (1.5 cycles) to 1-second (60 cycles) delay. When the ground-fault current exceeds a preselected level for the set time delay, the relay will activate the circuit-interrupting device, which usually is a shunt-trip circuit breaker or shunt-trip fused switch, to open the circuit.

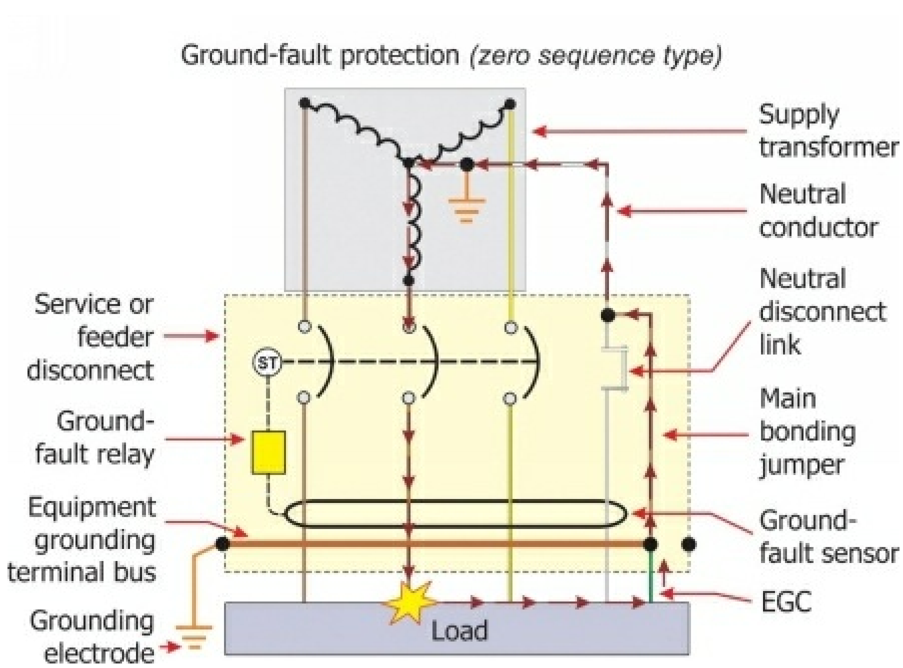


Figure 14.11 Zero-sequence GFPE system – ground-fault condition

Photos 14.6 and 14.7 GFP equipment (bolted pressure switch with GFPE)

Residual-Type Ground-Fault System

The basic difference between the zero-sequence and residual-type systems shown in figures 14.9 and 14.12 is the number of current sensors. These can be external or more commonly now the phase sensors are built into the circuit breakers with integral ground-fault protection (see photo 14.8). The integral ground-fault system will have an external ground-fault current sensor through which the neutral passes (see photo 14.9), where the neutral is part of the circuit. In some cases, this neutral sensor may be field-installed. Often, these same internal current sensors are used by the circuit breaker as a part of its internal overcurrent protection operating system.

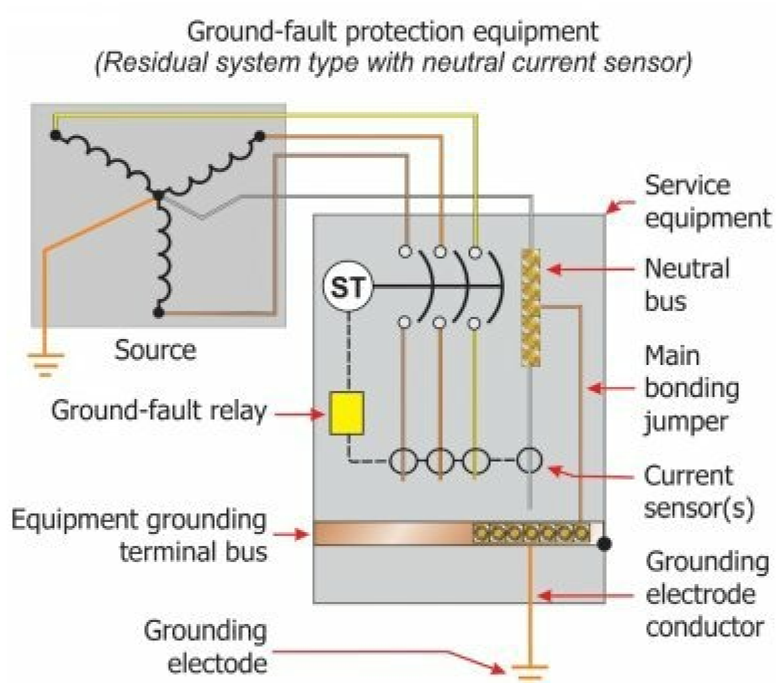


Figure 14.12 Residual GFPE system with neutral current sensor

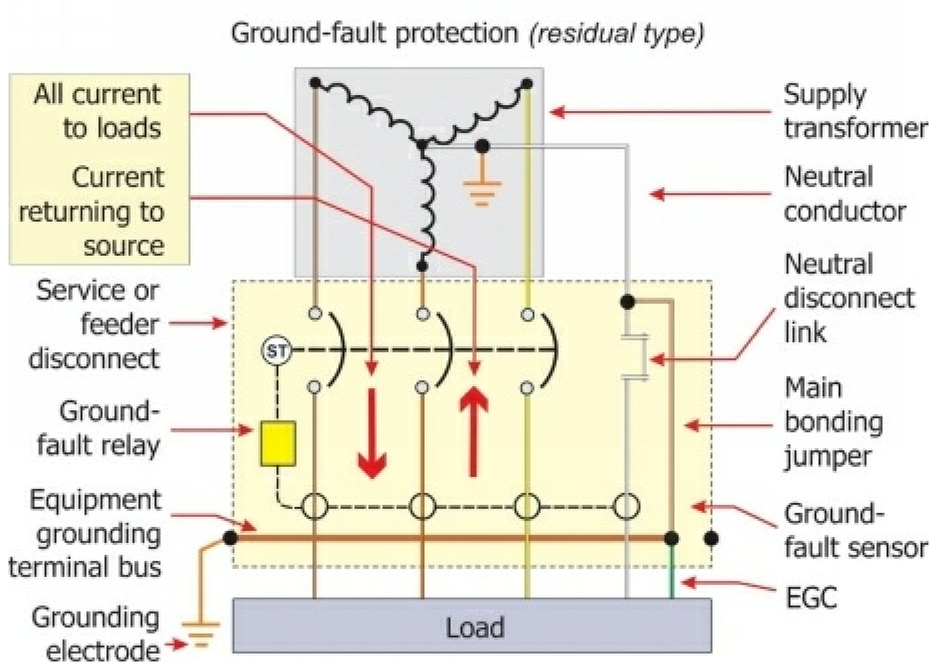


Figure 14.13 Residual GFPE system – normal operation

Photo 14.8 Residual GFPE equipment (breaker-types) in a switchboard

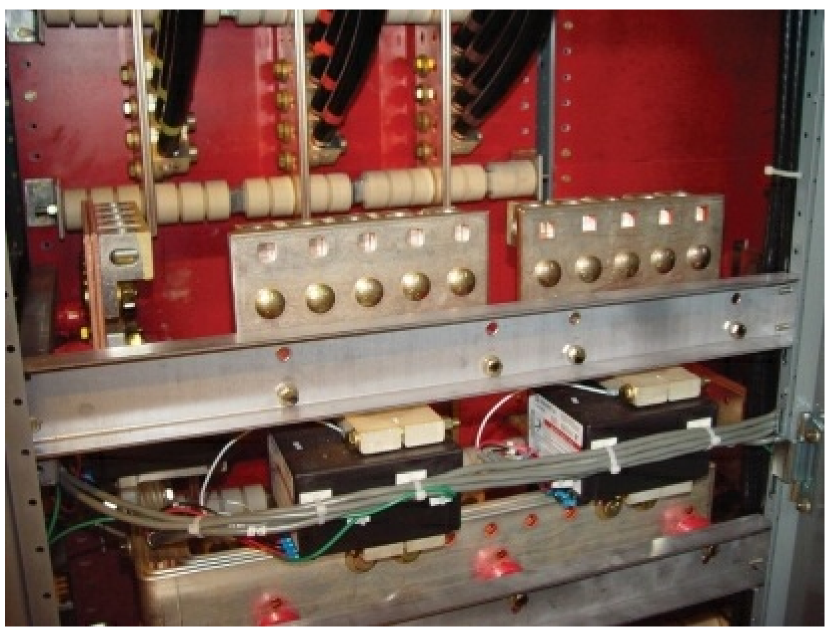


Photo 14.9 Residual current sensors on respective neutrals in switchboard

Like the zero sequence system, under normal operation, the vector summation of all phase and neutral (if used) currents approaches zero. This is due to the canceling effect of the currents in the conductors. Under ground-fault conditions, not all the current going from the source to the fault location and loads returns on the phase and neutral conductors. The summation from the sensors around the phase and neutral conductors detects the current imbalance and sends the resultant (residual) current signal to the ground-fault relay. The imbalance happens because of the current passing outside the current sensor “window(s)” on the ground-fault current path.

The output of the sensors is proportional to the magnitude of the ground-fault current. This output is fed to a ground-fault relay or the protection system inside the circuit breaker. The relays or breaker settings are usually field-adjustable with pickup ranges of from 4 to 1200 amperes. Time-delay settings are available from instantaneous (1.5 cycles) to 1-second (60 cycles) delay. When the ground-fault current exceeds a preselected level for the set time delay, the relay will activate the circuit-interrupting device, which is a shunt-trip circuit breaker, circuit breaker with integral flux-trip, or shunt-trip fused switch, to open the circuit (see photo 14.10).

Photo 14.10 GFPE setting adjustments (breaker-type)

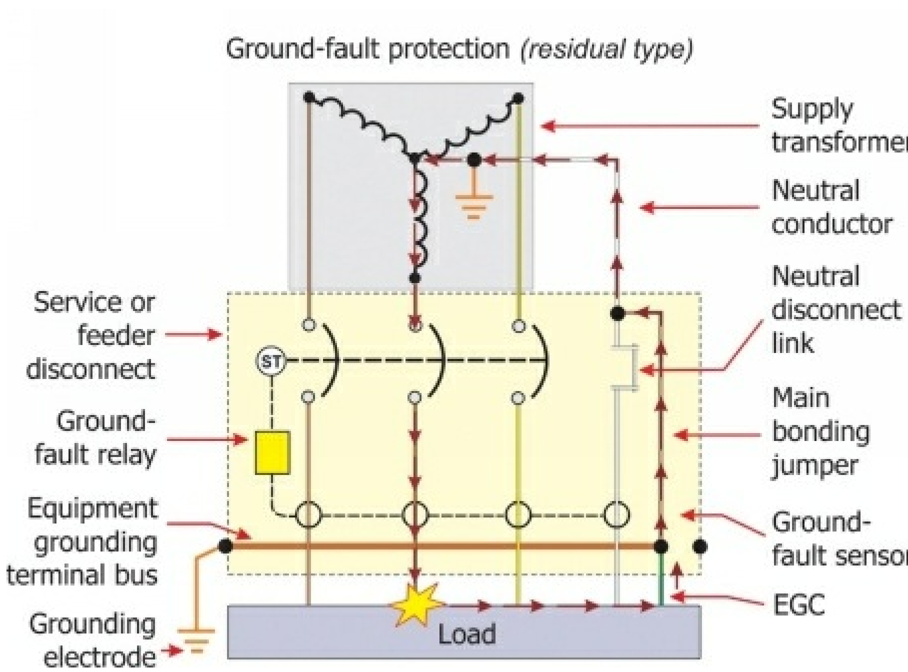


Figure 14.14 Residual GFPE system – ground-fault condition

For systems over 600 volts, medium voltage systems, the ground-fault protection scheme generally employed is the residual type system, although the zero sequence is sometimes used for feeders with cables. The residual system uses the same current transformers as the phase overcurrent protective relays and the summation current (residual) is connected to an overcurrent relay.

Testing of GFPE System

Section 230.95(C) requires that service ground-fault protection systems be performance-tested when first installed on site to ensure that they will operate properly. Experience has shown that the majority of these systems do not operate properly, or at all, when first installed. This is most often due to improper field wiring of the system. The three most common problems encountered with these systems are:

1. Undersized main or system bonding jumpers. These conductors are sized per 250.28 based on the ability to withstand the level of anticipated ground-fault current until the ground-fault protection causes the disconnecting device ahead of the fault to open. For example, a 4000-amperes service switchboard would typically require a 750-kcmil copper main bonding jumper. To save some cost, installers have incorrectly installed parallel 250-kcmil copper conductors because two 250-kcmil copper conductors have a greater ampacity than the single 750-kcmil. The problem is the overall cross sectional area is only 500-kcmil and the ability to survive a significant fault for the time needed is reduced by 33 percent.

2. Incorrect location of the sensor on the neutral bus in relation to the main bonding jumper and/or grounding electrode conductor termination points; or, conversely, the main bonding jumper or grounding electrode conductor being installed on the neutral bus downstream of the ground-fault sensor for zero-sequence and residual systems. In particular, for the zero-sequence and residual systems, if there is any grounding connection to the neutral downstream of the ground-fault sensor, then in a fault situation some of the current will be diverted onto the neutral conductor and appear to the ground-fault sensing system as “normal” neutral current.

3. Connecting downstream panelboard, generator or branch-circuit neutral conductors to ground (equipment grounding conductors, enclosures or earth). Again, these connections provide an alternate path for ground-fault current so that the ground-fault system is desensitized. Also, under normal conditions, neutral current has an alternate path on the equipment grounding system and this current will be “seen” by the ground-fault sensing system as “ground-fault current.” This situation has caused many improper trips on main disconnects where a ground-fault condition did not exist, not due to failure of the ground-fault system, but due to improper installation practices. These conditions are shown in figures 14.15 and 14.16.

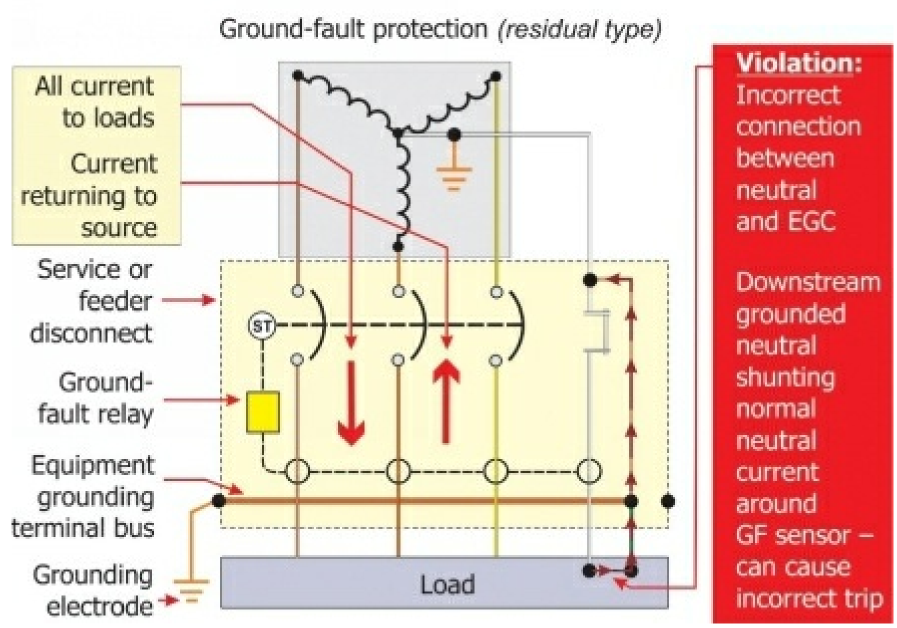


Figure 14.15 Residual GFPE system with downstream grounded neutral shunting normal neutral current around ground-fault sensor can cause incorrect trip

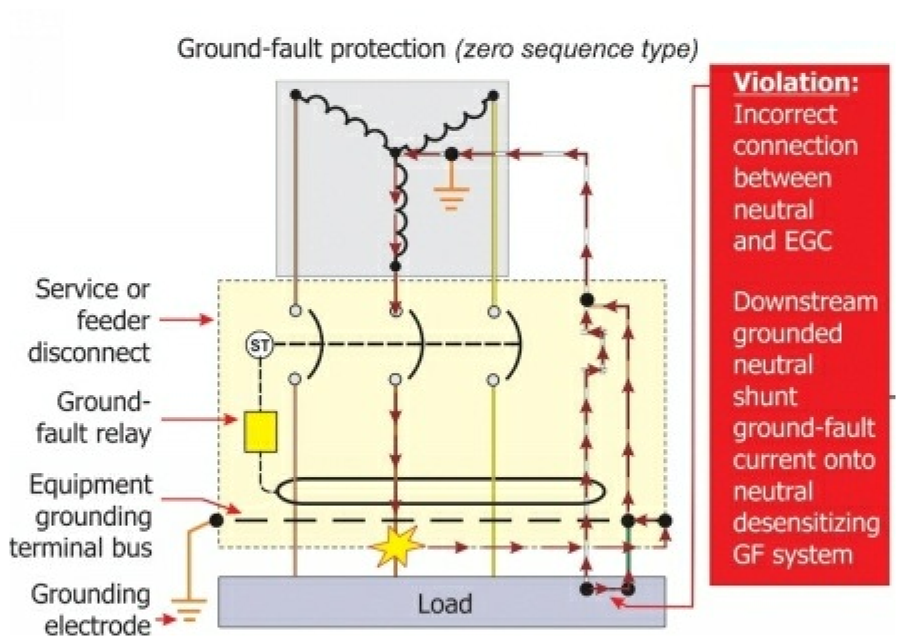


Figure 14.16 Zero-sequence GFPE system with downstream grounded neutral shunt ground-fault current onto the neutral desensitizing the ground-fault system.

The test must be performed in full compliance with the manufacturer's written instructions in accordance with 230.95(C). These instructions must be furnished with the equipment and are part of the listing requirements. The GFPE testing requirements apply to services, feeders, and branch circuits where it is first installed. A vital part of the test is to remove the neutral disconnect link in the distribution equipment and test the neutral system of conductors with a continuity tester or megohm meter to be certain that it is clear from any grounding connections downstream from main bonding jumper at the service. This test must be of all the neutral conductor system including the bus, feeders, and branch circuit wiring.

"A written record of this test shall be made and shall be available to the authority having jurisdiction."[1] System safety requires that the GFPE equipment be properly installed, tested and be maintained in an operable condition. Failure to do so can result in the threat of lawsuit where negligence of the installer or other responsible party can be proven. A good part of the legal case in the case study described above was about who de-energized the control power to the ground-fault system that was installed on the main fused disconnect. Many jurisdictions now require this test to be completed before they will authorize the equipment to be energized.

[1] **NFPA 70, *National Electrical Code*, 2017 (National Fire Protection Association, Quincy, MA 02169, 2016)**

[2] **IEEE 100-1992, *The New IEEE Standard Dictionary of Electrical and Electronic Terms*, 5th Edition (Institute of Electrical and Electronics Engineers, New York City)**

[3] **A. Albert Biss, Ground-Fault Circuit-Interrupter (GFCI) Technical Report, (Washington, D.C.: U.S. Consumer Product Safety Commission, February 28, 1992).**

[4] **Walter Skuggevig, *5-Milliampere Trip Level for GFCIs*, (Northbrook, IL: Underwriters Laboratories, March 1989).**

[5] **IITRI report, the voltage and current values are assumed to be "root-mean-square" RMS values.**

[6] ***Electric Shock Preventio*n, p. 25.**

[7] **Technical Report IEC 479-1, Effects of current on human beings and livestock. International Electrotechnical Commission. Available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112.**

[8] **A. Albert Biss, *Three-Wire Grounding Systems vs. GFCI*, (Washington, D.C.: U.S. Consumer Product Safety Commission, December 1985).**

[9] **Ralph H. Lee, "Electrical Grounding: Safe or Hazardous?" Chemical Engineering, July 28, 1969.**

[10] **A. W. Smoot, *Analysis of Accidents*, (Northbrook, IL: Underwriters Laboratories, 1971).**

[11] **Application Guide for Ground-Fault Circuit Interrupters, Standards Publication No. 280-1990, National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1847, Rosslyn, VA 22209. Reprinted with permission.**

[12] **UL Productspec at www.ul.com/productspec) [Underwriters Laboratories Inc., Northbrook IL 60062).**

[13] **NFPA 70, *National Electrical Code*, 2011 (National Fire Protection Association, Quincy, MA 02169, 2010)**

Review Questions

1. Where new receptacles are installed in locations that are required by the *Code* to be GFCI protected, they must be ___.

1. of the grounding-type
2. GFCI protected
3. on dedicated circuit
4. polarized

2. Circuit breaker or receptacle-type ground-fault circuit interrupters ____ be used to protect grounding-type receptacle, where non-grounding-types of receptacles are replaced with grounding-type receptacles where an equipment grounding conductor does not exist in the receptacle enclosure.

1. are permitted to
2. cannot
3. must always
4. by special permission can

3. With a current imbalance as low as ____ milliamperes, a GFCI will interrupt the circuit and this will be shown by a trip or "off" indicator on the device.

1. 3
2. 4
3. 5
4. 6

4. A GFCI of the Class ___ type is designed so that it will automatically trip when the current to ground is 6 mA or higher and do not trip when the current to ground is less than 4 mA.

1. A
2. B
3. C
4. D

5. The basic GFCI consists of a ground-fault detecting means that is coupled with a circuit-interrupting means. This detecting means measures the ground-fault current as the difference between outgoing and incoming load current on the ____ conductors.

1. protected
2. normally current carrying conductors
3. bonded

4. service

6. A condition which could result in injury or electrocution to a person, caused by electrical current through the body, is defined as ____.

1. a high resistance ground
2. an electrical shock hazard
3. a short circuit
4. ground fault

7. A system intended to provide protection of equipment from damaging line-to-ground fault currents, by operating to cause a disconnecting means to open all ungrounded conductors of the faulted circuit, is defined as ____.

1. ground-fault circuit interrupter
2. ground-fault protection of equipment
3. leakage current detector
4. saturable core reactor

8. The *NEC* requires ground-fault protection of all solidly-grounded wye electrical services of more than 150 volts to ground, but not exceeding 1000 volts phase-to-phase, for each service disconnect rated ____ amperes or more.

1. 800
2. 1000
3. 600
4. 400

9. Ground-fault protection of equipment is not applicable to ____ where a non-orderly shutdown would introduce additional or increased hazards.

1. electronically-actuated fuses
2. continuous industrial processes
3. fire pumps
4. both b and c

10. Where a service is protected by a system of GFPE, the maximum setting of the GFPE devices is ____ amperes and the maximum time delay is one second for ground-fault currents equal to or greater than ____.

1. 1300 - 2000
2. 1200 - 3000
3. 1400 - 1500

4. 1600 - 1000

11. For feeders rated 1,000 amperes or more in a solidly-grounded wye system with greater than 150 volts to ground, but not exceeding 600 volts phase-to-phase, ground-fault protection is not required ____.

1. when lockable means are provided
2. when there is ground-fault protection on the main ahead of the feeder
3. where AFCI protection is provided
4. if alarm notification is provided

12. The most common types of ground-fault protection for equipment is ____.

1. three-phase, three-wire
2. residual and bypass relaying
3. zero-sequence
4. isolation transformer and relay

13. One of the most critical elements of a ground-fault protection system is ____.

1. the grounded conductor (neutral) must be isolated from ground downstream
2. a choke coil is installed downstream
3. capacitors are installed downstream
4. all the above

14. The equipment ground-fault protection system must be performance tested ____.

1. by pushing the "push to test" button
2. on an annual basis
3. within 30 days of installation
4. when first installed on site

15. Ground-fault protection for equipment is generally required for solidly grounded wye electrical systems of more than 150 volts to ground and less than 600 volts phase-to-phase ____.

1. for feeders of less than 800 amperes
2. at a building disconnecting means rated at 200 amperes or more
3. for feeders rated more than 1000 amperes
4. for a continuous industrial process

16. Considering the total number of faults that occur in power systems, ________________ by far outnumber short circuits.

1. bolted faults
2. motor induced faults
3. ground-faults
4. lighting induced faults

Chapter 15
Grounding and Bonding for Special Locations

Objectives to understand

- Bonding in hazardous (classified) locations
- Static electricity protection practices
- Health care facilities
- Agricultural buildings

This chapter looks at grounding and bonding requirements for special occupancies found in NEC Chapter 5. General information is also provided about grounding and bonding for static electricity protection that is beyond the scope of the NEC, but is directly related to similar safety concerns for both Hazardous (Classified) Locations and to some degree Health Care Facilities.

A review of some general requirements from NFPA 77-2014 *Recommended Practice on Static Electricity* is provided; however, it is not inclusive. Section 90.3 sets out the organization of the *NEC*. Generally, the requirements in Chapters 1 to 4 apply everywhere except where modified or expanded in Chapter 5, Special Occupancies; Chapter 6, Special Conditions; or Chapter 7, Special Systems. This chapter and the next two chapters will provide discussion on those modifications and expansions to the basic requirements relative to grounding and bonding.

Hazardous (Classified) Locations Grounding and Bonding

The *Code* has some special requirements for grounding and bonding in hazardous (classified) locations (see figure 15.1). The basic requirement for grounding and bonding in hazardous locations is found in 250.100 with the additional installation requirements found in 501.30 for Class I locations, 502.30 for Class II locations, and 503.30 for Class III locations.

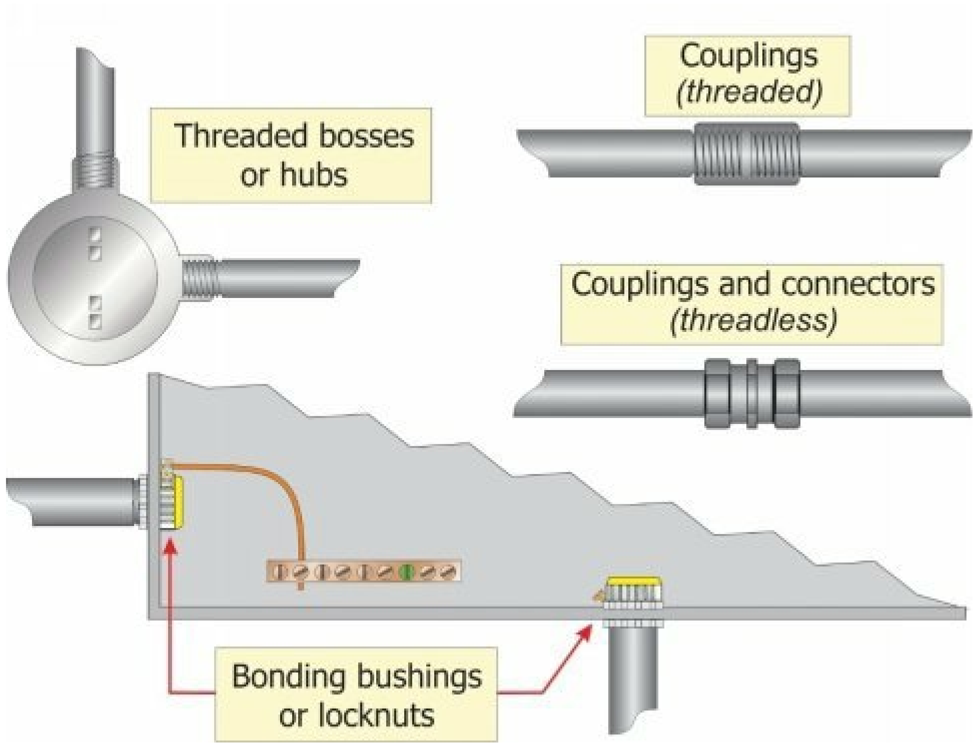


Figure 15.1 Bonding suitable for hazardous (classified) locations

For Class I, Zones 0, 1 and 2 hazardous (classified) locations, see 505.25 which requires compliance with the grounding and bonding rules in 505.25(A) and (B). For Class II Zones 20, 21 and 22 for combustible dusts or ignitable fibers/flyings, Section 506.25 requires compliance with specific grounding and bonding requirements.[1]

Grounding and bonding is essential for electrical safety in nonhazardous locations as well as in hazardous locations. In hazardous locations, it is additionally vital to have effective grounding and bonding to prevent an explosion. For example, under fault-current conditions when there are substantial ground fault currents through metal conduit, every connection point in the raceway system is a potential source of sparks and ignition. If there is an arcing fault to a metal enclosure in a hazardous (classified) location, the external surface temperature of the metal enclosure at the point of the arcing fault can rise to temperatures that could cause ignition of the flammable vapors or accumulations of combustible dust. Under these fault conditions it is essential that the overcurrent device operate as quickly as possible to prevent a hot spot on the enclosure or even arcs that can burn through the enclosure from igniting the atmosphere of flammable vapor, airborne dust, or fibers and flyings on the outside of the enclosure. It is extremely important that all threaded joints be made up wrenchtight to prevent sparking at those threaded joints. If joints are other than the threaded type, such as locknuts and bushings or double locknuts and bushings at boxes, enclosures, cabinets, and panelboards, it is essential that bonding be ensured around those joints in the fault-current path to prevent sparking and assure a low-impedance path for the fault current.

Bonding requirements are found in Part V of Article 250. Section 250.90 requires that "bonding shall be provided where necessary to ensure electrical continuity and the capacity to conduct safely any fault current likely to be imposed." Section 250.100 includes additional and more restrictive bonding requirements for hazardous locations and indicates that "regardless of the voltage of the electrical system, the electrical continuity of normally non-current-carrying metal parts of equipment, raceways, and other enclosures in any hazardous (classified) location as defined in 500.5, 505.5 and 506.5 shall be ensured by any of the bonding methods specified in 250.92(B)(2) through (B)(4). One or more of these bonding methods shall be used whether or not equipment grounding conductors of the wire-type are installed." [2]

By these special requirements, an effort is made to provide assured grounding and bonding to reduce the likelihood that a line-to-ground fault will cause arcing and sparking at connection points of metallic raceways and boxes or other enclosures. If such arcing or sparking were to occur in a hazardous (classified) location while a flammable gas, vapor, or dust is present in its explosive range, it is likely that the flammable atmosphere would be ignited.

Generally, these requirements provide that lock-nuts installed on each side of the enclosure, or a locknut on the outside and a standard bushing on the inside, cannot be used for bonding. Bonding locknuts or grounding bushings with bonding jumpers must be used to ensure the integrity of the bonding connection and its capability of carrying the fault current that can be imposed, hopefully, without arcing or sparking at the connections. A change in the 2014 *NEC* requires that where bonding lock nuts are not used, standard lock nuts are required on both sides of the enclosure to ensure mechanical continuity and then the use of a wedge or bonding bushing with bonding jumper is required for the electrical continuity.

The bonding means required in 501.30(A), 502.30(A), 503.30(A) are installed all the way from the hazardous (classified) location to the service equipment (see figure 15.2), or point of grounding of a separately derived system (see figure 15.3) that is the source of the circuit. "Such means of bonding shall apply to all intervening raceways, fittings, boxes, enclosures, and so forth between Class I locations and the point of grounding for service equipment or point of grounding of a separately derived system." [3]

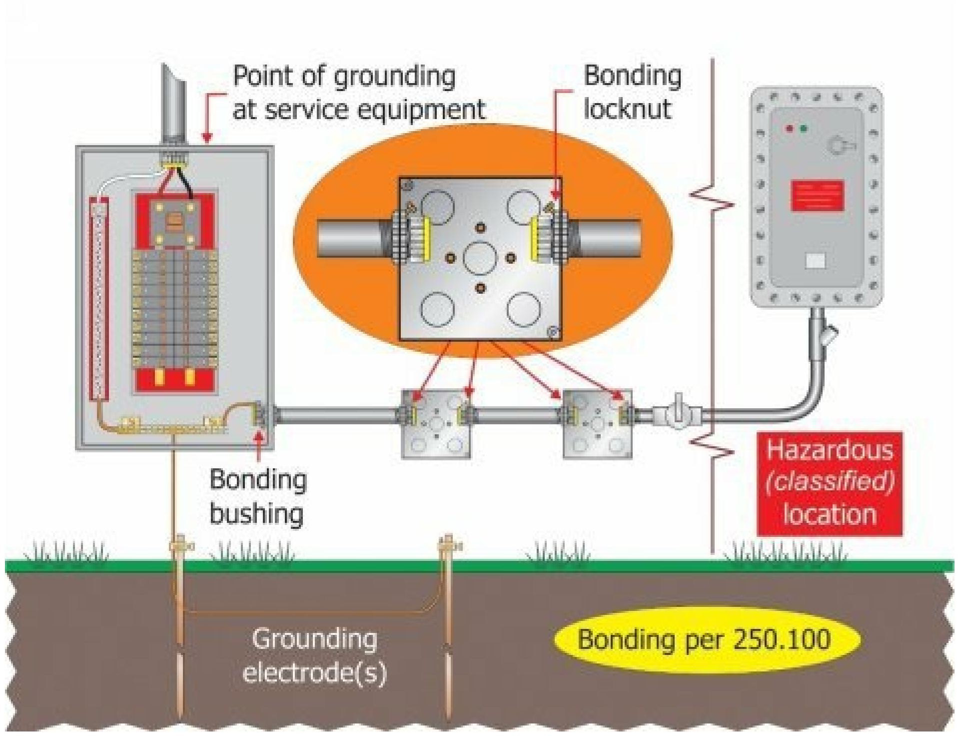


Figure 15.2 Bonding extended back to point of grounding at service equipment

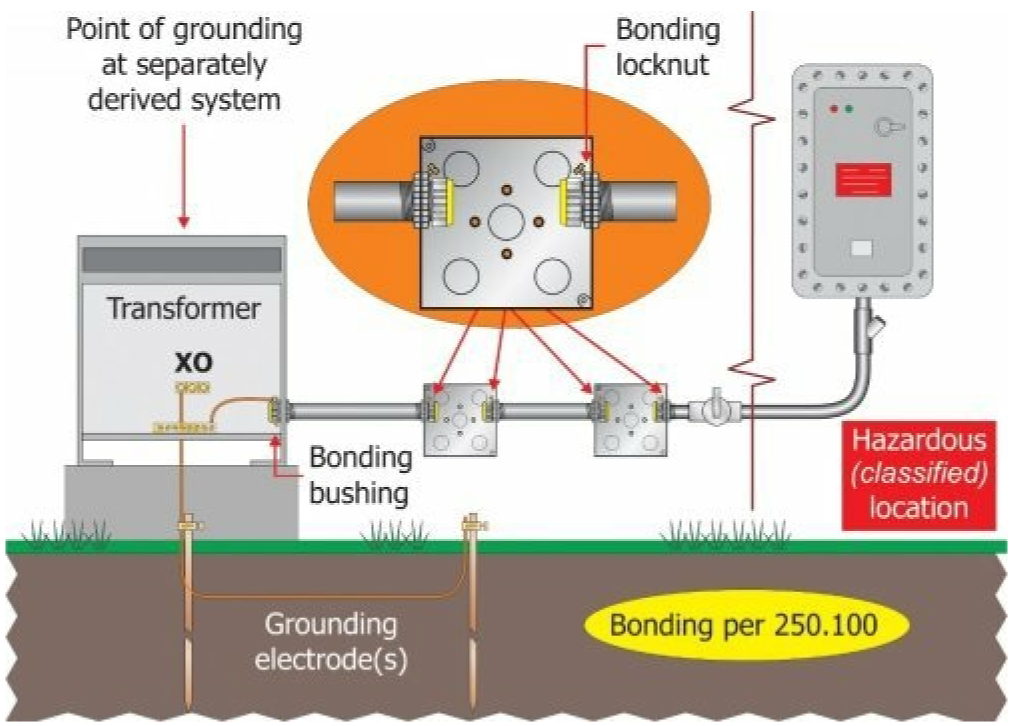


Figure 15.3 Bonding extended back to point of grounding at separately derived system

The goal is to ensure a substantial effective ground fault current path to facilitate fast operation of overcurrent protective devices supplying the circuit in the hazardous locations and for threaded fittings to provide a flame path for cooling escaping hot gasses that may exist in the enclosure or raceway.

Sections 501.30(B), 502.30(B), and 503.30(B) do not permit flexible metal conduit or liquidtight flexible metal conduit as the sole path for ground-fault current. Where equipment bonding jumpers are installed around these flexible conduits, they must meet the requirements in 250.102.

Hazardous atmospheres can also be ignited by hot temperatures on electrical enclosures. If a ground fault should occur inside an explosionproof enclosure, a hot spot at the point of fault on the enclosure could develop if the overcurrent device does not clear quickly. These more restrictive bonding rules are in *NEC* Chapter 5 for these reasons. Since ground-fault current returns to the source mainly on the installed ground-fault return path, this method of bonding must be accomplished for the circuit to the source where the system bonding jumper is installed or service grounding point, where the main bonding jumper is installed.

Section 250.32(B) provides grounding and bonding requirements where more than one building or structure are on the same premises and are supplied by feeder(s) or branch circuit(s). Where the grounded circuit conductor is not grounded at the building or structure, the exception to501.30(A), 502.30(A) and 503.30(A) requires that the additional bonding requirements extend from the hazardous location back to the service even if it is in another building. This then requires that the feeder raceway system be bonded if it is metallic [see chapter thirteen for additional information on grounding electrical systems at additional buildings or structures on the premises].

For buildings or structures supplied by feeder(s) or branch circuit(s), the exceptions to 501.30(A), 502,30(A), and 503.30(A) clarify that "the specific bonding means shall only be required to the nearest point where the grounded circuit conductor and the grounding electrode are connected together on the line side of the building or structure disconnecting means as specified in 250.32(B), provided the branch-circuit overcurrent protection is located on the load side of the disconnecting means" (see figure 15.4).

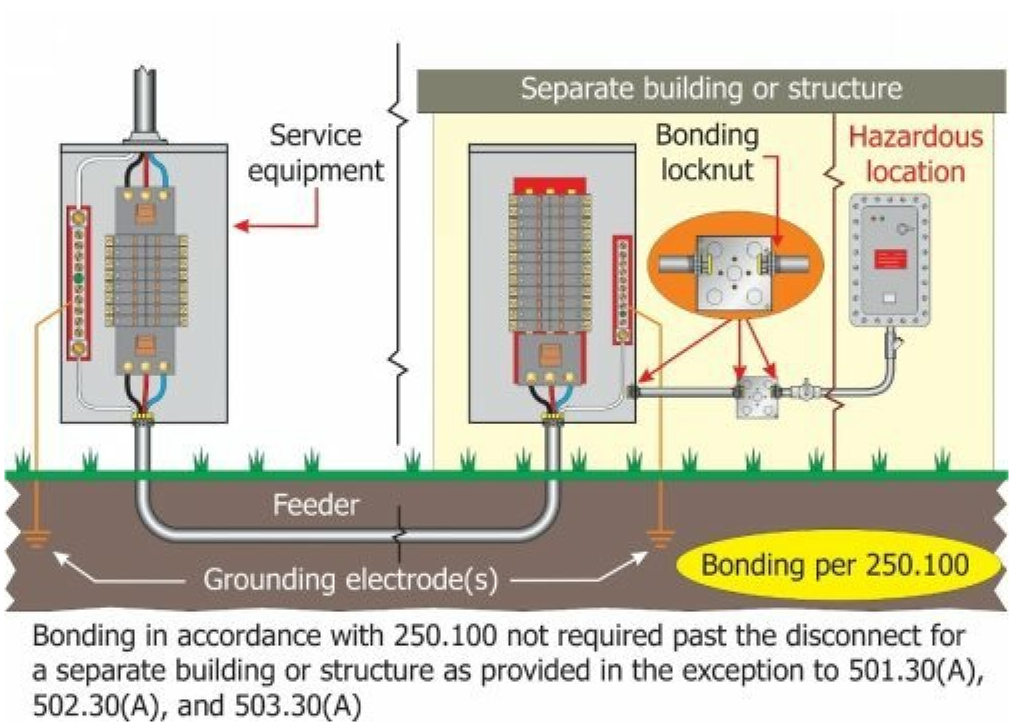


Figure 15.4 Bonding in hazardous (classified) locations is not required beyond the building disconnect at a separate building or structure supplied by a feeder(s) or branch circuit(s).

Flexible Conduits in Hazardous (Classified) Locations

Where flexible metal conduit or liquidtight flexible metal conduit is used as permitted in 501.10(B) and is to be relied on to complete a sole equipment grounding path, it shall be installed with internal or external bonding jumpers in parallel with each conduit and complying with 250.102. If installed outside the conduit, the bonding jumper is limited to 1.8 m (6 ft) in length per 250.102(E) [see 501.30(B) and Exception].

"Exception: In Class I, Division 2 locations, the bonding jumper shall be permitted to be deleted where all the following conditions are met:

"(1) Listed liquidtight flexible metal conduit 1.8 m (6 ft) or less in length, with fittings listed for grounding, is used.

"(2) Overcurrent protection in the circuit is limited to 10 amperes or less.

"(3) The load is not a power utilization load." [4]

[See 502.30(B) for similar rules for Class II areas and 503.30(B) for Class III locations].

Static Protection through Bonding and Grounding

Effective grounding and bonding are important components in the overall electrical safety scheme. As previously discussed, the benefits of properly grounded and bonded systems and conductive parts provide protection for persons and property. Protection against electrical shock and equalizing the potential to earth are accomplished by grounding conductive parts. Fast and sure operation of overcurrent protective devices if a fault occurs is ensured by creating an effective ground-fault current path back to the source, either the applicable service or source of separately derived system. The grounding and bonding requirements in the *Code* for electrical installations in hazardous locations provide protection from such events.

In hazardous locations, electrical wiring, including the grounding and bonding circuits are extremely important for safety. Because sources of ignition are a primary concern in explosive atmospheres, it is often necessary to also provide a more enhanced protection system of handling static electricity in hazardous locations.

Humidity

Protection from serious effects resulting from static electricity is a requirement of a number of industries and establishments. The grounding of equipment may or may not be the solution to static problems. Each static problem requires its own study and solution. Humidity plays an important part in the degree of concern. The higher the relative humidity is, the less the chances of a static discharge occurring. In some industries, increasing the humidity in the area where a static discharge can cause an undesirable event has been found very effective. One example is in the printing industry.

While humidification does increase the surface conductivity of the material, the charge will only dissipate if there is a conductive path. The surface resistivity of many materials can be controlled by the humidity of the surroundings. At a relative humidity of 65 percent and higher, the surface of most materials will adsorb enough moisture to ensure a surface conductivity that is sufficient to prevent accumulation of a static electricity charge. When the humidity falls below about 30 percent, these same materials could become good insulators, in which case accumulation of charge will increase. It should be emphasized that humidification is a not a solution for all static electricity problems encountered. Some insulating materials do not adsorb moisture from the air and high humidity will not noticeably decrease their surface resistivity. Examples of such insulating materials are uncontaminated surfaces of some polymeric materials, such as plastic piping, containers, and the surface of most petroleum liquids [NFPA 77 7.4.2.3].

Concerns of Static Electricity as Ignition Source

This and several following sections takes the reader beyond the requirements of the electrical *Code* and looks at means of protection from static electricity and the related sources of ignition. It should be clearly understood that the primary goal in providing static protection is to eliminate the ignition source of the fire triangle. Careful consideration and planning is necessary to evaluate all known possibilities of static ignition sources relative to providing this type of protection in hazardous locations. The degree of additional protection needed is specific to each condition encountered. There are no mandatory electrical *Code* requirements to provide such protection; however, the hazards do exist and must be considered for safety. Generally, the type of installation, type of explosive or flammable atmosphere (dust or gases), and the natural environment are all contributing factors to the degree or extent of static electricity as an ignition source. For a static electricity discharge to be a source of ignition, the following four conditions must exist simultaneously:

1. An effective means of separating the charge must be present.
2. A means of accumulating the separated charges and maintaining a difference of electrical potential must be available.
3. A discharge of the static electricity of adequate energy must occur.
4. The discharge must occur in an ignitable mixture [NFPA 77, 2014 – 5.5.1].

Sparks from ungrounded charged conductors, including the human body, are responsible for most fires and explosions ignited by static electricity. Sparks are typically intense capacitive discharges that occur in the gap between two charged conducting bodies, usually metal. The ability of a discharge spark to produce ignition or explosion is directly related to its energy. This will be some fraction of the total energy stored in the conductive object, which could be the human body.

Beyond the *NEC*

The *NEC* provides a reference through an informational note at 500.4(B) to the recommended practice on protection from static electricity. The referenced document is titled *Recommended Practice on Static Electricity*, NFPA 77-2014. Lightning protection systems are also important considerations and provide reasonable planned protection for those natural events in the weather that produce lightning.

There is an industry standard for these types of protection systems and it is titled *Standard for the Installation of Lightning Protection Systems* NFPA 780-2014. The American Petroleum Institute (API) also has produced a document that addresses protection techniques used to tackle these concerns and is titled *Protection Against Ignitions Arising Out of Static Lightning and Stray Currents* API RP 2003-2008 [*NEC* 500.4(B) Informational Note No. 3]. As previously discussed, the informational notes in the *NEC* are explanatory in nature and are not mandatory requirements of the *Code* based on the structure and style of the *NEC* [90.5(C)]. However, these references provide clear direction to resources that provide specific criteria and guidelines for this enhanced protection. It is important to emphasize that these methods of protection for static electricity and static ignition sources must overlay the requirements of the *Code* and are in addition to those requirements and are never intended to substitute for those requirements.

Definitions

Static electric discharge. " A release of static electricity in the form of a spark, corona discharge, brush discharge, bulking brush discharge, or propagating brush discharge that might be capable of causing ignition of a flammable atmosphere under appropriate circumstances." [NFPA 77 3.3.39].

Static electricity. "The branch of electrical science dealing with the effects of the accumulation of electric charge. " [NFPA 77 3.3.40].

Static Electricity Fundamentals

All matter (materials), whether liquid or solid, is made up of various arrangements of atoms. Atoms are made up of positively charged nuclear components that give them mass and are then surrounded by negatively charged electrons. Atoms are considered to be electrically neutral in their normal state. Basically, this means that there are equal amounts of positive and negative charges present. The atoms can become, what is referred to as, charged when there is an excess or deficiency of electrons relative to the neutral state (see figures 15.5 and 15.6).

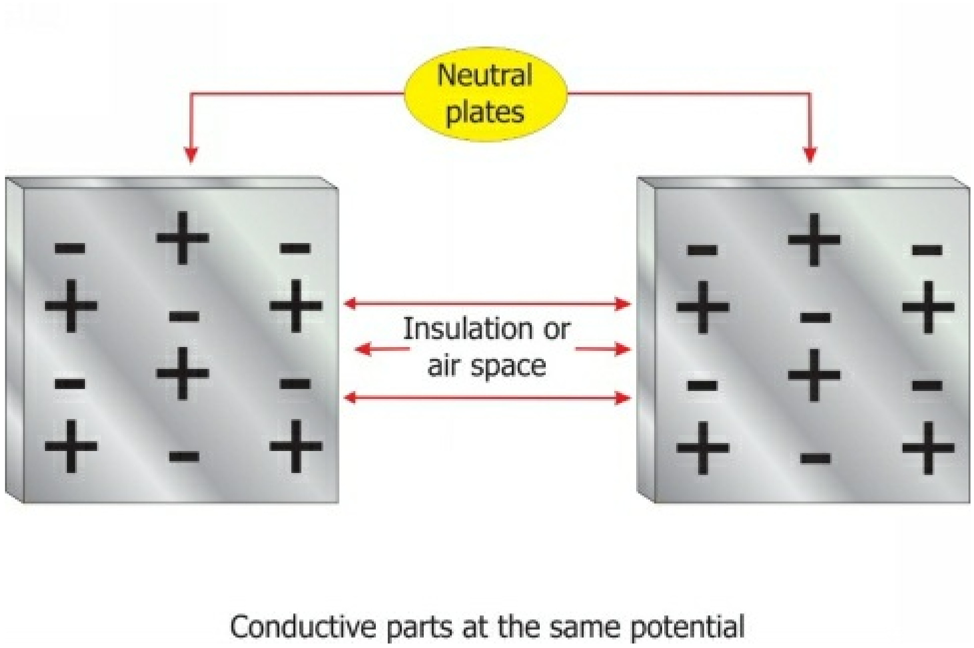


Figure 15.5 Two metal plates (conductors), each with like charges

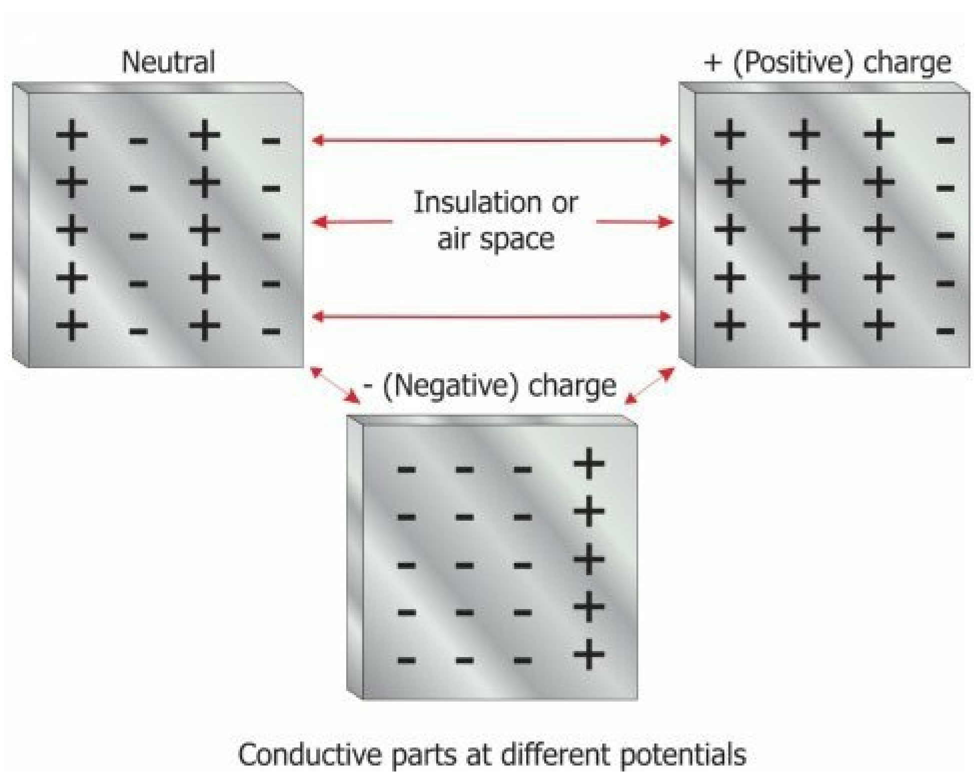


Figure 15.6 Two metal plates (conductors), with unlike charges

In electrically conductive materials, such as metals of the ferrous and nonferrous types, electrons move freely. In materials that are made up of insulating material — such as plastic, glass, motor oil, etc. — electrons are bonded more tightly to the nucleus of the atom and are not free to move. Some examples of electrically conductive materials are wire, metallic enclosures, busbars, etc., while insulating materials include such items as glass, and petroleum based products, paper, rubber, and so forth. For insulating materials in the form of fluids, an electron can separate from one atom and move freely or attach to another atom to form a negative ion. The atom losing the electron then becomes a positive ion. Ions are charged atoms and molecules.

Elimination or separation of the charge cannot be absolutely prevented, because the origin of the charge lies at the interface of materials. When materials are placed in contact, some electrons move from one material to the other until a balance (equilibrium condition) in energy is reached. This charge separation is most noticeable in liquids that are in contact with solid surfaces and in solids in contact with other solids. The flow of clean gasoline over a solid surface produces negligible charging [NFPA 77 - 5.2]. This is the primary reason for the gasoline dispensing hazard warnings at motor fuel dispensers. It is important to observe and adhere to all warnings and directions relative to the transfer of gasoline to a motor vehicle or portable container. Always place portable gasoline containers on the ground when filling them; otherwise, the flow of the liquid through the hose will allow static charges to build without a path to dissipate. The possibilities of ignition or explosion of gasoline vapors during these types of operations is increased if all appropriate safety procedures are not followed. Elimination of differences of potential (voltage or charge difference) between objects reduces these hazards.

Static Discharge and Separation

A capacitor is described basically as two conductors that are separated by an insulating material. In the static electric phenomena, the charge is generally separated by a resistive barrier, such as an air gap or some form of insulation between the conductors, or by the insulating property of the materials being handled or processed. In many applications, particularly those where the materials being processed are nonconductive (charged insulators), measuring their potential differences is challenging to say the least.

One is probably most familiar with the common static charge built up by walking or scuffing the feet on carpet fibers. People are conductors of electricity and therefore are capable of building up and “holding” a static charge. The release of such static charges is also a familiar experience for most individuals. Children often are amused and entertained when this phenomenon is first realized. The electrical static charging results from rubbing materials together and is known as triboelectric charging. It is the result of exposing surface electrons to a broad variety of energies in an adjacent material, so that charge separation (discharge) is likely to take place. The breakup of liquids by splashing and misting or even flow, in some instances, results in a similar charge release. It is only necessary to transfer about one electron for each 500,000 atoms to produce a condition that can lead to a static electric discharge. Surface contaminants at very low concentrations can play a significant role in charge separation at the interface of materials.

Electrically conductive materials can become charged when they are in the vicinity of another highly charged surface. The electrons in the conductive material are either drawn toward or forced away from the region of closest approach to the charged surface, depending on the nature of the charge on that surface. Like charges will repel and unlike charges will attract. If the electrically conductive material that is charged is connected to ground or bonded to another object, additional electrons can pass to or from ground or the object. If contact is then broken and the conductive material and charged surface are separated, the charge on the isolated conductive object changes. The net charge that is transferred is called induced charge.

The basic goal when dealing with concerns of static electricity and stray voltages is to try to eliminate or at least minimize any differences of potential between electrically conductive objects and other objects and the ground. The potential difference, that is, the voltage, between any two points is the work-per-unit charge that would have to be done to move the charges from one point to the other. Work must be accomplished to sep-arate charges, and there is a tendency for the charges to return to a neutral (uncharged) condition. The separation of electric charge might not, in itself, be a potential fire or explosion hazard depending on the amount of energy involved when a discharge happens. There must be a significant discharge or sudden recombination of the separated charges to create arcing to then pose an ignition hazard. One of the best methods of providing protection from static electric discharge is constructing an electrically conductive or semiconductive path that will allow the continued and controlled recombination of the charges and dissipation of charges (usually to earth). The two terms used most often when providing protection from static electricity and lightning are *grounding* or one of its derivatives, and *bonding* or one of its derivatives. Derivatives of these terms are as in the following examples:

Grounding – Ground or Grounded

Bonding – Bond or Bonded

Definitions from NFPA 70 and NFPA 77

Grounded (Grounding) "Connected (connecting) to ground or to a conductive body that extends the ground connection" [NFPA 70 Article 100].

Bonded (Bonding). "Connected to establish electrical continuity and conductivity" [NFPA 70 Article 100].

Grounding. "The process of bonding one or more conductive objects to the ground, so that all objects are at zero (0) electrical potential; also referred to as 'earthing' " [NFPA 77 - 3.3.22]. *Keep in mind that "earthing" is not currently a defined term.*

Bonding. "For the purpose of controlling static electric hazards, the process of connecting two or more conductive objects together by means of a conductor so that they are the same electrical potential, but not necessary at the same potential as the earth" [NFPA 77 - 3.3.2].

So for all practical purposes, when the term *grounding* is used in the above context, it should be thought of as including a connection or path to the earth to put electrically conductive materials at the same potential as the earth. When the term *bonding* is used, it should be thought of as connecting electrically conductive materials together to mitigate or ultimately eliminate differences of potential between them and form one conductive mass. Note that bonding generally includes a path to the earth, but the earth is not referred to in the definitions. Figures 15.7, 15.8, 15.9 and 15.10 graphically demonstrate the differences between the two concepts and also show the two working together to provide desired protection. It can be concluded, then, that bonding conductive parts together minimizes the potential differences between them, even when the resulting system is not grounded. Grounding (earthing), on the other hand, equalizes the potential differences between the objects and the earth. The relationship between bonding and grounding is shown in figures 15.7 through 15.10.

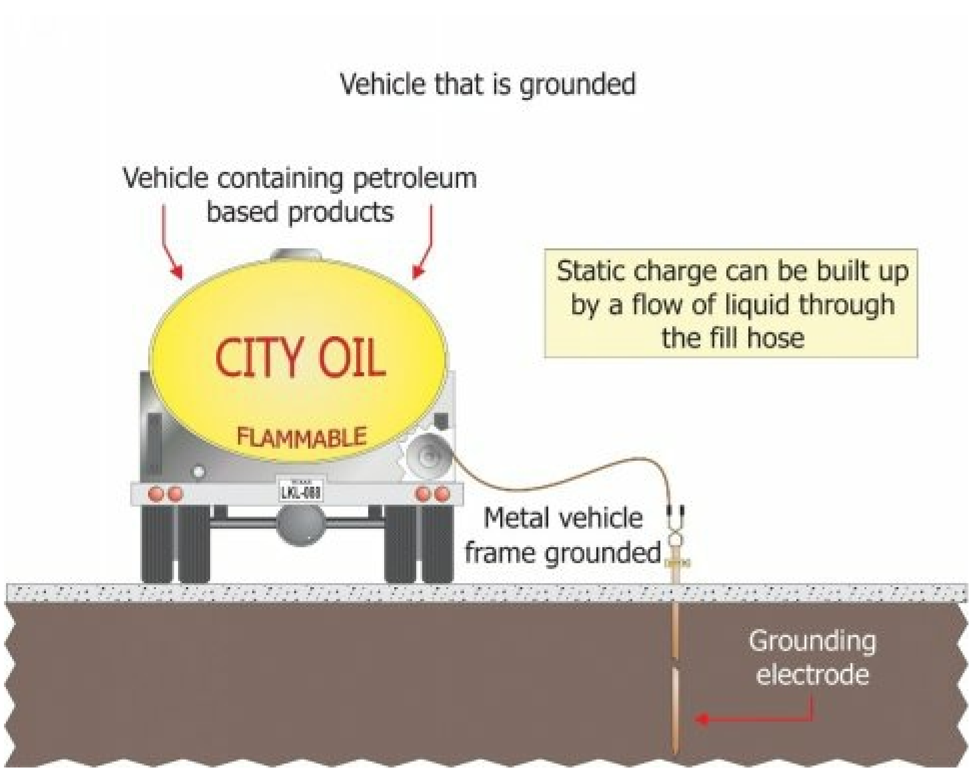


Figure 15.7 A vehicle connected to the earth (grounded)

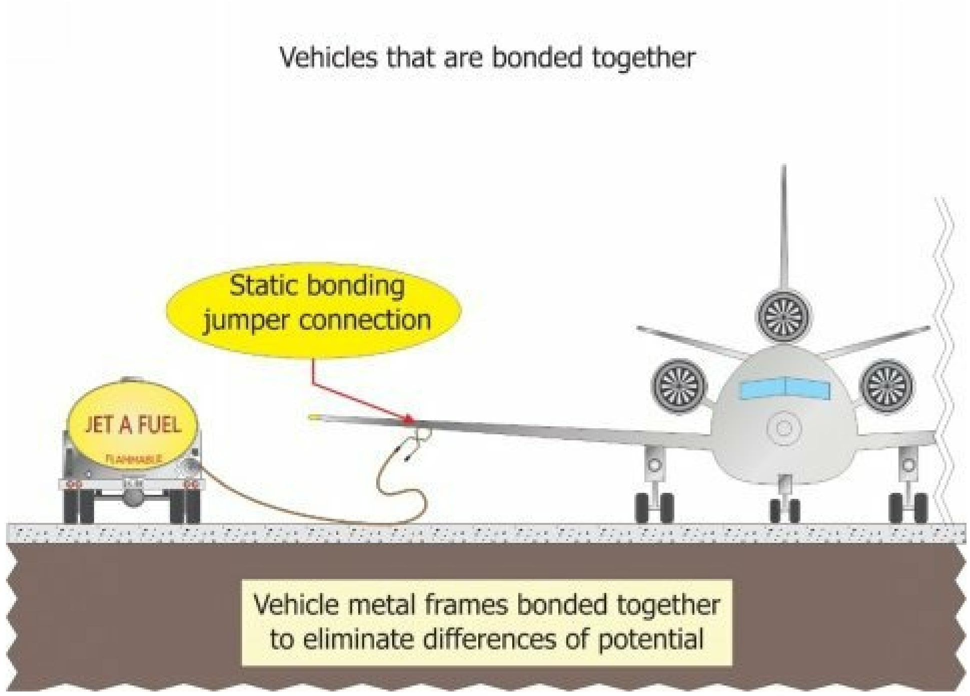


Figure 15.8 Two vehicles connected together (bonded)

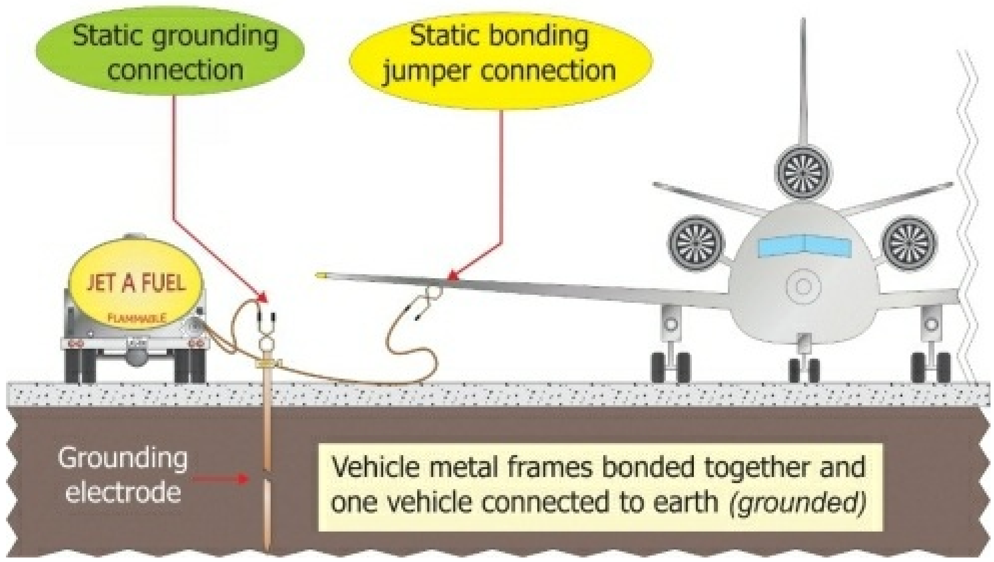


Figure 15.9 Two vehicles connected together (bonded), and one vehicle also connected to the earth

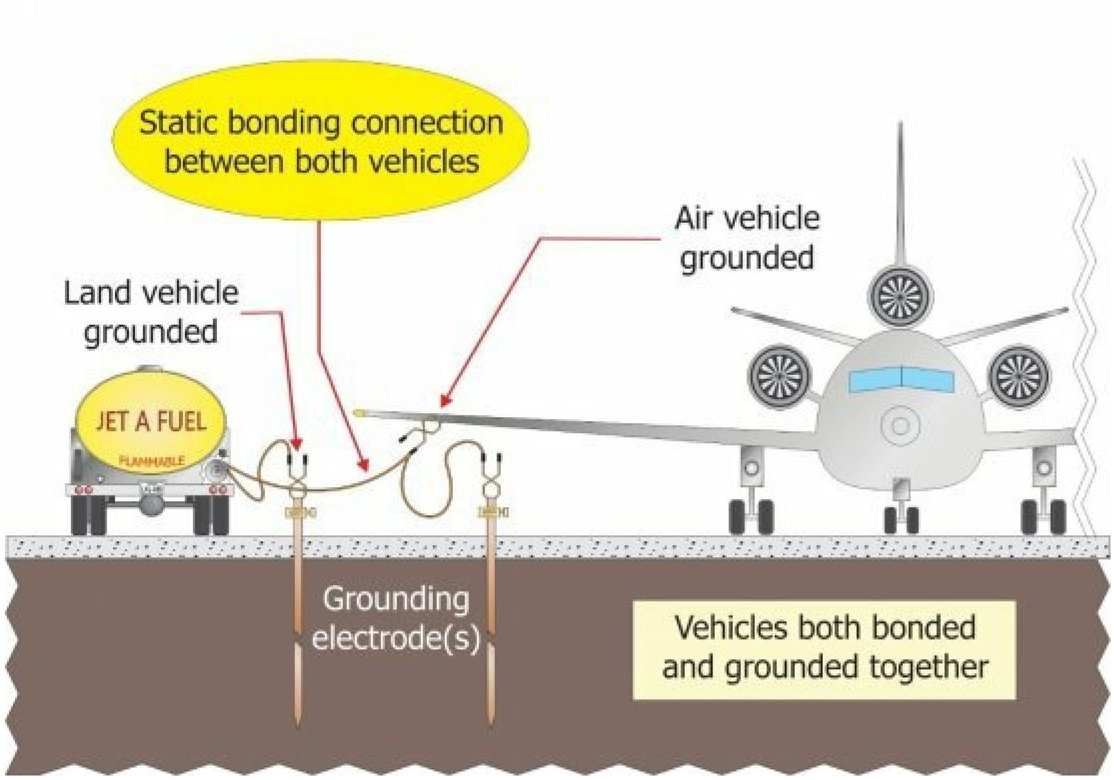


Figure 15.10 Two vehicles connected together (bonded), and also each vehicle is connected to the earth separately (grounded)

Controlling Static Electricity Ignition Hazards

Ignition hazards from static electricity can be controlled by the following methods:

- Removing the ignitable mixture from the area where static electricity could cause an ignition-capable discharge.
- Reducing charge generation, charge accumulation, or both by means of process or product modifications.
- Neutralizing the charges.

Grounding isolated conductors and air ionization are primary methods of neutralizing charges.

Resistance in the Path to Ground

To prevent the accumulation of static electricity in conductive equipment, the total resistance of the ground path to earth should be sufficient to dissipate charges that are otherwise likely to be present. A resistance of 1 megohm (10^6 ohms) or less is generally considered adequate. This is very different from the low-impedance path for ground-fault current discussed in Chapters 3, 9, 11 and 14. Where the bonding/grounding system is all metal, resistance in continuous ground paths will typically be well less than 10 ohms. Such systems include multiple component systems. Greater resistance usually indicates the metal path is not continuous, usually because of loose connections or the effects of corrosion. A grounding system that is acceptable for power circuits or for lightning protection is more than adequate for a static electricity grounding system.

Where wire conductors are used, the minimum size of the bonding or grounding wire is dictated by mechanical strength, not by its current-carrying capacity. Stranded or braided wires should be used for bonding wires that will be connected and disconnected frequently to provide suitable flexibility of the conductors [NFPA 77 7.4.1.4]. Equipment grounding conductors or grounding electrode conductors can be insulated (e.g., a jacketed or plastic-coated cable) or uninsulated (i.e., bare conductors). Uninsulated conductors are recommended, because it is easier to visually detect defects in them.

Where static problems are present, workers should be grounded through a total resistance that limits the current to ground to less than 3 mA for the full range of voltages experienced in the area. This method is called soft grounding and is used to prevent injury from an electric shock from line voltages or stray currents.

Liquids Flowing through Pipes

Charge separation occurs when liquids flow through pipes, hoses, and filters, when splashing occurs during transfer operations, or when liquids are stirred or agitated. The greater the area of the interface is between the liquid and surfaces and the higher the flow velocity, the greater the rate of charging. The charges become mixed with the liquid and are carried to receiving vessels where they can accumulate. The charge is often characterized by its bulk charge density and its flow as a streaming current to the vessel.

In the petroleum industry, for tank loading and distribution operations involving petroleum middle distillates, liquids in the semiconductive category are handled as conductive liquids. Such procedures are possible because regulations prohibit use of non-conductive plastic hoses and tanks and multiphase mixtures and end-of-line polishing filters are not involved.

Metallic Piping Systems

All parts of continuous metal piping systems should have a resistance to ground that does not exceed 10 ohms. Higher resistance could indicate poor electrical contact or connection, although this will depend on the overall system. For flanged couplings, neither paint on the flange faces nor thin plastic coatings used on nuts and bolts will normally prevent suitable bonding for static control across the coupling after proper tightening torque has been applied. Jumper cables and star washers are not usually needed at flanges. Star washers could even interfere with proper tightening. Electrical continuity of the bonding and grounding path should be confirmed after system is completely assembled and periodically thereafter.

Additional bonding wires (jumpers) might be needed around flexible, swivel, or sliding joints. Tests and experience have shown that resistance in these joints is normally below the 10-ohm value, which is low enough to prevent accumulation of any static charges.

Grounding Storage Tanks for Nonconductive Liquids

Storage tanks for nonconductive liquids should be grounded properly. Storage tanks on foundations constructed on the earth are considered inherently grounded, regardless of the type of foundation (e.g., concrete, sand, or asphalt) [NFPA 77 12.1.7.1]. For tanks on elevated foundations or supports, the resistance to ground could be as high as 10^6 ohms and still be considered adequately grounded for purposes of dissipation of static electric charges, but the resistance should be verified in these cases for assurances that an adequate path to ground is achieved. The addition of grounding rods and similar grounding systems will not reduce the hazard associated with static electric charges apparent in the liquid [NFPA 77 12.1.7.2].

Basic Static Concerns with Combustible Dust

A combustible dust is defined as any finely divided solid material 500 microns or smaller in diameter (i.e., material that will pass through a U.S. No. 35 standard sieve) that can present a fire or deflagration hazard. For a static electric discharge to ignite a combustible dust, the following four conditions need to be met:

- An effective means of separating charge must be present.
- A means of accumulating the separated charges and maintaining a difference of electrical potential must be available.
- A discharge of the static electricity of adequate energy must be possible.
- The discharge must occur in an ignitable mixture of the dust.

A sufficient amount of dust suspended in air needs to be present in order for an ignition to achieve sustained combustion. This minimum amount is called the minimum explosive concentration (MEC). It is the smallest concentration, expressed in mass per unit volume, for a given particle size that will support a deflagration when uniformly suspended in air.

For historical reasons, the ability of a solid to transmit electric charges is characterized by its volume resistivity. For liquids, this ability is characterized by its conductivity.

Powders are divided into the following three groups:

1. Low-resistivity powders having volume resistivities in bulk of up to 10^8 ohm. Examples include metals, coal dust, and carbon black.
2. Medium-resistivity powders having volume resistivities between 10^8 and 10^{10} ohm-m. Examples include many organic powders and agricultural products.
3. High-resistivity powders having volume resistivity's above 10^{10} ohm-m. Examples include organic powders, synthetic polymers, and quartz [NFPA 77 15.4.3].

Low-resistivity powders can become charged during flow. The charge rapidly dissipates when the powder is conveyed into a grounded container. However, if conveyed into a nonconductive container, the accumulated charge can result in an incendive spark.

Lightning Protection Systems

Lightning protection is an important factor at outdoor substations and at locations where thunderstorms are prevalent. Lightning discharges usually consist of very large currents of extremely short duration. Protection is accomplished by deliberately providing a path of low resistance to earth, compared to other paths. As with other electrical circuits, lightning will travel on all paths available, but by providing the low-impedance path, the goal is for most of the energy in the discharge to go on this low-impedance path. There is no guarantee that lightning will necessarily follow the lower resistance path that has been provided, but at least the low-resistance path will reduce the likelihood of damage.

"The lightning protection system ground terminals shall be bonded to the building or structure grounding electrode system" [5] (see figure 15.11). This section (250.106) no longer requires that metallic parts of electrical wiring system be bonded to the lightning protection system conductors where there is less than 1.8 m (6 ft) of separation. However, the accompanying informational note references specific requirements for bonding the systems together that are found in NFPA 780, *Standard for the Lightning Protection Systems*.

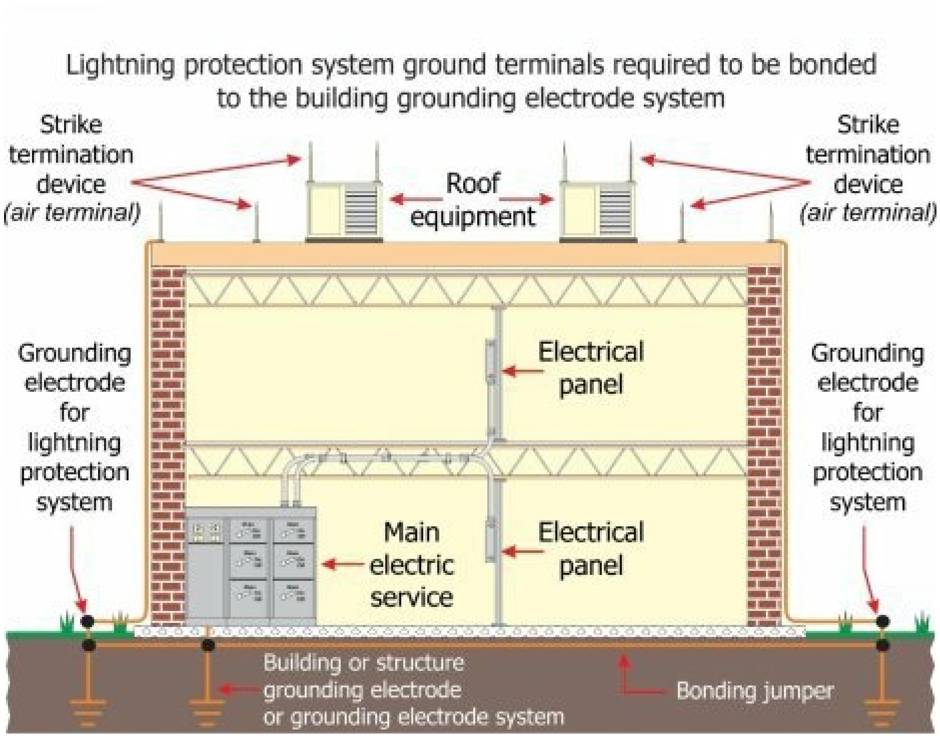


Figure 15.11 Ground terminals of lightning protection systems and grounding electrodes of power systems to be bonded together [NEC 250.106]

Chapter twenty-one provides basic information about lightning protection systems for pre-existing buildings and structures.

Health Care Facilities

Electrical systems in health care facilities are required to comply with at least two safety standards, the *National Electrical Code* NFPA 70 and NFPA 99-2015, *Standard for Health Care Facilities*. These standards provide the minimum requirements for installation as well as maintenance and testing of electrical systems in health care facilities.

Depending on the type of health care facility involved and the scope of the project, several other electrical codes and standards may be involved. These include, but are not limited to NFPA 20-2016, *Standard for the Installation of Stationary Pumps for Fire Protection*, NFPA 72-2016, *National Fire Alarm Code*, NFPA 110-2016, *Standard for Emergency and Standby Power Systems*, and NFPA 780-2017, Standard *for the Installation of Lightning Protection Systems.*

Article 517 provides special requirements for grounding of equipment in certain health care facilities, particularly in patient care spaces. Reasons for the extra or specialized requirements are given in the informational note following 517.11.[5]

In a health care facility, it is difficult to prevent the occurrence of a conductive or capacitive path to or from the patient's body to some grounded object, because that path can be established accidentally or through instrumentation directly connected to the patient. Other electrically conductive surfaces that can make an additional contact with the patient, or instruments that can be connected to the patient, then become possible sources of currents that can traverse the patient's body. The hazard is increased as more apparatus is associated with the patient, and, therefore, more extensive precautions are needed. Control of electric shock hazards requires the limitation of electric current that can exist in an electric circuit that involves the patient's body. The two basic principles that can be applied are to reduce the amount of current by insulation or reduce the potential difference by bonding. This is accomplished by either raising the resistance of the conductive circuit that includes the patient, or by insulating exposed surfaces that might become energized. Alternatively, reducing the potential difference that can appear between exposed conductive surfaces in the patient vicinity. Lastly, by combinations of these methods. A special problem is presented by the patient with an externalized direct conductive path to the heart muscle. The patient can be electrocuted at current levels so low that additional protection in the design of appliances, insulation of the catheter, and control of medical practice is required.[6]

Grounding in Patient Care Spaces

Section 517.13(A) requires that "all branch circuits serving patient care spaces shall be provided with an effective ground-fault current path by installation in a metal raceway system, or cable having metallic armor or sheath assembly. The metal raceway system, or metallic cable armor, or sheath assembly shall itself qualify as an equipment grounding conductor in accordance with 250.118" (see figure 15.12). Type AC, Type MC, and Type MI cables shall have an outer metal armor or sheath that is identified as an acceptable grounding return path.

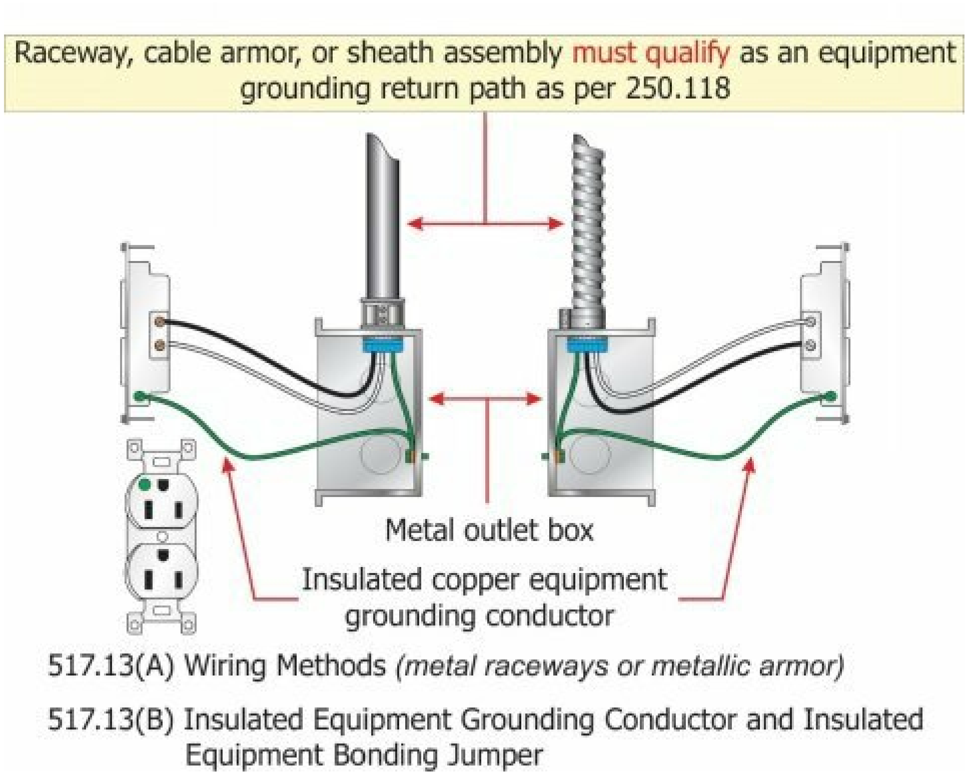


Figure 15.12 Grounding of receptacles and fixed equipment in patient care spaces

In addition to the metallic raceway, 517.13(B) requires an insulated copper equipment grounding conductor or insulated equipment bonding jumper to be installed with the branch circuit conductors. The equipment grounding conductor or equipment bonding jumper must be identified by a green color along its entire length.

In addition, section 517.13(B)(1) requires that in an space used for patient care, the metallic wiring method and enclosed equipment grounding conductor must be connected to:

(1) "the grounding terminals of all receptacles other than isolated grounding receptacles"

(2) "Metal outlet boxes, metal device boxes, or metal enclosures"

(3) "all non-current-carrying conductive surfaces of fixed electric equipment likely to become energized that are subject to personal contact, operating at over 100 volts."

Exception No. 1 provides that "For other than isolated ground receptacles, an insulated equipment bonding jumper that directly connects to the equipment grounding conductor is permitted to connect the box and receptacle(s) to the equipment grounding conductor. Isolated ground receptacles shall be connected in accordance with 517.16."

Exception No. 2 provides that "metal faceplates shall be permitted to be connected to the equipment grounding conductor by means of a metal mounting screw(s) securing the faceplate to a grounded outlet box or grounded wiring device." [7]

Exception No. 3 provides that "luminaires more than 2.3 m (7½ ft) above the floor and switches located outside of the patient care vicinity shall be permitted to be connected to an equipment grounding return path complying with 517.13(A)"[8] (see figure 15.13).

Section 517.13(B)(2) states, "Equipment grounding conductors and equipment bonding jumpers shall be sized in accordance with Table 250.122" and installed in metal raceways or [metal-clad cables] with the branch-circuit conductors supplying these receptacles or fixed equipment.

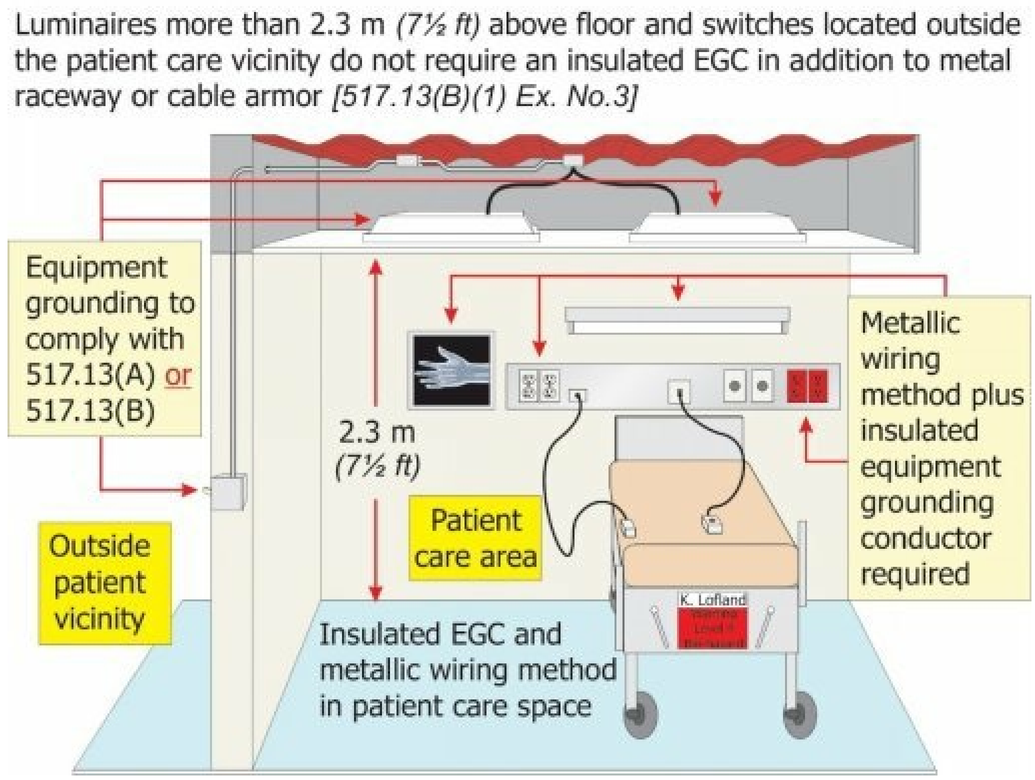


Figure 15.13 Grounding of receptacles and fixed electric equipment exception

These luminaires do have to be grounded by the wiring method used to supply the luminaires. Switches that are located either inside or outside the patient room but outside the patient vicinity are also not required to be grounded by the additional insulated equipment grounding conductor, but must still be grounded as required in 404.9.

The term *patient care vicinity* is defined in 517.2 as "a space within a location intended for the examination and treatment of patients extending 1.8 m (6 ft) beyond the normal location of the patient bed, chair, table treadmill, or other device that supports the patient during examination and treatment and extends vertically to 2.3 m (7 ft 6 in) above the floor."

Both the qualified metal raceway or cable armor and an additional wire type, or redundant, means of equipment grounding are required in patient care spaces of health care facilities [see 517.13]. The term "redundant" is commonly used but is not the language used in the *NEC* and this can cause some confusion. Both the metal raceway and wire type equipment grounding conductors are considered equal and both are required. The metal raceway or outer metal jacket of a listed cable that is suitable for equipment grounding provides the first means of equipment grounding. An insulated copper equipment grounding conductor (the additional wire type equipment grounding means) is required to also be installed or be a part of listed cable for grounding of receptacles and non-current-carrying metal portions of fixed electric equipment in the patient care spaces that are subject to personal contact. The basic concept or idea is that the *Code* requires two equipment grounding paths to be installed for electrical equipment in patient care spaces so it is assured that at least one positive return path for fault current is always present if either one or the other should fail.. The concept of this redundancy should be looked at from the standpoint that one is required to install two suitable equipment grounding return paths, to always be assured to have at least one provide the required effective equipment grounding path.

The *Code* is specific in requiring two separate and specific types of equipment grounding return paths in accordance with 250.118, one being the raceway or metallic cable armor enclosing the circuit conductors, and the other, an insulated copper equipment grounding conductor. Installing two wire type insulated copper equipment grounding conductors in a raceway that does not qualify as an equipment grounding conductor itself, such as PVC conduit, does not meet the letter or intent of the *NEC* for branch-circuit grounding requirements in patient care locations. (see figure 15.14).

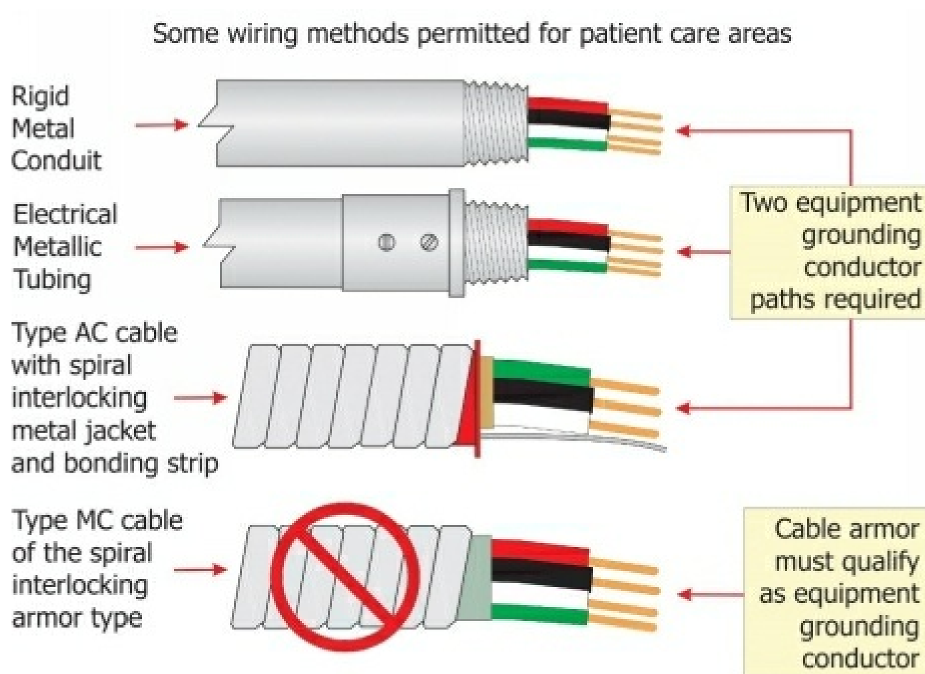


Figure 15.14 Wiring methods permitted for patient care spaces

Of course, where these wiring methods are installed, it is critical that good work practices be followed to ensure that the wiring method provides a reliable, continuous and low-impedance path for fault current. Workmanship is important.

Section 517.13(A) places additional restrictions on the use of cable wiring methods that are used for wiring in patient care spaces. Types AC, MC and MI cables are required in 517.13(A) to have an outer armor that itself qualifies “as an equipment grounding conductor in accordance with 250.118” (see figure 15.15). These requirements do not permit the combination of the cable outer jacket and one or more internal equipment grounding conductor to serve as providing the path for fault current required by this section.

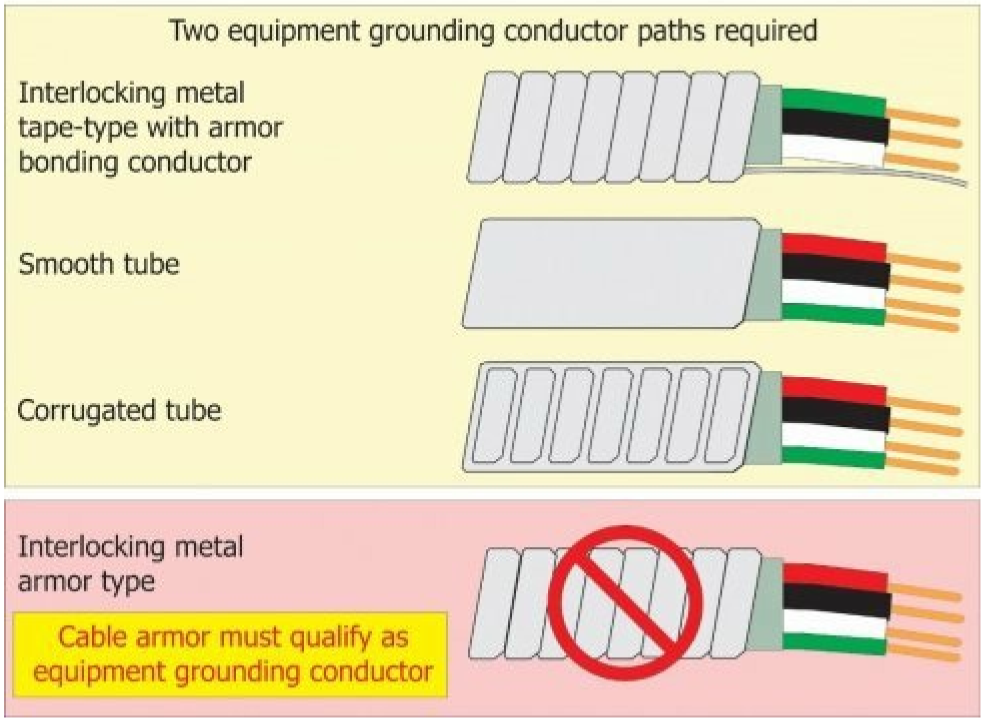


Figure 15.15 MC cable must provide two equipment grounding conductor paths where used for branch circuits in patient care spaces

By its construction and listing by a qualified electrical testing laboratory, Type AC cable with a spiral interlocking metal jacket and a bonding strip or wire in intimate contact with the outer jacket is suitable as an equipment grounding conductor (see figure 15.16). Type AC cable with this outer cable armor assembly plus the internal insulated equipment grounding conductor constitutes two ground return paths and qualifies the cable for use in wiring in patient care spaces.

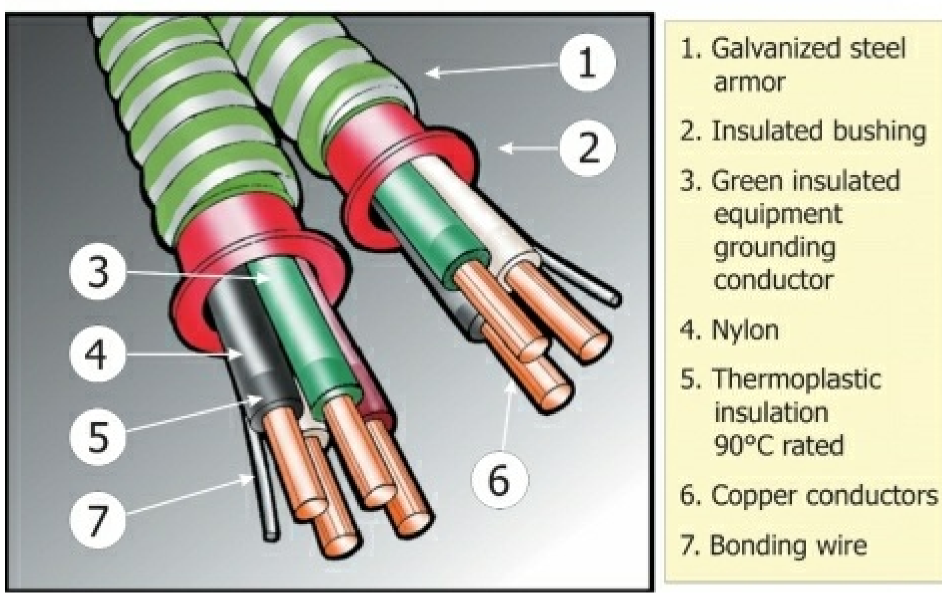


Figure 15.16 AC cable with insulated equipment grounding conductor meets the requirements of 517.13

Copper, Type MI cable, by nature of its construction, has an outer jacket that is suitable as an equipment grounding conductor. This cable is manufactured with bare conductors that are physically separated from each other by the mineral compound inside the metal sheath. The individual conductors are insulated by slip-on insulation at the time the cable is terminated.

Generally, the outer jacket of standard Type MC cable of the spiral-interlocking armor type. Smooth type or corrugated type is not suitable as an equipment grounding conductor and cannot be used in a patient care space of a health care facility that must comply with 517.13. Type MC cable with a smooth or corrugated continuous tube is suitable for these patient care spaces if it is identified and contains a green-insulated equipment grounding conductor with or without yellow stripes or surface marking or both A supplemental bare equipment grounding conductor in Type MC cable of the smooth or corrugated continuous type is an indication that the outer armor by itself does not qualify as an equipment ground. There is one type of MC cable of the interlocking metal tape-type construction that incorporates a metallic armor and bare bonding conductor combination that does qualify as an equipment grounding conductor. This type of MC cable along with the insulated green equipment grounding conductor inside is readily identified as providing the two required ground-fault current paths required by 517.13 (see photo 15.1). In figure 15.16 and photo 15.1 it is noted the outer armor is colored solid green or green stripes. This is a manufacturer's marking for ready identification of AC or MC cable for health care facilities but this marking is not a requirement from the *NEC* or the product safety standards.

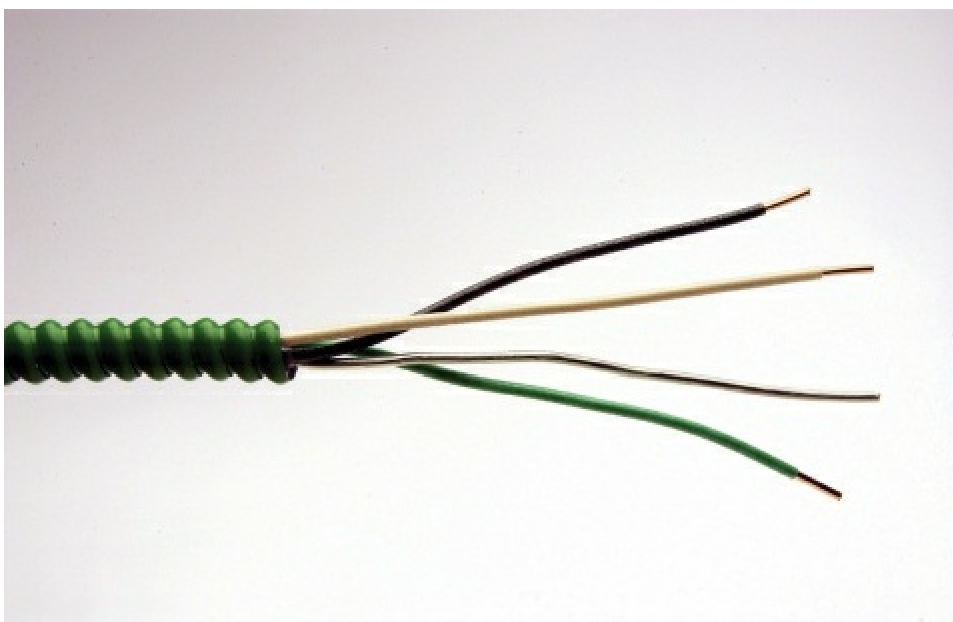


Photo 15.1 HCF MC AP Cable providing two grounding paths   Courtesy of Southwire Company

While recognized in 250.118 as equipment grounding conductors, severe restrictions are placed on the use of flexible metal conduit and liquidtight flexible metal conduit due to their limited capabilities of carrying current and functioning as a ground-fault return path. These include the limitation on length in the complete fault return path, overcurrent protection, use of listed fittings, and not being used where flexibility is required in use.

Additional restrictions are placed on the wiring of the emergency system in hospitals. While these requirements relate to mechanical protection of the circuits and not directly to grounding, the installer should be aware of these rules. [See 517.30(B)(2) for designation of these branches, 517.2 for definitions, and 517.31(C)(3) for wiring requirements.] For flexible metal raceways and armored cable, the following additional limitations apply in addition to those in the applicable raceway article and in 250.118. Section 517.31(C)(3) set the following limitations.

> "Listed flexible metal raceways and listed metal sheathed cable assemblies in any of the following:
>
> a. Where used in listed prefabricated medical headwalls
>
> b. In listed office furnishings
>
> c. Where fished into existing walls or ceilings, not otherwise accessible and not subject to physical damage
>
> d. Where necessary for flexible connection to equipment."
>
> e. For equipment that requires a flexible connection due to movement, vibration, or operation
>
> f. Luminaires installed in rigid ceiling structures where there is no access above the ceiling space after the luminaire is installed

Testing of Grounding System in Patient Care Spaces

NFPA 99, *The Standard for Health Care Facilities*, requires that the integrity of the equipment grounding path provided by the wiring method in patient care spaces of health care facilities be tested before acceptance of the initial installation and after any alterations or replacement of the electrical system is made [see NFPA 99: 6.3.1.1.1 and 6.3.1.1.4 and figure 15.17]. Both voltage and impedance measurements must be made of exposed conductive surfaces and include the grounding contacts of receptacles in the patient-care vicinity.

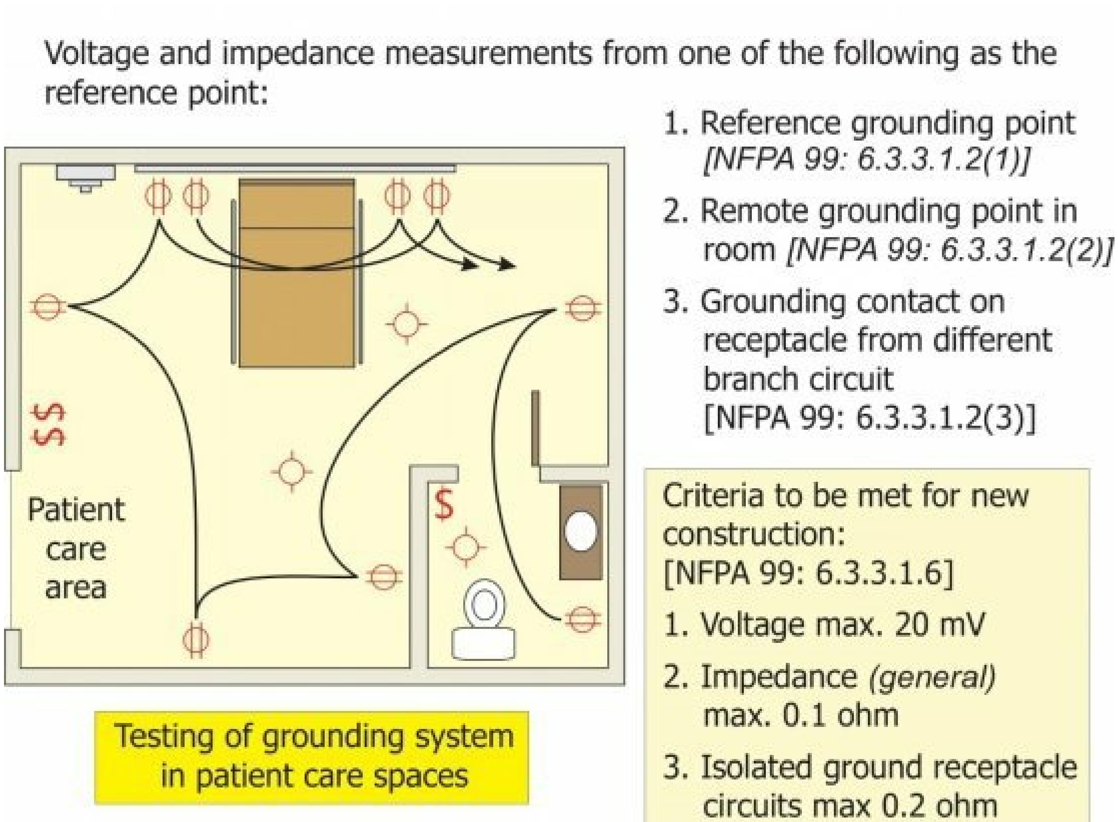


Figure 15.17 Testing of grounding system in patient care spaces

Excluded from the testing requirements are small, wall-mounted conductive surfaces not likely to become energized, such as surface-mounted towel and soap dispensers, mirrors and the like. [NFPA 99: 6.3.3.1.1.2]

Also exempt are large, metal conductive surfaces not likely to become energized, such as window frames, door frames, and drains [NFPA 99: 6.3.3.1.1.3]. The testing should include all the grounding system, including both metallic raceway and equipment grounding conductor, as an integral system. Removing equipment grounds from receptacles or equipment is not required or recommended to complete the required testing.

The voltage and impedance measurements must be measured against a reference point. The reference point is permitted to be one of the following: (1) a reference grounding point; (2) a grounding point in the room under test that is electrically remote from the equipment under test, such as a metal water pipe; and (3) the grounding contact of a receptacle that is powered from a different branch circuit from the receptacle being tested.

The criteria for new construction that must be met are as follows: (1) the voltage limit is 20 mV; (2) the impedance limit shall be 0.2 ohm for systems containing isolated ground receptacles and 0.1 ohm for all others. [NFPA 99: 6.3.3.1.6].

Changes in the 2014 *NEC* prohibited the use of isolated ground receptacles in all patient care vicinities. The 2017 *NEC* has added provisions for where and when isolated ground receptacles can be used outside the patient care vicinity but within the patient care space. Section 517.16(B) allows this application as follows:

> **517.16(B) Outside of a Patient Care Vicinity.** Isolated ground receptacle(s) installed in patient care spaces outside of a patient care vicinity(s) shall comply with 517.16(B)(1) and (2).
>
> (1) The grounding terminals of isolated ground receptacles installed in branch circuits for patient care spaces shall be connected to an insulated equipment grounding conductor in accordance with 250.146(D) in addition to the equipment grounding conductor path required in 517.13(A).
>
> The equipment grounding conductor connected to the grounding terminals of isolated ground receptacles in patient care spaces shall be clearly identified along the equipment grounding conductor's entire length by green insulation with one or more yellow stripes.
>
> (2) The insulated grounding conductor required in 517.13(B)(1) shall be clearly identified along its entire length by green insulation, with no yellow stripes, and shall not be connected to the grounding terminals of isolated ground receptacles but shall be connected to the box or enclosure indicated in 517.13(B)(1)(2) and to noncurrent-carrying conductive surfaces of fixed electrical equipment indicated in 517.13(B)(1)(3).
>
> Informational Note No. 1: This type of installation is typically used where a reduction of electrical noise (electromagnetic interference) is necessary, and parallel grounding paths are to be avoided.
>
> Informational Note No. 2: Care should be taken in specifying a system containing isolated ground receptacles, because the grounding impedance is controlled only by the grounding wires and does not benefit from any conduit or building structure in parallel with the grounding path. [99: 6.3.2.2.7.1]

To be compliant for this application, the equipment grounding path consists of the metal raceway as required in 517.13(A) plus the additional wire type equipment grounding conductors from 517.13(B) and a third wire type equipment grounding conductor meeting 250.146(D) for the receptacle. To keep the wire type equipment grounding conductors separated, the one for the 517.13(B) is required to be colored green and not have any yellow stripes and the one for the isolated equipment grounding conductors must be colored green with yellow stripes (see Figure 15.18).

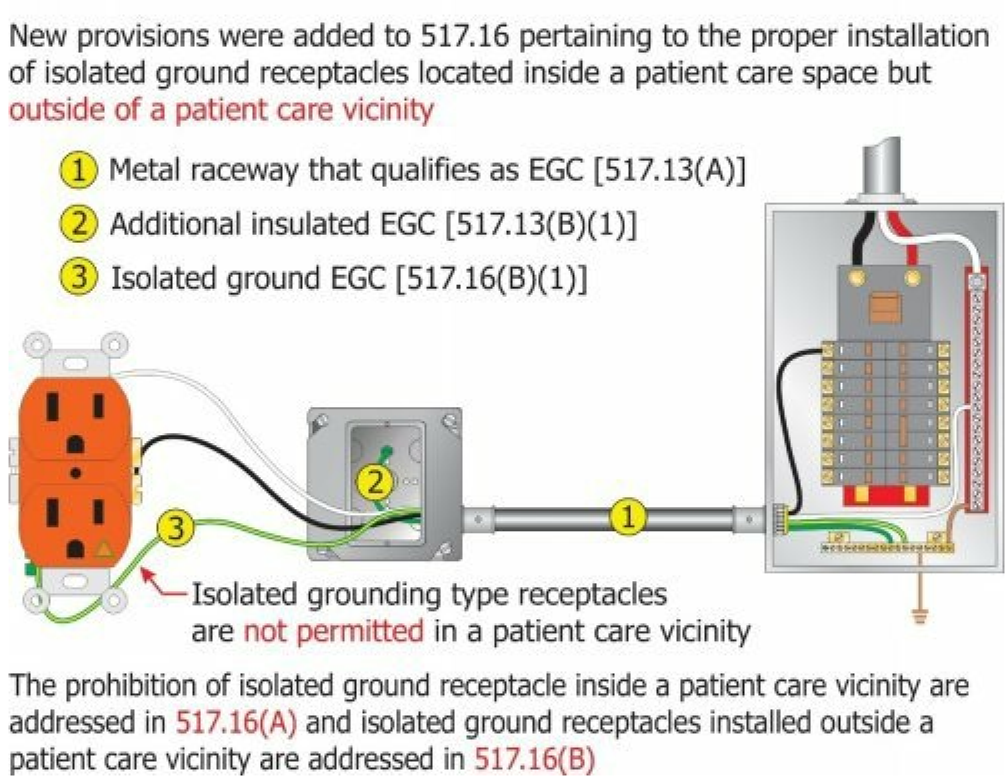


Figure 15.18 Isolated ground receptacles in patient care vicinity.

Receptacle Testing in Patient Care Spaces

In wet locations, fixed receptacles, equipment connected by cord and plug, and fixed electrical equipment must be tested: (1) when first installed, (2) where there is evidence of damage, or (3) after any repairs [NFPA 99 – 6.3.2.2.8.5(B)].

NFPA 99, Section 6.3.3.2 gives requirements for the testing interval for receptacles in patient care spaces. It is required that:

- Testing be performed after initial installation, replacement, or servicing of the device.
- Additional testing be performed at intervals defined by documented performance data.

Receptacles that are not listed as hospital-grade must be tested at intervals not exceeding 12 months [NFPA 99: 6.3.4.1.3].

Tests that are required to be performed for each receptacle include:

- Visual inspection to confirm physical integrity
- Continuity of the grounding circuit
- Correct polarity
- Retention force (except locking type) to be not less than 115 g (4 oz.) [9]

Record keeping requirements are found in NFPA 99: 6.3.4.2. A record must be maintained of the periodic testing required and associated repairs or modification. At a minimum, this record must contain the date, the rooms tested, and an indication of which items have met or have failed to meet the performance requirements.

Where an isolated power system is installed, NFPA 99: 6.3.4.4.2 requires that a permanent record be kept of the results of each of the tests for that system.

Bonding of Panelboards in Patient Care Spaces

Section 517.14 requires that the “equipment grounding terminal busses of the normal and essential branch-circuit panelboards serving the same individual patient vicinity … be connected together with an insulated continuous copper conductor not smaller than 10 AWG” (see figure 15.19).

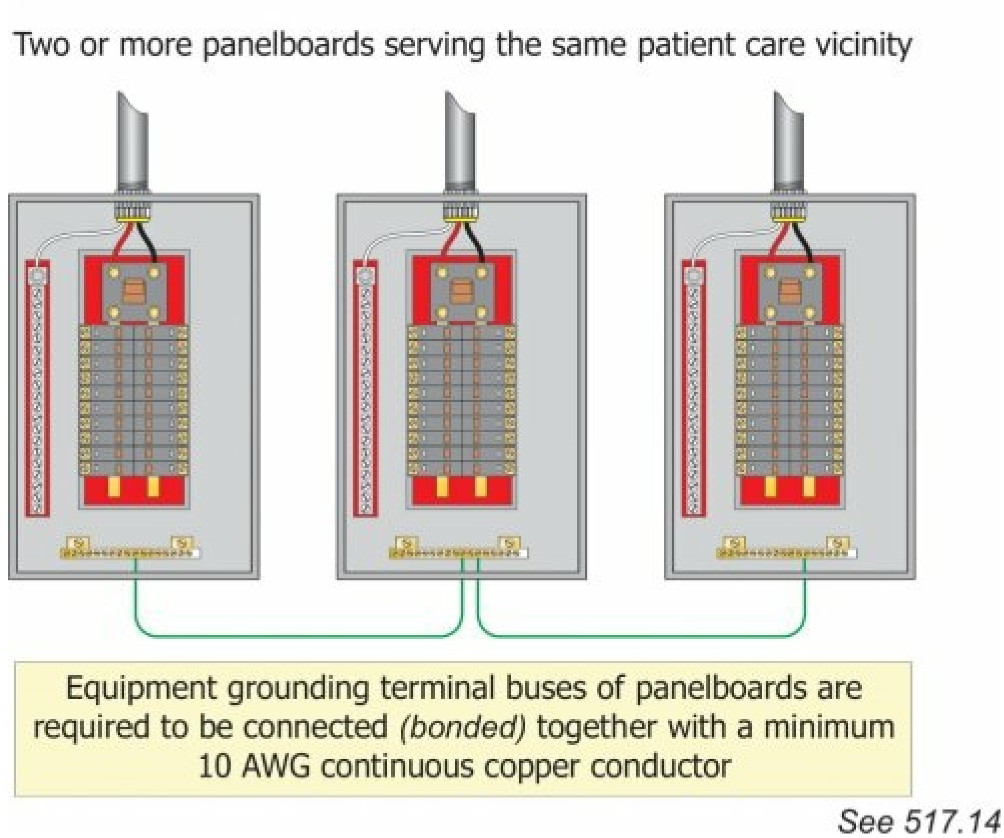


Figure 15.19 Equipment grounding terminals of panelboards serving the same patient care vicinity required to be bonded together. Also where supplied by separate transfer switches, which is usually the case.

“Where two or more panelboards serving the same individual patient care vicinity are served from separate transfer switches on the essential electrical system, the equipment grounding terminal buses of those panelboards shall be connected together with an insulated continuous copper conductor not smaller than 10 AWG.” This conductor shall be continuous from panel to panel but “shall be permitted to be broken in order to terminate on the equipment terminal bus in each panelboard.” [10]

Typically, the circuits supplying receptacles serving the patient bed locations are supplied from different separately derived systems. This bonding is intended to ensure that little if any potential difference exists between exposed non-current-carrying metal portions of equipment in the patient-care space. It is not required that this bonding conductor be installed in a raceway between panelboards where it is protected by normal building construction such as studs and gypsum board.

This bonding is provided to equalize the potential of electrical equipment in the patient vicinity that might be supplied from two different panelboards. This is especially important should a line-to-ground fault occur in one piece of equipment while another piece of equipment in the same patient vicinity is in a stable condition. There might be a slight voltage rise on the faulted circuit until the overcurrent device on the line side of the fault clears. The 10 AWG bonding conductor helps keep the electrical equipment in the patient care vicinity at the same potential thus reducing the shock hazard.

Patient Equipment Grounding Point

The patient equipment grounding point is an option for improving electrical safety in patient care spaces. Though an optional feature [see 517.19(D)], a patient equipment grounding point continues to be provided by many hospital equipment manufacturers and is specified by consulting engineers. Where installed, it consists of a grounding terminal bus and can include one or more grounding jacks. “An equipment bonding jumper not smaller than 10 AWG copper shall be used to connect the grounding terminals of all grounding-type receptacles to the patient equipment grounding point.” [11] Again, this is done to reduce any potential difference between conductive surfaces in the patient care vicinity (see photo 15.2).

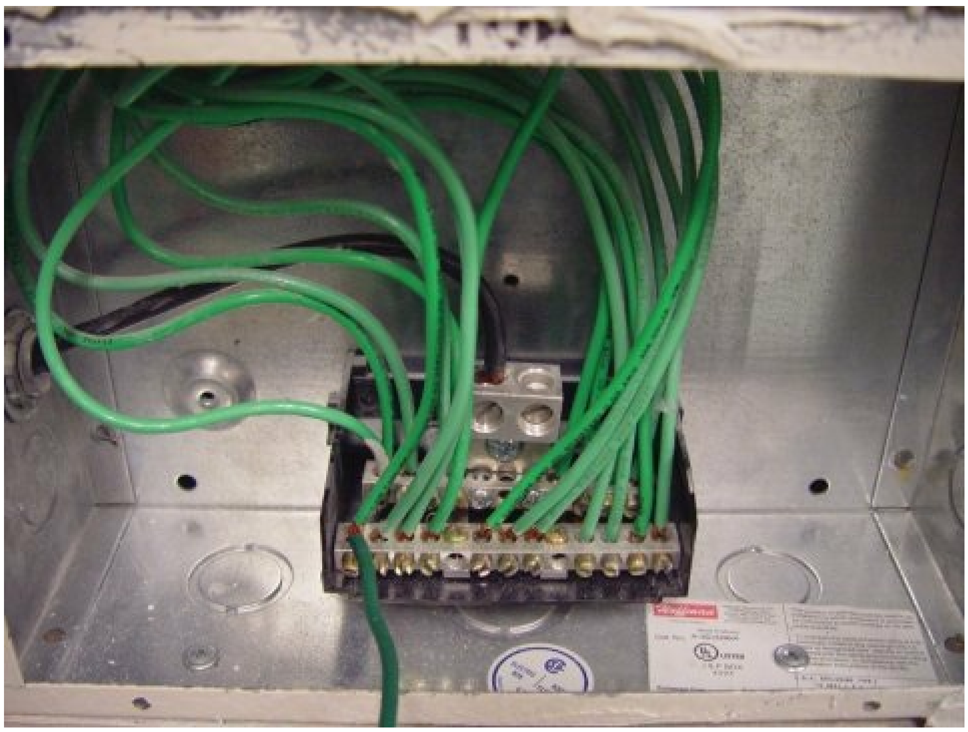


Photo 15.2 Patient equipment grounding point [517.19(E)]

Panelboard Grounding, Critical Care Areas

Section 517.19(E) requires that where metal raceways or Type MC or MI cables are used for feeders, grounding and bonding of panelboards and switchboards serving critical care areas must be assured (see figure 15.20). Acceptable methods include as follows:

> "(1) A grounding bushing and a continuous copper bonding jumper, sized in accordance with 250.122, with the bonding jumper connected to the junction enclosure or the ground bus of the panel
>
> "(2) Connection of feeder raceways or Type MC or MI cable to threaded hubs or bosses on terminating enclosures

Note that Type MC or MI cable used in panelboard feeders that supply branch circuits in critical care areas must qualify as an equipment grounding conductor in accordance with 250.118 [517.19(E)].

> "(3) Other approved devices such as bonding-type locknuts or bushings. Standard locknuts shall not be used for bonding" [12]

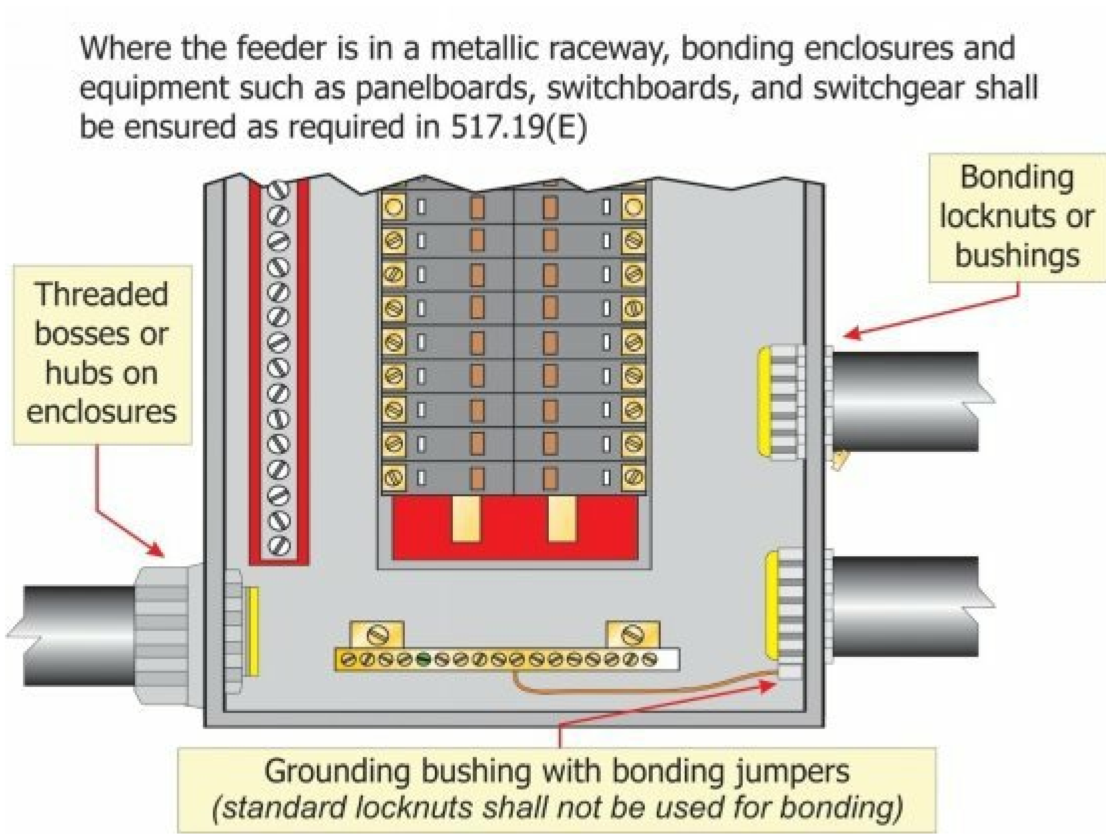


Figure 15.20 Panelboard bonding, critical care feeders installed in metallic raceways

Isolated Power Systems Permitted as Protection Technique

Isolated power systems are ungrounded systems, and 517.19(F) provides requirements for isolated power systems as: "shall be permitted to be used for critical care spaces, and, if used, the isolated power system equipment shall be listed [for the purpose and the] system … designed and installed [so that it meets the provisions of and is] in accordance with 517.160." [13] The exception to 517.19(F) states that "the audible and visual indicators of the line isolation monitor shall be permitted to be located at the nursing station for the area being served."

An isolated power system usually consists of a transformer that has an ungrounded secondary. A protective shield is placed between the primary and secondary windings. A line isolation monitor with visual and audible alarms is provided to warn of excessive line-to-ground leakage as well as to indicate that a line-to-ground fault has occurred. The primary purpose of an isolated power system is to allow equipment to function with the first line-to-ground fault without opening an overcurrent device. Faulty equipment can be repaired or replaced at the earliest opportunity but will remain in service until a second line-to-ground fault occurs which then becomes a line-to-line fault. This would cause the overcurrent device to operate and take the faulted equipment off the line. Reference equipment grounding terminal bars are included in isolated power systems enclosures for termination of equipment grounding conductors of the branch circuits supplied by the isolated power system. These systems must be tested prior to being put into service and periodically thereafter (see photo 15.3).

Photo 15.3 Isolated power systems equipment

There are specific requirements regarding the types of insulation on the branch-circuit conductors, length of the branch circuits, and color code for these conductors. Wire pulling compound is not permitted to be used for installation of these circuit conductors in raceways as it can have an adverse effect on the dielectric characteristics of the conductors and the system operation. It is important to follow the manufacturer's installation instructions to ensure compliance with the equipment listing requirements of 110.3(B) in addition to the requirements of 517.160. Other specific requirements for isolated power systems are in 517.160.

Special Purpose Receptacle Grounding

Section 517.19(G) states that "where an isolated ungrounded power source is used and limits the first-fault current to a low magnitude, the equipment grounding conductor associated with the secondary circuit shall be permitted to be run outside of the enclosure of the power conductors in the same circuit."

The informational note reads, "Although it is permitted to run the [equipment] grounding conductor outside of the conduit, it is safer to run it with the power conductors to provide better protection in case of a second ground fault." [14]

NEC 517.21 provides that "ground-fault circuit-interrupter protection for personnel shall not be required for receptacles installed in those critical care (category 1) spaces where the toilet and basin are installed within the patient room."

Grounding and Bonding Requirements for Agricultural Buildings

Sections 547.5(F) and 547.9 contain some specific requirements for grounding and bonding in agricultural buildings (see figure 15.21). The major concern is twofold. The first is for the integrity of the equipment grounding and bonding path(s) due to corrosive conditions that exist in these buildings, especially where livestock are present. The second concern is for neutral-to-earth and stray voltage, which, if excessive, causes behavior responses in livestock. These behavior responses particularly in dairy cattle can lead to loss of production, health problems and death in the herd.

Section 547.5(F) requires that "Where an equipment grounding conductor is installed underground within a location falling under the scope of Article 547, it shall be insulated." [15] The wire type equipment grounding conductor can be either copper or aluminum. The change to the *NEC* was based on substantiation showing the present-day aluminum alloys to be acceptable in the corrosive environments found in livestock areas.

Equipment Grounding

Where grounded equipment is installed in an agricultural building, a wire type equipment grounding conductor must be installed to ground the equipment as required by 250.112, 250.114, 250.134 and 250.136. This applies regardless of the type of wiring method employed. As stated above from 547.5(F), the copper or aluminum equipment grounding conductors installed underground are required to be insulated.

Motor-operated water pumps, including the submersible type are required to be grounded.

In addition to the water pump grounding requirements, where a submersible pump is used in a metal well casing, the well casing is required to be bonded to the pump circuit equipment grounding conductor [see *NEC* 250.112(L) and (M)].[16]

One of the most important elements of farm wiring systems, especially where dairy cattle are involved, is to isolate and maintain isolation of the system neutral from the equipment grounding conductor and non-current-carrying metal parts of the electrical system at barns, milking parlors, and so forth. Separation of the neutral conductor will help minimize and prevent the voltage drop on the feeder neutral from becoming a source of stray voltage in the building.

Isolation of the grounded conductor (usually the neutral) at an additional building or structure served by a feeder or branch circuit on the same premises as the electrical service is required by 250.32(B). In the case of agricultural buildings, the conditions of 547.9(B) must be satisfied as well. Here two general methods are provided [see figure 15.22].

Where the service disconnecting means and overcurrent protection is located at the agricultural building, grounding and bonding shall comply with 250.32 and

1. The EGC is to be the same size as the largest supply conductor if of the same material, or adjusted in size in accordance with the sizing columns of Table 250.122 if of different materials
2. The EGC is to be connected to the grounded circuit conductor and the site-isolating device enclosure at the distribution point

See 547.9(B)(3)

Figure 15.22 Grounding and bonding at agricultural buildings

Grounding of electrical systems at agricultural buildings is permitted to be performed in one of two ways in accordance with 547.9(B) or (C). The difference in the two methods permitted depends on whether the service disconnecting means and overcurrent protection is located at each building or structure served or is located at the central distribution point. Once the service location or locations are set, then it follows for the requirements for the neutral to be grounded at the site distribution point or at the service equipment located at each agricultural building separately.

Where the service disconnecting means and overcurrent protection are located at the buildings or structures, the supply conductors shall be sized in accordance with Article 220 and installed in accordance with the requirements of Part II of Article 225.[9] [547.9(B)(1) and (2)]. Article 220 provides the rules for calculating the load on conductors, feeders and services. Article 225 includes requirements for the disconnecting means at additional buildings and structures on the premises.

Where the service disconnecting means and overcurrent protection is located at the agricultural building or structure, the method for grounding shall comply with Section 250.32 and, in addition, the following two specific conditions [547.9(B)(3)(1) and (2)].[17]

1. The equipment grounding conductor is the same size as the largest supply conductor if of the same material, or is adjusted in size in accordance with the sizing columns of Table 250.122 if of different materials.

2. The equipment grounding conductor is connected to the grounded circuit conductor and the site-isolating device enclosure at the distribution point.[18]

As provided in 547.9(C), "Where the service disconnecting means and overcurrent protection for each set of feeder conductors are located at the distribution point, feeders to building(s) or structure(s) shall meet the requirements of 250.32 and Article 225, Parts I and II."

Stray (Tingle) Voltage

Voltage drop on a neutral conductor supplying a building or structure housing livestock can result in elevated levels of stray voltage if it is grounded at the building or structure. It is important to balance 120-volt loads to minimize neutral loads, operate motors at 240 volts wherever practical, and size neutral conductors in service drops and feeders as large as practical.

Livestock behavioral responses, including production and health problems, can be caused by stray voltage (also referred to as tingle-voltages). These voltages can appear between various portions of grounded or ungrounded metallic systems, such as electrical equipment or piping systems, and the earth or floor such that livestock can come between two different potentials. It is not uncommon to find voltage differences between adjacent concrete slabs or between a concrete slab and the adjacent earth. For dairy cows, it is known the cow can perceive a voltage difference as low as 1 volt and will have negative effects above 2 volts.

Common causes of neutral-to-earth voltages (stray voltage if it is at livestock contact points) are currents on primary distribution systems in parallel with the earth, farm secondary neutral conductors, and faulty wiring on the farm. Some electric utilities have installed primary-to-secondary neutral conductor isolators on their transformers in an attempt to solve the stray voltage problem. Neutral conductors that are too small for the load and length of run and loose or corroded splices and terminations will frequently elevate the neutral-to-earth voltage to a level that can adversely affect livestock.

Another common cause of stray voltage is ground faults where the fault current gets into the earth, concrete slabs or on metal equipment that can be contacted by livestock. Ground faults that can cause stray voltage can occur in water pumps, underground wires, sump pumps, manure pumps, electrically heated livestock watering fountains, electrically operated feeders and similar equipment. Proper grounding along with bonding this equipment together usually prevents the stray voltage from occurring even where there is a high-impedance fault. In addition, it is important to have a low-impedance ground-fault return path so overcurrent devices can clear ground faults.

Equipotential Planes and Bonding of Equipotential Planes

Section 547.10(A)(1) for indoor locations requires that "equipotential planes shall be installed in confinement areas with concrete floors where metallic equipment is located that may become energized and is accessible to livestock."

Also, outdoor confinement areas, such as feedlots, shall have equipotential planes per 547.10(A)(2). This section addresses outdoor locations and specifies "equipotential planes shall be installed in concrete slabs where metallic equipment is located that may become energized and is accessible to livestock. The equipotential plane shall encompass the area where the livestock stands while accessing metallic equipment that may become energized." [19]

This is the best method of controlling the effects of stray voltages on livestock. This bonding does not correct or remove the faults that are causing the problem but keeps everything in the livestock area at the same potential (see figure 15.23). This, in essence, prevents the livestock from being aware of and being affected by the stray voltage.

The term *equipotential plane* is defined in 547.2 as, "an area where wire mesh or other conductive elements are embedded in or placed under concrete, bonded to all metal structures and fixed nonelectrical equipment that may become energized, and connected to the electrical grounding system to minimize voltage differences within the plane and between the plane, the grounded equipment, and the earth."

Section 547.10(B) provides details on requirements for bonding of the equipotential plane. Wire mesh or other conductive elements, such as reinforcing steel rods, must be installed in the concrete floors in these areas and be bonded together, as well as to the building grounding electrode system. This is accomplished by bonding the reinforcing rods and wire mesh in the concrete together with a copper conductor that is insulated, covered or bare, not smaller than 8 AWG, and then connecting these bonding conductors to metal piping systems, stanchions and the building grounding electrode system (see figures 15.23 and 15.24). This creates the required equipotential plane, meaning everything in the area is at the same potential. The equipotential plane prevents voltage differences between conductive bodies with which livestock can make contact. Connections must be made with pressure connectors or clamps of brass, copper, copper alloy, or an equally substantial approved means. Connections can also be made by exothermic welding. "Slatted floor sections that are supported by structures that are a part of an equipotential plane shall not require bonding." [13] These floor sections are typically pre-cast concrete sections, which by their size and mass effectively become a part of the equipotential plane when supported by the rest of the structure. In addition, the installation of bonding conductors to these floating sections has proven difficult as these sections are removed for periodic wash downs and other cleaning.

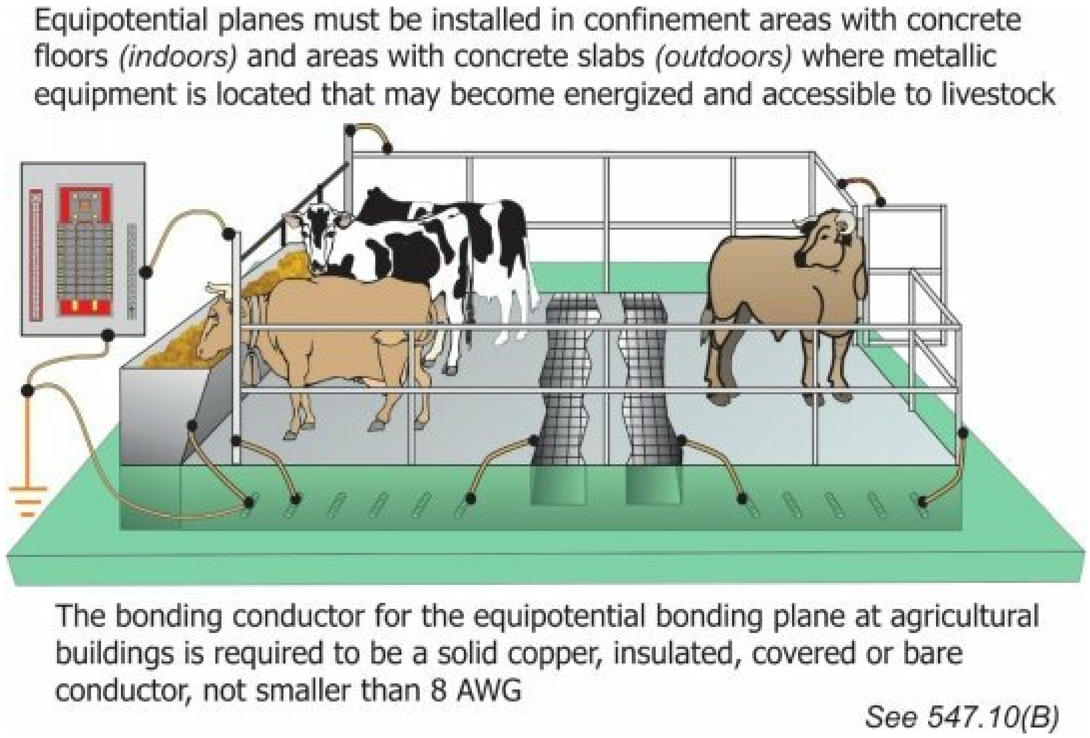


Figure 15.23 Equipotential bonding at agricultural buildings

Figure 15.24 Equipotential bonding plane

Obviously, it is best to install this bonding system during the original construction of the building or portion of a building that houses livestock or serves as a milking parlor. Equipotential planes have been installed in existing buildings by sawing grooves in the concrete floors and installing bonding conductors that bond all conductive elements together. After the wire is installed the groove is filled with an epoxy compound to seal the concrete floor. However, this is always much more expensive than making the installation before the concrete is poured.

Informational note No. 1 following 547.10(B) provides additional references on methods for installing equipotential planes and voltage gradient ramps and reads, "Methods to establish equipotential planes are described in American Society of Agricultural and Biological Engineers (ASABE) EP473.2–2001, *Equipotential Planes in Animal Containment Areas*." [20]

[1 - 20] **NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA, © 2016)**

Review Questions

1. The recommended practice guidance for static electricity control is found in ______

    1. NFPA 70
    2. NFPA 77
    3. NFPA 78
    4. NFPA 780

2. The *NEC* requires the installer to use NFPA 77 for hazardous location installations

    1. True
    2. False

3. Building or structure protection from lightning discharges is provided by ___.

    1. building low-rise structures
    2. building structures of wood construction
    3. providing a low-resistance path to earth
    4. providing a high-resistance path to earth

4. Ground terminals for lightning protection systems are required to be ____.

    1. connected (bonded) to the electrical power grounding electrode system
    2. bonded to the building water pipe system
    3. isolated from the building electrical system by at least six feet
    4. isolated from the building grounding electrode system

5. Bonding and grounding for hazardous locations is required by _______and has more detail in ______.

    1. 500.8; 501.30(B)
    2. 501.30(B); 502.30(B)
    3. 250.100; 501.30(B), 502.30(B); and 503.30(B)
    4. 250.100; 250.102

6. Generally, in hazardous (classified) locations, locknuts installed on each side of an enclosure, or a locknut on the outside and a standard bushing on the inside ___ be used for bonding.

    1. shall
    2. shall be permitted
    3. shall not
    4. may

7. Bonding locknuts or bonding bushings with bonding jumpers must be used in hazardous (classified) locations to ensure the integrity of the bonding connection and its capability of carrying any ____ that may be imposed.

1. unidentified currents
2. neutral currents
3. objectionable current
4. fault current

8. Where flexible metal conduit is permitted and used in a Class I, Division 2 location, it must have an internal or external bonding jumper installed to supplement the conduit. Where the jumper is installed on the outside, it is limited to ____ in length.

1. 1.8 m (6 ft)
2. 2.1 m (7 ft)
3. 2.5 m (8 ft)
4. 2.7 m (9 ft)

9. An additional means of equipment grounding is required for branch circuits in ____ of health care facilities.

1. limited-care facilities
2. office areas
3. all areas
4. patient care areas

10. Where used in patient care areas, the flexible metal raceway system is required to have outer metal armor or sheath that (is) ____ as an acceptable grounding return path in accordance with 250.118.

1. approved by special permission
2. permitted
3. approved
4. qualifies

11. Where metal raceways or Type MC or MI cables in accordance with 250.118 are used for feeders supplying critical care areas in health care facilities, grounding and bonding of panelboards and switchboards must be assured. Acceptable methods include all of the following EXCEPT ___.

1. grounding/bonding bushings with bonding jumpers
2. threaded bosses

3. bonding locknuts or bushings
4. standard locknuts

12. Isolated grounding receptacles are permitted _____.

1. at patient care beds
2. in patient care spaces
3. in the patient care vicinity
4. Isolated grounding type receptacles are prohibited in health care facilities

13. The isolated equipment grounding conductors in health care facilities is required to be identified by __________.

1. bare copper conductor
2. insulation colored green
3. insulation colored yellow with green markers
4. insulation colored green with yellow stripes

14. Where equipment is installed in an agricultural building that requires grounding, a ____ equipment grounding conductor must be installed to ground the equipment.

1. aluminum
2. copper, aluminum, or copper-clad aluminum
3. copper-clad
4. insulated

15. Common sources for stray "tingle" current are _________.

1. current on the primary distribution neutral in parallel with the earth
2. faulty wiring in the farm building(s)
3. ground fault currents on conductive structural parts
4. all the above

16. Minimizing or elimination of stray voltages in an agricultural building is accomplished by bonding together the reinforcing rods and wire mesh in the concrete and then connecting these to the metal piping systems, stanchions and grounding electrode systems with a solid copper conductor not smaller than ____ AWG.

1. 8
2. 6
3. 4
4. 2

17. Which of the following statements is true about wiring in an agricultural building?

1. A 2.5 m (8 ft) ground rod is required at each corner of the building.
2. GFCI protection is required for all 125-volt, 1-phase, 15- and 20-ampere receptacles installed in damp or wet locations.
3. Voltage-gradient ramps at entrances and exits are required.
4. Line-to-neutral loads are not permitted.

⏚ Chapter 16
Grounding and Bonding for Special Conditions

Objectives to understand

- Electric signs and outline lighting
- Swimming pools, hot tubs and spas

This chapter takes a look at grounding and bonding requirements for special conditions found in the NEC.

Section 90.3 sets out the organization of the *NEC*. Generally, the requirements in Chapters 1 to 4 apply everywhere except where modified or expanded in Chapter 5, Special Occupancies; Chapter 6, Special Conditions; or Chapter 7, Special Systems. This chapter will provide discussion on those modifications and expansions to the basic requirements relative to grounding and bonding where special conditions exist.

Grounding and Bonding for Electric Signs and Neon Installations

It is common knowledge to those in the electrical field that grounding and bonding of electrical equipment is essential for electrical safety as well as a *Code* requirement. Chapter 6 of the *NEC* provides minimum requirements for special equipment. The first article in this chapter is Article 600, Electric Signs and Outline Lighting. This article contains specific rules for this type of equipment that, in some cases, modify or amend the basic requirements set forth in Chapters 1 – 7. A change was made to section 90.3 in the 2017 *NEC* about the relationship of articles to now include applicable requirements between Chapters 5, 6 and 7. For the newer technology LED signs, this means Article 725 can be applied where needed. Otherwise, the basic rules in Chapters 1 – 7 of the *NEC* have application to this equipment as do the specific requirements of Article 600 that add to or modify requirements from Chapters 1 to 7.

Electric Sign Grounding and Bonding Basics

To fully understand and apply the rules relating to grounding and bonding of this special equipment, one must grasp an understanding of the two concepts grounding and bonding. Grounding and bonding do not have to be as mysterious or complicated as many make them out to be. Let's review each of these basic concepts before looking at the *Code* rules and how they apply to this special equipment. When the word grounding or ground is used, one should think of something that is connected to the earth or ground with an electrically conductive path. The term *grounded* (*grounding*) is defined by the *Code* as "connected (connecting) to ground or to a conductive body that extends the ground connection," [*NEC* Article 100]. The words *bonded* (*bonding*) are defined as "connected to establish electrical continuity and conductivity." So basically bonded means metal parts connected together and grounded means connected to ground (the earth) (see figure 16.1). Both concepts are essential elements and fundamentally important for electrical safety in electric signs and neon installations.

Section 600.7 contains the general requirement for grounding and bonding of electric signs and metal equipment of outline lighting systems and indicates generally that metal parts of signs and outline lighting systems must be grounded. The general rules for grounding and bonding are also provided in Article 250. So when applying the *Code* to these installations, if the general rules are not modified in any way by Article 600, then grounding and bonding requirements in Article 250 would apply as written.

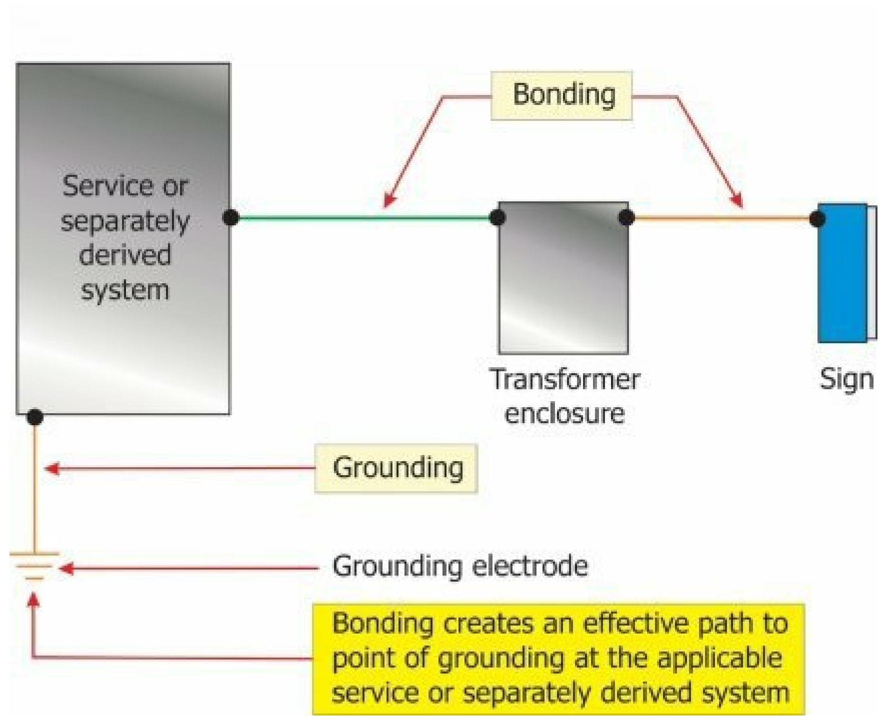


Figure 16.1 Basic concepts of grounding and bonding

Equipment (electric sign and equipment) Grounding

The equipment grounding conductor and proper bonding are essential elements for safety in electrical signs and neon installations. The branch circuit supplying the equipment provides the required equipment grounding conductor for accomplishing the grounding (the connection to ground). The acceptable equipment grounding conductors are specified in 250.118 and the method of connection to the sign or metal enclosure is provided in *NEC* 250.120(A) and 250.8. The equipment grounding conductor must be connected to the equipment using methods consistent with 250.8 (see photo 16.1).

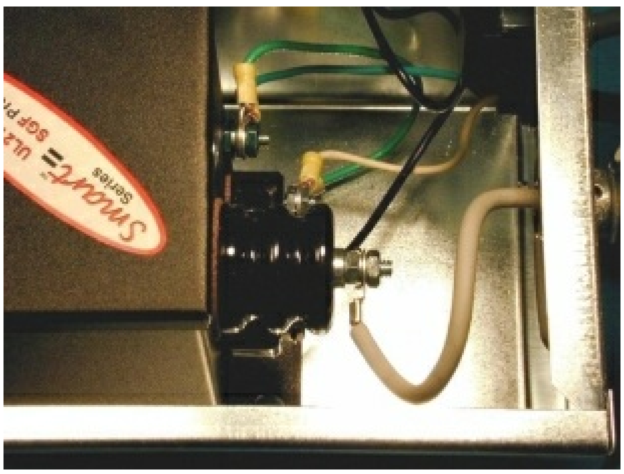


Photo 16.1 Equipment grounding conductor connected to neon transformer and enclosure

The minimum size of the equipment grounding conductor with the branch circuit must not be less than the sizes in Table 250.122 based on the branch-circuit breaker or fuse rating. The equipment grounding conductor connects the equipment to ground and works to maintain it at or near earth potential (see figure 16.2). This safety component of the circuit also acts as the silent servant waiting to perform its ever-important function of facilitating the operation of the branch-circuit overcurrent protection in the event of a ground-fault occurring [the term ground fault is defined in Article 100]. Electrical installations for sign circuits and neon installations are not exempt from these basic grounding requirements and they must be grounded. It is important to note that 250.134(A) specifies in detail the required connections for the equipment grounding conductor. It must be routed with the branch circuit as indicated in 250.134(B) back to the source of a separately derived system or service grounding point. Structural metal frames of buildings are not permitted to be used as the required equipment grounding conductor as clearly indicated in 250.136 and 600.7(B)(3).

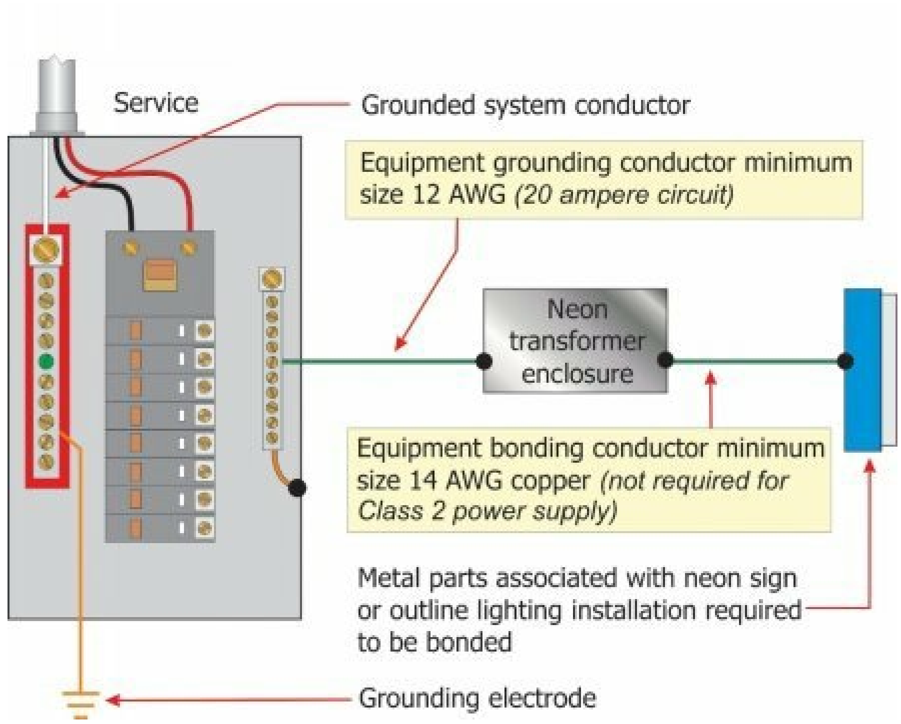


Figure 16.2 Equipment grounding conductor connected to the electric sign

Bonding Requirements

Bonding basically means connecting metallic parts together. Section 600.7(B) includes the bonding requirements for metal parts and equipment of signs and outline lighting systems. When bonding metal equipment and parts associated with electric signs and neon lighting systems the primary objective is to establish the bonding in an acceptable manner and connect them to the equipment grounding conductor of the branch circuit supplying the sign or neon system. This accomplishes the bonding and grounding for the equipment or system. Proper grounding and bonding of metal enclosures and associated metal parts ensure that these parts remain close to earth potential, and minimize differences of potential between metallic parts (see photo 16.2).

Photo 16.2 Metallic parts shown effectively bonded together

High voltage secondary circuits (gas tube sign and ignition cable type) GTO in a wiring method that extends from the transformer to the discharge tubing for neon installations produce various levels of capacitance which is inherent to these secondary circuits and is unavoidable. Capacitance coupling in the neon or cold cathode secondary circuit can actually raise the potential (voltage) on ungrounded metal equipment and metal parts if not bonded together and connected to ground (see photos 16.3 and 16.4.

Photo 16.3 Metal parts bonded together using equipment suitable for the use

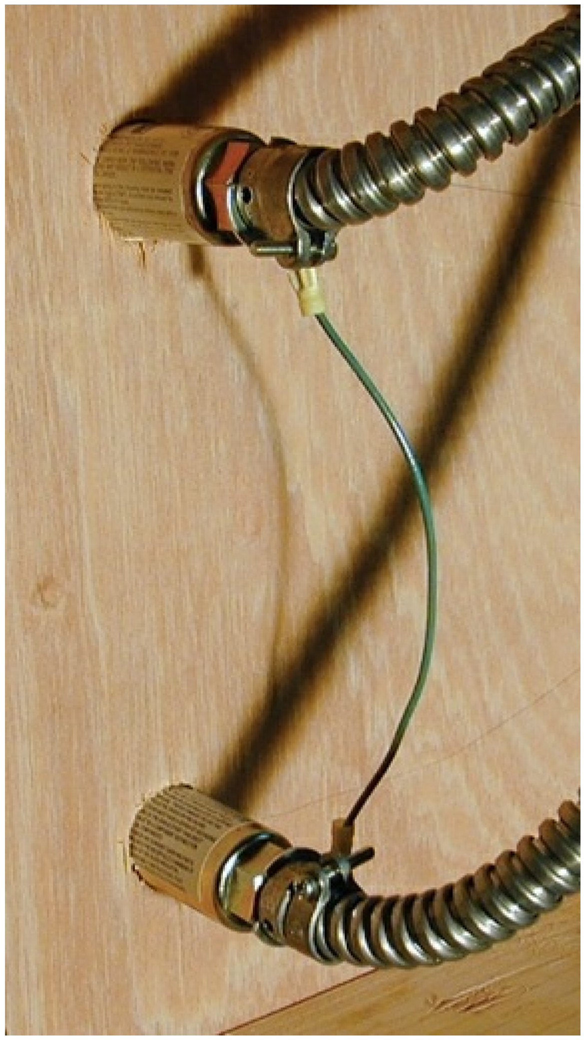


Photo 16.4 Minimum size for bonding conductor not less than 14 AWG copper

The *Code* allows for listed flexible metal conduit or listed liquidtight flexible metal conduit to be used as a bonding means in total accumulative lengths not exceeding 30 m (100 ft) on the secondary side of the sign transformer or power supply. These flexible metal conduits are suitable as a bonding means in lengths up to 30 m (100 ft) because the current on the secondary side of a neon transformer is in the milliampere range and the bonding provided through the conduit or bonding conductor here is not to clear an overcurrent device on the primary (supply side) of the neon transformer or power supply [600.7(B)(4)]. One should keep in mind that there is a length limitation on secondary GTO conductors of 6 m (20 ft) when installed in metallic wiring methods and 16 m (50 ft) when installed in nonmetallic wiring methods. This limitation is required to minimize the capacitance effect in the secondary that impacts both the secondary conductors (GTO cable) and the transformer [see 600.32(J) (1) and (2) and figures 16.3 and 16.4].

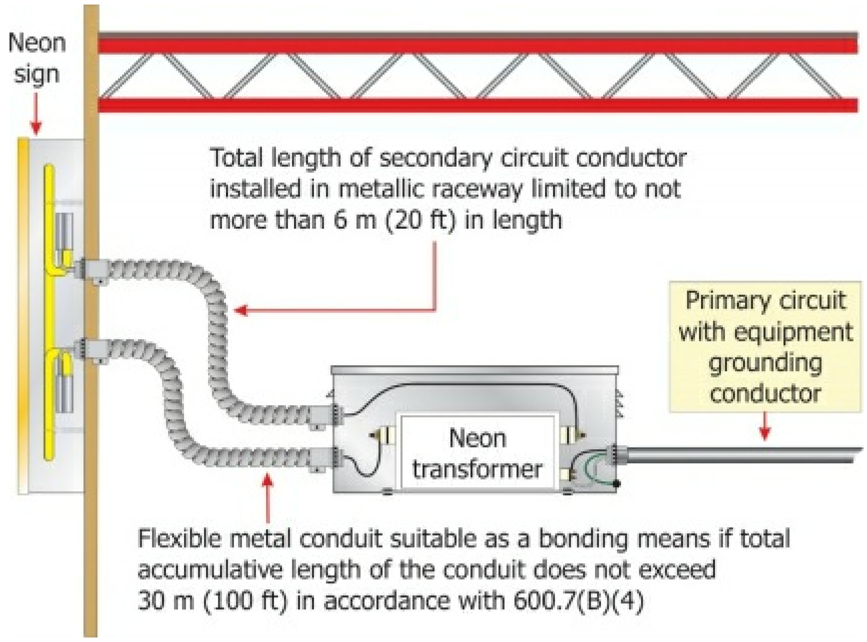


Figure 16.3 Length of secondary circuit limited to 6 m (20 ft) in metal raceway

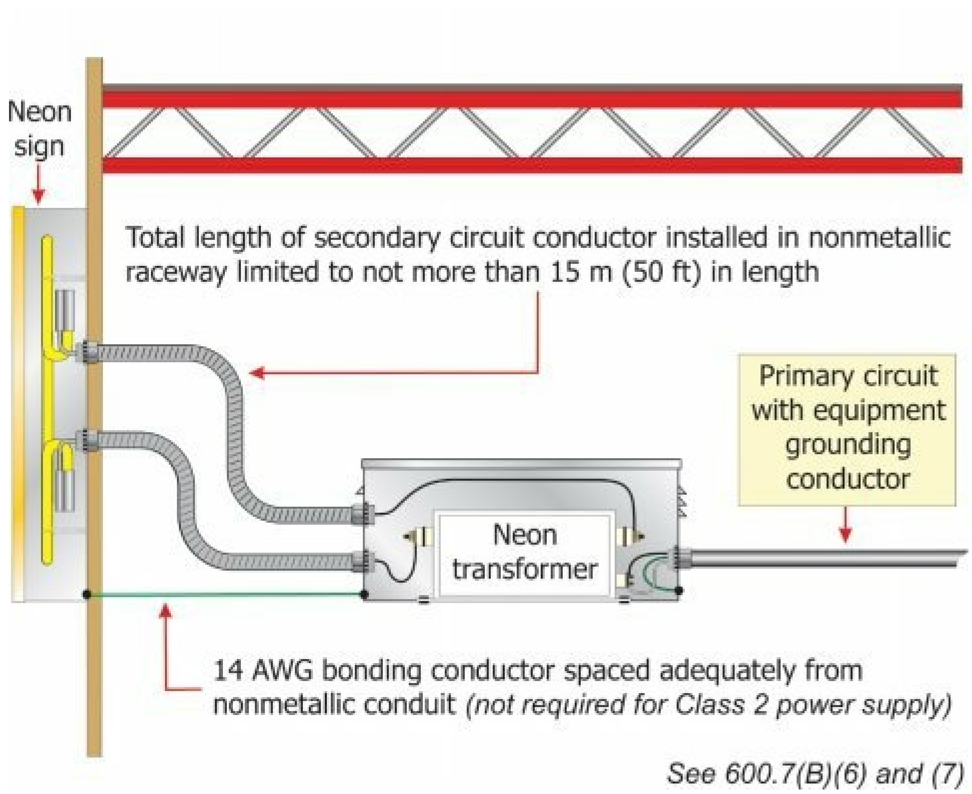


Figure 16.4 Length of secondary circuit limited to 15 m (50 ft) in nonmetallic raceway

Bonding of electrical equipment and enclosures simply means that the enclosures will be connected together in an appropriate manner to ensure electrical continuity and conductivity.

Remember that normal current will always try to return to its source, which is the transformer or power supply secondary. The same is true for any fault current. Any metal parts or components requiring bonding must be bonded back to the source (transformer and/or combination of transformer and enclosure). When a metal conduit is connected to a metal electrical junction box with a proper conduit connector or proper fittings, the two parts are at the same potential because they are bonded together (see figure 16.5).

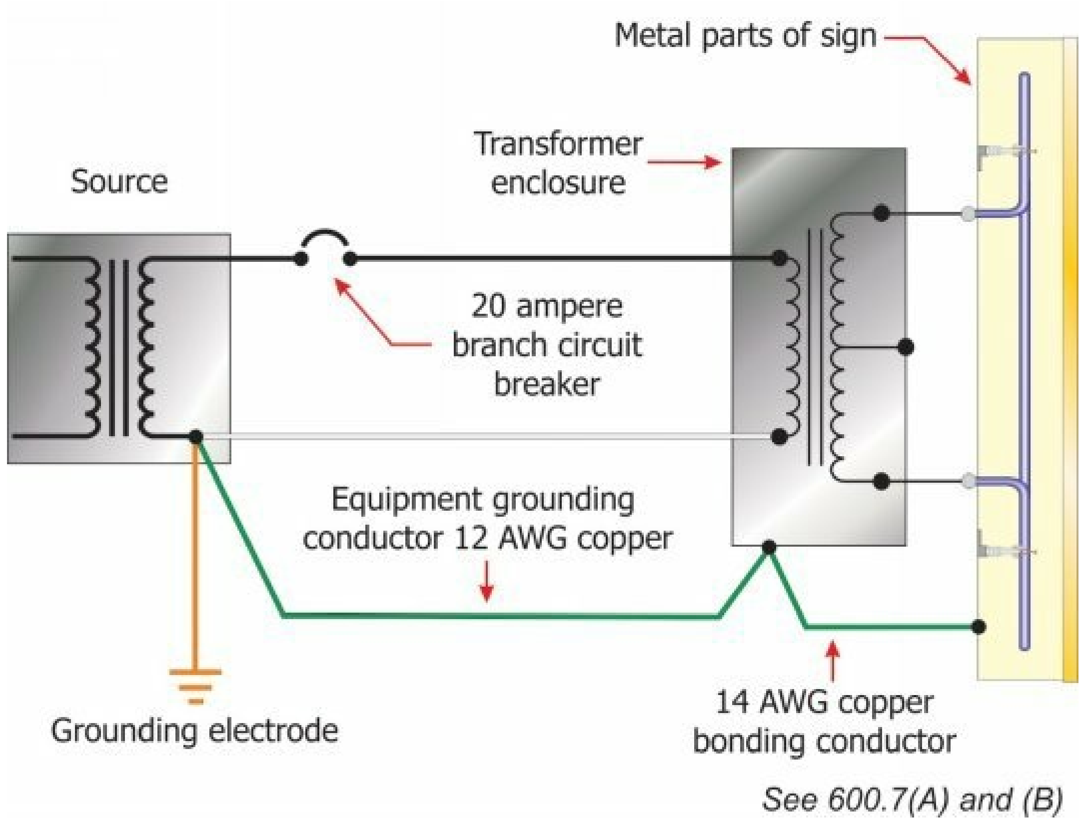


Figure 16.5 Metal parts properly bonded together

When metallic wiring methods are used for secondary circuits and the type of electrode connection to the neon tubing is through an electrode receptacle, particular attention to bonding must be applied. Electrode receptacles (often referred to in the industry as PK housings) provide gaskets that must be installed, particularly in wet locations. The installation instructions of listed parts must be followed [*NEC* 110.3(B)]. Basically, this means that bonding of metallic parts must be assured around any gaskets that cause isolation between the channel letter of a sign and the metallic conduit connect to the electrode receptacle. This happens all too often in the field. This is one reason it is important to be thorough in the inspection of secondary circuits of neon signs and outline lighting systems (see figures 16.6 and 16.7).

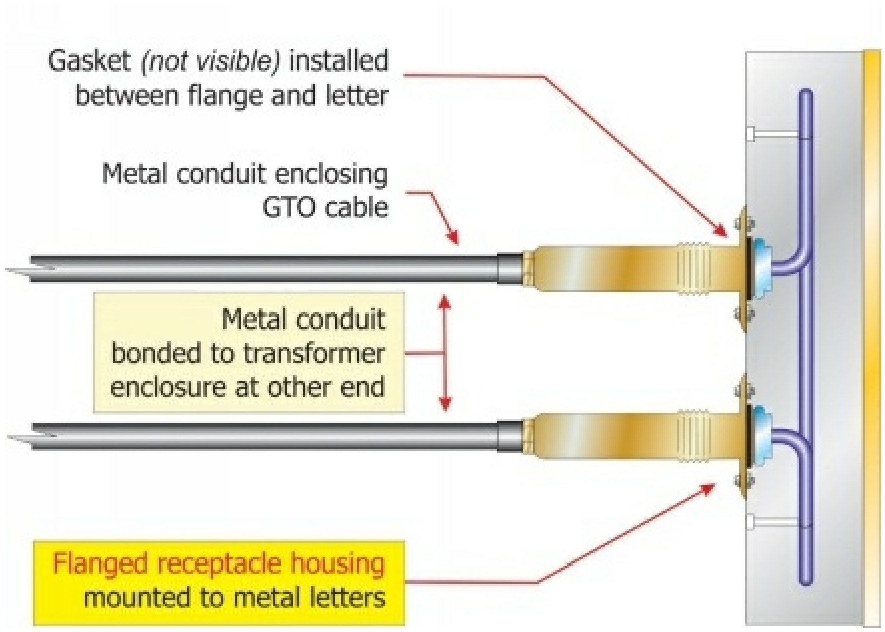


Figure 16.6 Electrode receptacle establishing bonding connection to metal channel letter by mechanical connection. (Flanged electrode receptacles are available for this purpose).

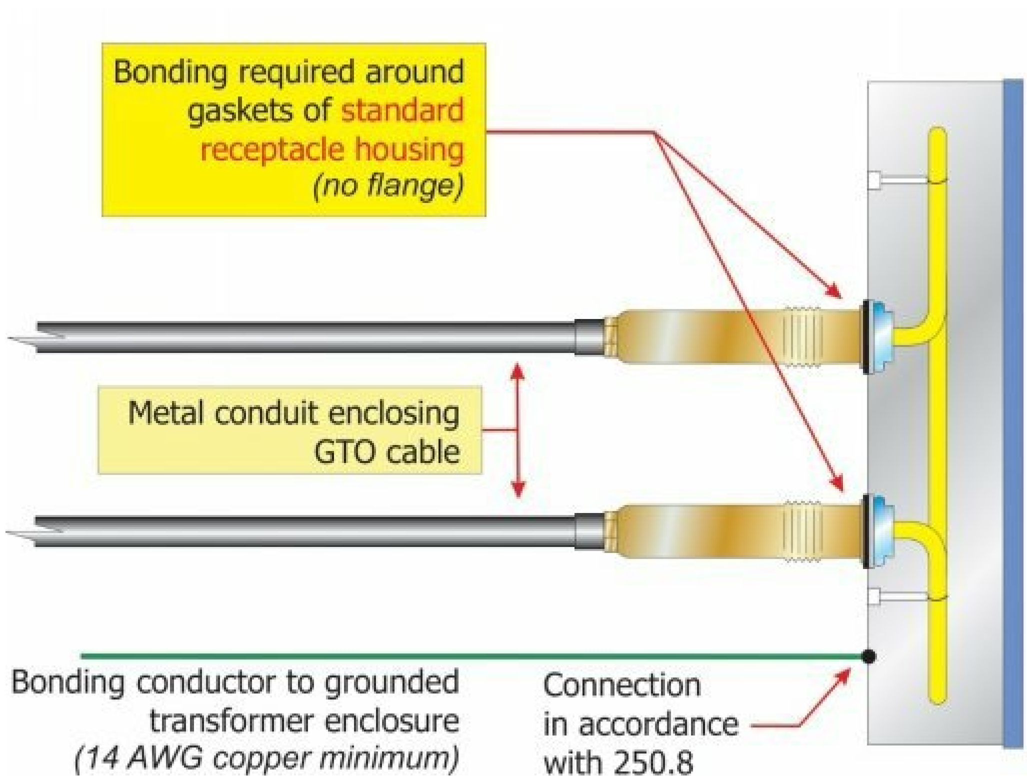


Figure 16.7 Electrode receptacle with gaskets installed requires separate 14 AWG copper bonding conductor to establish bonding connection to metal channel letter.

Small associated metal parts not exceeding 50 mm (2 in.) in any dimension and not likely to become energized (such as the metal mounting means for tubing supports), and spaced at least 19 mm (¾ in.) from the neon tubing are not required to be bonded [*NEC* 600.7(B)(5)]. Where listed liquidtight nonmetallic conduit is used for installing the secondary high voltage GTO conductors from the transformer or power supply to the neon tubing and where there are associated metal parts that require bonding, a bonding conductor is required to be installed. This bonding conductor is required to be installed separate and remotely spaced from the nonmetallic conduit [see 600.7(B)(6)]. The wiring method referred to here is liquidtight flexible nonmetallic conduit or rigid PVC conduit.

Stress in the Secondary Circuit

Where listed nonmetallic conduit is used to enclose the secondary wiring of a transformer or power supply and a bonding conductor is required, the bonding conductor shall be installed separate and remote from the nonmetallic conduit. Bonding conductors are required to be copper and not smaller than 14 AWG. This spacing requirement is established to reduce stresses that might be imposed on the GTO conductor because the magnetic flux lines would no longer be symmetrical around the conductor.

An exception to 600.7(B)(1) eliminates this bonding conductor for remote metal parts of section signs or outline lighting systems when supplied by a remote Class 2 power supply such as an LED sign (see Figure 16.8). Two spacing requirements in the *Code* are intended to deal with this situation [*NEC* 600.7(B)(6) and 600.32(A)(4)]. When a conductor is carrying ac current, it generates a magnetic field, which surrounds the conductor as the current flows during normal operation. This electromagnetic field produces electromagnetic lines of force.

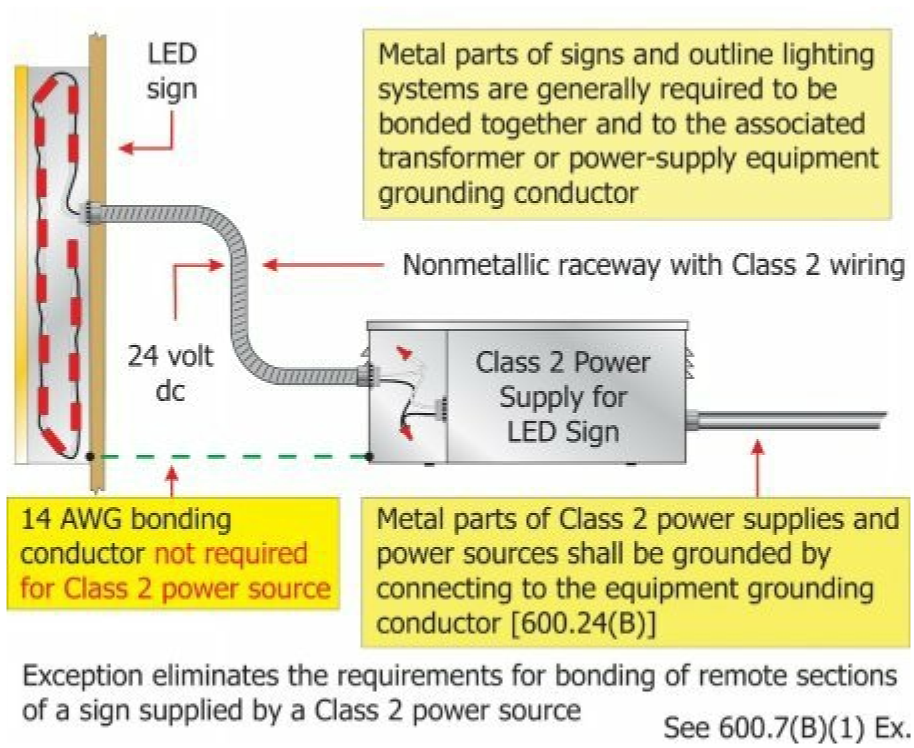


FIGURE 16.8 Bonding conductor is not required for Class 2 power source.

When the conductor is installed in a metal wiring method, these electromagnetic lines of force will work to compress into the metal wiring method encircling the secondary conductor, because the metal conduit introduces less resistance to the magnetic lines of force than air. Even though the magnetic lines of force (flux) are more concentrated, they are maintained in a more symmetrical fashion around the conductor. This keeps the stress on the conductor more uniform or equal for the most part all around the GTO conductor.

When a current-carrying conductor is installed in a nonmetallic wiring method, for example liquidtight flexible nonmetallic conduit, and a bonding conductor is required to be installed for bonding metal parts associated with the neon sign or neon installation, the magnetic lines of force (flux) will try to compress into the bonding conductor or grounded metal parts on that side of the conductor and remain expanded on the other sides. As the compressed magnetic field flows in this circuit, the current is flowing with this unbalanced magnetic flux from zero to maximum voltage and back to zero with every cycle of ac current flow. The stresses on the secondary GTO conductor insulation are much greater on one side than the other. Continuation of this unbalanced stress condition can cause degradation of the high voltage secondary conductor insulation in time. By spacing this bonding conductor at least at the minimum required intervals, the amount of unbalanced stresses imposed on the high voltage secondary conductors will be significantly reduced.

Sections 600.7(B)(6) and 600.32(A)(4) both require a spacing of 38 mm (1½ in.) to be maintained between grounded metal parts or bonding conductors when the secondary circuit operates at 100 Hz or less. When the secondary circuit operates at over 100 Hz, the spacing requirement increases to 45 mm (1¾ in) [see figures 16.9 and 16.10].

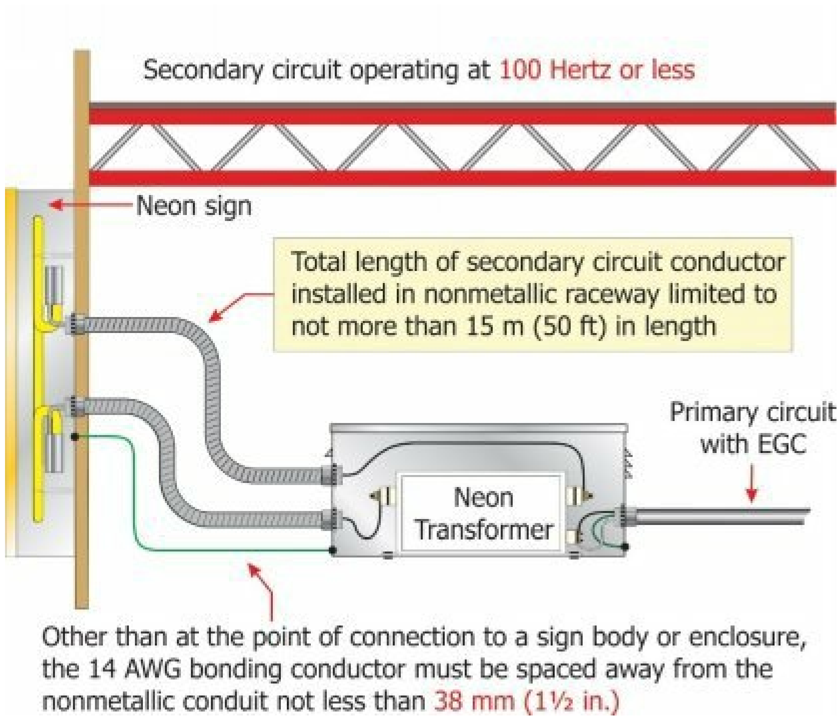


Figure 16.9 Bonding conductor spacing for circuits operating at 100 Hz or less

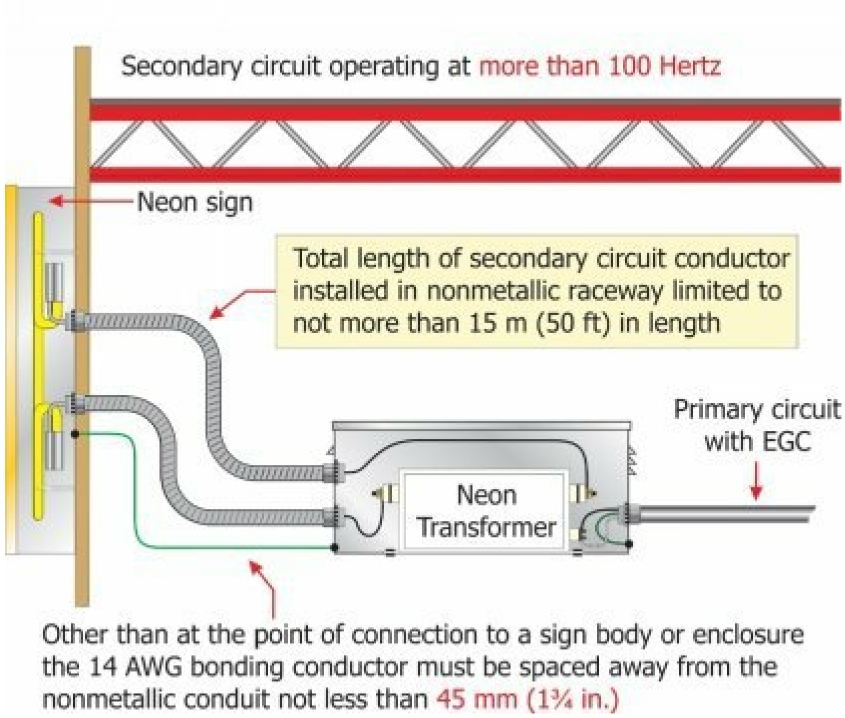


Figure 16.10 Bonding conductor spacing for circuits operating at over 100 Hz.

Metal parts of a building or structure are not permitted to be used as a secondary return conductor or equipment grounding conductor [600.7(B)(3) and 600.32(A)(5)]. Return secondary leads cannot be connected to the metal parts of a building or structure and used as a return path for a mid-point return wired secondary circuit. This is a bad situation that can lead to fire and shock hazards (see photos 16.5, 16.6 and 16.7 and figure 16.11).

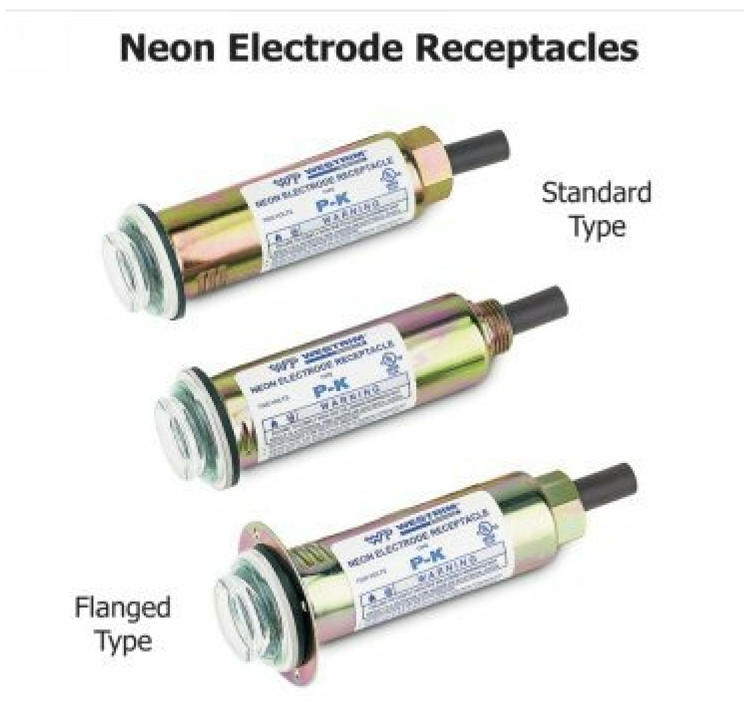


Photo 16.5 Electrode receptacles (flanged and standard types shown) Courtesy of Westrim [Photo is from Neon Lighting]

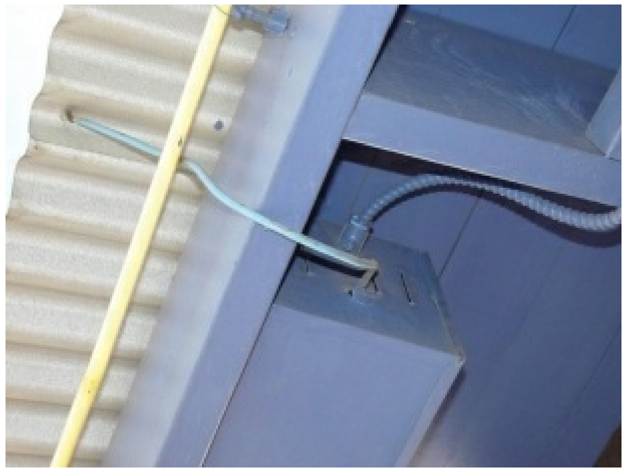


Photo 16.6 Violation shows metal parts of a structure being used as a neon secondary (high voltage) return circuit to transformer. There are numerous other violations in the photo as well.

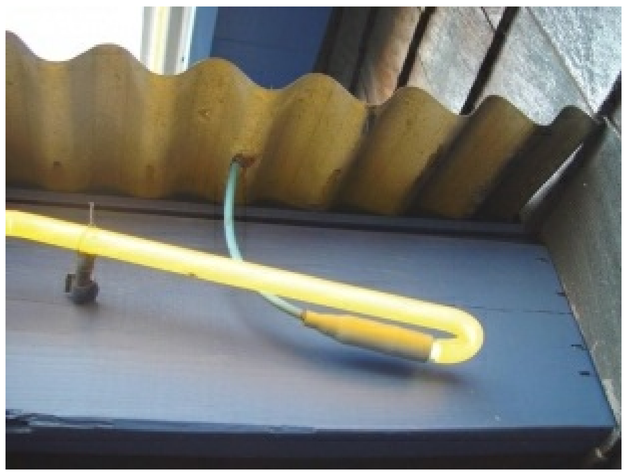


Photo 16.7 Violation shows a connection from the last tubing electrode to the metal parts of a structure used as the high voltage secondary return to the neon transformer. There are numerous other violations in the photo as well.

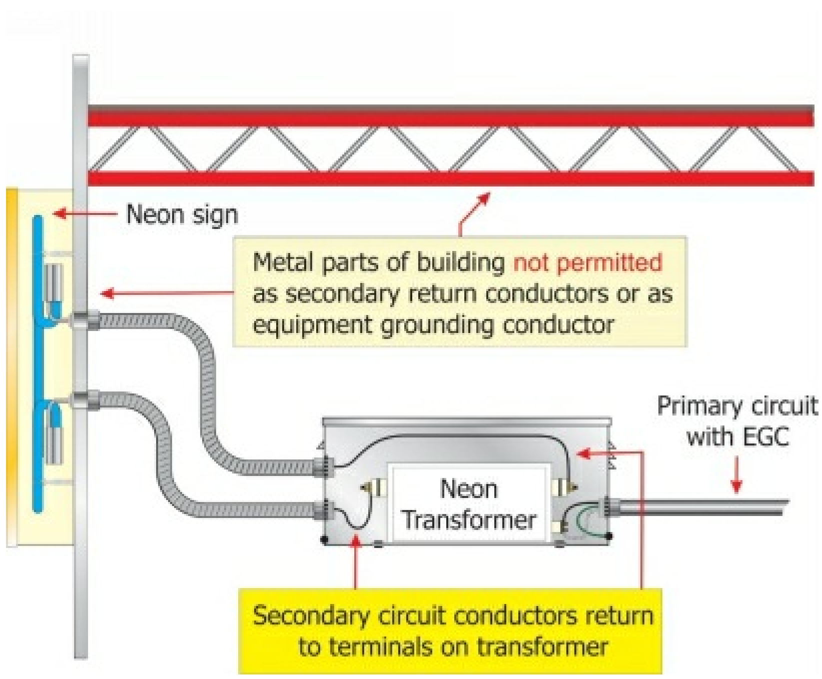


Figure 16.11 Metal parts of a building are not permitted as secondary return conductor or EGC.

Proper grounding and bonding is a basic requirement in the *NEC* and is found in Chapter 2, which is appropriately titled, Wiring and Protection. The *NEC* provides the minimum requirements for essentially safe electrical installations. That means we must do at least that much. These *Code* requirements are set forth to protect persons and property from the hazards that arise from the ever-expanding use of electricity. Chapter 6 covers special equipment including electric signs and neon outline lighting systems. The requirements in Article 600 often amend or supplement the requirements in Chapter 2. Following these basic minimum requirements for grounding and bonding of signs and neon lighting installations contributes to the safe use of electricity.

Swimming Pools, Fountains, and Similar Installations

It is important to understand the organization of Article 680 for proper application of its requirements. Article 680 is divided in several parts, namely Part I through Part VIII. Part I includes general requirements and applies to all equipment and installations covered in Article 680 except for Parts VII and VIII. Part II covers permanently installed pools (see photo 16.8). Other parts cover the equipment or installation identified in the title of the part and do not necessarily apply to all equipment included in Article 680. For example, the rules in Part II for grounding panelboards do not apply to the wiring of a hydromassage bathtub covered in Part VII (see photo 16.8).

Photo 16.8 Permanently installed swimming pool

However, be aware of the requirements for wiring spas and hot tubs. Section 680.40 reads, "electrical installations at spas or hot tubs shall comply with the provisions of Parts I and IV of this article." Generally, a spa or hot tub installed outdoors must be in accordance with 680.42 and is required to meet all the rules for swimming pools, while a spa or hot tub installed indoors is required to meet the rules in 680.43, which are different from those for swimming pools.

> "680.1 Scope. The provisions of this article apply to the construction and installation of electrical wiring for and equipment in or adjacent to all swimming, wading, therapeutic, and decorative pools; fountains; hot tubs; spas; and hydromassage bath tubs, whether permanently installed or storable, and to any metallic auxiliary equipment, such as pumps, filters, and similar equipment. The term *body of water* used throughout Part I applies to all bodies of water covered in this scope unless otherwise amended." [1]

Grounding Requirements

The following swimming pool and outdoor spa and hot tub equipment is required to be grounded [680.6]:

"1. Through-wall lighting assemblies and underwater luminaires, other than those low-voltage lighting products listed for the application without a [equipment] grounding conductor

"2. All electric equipment located within 1.5 m (5 ft) of the inside wall of the specified body of water

"3. All electric equipment associated with the recirculating system of the specified body of water

"4. Junction boxes

"5. Transformer and power supply enclosures

"6. Ground-fault circuit interrupters

"7. Panelboards that are not part of the service equipment and that supply any electric equipment associated with the specified body of water." [2]

A new section, 680.7, was added for the 2017 *NEC*. This was one of many changes to recognize the corrosive environment surrounding pool equipment, be it from chlorination of fresh water pools to pools filled with salt water. This new section now requires all grounding and bonding terminations to be identified for use in the environment present, to be manufactured from specific corrosion resistant materials, and field installed terminals to be listed for direct burial use. (see figure 16.12)

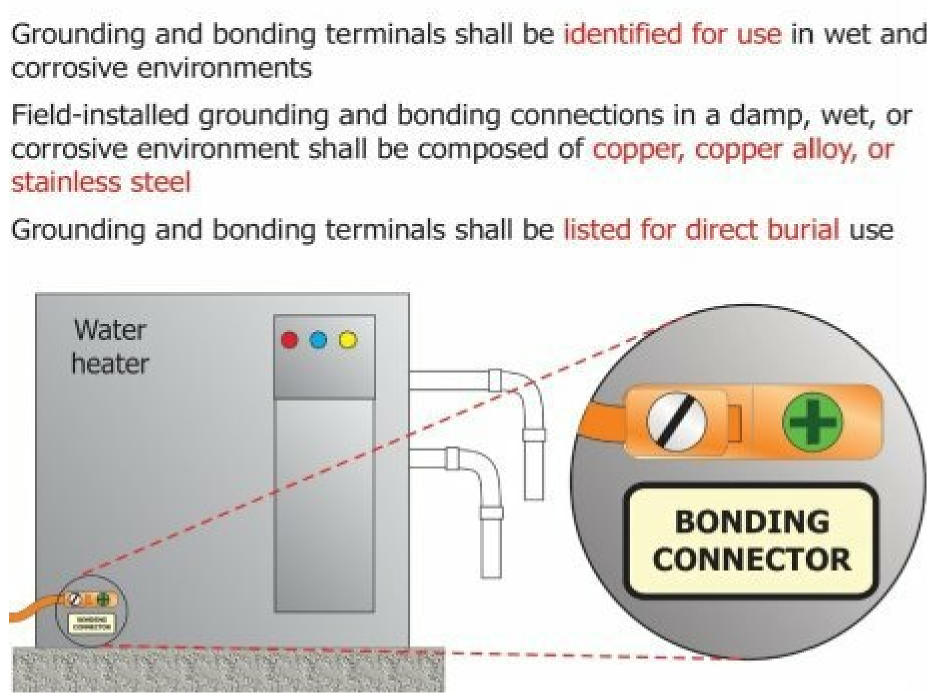


Figure 16.12 Grounding and bonding terminals (swimming pools, fountains and similar locations)

Cord-Connected Equipment

Where fixed or stationary equipment is connected with a flexible cord and plug to facilitate removal or disconnection for maintenance, repair, or storage as provided in 680.8, the equipment grounding conductor must “be connected to a fixed metal part of the assembly. The removable part must be mounted on or bonded to the fixed metal part” [see 680.8(C)].

All other electrical equipment must be grounded in accordance with Article 250 and be connected by an approved wiring method covered in *NEC* Chapter 3.

Methods of Grounding

Section 680.23(F)(2) reiterates that "through-wall lighting assemblies, wet-niche, dry-niche, and no-niche luminaires shall be connected to an insulated copper equipment grounding conductor installed with the circuit conductors. The equipment grounding conductor shall be installed without joint or splice except as permitted in (F)(2)(a) and (F)(2)(b). The equipment grounding conductor shall be sized in accordance with Table 250.122 but shall not be smaller than 12 AWG." The equipment grounding conductor installed "between the wiring chamber of the secondary winding of a transformer and a junction box shall be sized in accordance with the overcurrent device in this circuit" (see Table 250.122). The equipment grounding conductor must be an insulated copper conductor and generally be installed with the circuit conductors in rigid metal conduit, intermediate metal conduit, liquidtight flexible nonmetallic conduit, or rigid nonmetallic conduit.

Electrical metallic tubing is permitted to be used for these conductors where installed on or within buildings. Electrical nonmetallic tubing is permitted to be used to protect circuit conductors where installed within buildings as ENT is generally limited to installation inside buildings as it is not suitable for direct-sunlight exposure [see 680.23(F)(1)].

Where connecting to transformers for pool luminaires, liquidtight flexible metal conduit or liquidtight flexible nonmetallic conduit Type B (LFNC-B) is permitted to be used.

> "The junction box, transformer enclosure, or other enclosure in the supply circuit to a wet-niche or no-niche luminaire and the field-wiring chamber of a dry-niche luminaire shall be connected to the equipment grounding terminal of the panelboard. This terminal shall be directly connected to the panelboard enclosure." [3] [680.24(F)]
>
> "(a) If more than one underwater luminaire is supplied by the same branch circuit, the equipment grounding conductor, installed between the junction boxes, transformer enclosures, or other enclosures in the supply circuit to wet-niche luminaires, or between the field-wiring compartments of dry-niche luminaires, shall be permitted to be terminated on grounding terminals." [680.24(F)(2)(a)]
>
> "(b) If the underwater luminaire is supplied from a transformer, ground-fault circuit interrupter, clock-operated switch, or a manual snap switch that is located between the panelboard and a junction box connected to the conduit that extends directly to the underwater luminaire, the equipment grounding conductor shall be permitted to terminate on grounding terminals on the transformer, ground-fault circuit interrupter, clock-operated switch enclosure, or an outlet box used to enclose a snap switch." [4] [680.24(F)(2)(b)]

Section 680.23(B)(3) requires "wet-niche luminaires that are supplied by a flexible cord or cable shall have all their exposed non-current-carrying metal parts grounded by an insulated copper equipment grounding conductor that is an integral part of the cord or cable. This [equipment] grounding conductor shall be connected to a [equipment] grounding terminal in the supply junction box, transformer enclosure, or other enclosure. The [equipment] grounding conductor shall not be smaller than the supply conductors and not smaller than 16 AWG." [5]

Pool-Associated Motors for Permanently Installed Pools

All pool-associated motors for permanently installed pools must be connected to an equipment grounding conductor sized in accordance with Table 250.122 [see 680.21(A)(1)]. This equipment grounding conductor must be a copper conductor and cannot be smaller than 12 AWG. "Wiring methods installed in the corrosive environment described in 680.14 shall comply with 680.14(B) or shall be type MC cable listed for that location. Wiring methods installed in these locations shall contain an insulated copper equipment grounding conductor sized in accordance with Table 250.122 but not smaller than 12 AWG.

Where installed in noncorrosive environments, branch circuits shall comply with the general requirements in Chapter 3.."[6] The Type MC cable referenced will have an overall outer jacket of PVC material and an insulated equipment grounding conductor not smaller than 12 AWG. 9

Where flexible connections are necessary at or adjacent to the motor, liquidtight flexible metal or liquidtight flexible nonmetallic conduit with listed fittings are permitted."

Permanently installed pools are permitted to be provided with listed cord- and plug-connected pool pumps that are protected by a system of double insulation. They are to be provided with a means for grounding only the internal and nonaccessible non-current-carrying metal parts of the pump [680.21(B)].

Panelboard Grounding

Where a feeder is installed to a panelboard that serves pool equipment section 680.25(A) was revised in the 2017 *NEC* to align with other changes depending on if there is a corrosive environment or not. The new section states. "Where feeders are installed in corrosive environments as described in 680.14, the wiring method of that portion of the feeder shall be as required in 680.14(B) or shall be liquidtight flexible nonmetallic conduit. Wiring methods installed in corrosive environments as described in 680.14 shall contain an insulated copper equipment grounding conductor sized in accordance with Table 250.122, but not smaller than 12 AWG.

Where installed in noncorrosive environments, feeders shall comply with the general requirements in Chapter 3 (see fig. 16.13)

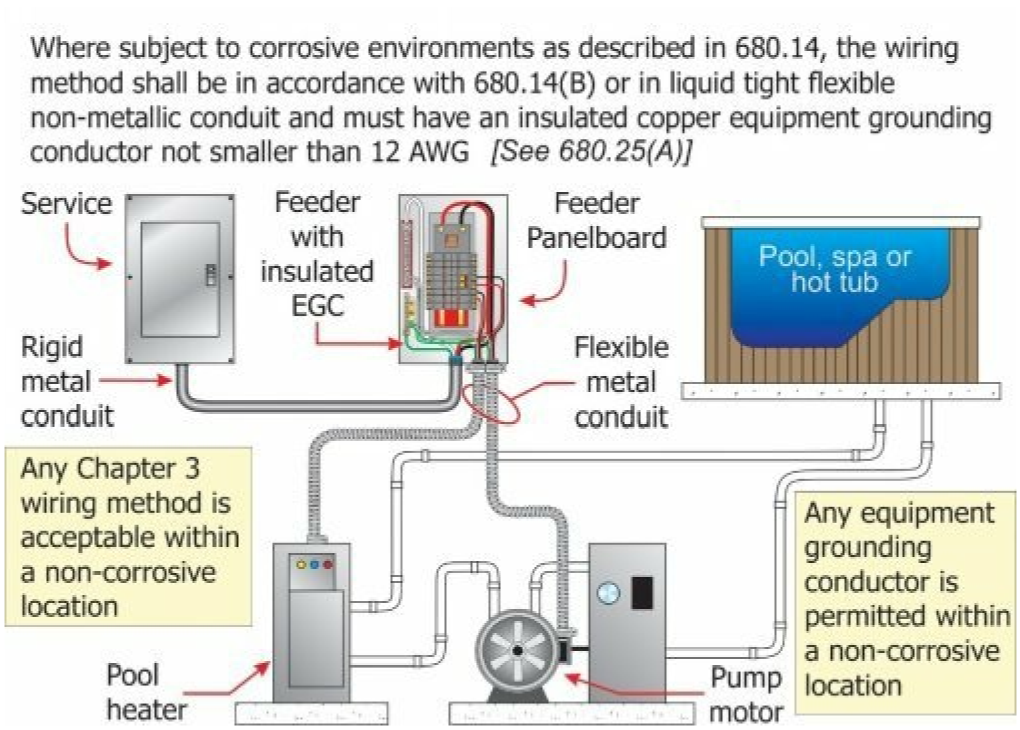


Figure 16.13 Grounding of pool-associated panelboards

As now permitted, electrical metallic tubing is allowed to be used to protect conductors where installed on or within buildings in accordance with Article 358 and where it is not a corrosive environment. Electrical nonmetallic tubing is permitted to be used to protect conductors where installed within buildings in accordance with Article 362. The equipment grounding conductor must be connected to an equipment grounding terminal of the panelboard and, where installed, to the enclosure for a disconnecting means.

Panelboards from Separately Derived Systems

There are several ways of grounding swimming pool panelboards that are supplied from a separately derived system. It is important to follow the rules for grounding the separately derived system as given in 250.30(A) and as covered extensively in chapter twelve.

Existing Panelboards

A change in the 2014 *NEC* deleted the exception to 680.25(A) in previous editions of the *NEC* that had allowed an existing feeder between an existing remote panelboard and the service equipment to be run in flexible metal conduit or an approved cable assembly that included an equipment grounding conductor within its outer sheath. During the 2014 cycle this was done with a TIA and reconfirmed during the 2017 *NEC* cycle. The equipment grounding conductor had to comply with 250.24(A)(5). With the removal of this exception the wiring methods to a remote panelboard would now have to comply with 680.25.

Swimming Pool Panelboards in Other Buildings

Grounding at the disconnecting means for remote buildings is covered in 250.32 and in chapter thirteen where the methods for complying with the code rules are given. For any new construction, 250.32(B) requires an equipment grounding conductor of one of the types identified in 250.118 to be installed with the feeder conductors.

For existing installations only, the limited exception to 250.32(B) permits the feeder grounded conductor to be used where (1) an equipment grounding conductor is not run with the supply to the building or structure, (2) there are no continuous metallic paths bonded to the grounding system in both buildings or structures involved, and (3) ground-fault protection of equipment has not been installed on the common ac service, the grounded circuit conductor run with the supply to the building or structure shall be connected to the building or structure disconnecting means and to the grounding electrode(s) and shall be used for grounding or bonding of equipment, structures, or frames required to be grounded or bonded." [7] Where an equipment grounding conductor is installed in accordance with 250.32(B), and is included with a feeder to a separate building, it must be an insulated conductor in accordance with 680.25(A).

Bonding Requirements (Equipotential Bonding)

Bonding requirements for pool areas are found in 680.26. Section 680.26(A) includes performance language relative to the purpose of bonding for these types of installations. The *Code* clarifies that the bonding required for the pool must “be installed to reduce voltage gradients in the pool area.” [described in the article]. Swimming pools, spas and hot tubs present special shock hazards to people due to mixing water enriched with chemicals, people and electricity together. Electric shock hazards will be reduced to an acceptable level if the measures prescribed in Article 680 are carefully followed. In addition, regular inspection and maintenance are required to ensure the installation maintains it integrity, especially where exposed to corrosive environments. One of these measures is the bonding together of conductive portions of the pool and metal parts of electrical equipment associated with the pool. The goal is to provide a means of equalizing the potential of all equipment and parts so there will be no current when a person provides a path between parts. This is accomplished by connecting all the parts together by an adequately sized and properly connected copper conductor. This concept is often referred to as equipotential bonding (see 680.26).

These requirements emphasize the purpose of bonding in a swimming pool, spa or hot tub area as that of equalizing the potential (voltage) between various parts of the pool. By keeping the potential difference as low as practicable, the shock hazard is reduced significantly.

Since several pieces of electrical equipment commonly used with pools, hot tubs or spas that are bonded together are required to also be grounded with an insulated equipment grounding conductor. At the service or at the source of a separately derived system, an interconnection between the grounded (neutral) conductor and bonding grid also exists, but this interconnection is often remote from the pool and is not intended to play a part in equipotential bonding.

The *Code* requires the conductive parts identified in 680.26(B)(1) through (B)(7) to be bonded together (see figure 16.14). The bonding can be accomplished using a solid 8 AWG copper conductor, insulated, covered, or bare, or rigid metal conduit that is made of brass or other corrosion-resistant material. All connections of the 8 AWG copper bonding conductor used in constructing the equipotential bonding grid are required to be accomplished using one of the methods specified in 250.8 [680.26(B)].

Section 680.26(B)(1) describes the differences between a conductive pool shell construction and pool shells that are nonconductive. This is important because bonding requirements are predicated under this differentiation.

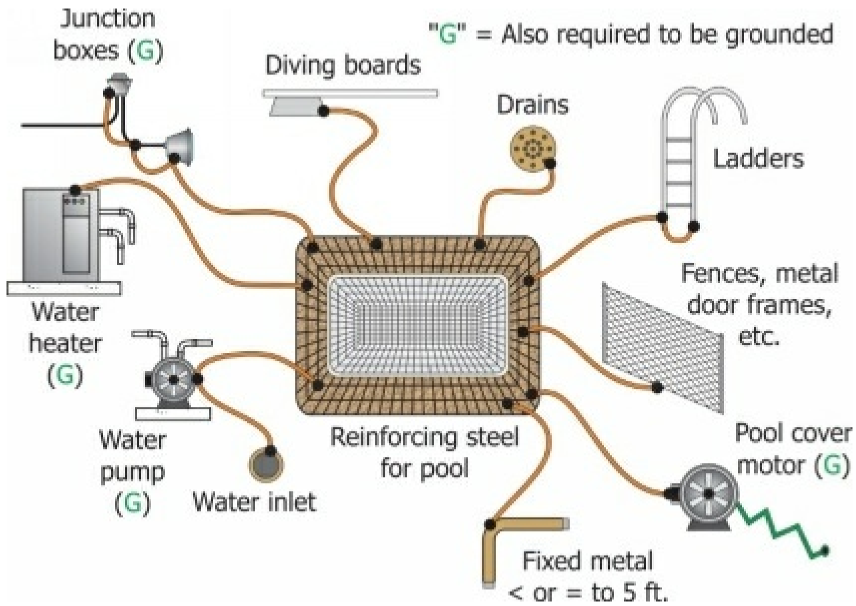


Figure 16.14 Equipotential bonding grid required

Conductive and Nonconductive Pool Shells

Poured concrete, pneumatically applied concrete, or painted concrete block are considered conductive because of their water permeability and porosity. Of course, metal pool frames such as those for many aboveground pools are also conductive and are required to be bonded. Pools that are made of fiberglass (usually prefabricated) or made of vinyl liners are considered nonconductive and more specific bonding requirements apply.

Where structural reinforcing steel for a conductive shell pool is not encapsulated in a nonconductive compound (bare or with conductive coating), the steel is required to be bonded together using the usual steel tie wires or the equivalent. This section recognizes both steel reinforcing rods or bars and wire mesh construction methods for equipotential bonding. Where the structural reinforcing steel of a conductive pool shell is encapsulated (coated rebar), a copper conductor bonding grid meeting the requirements in 680.26(B)(1)(b) must be installed in accordance with the following criteria (see figure 16.15):

- It is required to consist of a minimum 8 AWG solid copper conductor bonded together at points of crossing.
- It shall conform to depth contour of the pool.
- It is required to be in a 300 mm (12 in.) x 300 mm (12 in.) pattern (mesh) with a tolerance up to 100 mm (4 in.).
- It is required to be secured within or under the pool no more than 150 mm (6 in.) from the contour of the pool shell [680.26(B)(1)(b)]

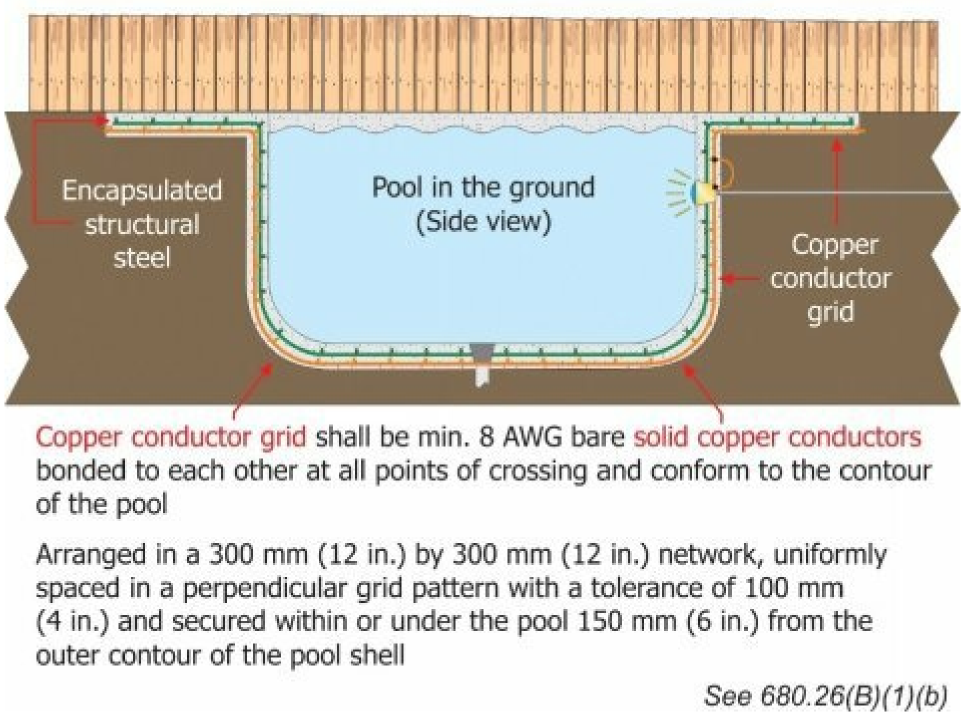


Figure 16.15 Where encapsulated reinforcing steel is installed, an equipotential bonding grid structure must be installed.

Bonding Grid at Perimeter Surfaces

The surface area at the pool perimeter extending 1 m (3 ft) horizontally beyond the inside walls of the pool including, but not limited to, unpaved, conductive and poured concrete surfaces shall be included in the equipotential bonding grid requirements in accordance with either 680.26(B)(2)(a) or (2)(b). The installed bonding grid at the perimeter surface is required to be attached to the pool reinforcing steel or copper conductor at a minimum of four locations at uniformly spaced corners of the structure. Structural reinforcing steel, including wire mesh in the deck surface is required to be bonded in accordance with 680.26(B)(1)(a) and where no structural reinforcing steel is installed in the perimeter surface an alternate means is required to be installed and must meet all of the following criteria:

- It must be made up of at least a single 8 AWG solid copper conductor.
- The conductor is required to follow the contour of the pool perimeter surface.
- Any splices of this single conductor or splices of conductors connecting to this single conductor must be made with a listed means [680.26(B)(2)(b)].

The single conductor must be installed 450 – 600 mm (18 in. – 24 in.) from the inside walls of the pool and secured within or under the perimeter surface 100 mm – 150 mm (4 in. – 5 in.) below the subgrade. Note that the term *subgrade* is not specifically explained in this section, but can be interpreted to mean “the earth surface that is located below a decorative surface such as pavers or decorative rock and so forth “(see figure 16.16).

Section 680.26(B)(3) through (B)(7) provides additional items that are required to be bonded to the equipotential bonding grid as follows:

(3) Metallic Components. All metallic parts of the pool structure, including the reinforcing metal not addressed in 680.26(B)(1)(a), shall be bonded. The usual steel tie wires shall be considered suitable for bonding the reinforcing steel (including wire mesh) together.

(4) Underwater Lighting. All forming shells and mounting brackets of no-niche luminaires shall be bonded, unless a listed low-voltage lighting system with nonmetallic forming shells not requiring bonding is used.

(5) Metal Fittings. All metal fittings within or attached to the pool structure shall be bonded. Isolated parts that are not over 100 mm (4 in.) in any dimension and do not penetrate into the pool structure more than 25 mm (1 in.) shall not require bonding.

(6) Electrical Equipment. Metal parts of electric equipment associated with the pool water circulating system, including pump motors and metal parts of equipment associated with pool covers, including electric motors, shall be bonded. Accessible metal parts of listed equipment incorporating an approved system of double insulation and providing a means for grounding internal nonaccessible, non-current-carrying metal parts shall not be required to be bonded. Where a double-insulated water-pump motor is installed under the provisions of this rule, a solid 8 AWG copper conductor that is of sufficient length to make a bonding connection to a replacement motor shall be extended from the bonding grid to an accessible point in the motor vicinity (see figure 16.17). Where there is no connection between the swimming pool bonding grid and the equipment grounding system for the

premises, this bonding conductor shall be connected to the equipment grounding conductor of the motor circuit. Pool heating equipment rated more than 50 amperes are required to be bonded to the gird, but also must meet any specific grounding and bonding instructions that are provided by the manufacturer. In this case, only specifically designated metal parts of such equipment are required to be bonded into the equipotential bonding grid [680.26(B)(6)].

(7) Metal Wiring Methods and Equipment. Metal-sheathed cables and raceways, metal piping, and all fixed metal parts that are within the following distances of the pool except those separated from the pool by a permanent barrier shall be bonded:

1. Within 1.5 m (5 ft) horizontally of the inside walls of the pool

2. Within 3.7 m (12 ft) measured vertically above the maximum water level of the pool, or any observation stands, towers, or platforms, or any diving structures [680.26(B)(7) Exceptions 1, 2, and 3].

Section 680.26(C) requires pool water to be bonded to the equipotential bonding grid. This bonding can be accomplished by conductive parts that are in contact with the pool water such as a wet-niche luminaire forming shell or stainless steel handrails or ladders in contact with the water (see photos 16.9 and 16.10). The minimum surface area of the conductive surface in contact with the pool water cannot be smaller than 5800 mm^2 (9 $in.^2$) [680.26(C)]. Where a nonconductive pool shell is installed, such as a prefabricated fiberglass pool, and no conductive parts are in contact with the pool water to bond the water to the grid, provisions must be made to bond the pool water to the gird. All of 680.26(C) was revised in the 2014 *NEC* to provide more clarity of the requirements.

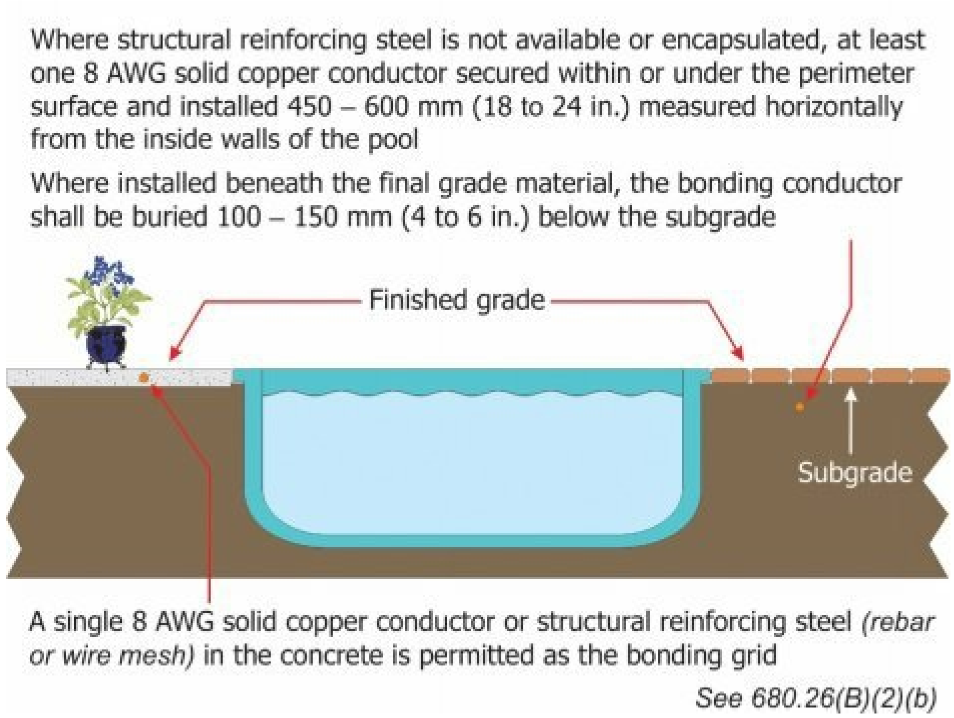


Figure 16.16 Equipotential grid installation for perimeter surfaces (non-conductive pool shell shown).

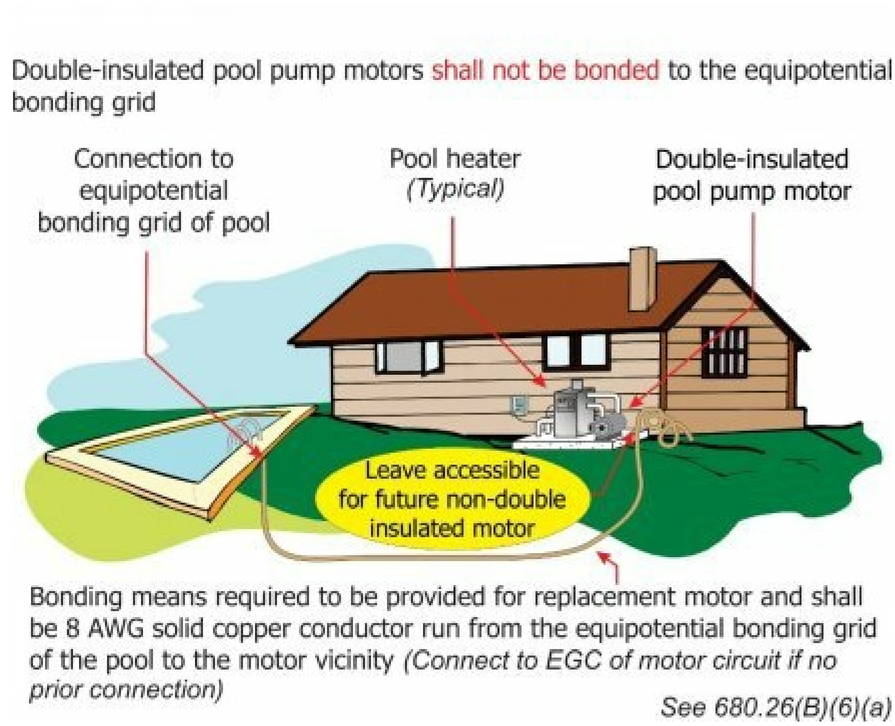


Figure 16.17 Bonding grid conductor routed to the double-insulated pool pump motor vicinity

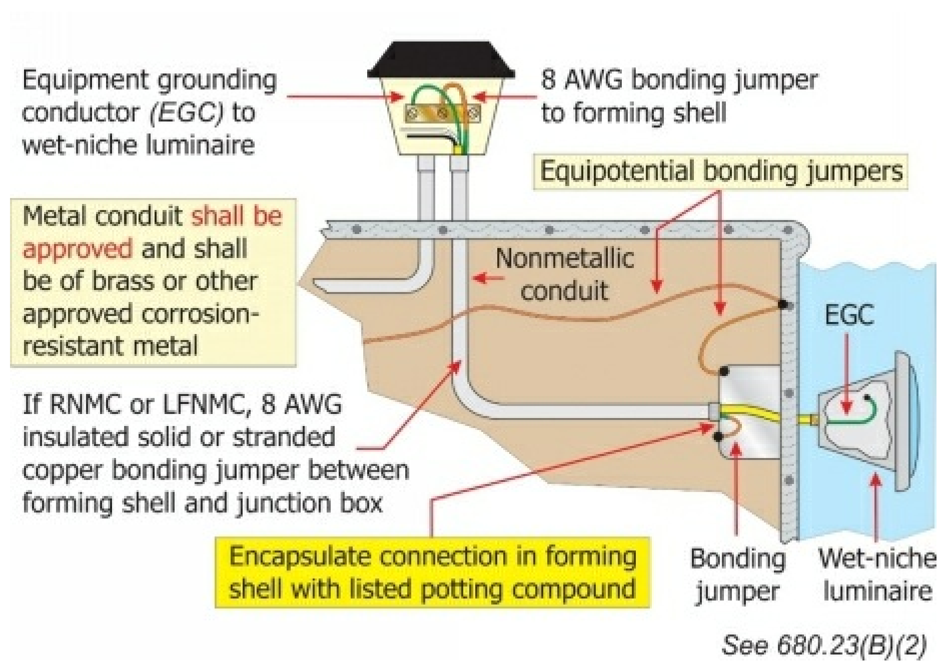


Figure 16.18 Bonding of forming shells of wet-niche luminaires is required.

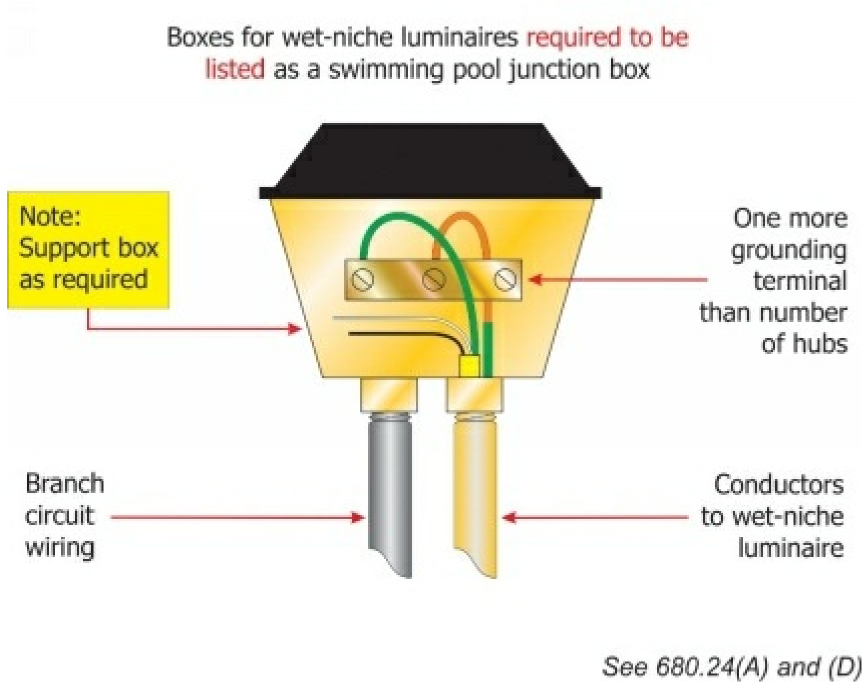


Photo 16.9 A forming shell of wet-niche luminaire provides the bonding means for the pool water.

Photo 16.10 A stainless steel handrail provides the bonding means for the pool water.

Bonding of Wet-Niche Luminaires

Where mounted in a pool or fountain structure, a wet-niche luminaire must be installed in a forming shell that is designed to support a wet-niche luminaire assembly. The luminaire unit will be completely surrounded by water [see definition of wet-niche luminaire in Article 680 and 680.23(B)(1)].

A forming shell must be installed for the mounting of all wet-niche underwater luminaires. The forming shell must also be equipped with provisions for threaded conduit entries.

Wiring methods permitted to be used to connect the forming shell to a suitable junction box or other permitted enclosure include rigid metal conduit, intermediate metal conduit, liquidtight flexible nonmetallic conduit or rigid PVC conduit [see 680.23(B)(2)].

Rigid metal or intermediate metal conduit used to connect the wet-niche fixture housing must be made of brass or other approved corrosion resistant metal, such as stainless steel.

Where rigid PVC or liquidtight flexible nonmetallic conduit is used, an 8 AWG insulated solid or stranded copper bonding jumper must be installed along with the pool flexible cord assembly so that it can be terminated on a suitable lug in the forming shell, junction box, transformer enclosure or ground-fault circuit-interrupter enclosure (see figure 16.18). This conductor is referred to as a bonding jumper in this section and the sizing must be 8 AWG copper minimum. This conductor performs as a bonding jumper to connect non-current-carrying electrical equipment together. Where a metallic raceway method is used from the junction box to the forming shell, the bonding of the two enclosures is accomplished through the metal conduit. An equipment grounding conductor is included in the cord assembly of the wet-niche luminaire for returning any line-to-ground fault current back to the source (see figure 16.19).

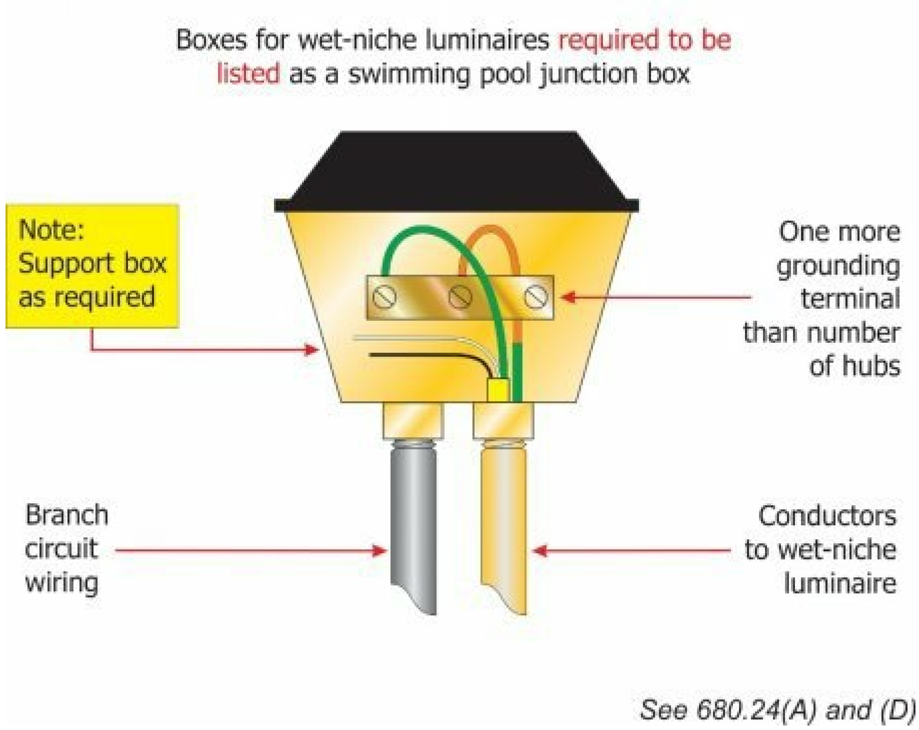


Figure 16.19 Junction boxes for wet-niche luminaires are required to be listed.

At the point of termination within the forming shell, the 8 AWG bonding jumper must be covered with, or encapsulated in, a listed potting compound [680.23(B)(2)(b)]. This compound provides protection from deteriorating effects often caused by the pool water. Where a listed potting compound is not used to encapsulate the 8 AWG bonding jumper inside the forming shell, brass or stainless steel conduit must be used between the pool junction box and the forming shell to eliminate the need for the bonding jumper.

Where in contact with the pool water, metal parts of the luminaire and forming shell must also be of brass or other approved corrosion-resistant metal. Forming shells used with nonmetallic conduit systems other than those that are part of a listed low-voltage lighting system not requiring grounding, include provisions for the termination of an 8 AWG copper conductor [see 680.23(B)(1)]. The end of the flexible cord jacket and flexible cord conductor terminations located within a wet-niche fixture must be covered with, or encapsulated in, a suitable potting compound. This will help to prevent the siphoning of water into the luminaire through the cord jacket or its contained conductors. This requirement is met by the manufacturer of the wet-niche luminaire. In addition, an equipment grounding conductor connection within a wet-niche fixture must be similarly treated to protect it from the deteriorating effect of pool water in the event of water entry into the luminaire.

The luminaire must be bonded to and secured to the forming shell by a positive locking device that will ensure a low resistance contact. A special tool is required to remove the luminaire from the forming shell. Bonding is not required for luminaires listed for the application, having no non-current-carrying metal parts.

Underwater wet-niche luminaires include markings that will indicate the proper housing or housings with which they are to be used, and the fixture housings are marked to indicate the fixture or fixtures with which the housings are to be used. These luminaires are provided with a factory-installed permanently-attached flexible cord that extends at least 3.7 m (12 ft) outside the luminaire enclosure. This will permit removal of the luminaire from the forming shell so that it can be lifted onto the pool or spa deck for servicing without lowering the water level or disconnecting the fixture from the branch-circuit conductors.

Luminaires with longer cords are available for installation where the junction box or splice enclosure is so located that a 3.7 m (12 ft) long cord will not permit the fixture to be removed from the forming shell and placed on the deck for servicing. To avoid possible cord damage, any cord length in excess of that necessary for servicing should be trimmed from the supply end rather than stored in the forming shell.

Listed Junction Boxes and Enclosures

Special requirements are contained in 680.24(A) for "a junction box connected to a conduit that extends directly to a forming shell or mounting bracket for a no-niche luminaire…

"(1) Construction. The junction box shall be listed as a swimming pool junction box and shall comply with the following conditions:

"(1) Be equipped with threaded entries or hubs or a nonmetallic hub

"(2) Be comprised of copper, brass, suitable plastic, or other approved corrosion-resistant material

"(3) Be provided with electrical continuity between every connected metal conduit and the grounding terminals by means of copper, brass, or other approved corrosion-resistant metal that is integral with the box." [8]

Section 680.24(D) requires that junction boxes have a number of grounding terminals that shall be at least one more than the number of conduit entries. For example, where there are two conduit entries, the grounding terminal bar is required to have not less than three terminals (see figure 16.19).

Installation of Luminaires over 15 Volts

The junction box or other suitable enclosure must be located not less than 100 mm (4 in.), measured from the inside of the bottom of the box or other enclosure, above the ground level or pool deck, or not less than 200 mm (8 in.) above the maximum pool water level, whichever provides the greatest elevation [see 680.24(A)(2)(a)]. It must also be located so that it is not less than 1.2 m (4 ft) from the inside wall of the pool unless it is separated from the pool by a solid fence, wall or other permanent barrier [see 680.24(A)(2)(b)]. If used on a lighting system operating at 15 volts or less, a flush deck box is permitted providing both of the following conditions are complied with:

"(1) An approved [*acceptable to the authority having jurisdiction, not listed or labeled*] potting compound is used to fill the box to prevent the entrance of moisture.

(2) The flush deck box is located not less than 1.2 m (4 ft) from the inside wall of the pool."[9]

Bonding of Spa or Hot Tub Installed Indoors

The following parts of a spa or hot tub are required by 680.43(D) to be bonded together:

"1) All metal fittings within or attached to the spa or hot tub structure

"2) Metal parts of electrical equipment associated with the spa or hot tub water circulating system, including pump motors unless part of a listed, labeled, and identified self-contained spa or hot tub.

"3) Metal raceway and metal piping that are within 1.5 m (5 ft) of the inside walls of the spa or hot tub and that are not separated from the spa or hot tub by a permanent barrier

"4) All metal surfaces that are within 1.5 m (5 ft) of the inside walls of a spa or hot tub and that are not separated from the spa or hot tub area by a permanent barrier.

Exception: Small conductive surfaces not likely to become energized, such as air and water jets and drain fittings, where not connected to metallic piping, towel bars, mirror frames, and similar nonelectric equipment, shall not be required to be bonded.

"5) Electrical devices and controls that are not associated with the spas or hot tubs and that are located not less than 1.5 m (5 ft) from such units; otherwise they shall be bonded to the spa or hot tub system." [10]

Methods of Bonding of Spa or Hot Tub Installed Indoors

680.24(E) states, "All metal parts associated with the spa or hot tub shall be bonded by any of the following methods:

"1) The interconnection of threaded metal piping and fittings

"2) Metal-to-metal mounting on a common frame or base

"3) The provisions of a solid copper bonding jumper, insulated, covered, or bare, not smaller than 8 AWG." [11]

Bonding Requirements for Hydromassage Bathtubs

As stated in 680.70 under Part VII, "Hydromassage bathtubs as defined in Article 680.2 are required to comply with Part VII of this article. They shall not be required to comply with other parts of this article".[12] This part has requirements for both GFCI protection and bonding of hydromassage bathtubs.

Hydromassage bathtubs and their associated electrical components must be protected by a GFCI. This GFCI is to be of the Class A type that trips at a range of 4 to 6 mA leakage. In addition, all 125-volt, single-phase receptacles within 1.83 m (6 ft) measured horizontally of the inside walls of a hydromassage tub must be protected by a GFCI(s) (see figures 16.31 and 16.32).

Section 680.74 was revised in the 2017 *NEC* with two requirements. The first in 680.74(A) is new and provides the general requirement for bonding and 680.74(B) is he revised requirements from previous codes. It should be noted that these requirements apply to dwelling units as well as to other than dwelling units.

> "680.74 (A) General. The following parts shall be bonded together:
>
> (1) All metal fittings within or attached to the tub structure that are in contact with the circulating water
>
> (2) Metal parts of electrical equipment associated with the tub water circulating system, including pump and blower motors
>
> (3) Metal-sheathed cables and raceways and metal piping that are within 1.5 m (5 ft) of the inside walls of the tub and not separated from the tub by a permanent barrier
>
> (4) All exposed metal surfaces that are within 1.5 m (5 ft) of the inside walls of the tub and not separated from the tub area by a permanent barrier
>
> (5) Electrical devices and controls that are not associated with the hydromassage tubs and that are located within 1.5 m (5 ft) from such units
>
> *Exception No. 1: Small conductive surfaces not likely to become energized, such as air and water jets, supply valve assemblies, and drain fittings not connected to metallic piping, and towel bars, mirror frames, and similar nonelectrical equipment not connected to metal framing shall not be required to be bonded.*
>
> *Exception No. 2: Double-insulated motors and blowers shall not be bonded.*
>
> (B) All metal parts required to be bonded by this section shall be bonded together using a solid copper bonding jumper, insulated, covered, or bare, not smaller than 8 AWG. The bonding jumper(s) shall be required for equipotential bonding in the area of the hydromassage bathtub and shall not be required to be extended or attached to any remote panelboard, service equipment, or any electrode. In all installations a bonding jumper long enough to terminate on a replacement nondouble-insulated pump or blower motor shall be provided and shall be terminated to the equipment grounding conductor of the branch circuit

of the motor when a double-insulated circulating pump or blower motor is used."[12]

With this change all metallic parts, cable armor, all electrical devices, even if not associated with the hydromassage tub are now required to be bonded with some limited exceptions as stated above. (see figure 16.20 and Photo 16.11). Where the pump motor is double insulated, the 8 AWG copper bonding conductor must be connected to the pump motor branch circuit equipment grounding conductor. Note that this bonding jumper is not required to be routed to any panelboard, service equipment, or grounding electrode because it is for equipotential bonding purposes in the hydromassage bathtub vicinity (680.74).

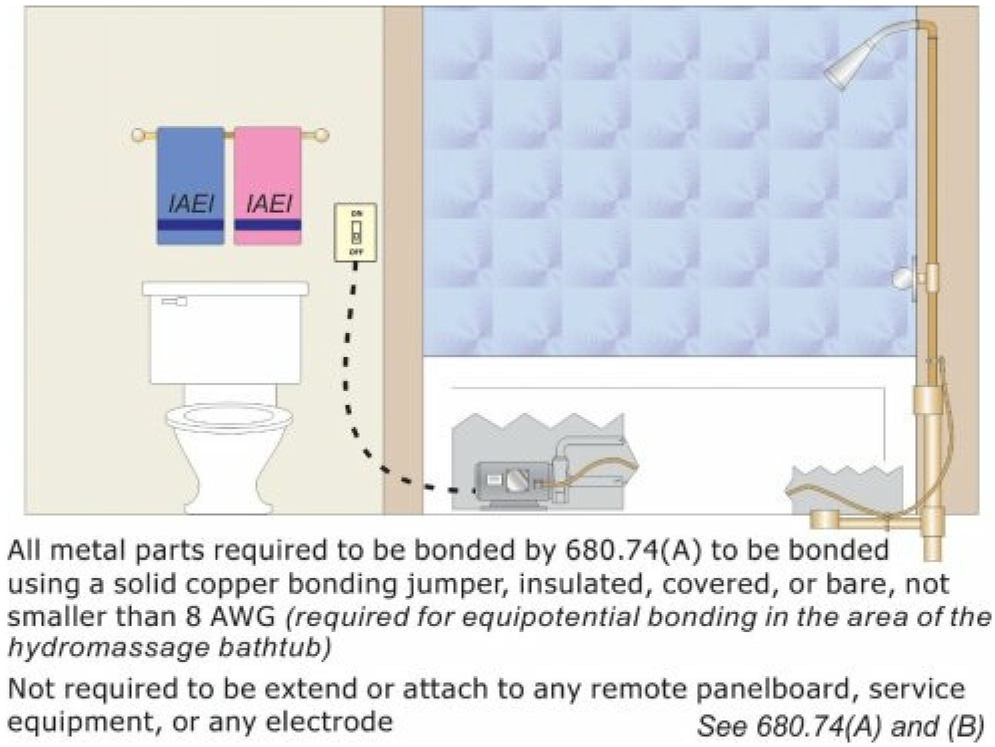


Figure 16.20 Bonding requirements for hydromassage bathtubs exclude double insulated pump motors.

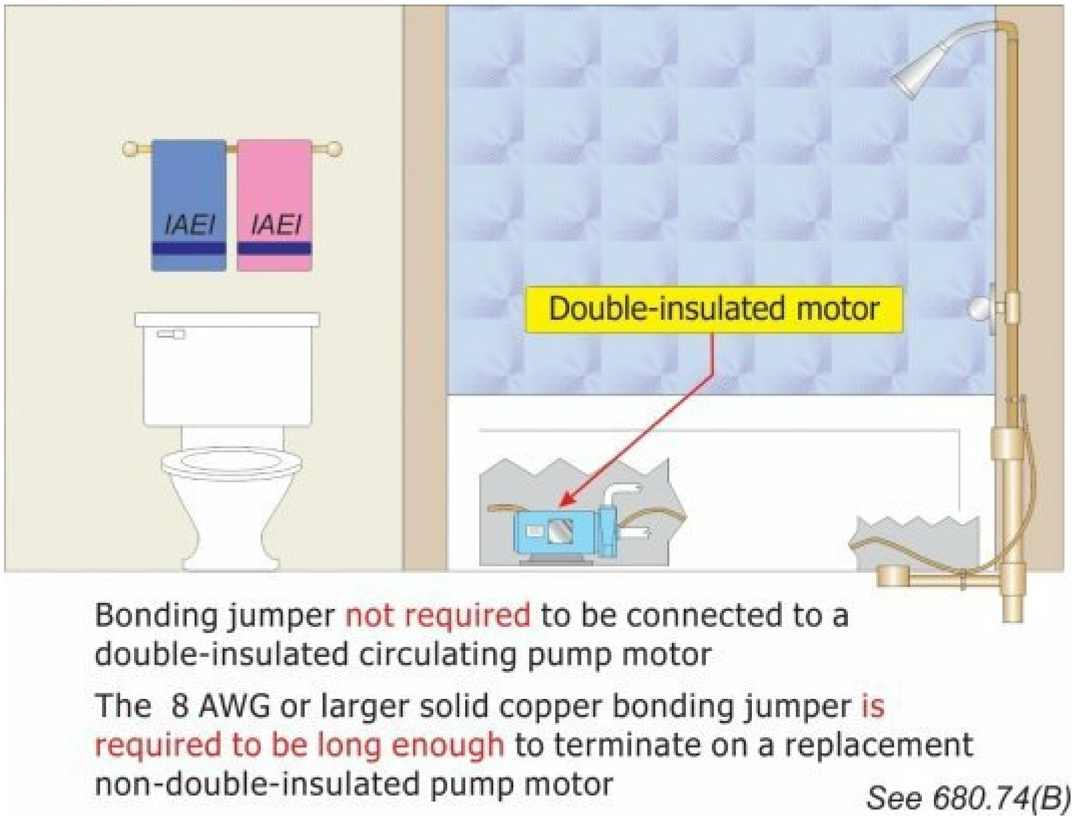


Figure 16.21 Bonding jumper not required to be connected to a double-insulated circulating pump motor.

Photo 16.11 bonding of hydromassage bathtubs

[1 - 12] NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA, © 2016)

Review Questions

1. In addition to the requirements found in Article 600, grounding and bonding for signs must also comply with ______.

    1. Article 200
    2. Article 250
    3. Article 410
    4. Article 725

2. The devices suitable for connecting grounding and bonding conductors are found in _____.

    1. Section 600.7
    2. Section 250.120(A)
    3. Section 250.8
    4. Section 250.134(A)

3. Metal equipment of electric signs and ___ shall be grounded by connection to an equipment grounding conductor.

    1. all line-side equipment
    2. electrode receptacle housings
    3. metal equipment of outline lighting and skeleton tubing
    4. electrical-discharge tubing

4. Where flexible nonmetallic conduit is used on the high voltage secondary circuit (100 Hz or less) of a sign transformer, any separate bonding conductor installed to bond metal parts must be ____.

    1. installed inside the conduit
    2. not more than 1.8 m (6 ft) long
    3. installed separate and remote from the nonmetallic conduit and spaced not less than 38 mm (1 ½ in.) from the conduit
    4. listed GTO cable

5. Listed flexible metal conduit that is used to enclose the secondary wiring of a sign transformer is permitted as the bonding means for total accumulative lengths not exceeding ____.

    1. 1.8 m (6 ft)
    2. 7.5 m (25 ft)
    3. 15 m (50 ft)
    4. 30 m (100 ft)

6. Which of the following methods is not permitted for connecting equipment grounding conductors or bonding conductors for electric signs and outline lighting systems ____?

1. a listed pressure connector
2. a sheet metal screw
3. a pressure connector listed as grounding and bonding equipment
4. machine screw-type fasteners that engage not less than 2 threads or are secured with a nut

7. Small associated metal parts not exceeding _____ in any dimension and not likely to become energized and spaced at least ___ from neon tubing are not required to be bonded.

1. 1 inch; ¾ inch
2. 2 inch; 1 inch
3. ¾ inch; 2 inch
4. 2 inch; ¾ inch

8. Metal parts of signs supplied by a remote Class 2 transformer or power supply (driver) are required to be bonded by a ________.

1. 16 AWG copper conductor
2. 14 AWG copper conductor
3. 12 AWG copper conductor
4. bonding is not required

9. Equipment in the vicinity of swimming pools must be bonded together with an 8 AWG or larger solid copper conductor. This also includes metal raceways and cables, piping and fixed metal parts within ____ horizontally or ____ vertically of the pool, observation stands, towers, platforms or diving structures.

1. 1.5 m (5 ft) – 5.5 m (18 ft)
2. 1.8 m (6 ft) – 6.0 m (20 ft)
3. 1.5 m (5 ft) – 3.7 m (12 ft)
4. 2.7 m (9 ft) – 4.3 m (14 ft)

10. An equipotential bonding grid at a conductive pool shell is permitted to be the structural reinforcing steel of a concrete pool, the wall of a bolted or welded pool, or a(n) ____ AWG or larger, bare, solid copper conductor grid.

1. 8
2. 6
3. 4

4. 2

11. The conductive rebar for the shell of an in-ground swimming pool shall be used as a grounding electrode for the premises wiring system.

1. True
2. False

12. A dry-niche luminaire, other than listed low voltage luminaires not requiring grounding, is required to be provided with a provision for the drainage of water and a means for accommodating ____ equipment grounding conductor(s) for each conduit entry.

1. 1
2. 2
3. 3
4. 0 or none

13. Where metal conduit is used to supply a ____ niche luminaire, it is required to be of brass or other approved corrosion-resistant metal.

1. hard-
2. wet-
3. no-
4. metal-

14. A wet-niche luminaire is required to be bonded to and secured to the forming shell by a positive locking device that assures a low-resistance contact and requires a ____ to remove the luminaire from the forming shell.

1. tool
2. permit
3. fitting
4. helper

15. Pool water of an in-ground permanent swimming pool is required to be bonded to the equipotential bonding grid ____.

1. True
2. False

⏚ Chapter 17
Grounding and Bonding for Alternate Energy Systems

Objectives to understand...

- The move to alternate energy systems
- Alternate energy systems – separately derived or not separately derived
- The neutral conductor
- Grounding and bonding alternate energy systems as stand-alone systems
- Parallel operation with serving utility – grid interconnected systems
- Grounding and bonding for different alternate energy systems

This chapter looks at grounding and bonding requirements for alternate energy systems found in the NEC. The whole area of alternate energy systems and distributed generation is growing at a very rapid pace both in terms of advancing technology and also the number of installations completed or underway. This rapid growth in the technology and rapid construction has created some challenges to ensure proper grounding and bonding.

The basic demand is to offset major capital investments of large power generating plants and the associated transmission system that are very expensive and take years to get permitted and then constructed. These alternate energy or distributed generation systems can include engine generators, hydroelectric generation, photovoltaic, wind, fuel cell, battery / converter energy storage systems and new technologies still under development. There are many common requirements when considering the grounding and bonding of these systems whether stand alone or connected in parallel with the utility power grid. These common requirements as well as those that are specific to a particular type of alternate energy system will be covered in this chapter.

To begin, it is important to note the organization of the *NEC*. Section 90.3 sets out the organization of the *NEC*. Generally, the requirements in Chapters 1 to 4 apply everywhere except where modified or expanded in Chapter 5, Special Occupancies; Chapter 6, Special Conditions; or Chapter 7, Special Systems. It is also noted that section 90.3 was modified in the 2017 *Code* cycle to also state there are relationships between chapters 5, 6 and 7 that apply except as specified within one of these chapters and some of this will apply with alternate energy systems. For all those involved in the rapid movement to alternate energy systems, this must be understood that not all the requirements in within the single article that may be titled for that type of system. These specific articles are only the additions or modifications to the basic requirements found elsewhere in the *Code*. This chapter will provide discussion on those modifications and expansions to the basic requirements relative to grounding and bonding found in Article 250.

Definitions

Interactive System. An electric power production system that is operating in parallel with and capable of delivering energy to an electric primary source supply system

Interactive Inverter. An inverter intended for use in parallel with an electric utility to supply common loads that may deliver power to the utility.

Separately Derived System. An electrical source, other than a service, having no direct connection(s) to circuit conductors of any other electrical source other than those established by grounding and bonding connections.

Service. The conductors and equipment for delivering electric energy from the serving utility to the wiring system of the premises served."

Stand-Alone System. A system that supplies power independently of an electrical production and distribution network.

Alternate Energy and Distributed Generations Systems

As new energy generation construction costs, regulatory requirements, and energy demand have all grown, alternatives are being sought and implemented. The concept of someone providing some or all of the power that an individual needs are not new, but in the past where inexpensive power and convenience existed, choosing alternatives was not done or was done only for personal philosophical reasons. Today, there are multiple options growing in popularity and/or dictated by government regulations or incentives. These include photovoltaic systems (PV) [Article 690], fuel cells [Article 692], wind generation [Article 694] energy storage systems [Article 706], co-generation using natural gas or process steam, solar-thermal, and small hydro, these last few technologies which do not have a specific *NEC* article.

These systems can be installed to provide power "off grid," meaning they are stand alone and may include some means for energy storage (batteries) to make up for when the main power generating source is not available, or not sufficient for the immediate demand. Examples of stand along systems include PV-powered homes with no connection to any utility, PV-powered signs such as flashing light traffic warning or directional or alerting signs. Many of these, using energy efficient LED technology, are finding great popularity in school zones warning of reduced speed limits and even providing radar feedback of a driver's actual speed (see photo 17-1). Another example is wind generation that has been used for many years on farms and similar locations to operate irrigation pumps and other equipment remote from traditional power sources. There are several cases where a combination PV and Wind mobile trailer provides power for security cameras and a transmitter so that remote or isolated areas can be monitored and take advantage of having either the sun or a source of wind to provide power with some storage using batteries. Another technology gaining popularity and cost reduction is fuel cells in various sizes taking a fuel such as hydrogen or natural gas and through chemical reaction generate electric power with water being the byproduct. These systems also can stand alone.

Photo 17.1 PV-powered school zone sign

Another method of installation is to interconnect the alternate power generation system or in some cases multiple systems to the utility power grid. This interconnection will either reduce the amount of power being drawn from the grid or even possibly export power to the utility under a power sales agreement. In the past few years, very large privately owned PV, solar-thermal, and wind generation plants have been constructed solely to sell power to the utility power grid.

Whether a homeowner adds a small PV, fuel cell, or wind system, or larger systems are constructed, grounding and bonding of these sources of power and related equipment needs to be addressed. The foundation requirements start with the *NEC* in Article 250.

Separately Derived System or Not?

One of the first items to determine is if the alternate energy system is a separately derived system. Note, that since these systems are privately owned, they are not considered as *services* as defined in Article 100 because they are not power supplied by the utility or systems. In addition, the privately-owned systems, even those built just as power production plants, are not wholly owned and controlled by the utility, therefore they do fall under the requirements of the *NEC*.

The definition of "service" given above is very important because the requirements for services in Article 230 and related requirements in Chapters 1 to 3 do not apply to these installations. Stand alone "off grid" systems are very likely separately derived, therefore the grounding and bonding requirements in 250.20, 250.26, 250.30 and other sections would apply. Depending on the type of system, PV, fuel cell, wind, or energy storage systems, some of these grounding and bonding requirements are supplemented or modified in Articles 690, 692, 694 and 706 respectfully.

For grid interconnected systems, these are not separately derived systems since there is a direct connection of circuit conductors from the alternate energy system to the utility gird. To be clear, the DC generated by a PV or wind system to the grid interactive inverter may very well be a separately derived system and installation grounding and bonding requirements are provided accordingly. Using the definition of *separately derived system* above, the grid interactive inverter feeder output that is connected directly to the ungrounded (phase) conductors and sometimes a grounded (neutral) conductor by the definition is not a separately derived system and the grounding and bonding requirements applicable for this part of the installation are provided in Articles 250 and 705.

Stand Alone Systems

As defined and briefly discussed above as stand-alone system is one where one or more alternate energy sources are installed to supply power to premises wiring or specific equipment. These are then treated as separately derived systems and follow the requirements from *NEC* 250.30(A). If the system is required to be grounded, in accordance with 250.20(B), or chosen to be grounded under 250.21, then the steps and requirements for completing the grounding and bonding follow 250.30(A) for grounded systems. If the choice is to have an ungrounded system as permitted under 250.20(B) or 250.21, then the requirements given in 205.30(B) are applicable.

It needs to be noted that while it may appear to be one system, many alternate energy sources, such as typical photovoltaic systems, may in fact be two systems. The photovoltaic system, that will be discussed in more detail later in this chapter, has two major parts. One is the photovoltaic cells and modules providing DC voltage and current and are assembled together in a matrix of parallel and series connections to achieve the desired DC voltage and current as well as the resulting power. This DC is then changed into AC with the inverter. The inverter takes in the DC power and creates an AC output at a given voltage, and frequency. This is a "new" system and again would be considered separately derived. The simplest installation may be the single stand-alone luminaire or sign as shown in photo 17.1. Conversely the installation can be quite complex where several alternate energy sources are being applied to a building or structure with extended distribution. Lastly, it is common for the stand-alone systems to include a means of energy storage to provide for power to the loads being served when the alternate energy source is unable to produce power. For example, with PV, when it is dark outside and there is insufficient light energy to support the photovoltaic cells.

For any of these installations this means that a grounding electrode or grounding electrode system meeting Part III of Article 250 is required to be used or installed. The grounding electrode conductor is required to go to the equipment as the source or optionally the main disconnect and would be connected to a neutral conductor if one is provided. Otherwise the grounding electrode conductor is connected to the equipment grounding terminal or bus at the source or the first disconnect. Equipment grounding follows 250.120 and 250.122 as well as any additional modifications or requirements found in the respective articles for the particular alternate energy system.

Grid Connected Systems

The grid connected alternate energy systems will have an appearance very much like a stand-alone system with the energy source, an inverter or converter, disconnects and similar equipment. What is different is that the output power is connected in some manner in parallel with the utility power supply. The aspects of the alternate energy source, such as the DC side of the PV system example above, have the same requirements for treating as a separately derived system as done with the stand-alone system. The main difference is on the AC side where there is interconnection with the utility. From a grounding and bonding standpoint for the derived system a grounding electrode conductor is required to be installed to the inverter or alternate source neutral conductor at the main AC disconnect, if there is one, or to the equipment enclosure if there is no neutral. The grounding electrode used is generally the same electrode there for the building electrical service supply.

The primary article in the *NEC* for this is Article 705, Interconnected Electric Power Production Sources. This article applies for any alternate energy source, not just photovoltaic, wind, fuel cells, etc. One of the first items noted in Article 705 is section 705.6 for equipment approvals. This was revised in the 2017 edition to now read as follows:

> "**Equipment Approval**. All equipment shall be approved for the intended use. Interactive inverters for interconnection to systems interactive equipment intended to operate in parallel with the electric power system including, but not limited to, interactive inverters, engine generators, energy storage equipment, and wind turbines shall be listed and or field labeled for the intended use of interconnection service."

Approval, by definition, is acceptable to the Authority Having Jurisdiction. This section goes on to require those items directly connected, such as the grid interactive inverter, any direct source like wind or engine generators, to be listed or field evaluated. This is critical as the product safety standards from UL, CSA and IEEE for the power interconnection have significant safety requirements to protect the utility grid as well as the alternate energy system while in normal and also where abnormal conditions occur. One of these protections is anti-islanding which means if the utility power grid were to fail (have an outage) then the alternate energy system must automatically turn off the output power to the grid to minimize and hazards that could be presented to utility workers making repairs to lines or equipment.

In recent years, some larger power production alternate energy plants have agreements and other protections with the utility to allow local islanding or some support of the grid during a utility outage or undervoltage condition. Again, these inverters or alternate energy systems need to be verified by listing as being suitable to operate safely under these conditions.

The main section in Article 705 that affects grounding and bonding is Section 705.12. Section 705.12 permits the connection of the alternate energy system to either the load side of the service disconnect or to the line side as follows.

> **705.12 "Point of Connection**. The output of an interconnected electric power source shall be connected as specified in 705.12(A) or (B).

> **(A) Supply Side**. An electric power production source shall be permitted to be connected to the supply side of the service disconnecting means as permitted in 230.82(6). The sum of the ratings of all overcurrent devices connected to power production sources shall not exceed the rating of the service.
>
> **(B) Load Side**. The output of an interconnected electric power source shall be permitted to be connected to the load side of the service disconnecting means of the other source(s) at any distribution equipment on the premises. Where distribution equipment, including switchgear, switchboards, or panelboards, is fed simultaneously by a primary source(s) of electricity and one or more other power source(s), and where this distribution equipment is capable of supplying multiple branch circuits or feeders, or both, the interconnecting provisions for other power sources shall comply with 705.12(B)(1) through (B)(5)."

Where the connection is made on the load side the concern is that the common bus can become overloaded and not have protection. For example, assume there is a 30 circuit 200 ampere rated panelboard with a 200 ampere main breaker. If all 30 branch circuits are rated 20 amperes, the sum of that load would be 600 amperes before any of the branch circuits would perceive there is an overload. The 200 ampere main breaker works to protect the 200 ampere busbar at its rated ampacity thereby limiting the overload from happening. Now let's assume we have another source connected on the load side of the main to the same busbar. If this source were capable of producing 100 ampere, then when all the branch circuits are loaded to rating at 600 ampere there are now 300 amperes available to the busbar before the utility main breaker and the alternate source supply breaker would notice an overload conditions. This is the danger from load side connections and the background on why there are limits as detailed in 705.12(B)(1) to (B)(5) for the alternate source connection.

Where the connection is made to the line side of the main overcurrent device, the main breaker provides the protection to the main bus since all the power to the loads must pass through it. The only limits then to the size of the alternate source is the ampacity of the service entrance conductors where the interconnection is made. This then allows for larger systems to be installed and more gain from the investment into installing the alternate energy system. While the *Code* is very clear that the AC disconnect from alternate source to the premises service is not a "service", from a grounding and bonding standpoint this installation needs to be treated as if it was another service disconnect. What has to be considered is that the conductor from the line side connection to the AC disconnect are very much like service entrance conductors. Also, consider that while power will flow from the alternate energy system to the utility system under normal conditions, under ground fault conditions, for example at the inverter, the fault current is supplied by both the utility and the alternate source system. In fact, the utility fault current contribution will typically much greater than what is supplied from the alternate source. For the ground fault condition, there also must be a low impedance path back from the fault to the supply system, therefore a neutral conductor sized to Table 250.102(C)(1) is required for this fault current path. The following points then need to be considered for this interconnection on the line side of the service disconnect:

- There must be a low impedance ground fault return path that is accomplished by installing a neutral conductor sized at least to Table 250.102(C)(1) to the alternate energy AC disconnect.

- The disconnect and overcurrent protection for the alternate energy system is required to be within 10 feet of the connection to the line side of the service in accordance with 705.31 unless suitable cable limiters are installed.
- If these conductors are installed in a metal raceway, grounding and bonding is required to be in accordance with 250.92(B) for service raceways.
- Where there is the neutral and/or metal raceway, a separate supply side bonding jumper should not be installed, otherwise a parallel path for any normal neutral current may be provided.
- The AC disconnect should have the grounding electrode conductor installed to it and the neutral bus within the AC disconnect shall be bonded to the enclosure. One change in the 2017 *NEC* in 690.13(C) was to require the AC disconnect to be rated as "Suitable for Use as Service Equipment" or SUSE.

A last comment is where there may be multiple alternate energy systems that work together and come to a single point, these should be viewed as a single separately derived system for grounding and bonding purposes. For example, a recent installation had an approximately 2 megawatt roof mounted photovoltaic system with 30 inverters located around the roof area. The AC output of these inverters were connected to several 400 ampere panelboards which in turn had feeders that terminated onto the bus of a 1600 ampere fused switch that was the AC disconnect for the photovoltaic system. All the feeders to the 400 ampere panelboards and the branches to each inverter had a correctly sized neutral conductor and properly sized equipment grounding conductors included. For grounding and bonding of this large separately derived system, the best place to complete this was at the 1600 ampere disconnect for single point grounding of the neutral.

Photovoltaic Systems – Article 690

Article 690 has undergone extensive changes in the last few *Code* cycles, including the 2017 cycle, as this type of system has developed to become more economical and gained much more widespread use in many varied installation applications. As Article 690 evolved, so did the grounding and bonding requirements. In addition to the requirements found in Article 250, the additional or modified grounding and bonding requirements for PV systems are found in Part V of Article 690. Before going to the Part V changes there are several other changes in the 2017 *Code* that affect the grounding and bonding for PV systems.

One change found in 690.2 was the introduction and definition of the term "functional grounded PV system". This term is defined as "A PV system that has an electrical reference to ground that is not solidly grounded" and it will be important to note this when making installations.

Two other changes of note happened in 690.31. First, in 690.31(B)(1) the change was that the dc source conductor identification only needs to be white when the system is truly solidly grounded. So, for other than solidly grounded systems complying with 690.41(A)(5), the identification of the "functionally grounded conductor" shall be permitted by other means. The second item is in 690.31(D) for multiconductor cables. These are commonly used to take the power from a group of PV modules in a part of the array to a combiner box and typically are installed in cable tray or a wireway. The previous code required that each multiconductor cable include a full-sized equipment grounding conductor within each cable even when installed in the wireway or cable tray that qualified as an equipment grounding conductor. If the installation had used individual conductors, the *NEC* would allow a single wire type equipment grounding conductor, the cable tray or wireway if they were suitable per 250.118. The 2017 change now requires that the multiconductor cable be "listed and identified for the application". The presumption is that if listed and identified for the application the internal equipment grounding conductor would not be provided since the application in cable tray or wireway would be suitable.

As stated earlier, Part V of Article 690 provides the grounding and bonding requirements. Section 690.41 starts out with requirements for "system" grounding. This section discusses different scenarios as follows:

> "(A) **PV System Grounding Configurations**. One or more of the following system grounding configurations shall be employed:
>
> (1) 2-wire PV arrays with one functional grounded conductor
>
> (2) Bipolar PV arrays according to 690.7(C) with a functional ground reference (center tap)
>
> (3) PV arrays not isolated from the grounded inverter output circuit
>
> (4) Ungrounded PV arrays
>
> (5) Solidly grounded PV arrays as permitted in 690.41(B) Exception
>
> (6) PV systems that use other methods that accomplish equivalent system protection in

accordance with 250.4(A) with equipment listed and identified for the use."

It is noted the last item, (6) allows alternatives for system grounding as long as the performance requirements found in 250.4(A) for grounded systems are met.

Section 690.42 states where ground fault protection is provided and where the system has ground-fault protection as required or permitted in 690.41(B), then the required system grounded conductor to ground connection is to be made through the ground-fault protective device. If this bonding connection is inherent within the ground-fault protective device, then it shall not be duplicated with another connection elsewhere in the system. Otherwise for solidly grounded PV system this section permits the dc system grounding to be completed at any single convenient location in the system. The most common location for this dc system grounding is at the inverter (see figure 17.1).

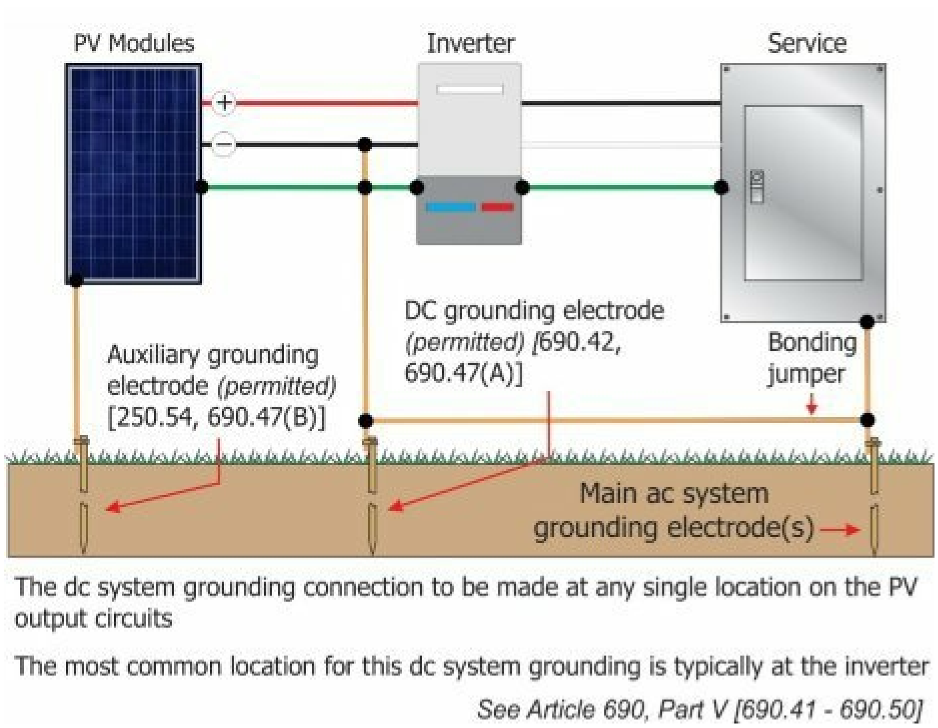


Figure 17.1 Grounding of PV output circuits of the dc system.

As shown in figure 17.1, and as required by 690.43, all equipment frames and enclosures, modules, combiner boxes, junction boxes, metallic raceways, disconnect enclosures and the inverters are to be connected together by equipment grounding conductor(s). The prescriptive requirements from 690.43 refer back to the requirements found in 250.134, and 250.136(A). Sections 690.43(A), (B), and (C) had extensive revisions to have specific requirements for using the framework and specially listed devices to achieve bonding of the various parts and these bonded parts become part of the equipment grounding path (see figure 17.2).

690.43 "(A) Photovoltaic Module Mounting Systems and Devices. Devices and systems used for mounting PV modules that are also used for bonding module frames shall be listed, labeled, and identified for bonding PV modules. Devices that mount adjacent PV modules shall be permitted to bond adjacent PV modules.

(B) Equipment Secured to Grounded Metal Supports. Devices listed, labeled, and identified for bonding and grounding the metal parts of PV systems shall be permitted to bond the equipment to grounded metal supports. Metallic support structures shall have identified bonding jumpers connected between separate metallic sections or shall be identified for equipment bonding and shall be connected to the equipment grounding conductor.

(C) With Circuit Conductors. Equipment grounding conductors for the PV array and support structure (where installed) shall be contained within the same raceway, cable, or otherwise run with the PV array circuit conductors when those circuit conductors leave the vicinity of the PV array."

The requirements for sizing of the equipment grounding conductor for PV systems are found in 690.45. The sizing utilizes Table 250.122 based on overcurrent device rating and provisions are also given for when there is no overcurrent protection device ahead of the equipment grounding conductor.

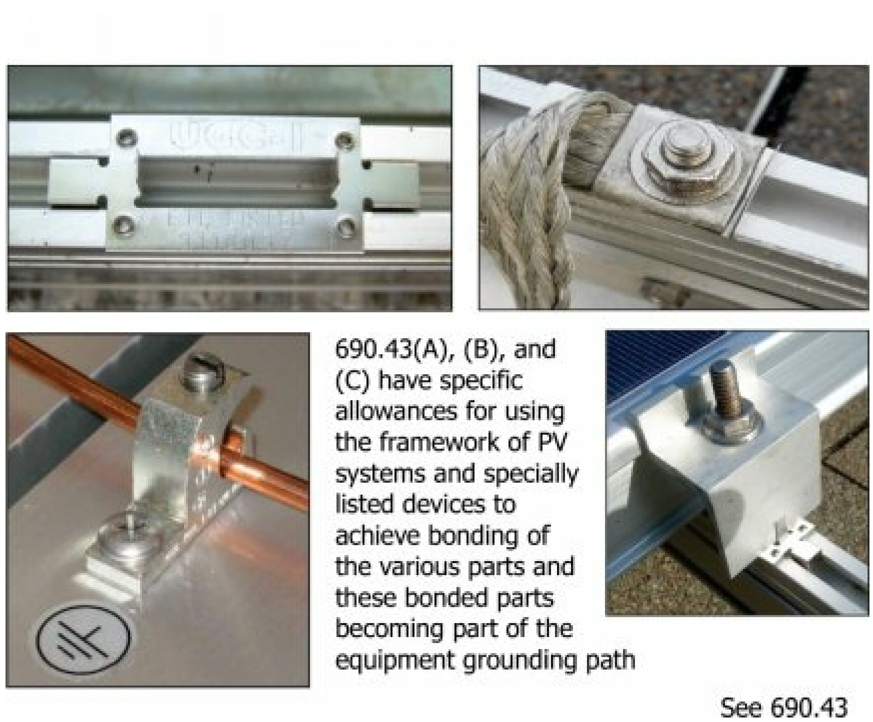


Figure 17.2 PV equipment grounding connectors and devices

The grounding electrode system requirements are found in 690.47 which also had extensive revisions as shown below.

"690.47 Grounding Electrode System.

"(A) Buildings or Structures Supporting a PV Array. A building or structure supporting a PV array shall have a grounding electrode system installed in accordance with Part III of

Article 250.

PV array equipment grounding conductors shall be connected to the grounding electrode system of the building or structure supporting the PV array in accordance with Part VII of Article 250. This connection shall be in addition to any other equipment grounding conductor requirements in 690.43(C). The PV array equipment grounding conductors shall be sized in accordance with 690.45.

For PV systems that are not solidly grounded, the equipment grounding conductor for the output of the PV system, connected to associated distribution equipment, shall be permitted to be the connection to ground for ground-fault protection and equipment grounding of the PV array.

For solidly grounded PV systems, as permitted in 690.41(A) (5), the grounded conductor shall be connected to a grounding electrode system by means of a grounding electrode conductor sized in accordance with 250.166.

Informational Note: Most PV systems installed in the past decade are actually functional grounded systems rather than solidly grounded systems as defined in this *Code*. For functional grounded PV systems with an interactive inverter output, the ac equipment grounding conductor is connected to associated grounded ac distribution equipment. This connection is often the connection to ground for ground-fault protection and equipment grounding of the PV array.

(B) Additional Auxiliary Electrodes for Array Grounding. Grounding electrodes shall be permitted to be installed in accordance with 250.52 and 250.54 at the location of ground and roof-mounted PV arrays. The electrodes shall be permitted to be connected directly to the array frame(s) or structure. The grounding electrode conductor shall be sized according to 250.66. The structure of a ground-mounted PV array shall be permitted to be considered a grounding electrode if it meets the requirements of 250.52. Roof mounted PV arrays shall be permitted to use the metal frame of a building or structure if the requirements of 250.52(A)(2) are met."

"**690.50 Equipment Bonding Jumpers**. Equipment bonding jumpers, if used, shall comply with 250.120(C)."

These changes simplified some of the requirements and clarified others. In general, the PV modules, mounting frames and other metal parts shall be connected to earth either by the equipment grounding conductor through the ground fault protective device or for solidly grounded systems by a grounding electrode conductor connected to the building or structure grounding electrode system. Where there is not building or structure, such as a ground mounted array, then the ground mounting columns could be used if they meet the requirements of 250.52(A)(2) or another type grounding electrode is to be installed.

It should be noted that a past change to 250.166 established limits to the maximum size of grounding electrode conductor for dc systems at 3/0 copper or 250 kcmil aluminum. Figure 17.1 shows an example of the bonding between a dc grounding electrode and the ac grounding electrode. Note that in the figure the extra grounding electrode at the panel array is an auxiliary electrode covered by 250.54.

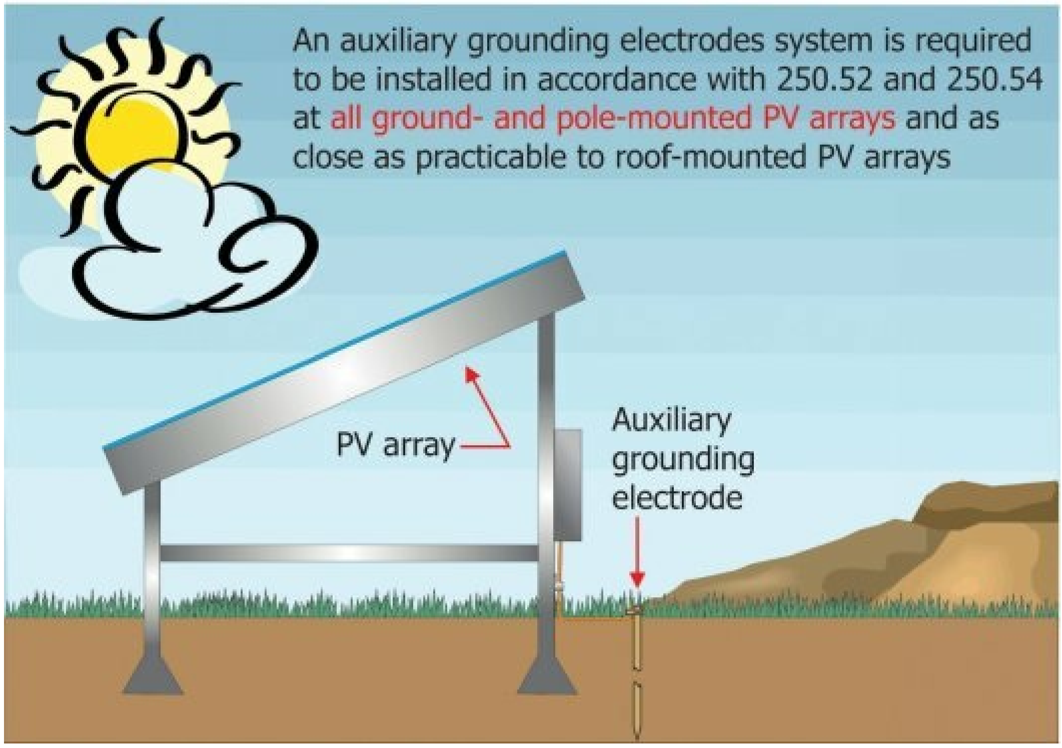


Figure 17.3 Auxiliary grounding electrode for PV array

Fuel Cell Systems – Article 692

The grounding and bonding requirements for fuel cell systems are found in Part V of Article 692. System grounding is covered by 692.41 where ac systems are to follow the requirements found in 250.20 and 250.30, where the fuel cell is a separately derived system. DC system grounding is to follow the requirements found in 260.160. Where there are ac and dc grounding requirements, 692.41(C) provides the following:

> "**(C) Systems with Alternating-Current and Direct-Current Grounding Requirements.** When fuel cell power systems have both alternating-current (ac) and direct current (dc) grounding requirements, the dc grounding system shall be bonded to the ac grounding system. The bonding conductor shall be sized according to 692.45. A single common grounding electrode and grounding bar may be used for both systems, in which case the common grounding electrode conductor shall be sized to meet the requirements of both 250.66 (ac) and 250.166 (dc)."

Section 692.44 requires that a separate equipment grounding conductor be installed, and 692.45 provides for the sizing of that equipment grounding conductor, referencing Table 250.122. Lastly, the grounding electrode system requirements in 692.47 state that when an auxiliary electrode is installed, as required by manufacturer's installation instructions, then it shall be connected to the equipment grounding conductor specified in 250.118.

Wind Systems – Article 694

Wind generating system grounding and bonding are found in Part V of Article 694, and specifically 694.40(A). There are two parts to this section, equipment grounding and tower grounding and bonding. Section 694.94(A) requires the exposed non-current-carrying metal parts of towers, turbine nacelles, other equipment, and conductor enclosures be grounded and bonded to the premises grounding and bonding system in accordance with Article 250 Parts IV, V, and VI. Parts that are not likely to become energized, such as the blades are not required to be connected to an equipment grounding conductor.

Photo 17.2 Wind electric generators

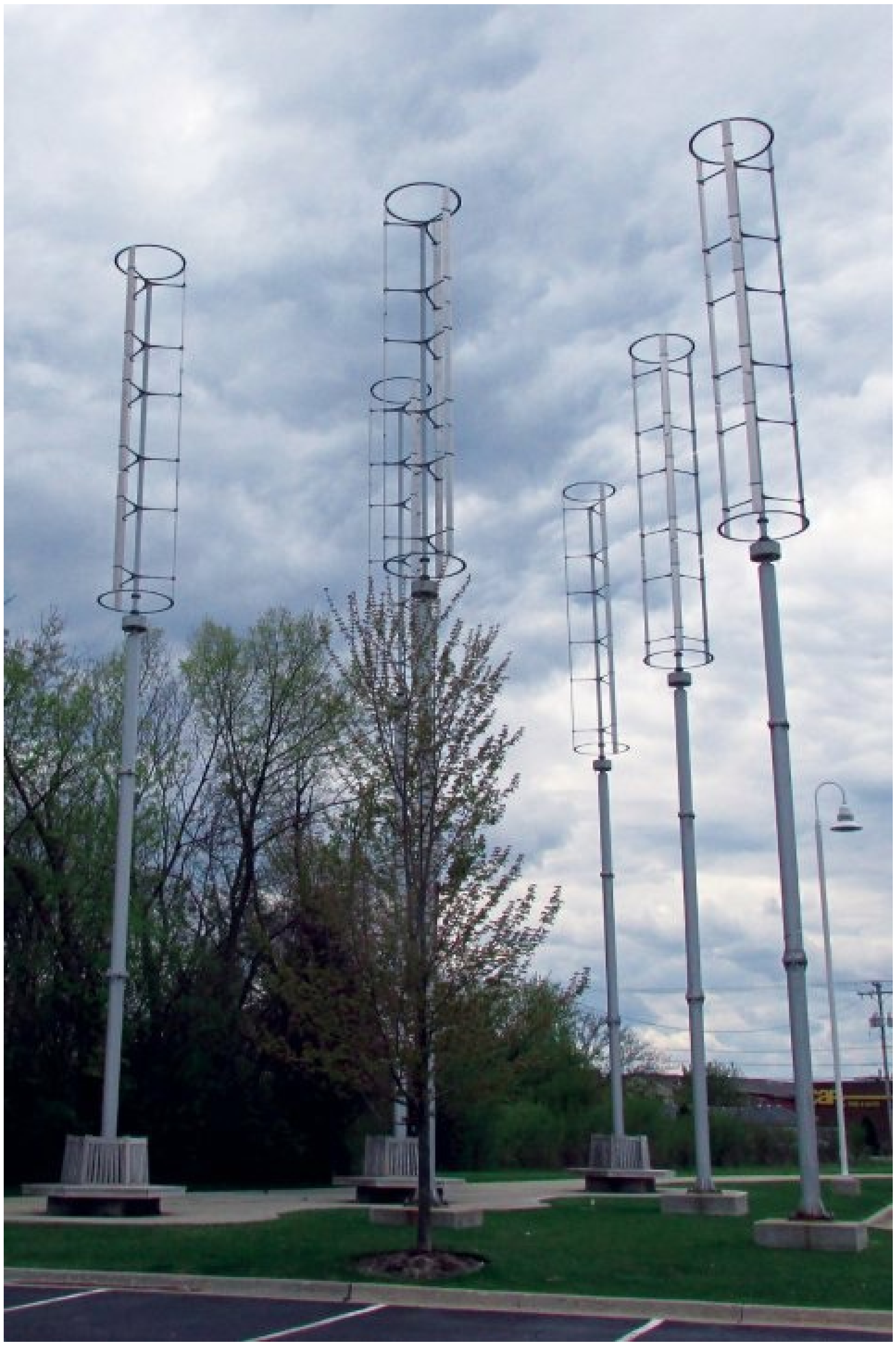


Photo 17.3 Wind turbines in a parking lot

The grounding requirements for the tower are found in 694.40(B). Where the tower is comprised of galvanized metal, then the grounding electrode used is to also be galvanized where the electrode is in close proximity to the tower structure. An informational note provides the reasoning for this stating:

"Informational Note: Copper and copper-clad grounding electrodes, where used in highly conductive soils, can cause electrolytic corrosion of galvanized foundation and tower anchor components."

Section 694.40(B)(2), (3) and (4) provide specific requirements for bonding of parts together and to the grounding electrode system, connections to the tower and lastly connections to guy wires were used.

[1 - 38] NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA, © 2016)

Review Questions

1. Alternate energy system sources can be from ______.

   1. Engine generators
   2. Photovoltaic (PV) modules and system
   3. Fuel cells
   4. Wind generators
   5. All the above

2. An alternate energy system that has no connection to the utility system is called __________.

   1. hybrid system
   2. grid interconnected system
   3. stand-alone system
   4. bidirectional system

3. A stand-alone alternate energy system is generally a separately derived system.

   1. True
   2. False

4. One feature commonly found in stand-along systems is it _______.

   1. includes a service disconnect
   2. parallels power with the utility
   3. includes an energy storage system
   4. stores thermal energy

5. One of the earliest alternate energy applications is ____________.

   1. solar-thermal generator
   2. wind mill for pumping irrigation water
   3. photovoltaic power plant
   4. hydroelectric generator

6. An alternate energy system with the grid interactive inverter and no neutral conductor connected to the utility grid is considered __________.

   1. stand-alone system
   2. as a separately derived system

3. not as a separately derived system
4. as a bi-directional system

7. Grid interconnected systems are not separately derived systems because the ____________.

1. ungrounded circuit conductors in both systems are connected together
2. the neutral is switched
3. both systems are connected to earth
4. the equipment frame of the alternate energy source is grounded

8. Generally, for a photovoltaic (PV) system, the DC side from the modules to the inverter is _______, while the inverter output to the grid interconnection is _______.

1. not a separately derived system; a separately derived system
2. separately derived system; not a separately derived system
3. three wire system; four wire system
4. low power system; high power system

9. Where the alternate energy system consists of multiple points such as several inverters with the outputs connected together in parallel, the overall assembly should be considered as one system.

1. True
2. False

10. The grounding electrode for the alternate energy system installed in or on a building or structure generally shall be _______

1. a separate grounding electrode
2. the same grounding electrode system as the building or structure
3. the metallic cold water piping system inside the building or structure
4. a ground rod

11. The equipment installed for the grid interconnection must be ________

1. approved
2. listed by a recognized testing laboratory
3. declared safe by the engineer of record
4. a and b

12. Grid interconnected systems are permitted to be connected on the _____ side and the

____ side of the main service disconnect

1. opposite; common
2. supply; load
3. end; middle
4. DC; AC

13. Connection to the load side of the service disconnect is limited so the total current to the common bus cannot exceed _______ percent of the bus rating.

1. 100
2. 158
3. 120
4. 125

14. Grid interconnect to the line side of the service disconnect is limited to ____

1. 100 percent of the ampere rating of the bus
2. ampacity of the service entrance conductors
3. 125 percent of the alternate energy source output rating
4. 125 percent of the sum of the alternate energy source and the rating of the main service disconnect.

15. Factors to be considered when installing a line side alternate energy system connection include ______.

1. a low impedance ground fault return path to the utility source
2. the alternate energy system disconnect must be within 10 feet of the service
3. the metal raceway to the alternate energy system AC disconnect needs to be grounded and bonded like a service raceway
4. if there is a neutral and metal raceway a supply side bonding jumper should not be installed
5. all of the above

16. PV source DC conductors that are "functionally grounded" are required to be identified by ________ color.

1. white
2. gray
3. three white stripes
4. in accordance with 690.31(B)(1)

17. A PV ground mounted array is permitted to use the support pilings or columns meeting

250.52(A)(2) as the grounding electrode to ground the racking system.

1. True
2. False

18. Fuel cell systems with AC and DC grounding requirements shall use _______.

1. a DC grounding electrode system
2. the AC grounding electrode system
3. a common grounding electrode system
4. both b and c

19. Where a wind generator tower is constructed of galvanized steel, the grounding electrode(s) installed shall be _________.

1. copper
2. copper clad
3. galvanized steel
4. bare steel or iron

Chapter 18
Grounding and Bonding for Electronic Equipment

Objectives to understand

- Requirements for grounding information technology equipment
- Isolated equipment grounding conductors
- Proper grounding methods for a data processing system
- Reducing ground loop effects
- Equalizing potential in an information technology (computer) room
- High frequency effects in equipment grounding conductors
- Surge arresters and surge protective device (SPD) usage
- Harmonic currents

Article 645 covers electrical requirements for information technology equipment. Section 645.1, Scope, reads, "This article covers equipment, power-supply wiring, equipment interconnecting wiring, and grounding of information technology equipment and systems in an information technology equipment room" (see photo 18-1).

Articles 725 and 800 apply to nonpower interconnection of information technology equipment located outside the computer room, such as for personal computers, workstations, and printers. An informational note to 645.1 reads, "For further information, see NFPA 75-2017, *Standard for the Fire Protection of Information Technology Equipment*."

As indicated, some grounding and bonding requirements for information technology equipment are contained in Article 645. Due to the rules on organization found in 90.3, the requirements for grounding in Article 250 apply to information technology equipment except as modified in Article 645.

Photo 18.1 Information technology equipment

Special conditions are imposed in 645.4 before the provisions of Article 645, including those for grounding, are permitted to be used for the information technology room under consideration. These requirements are as identified below.

"(1) Disconnecting means complying with 645.10 are provided.

"(2) A heating/ventilating/air-conditioning (HVAC) system is provided in one of the methods identified in 645.4(2)(a) or (b).

a. A separate HVAC system that is dedicated for information technology equipment use and is separated from other areas of occupancy; or

b. An HVAC system that serves other occupancies and:

1. Also serves the information technology equipment room; and

2. Provides fire/smoke dampers at the point of penetration of the room boundary; and

3. Activates the damper operation upon initiation by smoke detector alarms, by operation of the disconnecting means required by 645.10, or both.

"**Informational note:** For further information, see NFPA 75-2017, *Standard for the Fire Protection of Information Technology Equipment*, Chapter 10, 10-1, 10-1.1, 10-1.2 and 10-1.3.

"(3) All information technology and communication equipment installed in the room is listed.

"(4) The room is occupied by, and accessible to, only those personnel needed for the maintenance and functional operation of the installed information technology equipment.

"(5) The room is separated from other occupancies by fire-resistant-rated walls, floors, and ceilings with protected openings.

"Informational Note: For further information on room construction requirements, see NFPA 75-2017, *Standard for the Fire Protection of Information Technology Equipment*, Chapter 5.[1]

"(6) Only electrical equipment and wiring associated with the operation of the information technology room is installed in the room.

"**Informational Note:** HVAC systems, communications systems, and monitoring systems such as telephone, fire alarm systems, security systems, water detection systems, and other related protective equipment are examples of equipment associated with the operation of the information technology room."

Rooms for information technology equipment that do not meet all these conditions must be wired and the contained equipment grounded and bonded in accordance with the general requirements of *NEC* Chapters 1–4. It should also be pointed out that the provisions of Article 645 apply only within the information technology equipment room and not to other spaces, such as in general office areas, where all the features of 645.4 (1) through (6) are not provided.

Grounding requirements in 645.15 read, "All exposed non-current-carrying metal parts of an information technology system shall be bonded to the equipment grounding conductor in accordance with Parts I, V, VI, VII, and VIII of Article 250 or shall be double insulated." This is a general reference to Article 250 where grounding requirements for all types of equipment are found. Few additional requirements or modifications of the general grounding requirements in Article 250 are found in Article 645.

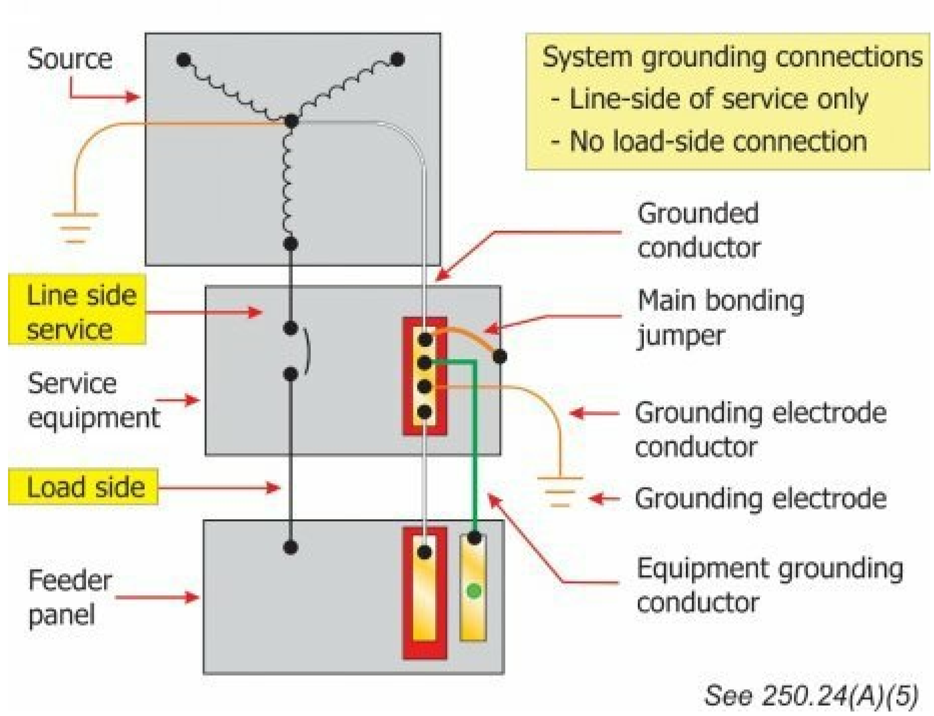


Figure 18.1 Typical power system grounding connections

Section 250.20 provides the requirements for grounding of electrical systems, such as for services provided by the electric utility, as well as for systems that are separately derived. Without the modification that is provided in 645.15, electrical systems produced from power distribution units or uninterruptible power systems (UPS) that are commonly used for information technology equipment must be grounded as separately derived systems in accordance with 250.30.

A new requirement from the 2014 *NEC* located at 645.14 specifies, "Separately derived power systems shall be installed in accordance with the provisions of Parts l and ll of Article 250." The new provision goes further to say, "Power systems derived within listed information technology equipment that supply information technology systems through receptacles or cable assemblies supplied as part of this equipment shall not be considered separately derived for the purpose of applying 250.30."

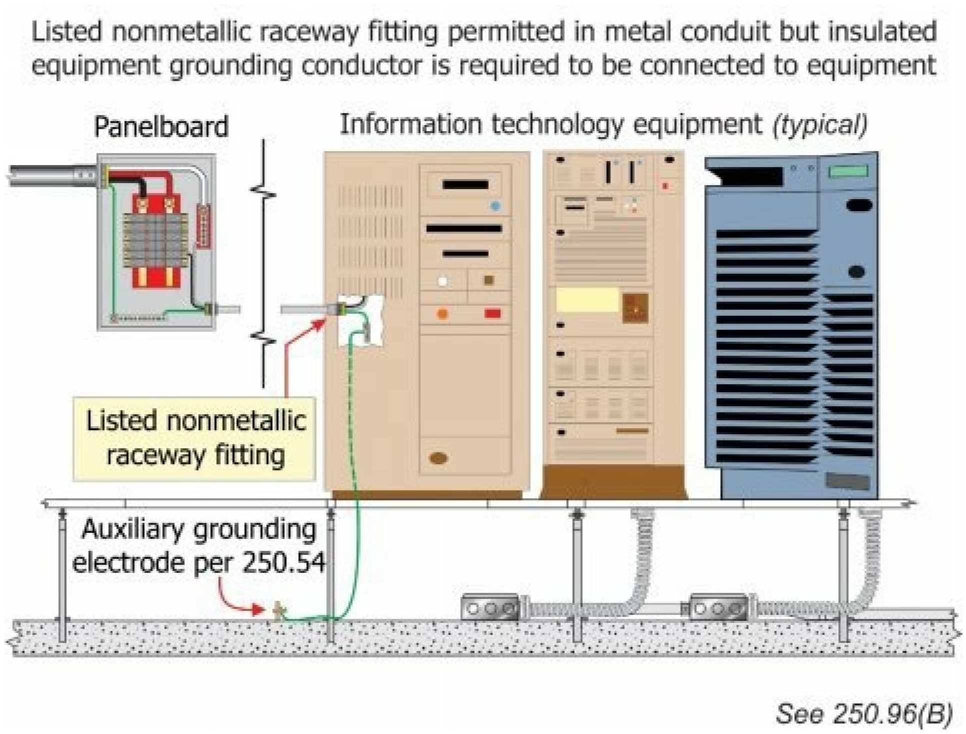


Figure 18.2 Isolated grounding connections for equipment

Section 645.15 also requires, "Where signal reference structures are installed, they shall be bonded to the equipment grounding conductor provided for the information technology equipment." This requirement will be explored later in this chapter.

Two informational notes provide additional information. Finally, 645.14 states, "Any auxiliary grounding electrodes(s) installed for information technology equipment shall be installed in accordance with 250.54." Informational Note No. 1 reads, "The bonding and grounding requirements in the product standards governing this listed equipment ensure that it complies with Article 250." Informational Note No. 2 states, "Where isolated grounding-type receptacles are used, see 250.146(D) and 406.3(D)" [2] (see figures 18.3, 18.4, 18.5 and photo 18.3).

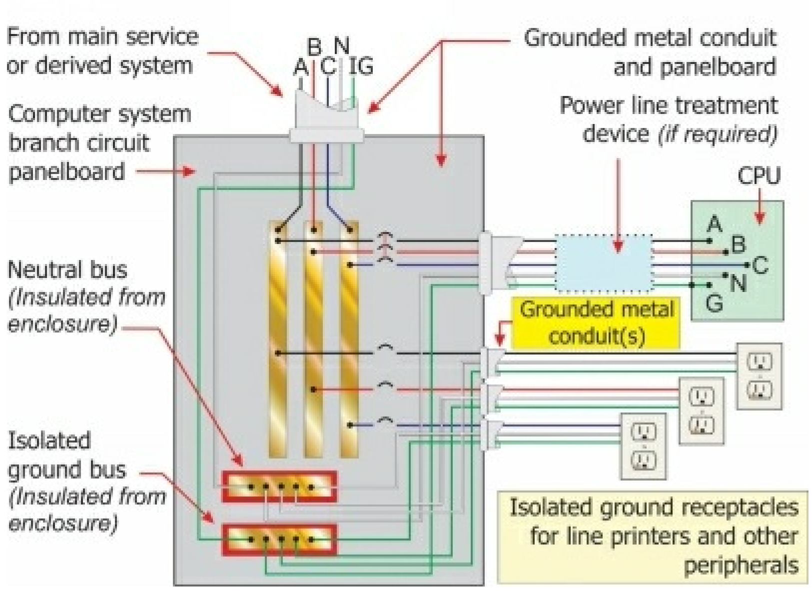


Figure 18.3 Isolated grounding receptacle connections

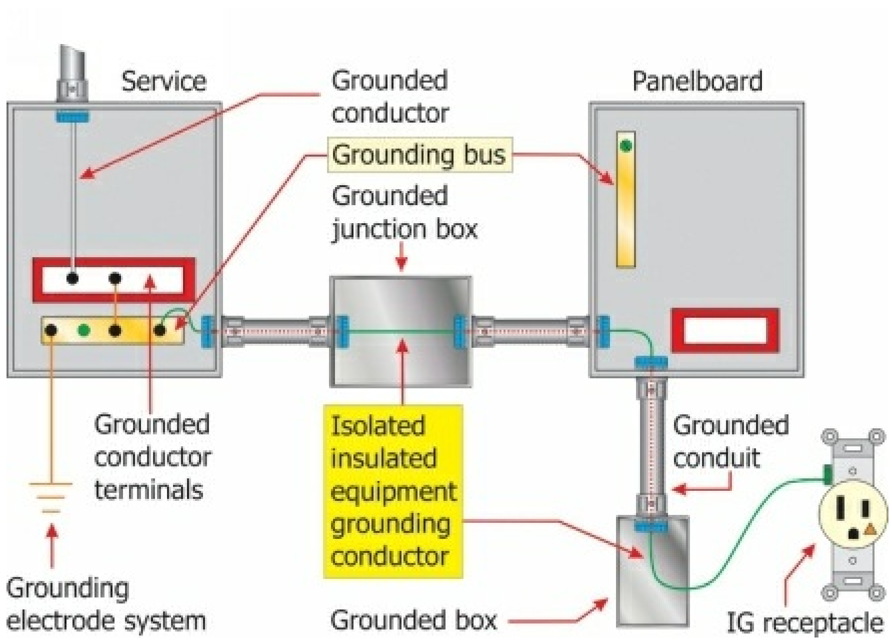


Figure 18.4 Isolated grounding receptacle connections

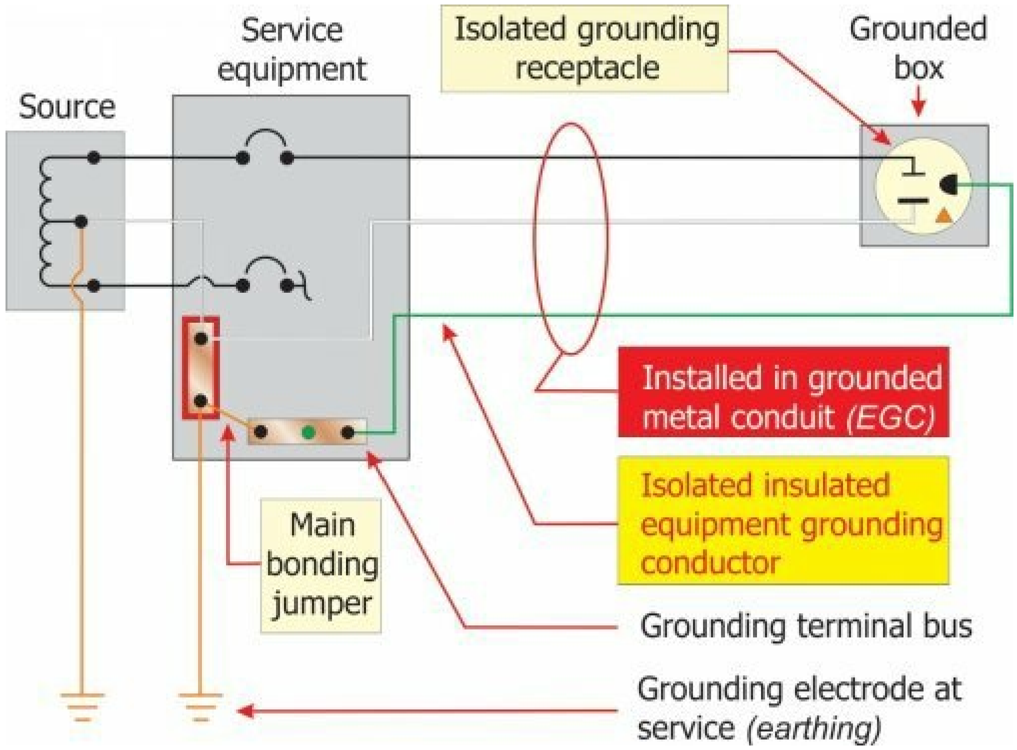


Figure 18.5 Isolated grounding receptacle connections

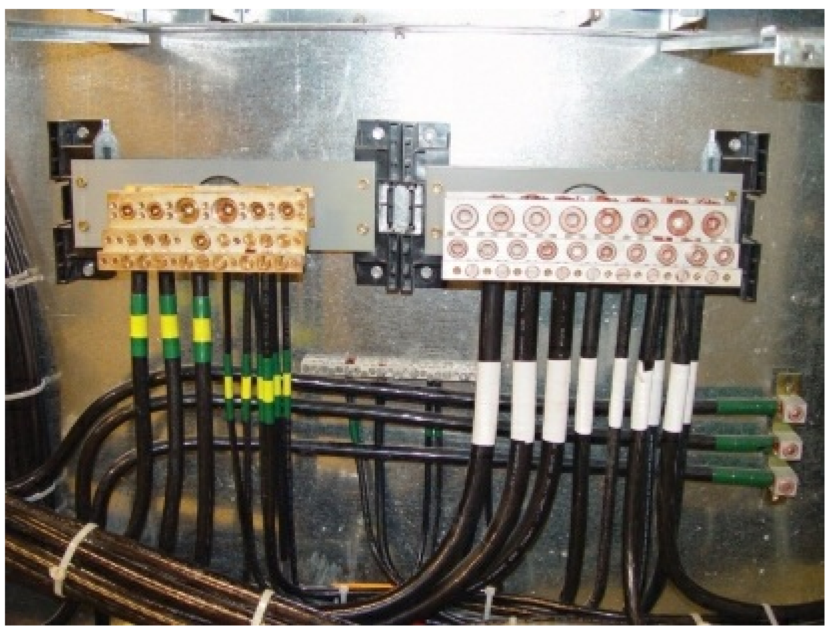


Photo 18.2 Neutral conductors, equipment grounding conductors, and isolated equipment grounding conductors separated from one another as required by 250.24(A)(5) and permitted by 250.146(D). Normal and isolated equipment grounding terminal bars are shown.

Photo 18.3 Isolated grounding receptacles installed under a raised floor in an information technology (IT) room

An additional reference to grounding of IT equipment is found in 250.6, Arrangement to Prevent Objectionable Current. The general requirement is that equipment grounding conductors and grounding electrode conductors be installed to prevent objectionable current through the grounding path(s). The *NEC* does not define or describe what *objectionable current* is but, certainly, any current through equipment grounding conductors or grounding electrode conductors that would in any way impair the performance of their intended function would be objectionable.

Section 250.6(B) outlines the following steps that can be taken to stop objectionable current:

- Discontinue one or more but not all of such grounding connections.
- Change the locations of the grounding connections.
- Interrupt the continuity of the conductor or conductive path causing the objectionable current
- Take other suitable remedial and approved action.[3]

Section 250.6(D), however, specifically applies to IT equipment or more broadly to all electronic equipment. It reads, “The provisions of this section shall not be considered as permitting electronic equipment from being operated on ac systems or branch circuits that are not connected to an equipment grounding conductor as required by this article. Currents that introduce noise or data errors in electronic equipment shall not be considered the objectionable currents addressed in this section.”[4] This requirement was added after reports that some IT manufacturers or installers were not installing the equipment grounding conductors with the branch circuit to the equipment but were purposefully isolating it by connecting IT equipment only to a local grounding point such as a driven ground rod. Clearly this does not meet one of the foundation requirements to provide a low impedance ground fault current path back to the source of supply.

Another general requirement, the importance of which cannot be overstated, is that the neutral or grounded system conductor not be reconnected to ground past the service disconnecting means (see figure 18.1, 250.24(A)(5), and photo 18-2). With any system, grounding of the neutral conductor or system grounded conductor on the load side of the service or disconnecting means creates parallel paths for neutral current over each path that is established such as over conduit, piping systems, cable shields and cable trays.

Purposes of Grounding Electrical Equipment

A broad, general performance requirement is provided in 250.4(A)(2) on grounding of electrical equipment. This rule applies to all electrical equipment, including information technology equipment, as there is no modification of this rule in Article 645. The rule states, “Normally non-current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected to earth so as to limit the voltage to ground on these materials.” [5]

Section 250.4(A)(5) contains another important performance rule that also clearly applies to information technology equipment. It reads, “Electrical equipment and wiring and other electrically conductive materials likely to become energized shall be installed in a manner that creates a low-impedance circuit … capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point on the wiring system where a ground fault may occur to the electrical supply source.”

The electrical supply source is either the trans-former by the electric utility for the service or a separately derived electrical system. Electrical systems all follow the basic laws of physics: a complete circuit is required before current can exist, and current will always return to its source. The task, then, is to provide the “permanent, low-impedance circuit capable of safely carrying the maximum ground-fault current likely to be imposed on it.” [6]

This section goes on to require that “the earth shall not be considered as an effective ground-fault current path.” [7]

Safety Grounds and Clean Grounds

The *NEC* does not use the terms *safety ground* or *clean ground.* These terms are sometimes used in the information technology industry to differentiate between the equipment grounding conductor required in the branch circuit to the equipment and the isolated equipment grounding conductor sometimes installed for IT equipment. Much of the difficulties between designers, installers, manufacturers, and inspection authorities arises from use of undefined trade jargon terms such as these. The reference to the safety ground in IT jargon is to the equipment grounding conductor as defined in Article 100. This safety ground is often the conduit for the branch circuit and is sometimes referred to as the *dirty ground* because it is considered to possibly carry unwanted electrical noise from a variety of sources (see figure 18-2). Sometimes unsafe actions are taken to interrupt the equipment grounding conductors(s) (safety or dirty ground) and install grounding means near the IT equipment. Such practice is not permitted by any safety code and can create shock or electrocution hazards.

As mentioned above, 645.15 requires that IT equipment be grounded in accordance with Article 250. Section 250.86 applies generally and requires, "except as permitted by 250.112(I), metal enclosures and raceways for other than service conductors shall be connected to the equipment grounding conductor." The three exceptions to this rule do not apply to IT equipment, nor does the rule in 250.112(I).

However, 250.110 provides conditions under which "exposed non-current-carrying metal parts of fixed equipment likely to become energized shall be connected to the equipment grounding conductor." Three conditions from the six in this section that might apply to IT equipment and require grounding include:

> "(1) Where within 2.5 m (8 ft) vertically or 1.5 m (5 ft) horizontally of ground or grounded metal objects and subject to contact by persons
>
> "(3) Where in electrical contact with metal
>
> "(5) Where supplied by a wiring method that provides an equipment grounding conductor …" [8]

It is safe to say that metal enclosures for IT equipment must be grounded by connection to an equipment grounding conductor. This equipment grounding conductor is required to be either the metal raceway acceptable in 250.118 or a wire type equipment grounding conductor contained within the wiring method to the IT equipment. Under no circumstances should the effective fault-current path to the source of power be interrupted and an equipment grounding connection be made only to a local grounding electrode such as water pipe, building steel or driven electrodes. To do so violates all the principles of safety. This connection certainly will provide a high-impedance path and will constitute ineffective grounding. Serious shock hazards can occur in this arrangement since the overcurrent device that supplies the equipment will not clear the fault because there will be little current due to the high-impedance ground-fault path.

As mentioned, the term *clean ground* often refers to the isolated equipment grounding conductor sometimes specified for IT equipment or receptacle outlets by the equipment manufacturer or owner. This isolated equipment grounding conductor is permitted in 250.96(B). However, the section begins by stating, "Where installed for the reduction of electrical noise (electromagnetic interference) on the grounding circuit…." The *NEC* does not address the issue of who makes the decision about what the circumstances are that would justify the use of isolated equipment grounding. Usually, the owner, design engineer, or equipment manufacturer specifies the circuit to have isolated equipment grounding conductor(s).

Section 250.96(B) goes on to state, "an equipment enclosure supplied by a branch circuit shall be permitted to be isolated from a raceway containing circuits supplying only that equipment by one or more listed nonmetallic raceway fitting(s) located at the point of attachment of the raceway to the equipment enclosure" (see figure 18.2).

"The metal raceway shall comply with provisions of this article and shall be supplemented by an internal insulated equipment grounding conductor installed in accordance with 250.146(D) to ground the equipment enclosure." Note that this section does not require the use of a metal raceway to supply the IT equipment. If PVC conduit were used, the special insulating connector between the metal raceway and the IT equipment would not be required. Of course, the insulated equipment grounding conductor must be installed inside the PVC conduit to ground the IT equipment (see figure 18.2).

The reference here to installing the insulated equipment grounding conductor in accordance with 250.146(D) then permits the equipment grounding conductor to pass through one or more panelboards, boxes, wireways, or other enclosures without being connected to equipment grounding terminal bars in the panelboard. The insulated equipment grounding conductor must be connected no further than to the first of the following points to provide the low-impedance ground-fault current path required:

- Source of the separately derived system if it supplies the branch circuit
- Building disconnecting means
- Service equipment

Note that if a metal raceway is used, the raceway must be installed in a manner to ensure an adequate return fault-current path even though an insulated equipment grounding conductor is installed through the raceway for grounding the IT equipment. This ensures that the raceway does not become a shock hazard if a line-to-ground fault to, or in, the raceway occurs. Lastly, it should be noted all the above provisions are permissive and the additional prescriptive requirements or restrictions apply if the permissive option is chosen for the installation.

Proper Grounding Methods for a Data Processing System

To comply with the safety requirements of Article 250, an equipment grounding conductor of a type recognized in 250.118 must be installed as either the wiring method itself, such as a metal conduit or tubing, or an equipment grounding conductor of the wire type inside the conduit or tubing. The equipment grounding means is required to be connected to the metal enclosure for the IT equipment. The equipment grounding conductor, where it is a wire, is sized from Table 250.122 based on the rating of the overcurrent protective device ahead of the branch circuit. For example, a 10 AWG copper wire is permitted as the equipment grounding conductor in branch circuits having from 30-ampere through 60-ampere overcurrent protection. This will ensure the effective ground-fault return path will meet the rules in 250.4(A)(5) in being a "permanent, low-impedance circuit, capable of safely carrying the maximum ground-fault current likely to be imposed on it." This rule applies regardless of whether the branch circuits that supply the IT equipment originate in the electrical system provided from the electric utility service or in a dedicated power distribution unit (PDU) for the IT equipment.

As mentioned above, under no conditions should the effective ground-fault return path be interrupted and be connected to some other grounding means such as a local grounding electrode. Doing so can create a shock or electrocution hazard and aggravate the very problem such action is intended to solve.

Reducing Ground Loop Effects

Ground loops is another term that is not defined in the *NEC*. It is used in the IT industry to refer to installations where ground current exists through multiple paths, and it is believed this ground current or electrical noise travels in a circular fashion, hence the term ground loops. Connecting computers and terminals on different circuits that are grounded to building steel while the shielded communications cable between the computer and terminal completes the ground loop can cause this situation. Other connections through equipment grounding paths can add additional ground loops. Differences in ground potential will cause *small currents (noise)* and can couple with data signals. Many computer data signals operate at 5 V or less, which makes the system more susceptible to acquiring electrical noise interference from power circuits if cables are run closely together.

One method for solving this problem is to supply all related IT equipment from the same power supply. The equipment grounding means of the branch-circuit wiring will serve to keep the ground (earth) potential the same. This solution can be impractical where the computer is located a long distance from peripherals and is supplied by different power supplies or different panelboards that, in turn, are supplied by different feeders. Known solutions to the problem of ground loops include:

Single point grounding. This solution might not be suitable at very high frequencies or where equipment is located a long distance from another and is connected by shielded cables.

A *balun coil*, which is a coil of insulated wire on a nonmetallic core. This can be installed in the power branch circuit or the data circuit. Manufacturers sometimes build this into equipment. Baluns are not effective at all frequencies.

- Modems which are normally used as interfaces with telephone circuits.
- Fiber optic transmission over completely non-conducting paths.
- Optical isolators.
- Interface devices such as surge arresters and surge protective devices (SPDs).

Equalizing Potential in a Computer Room

For the purposes of grounding IT equipment, an equipotential plane is described as, “a mass (or masses) of conducting material that, when bonded together, provide a uniformly low impedance to current over a large range of frequencies” [9] (see figures 18.6 through 18.8). The *signal reference structure* is defined as “a system of conductive paths among interconnected equipment that reduces noise-induced voltages to levels that minimize improper operation. Common configurations include grids and planes.” [10]

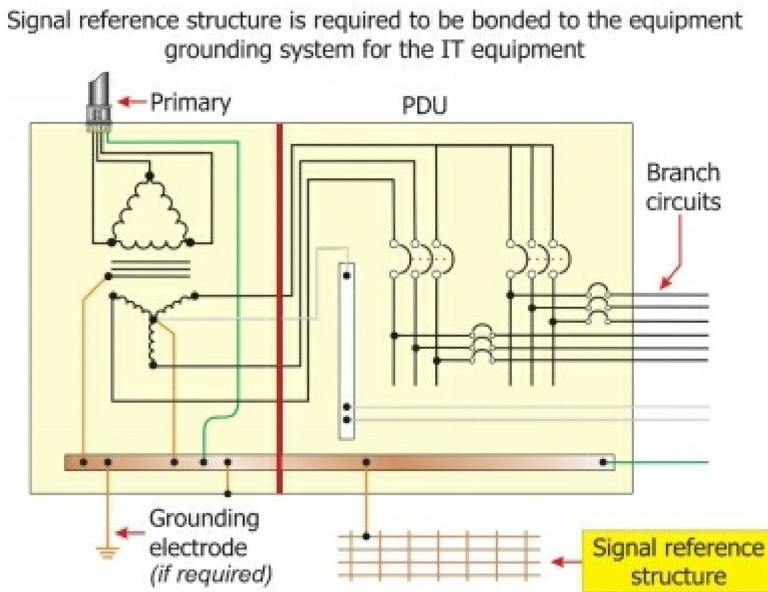


Figure 18.6 ***Signal reference grid is required to be bonded to equipment grounding conductor of the supply system(s)***

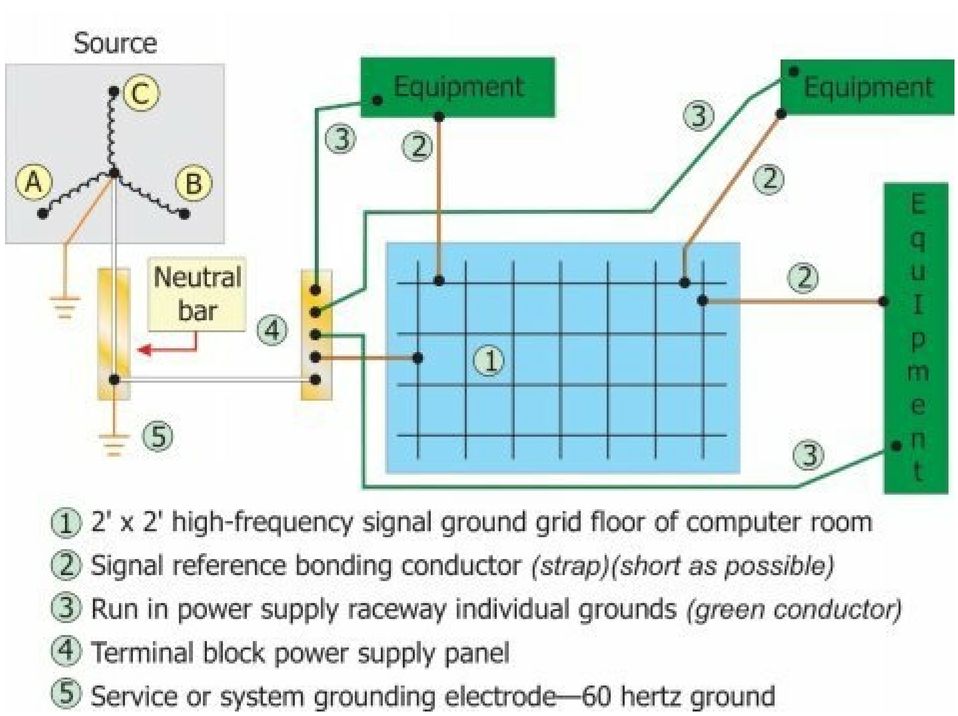


Figure 18.7 ***Typical signal reference grid connections showing the grid and the required equipment grounding conductors to equipment***

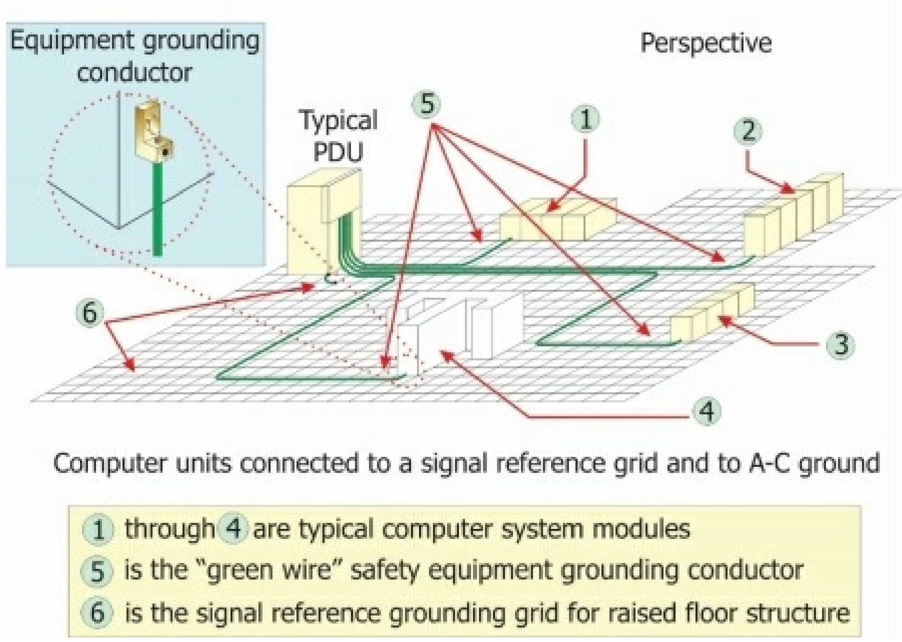


Figure 18.8 ***Signal reference grid and equipment grounding conductors connected back to a single point at the source, usually a power distribution unit (PDU)***

Keeping all electrical equipment, including IT equipment, at the same potential is necessary in an attempt to minimize disruptions in the operation of IT equipment.

Advantages of an equipotential plane include:

- Low impedance return path for radio frequency (RF) noise currents
- Containment of electromagnetic (noise) fields between their source (cables and similar) and the plane
- Increasing filtering effectiveness of contained electromagnetic fields, and
- Shielding of adjacent circuits or equipment

Equipotential plane structures can be established in several forms. Typical forms include:

- A conductive grid embedded in, or attached to, a concrete floor
- Metallic screen or metal strips under floor tile
- Ceiling grid above equipment, and
- Supporting grid of raised access flooring typical in computer rooms

Purpose of a Signal Reference Grid

The term *signal reference grid* refers to a structure such as a computer floor or a copper mesh grid installed under the computer floor. Information technology equipment is connected to the signal reference grid to equalize potential between components at various frequencies. All equipment in the room, including equipment that is wall-mounted, should be connected to the grid. The *NEC* is silent on this subject likely due to this being primarily an operational (performance) consideration and not necessarily safety related. But, as with other bonding or grounding methods used for IT equipment, such bonding cannot substitute for the equipment grounding conductor required to be installed with the branch-circuit conductors. The signal reference grid can be thought of as overlaying the equipment grounding conductors (sometimes referred to as safety grounds) that are required.

The signal reference grid serves as a signal reference plane over a broad range of frequencies. They are correctly referred to as *broadband grounding systems*. An effort is being made to reduce, eliminate or control the tendency of conductors connected to computers to resonate at higher frequencies. A grid provides multiple parallel conducting paths between its metal parts. If one path is a high-impedance path because of full or partial resonance, other paths of different lengths will be able to provide a lower impedance path. A signal reference grid could be constructed of continuous sheet copper or aluminum, zinc-plated steel, or any number of pure or composite metals with good surface conductivity (see photo 18.4). However, this type of construction is not only expensive but difficult to install in a computer room where other services have been or will be installed.

Grids of copper or aluminum strips are sometimes installed under a computer-raised floor. This grid provides a satisfactory constant potential reference network over a broad range of frequencies from dc to higher than 30 MHz. Typically, these have been formed of 4 AWG copper or aluminum conductors which have been electrically joined at their intersections, or by copper straps approximately 0.254 mm (0.010 in.) thick by 76 mm to 102 mm (3 in. to 4 in.) wide, also joined at their intersections. These grids typically lie directly upon the subfloor under the IT room raised floor. Cables and conduits under the floor would normally lie below the raised floor but above the grid.

Photo 18.4 Signal reference grid connections independent of floor supports using 2" wide copper strips in a 2' x 2' pattern

Photo 18.5 Raised floor platform structure used as a signal reference grid

As mentioned, the metal structure for the raised floor is sometimes used for the signal reference grid (photo 18.5). Typically, the floor grid is 600 mm x 600 mm (2 ft x 2 ft) as this size fits with standard cellular raised floor systems and roughly fits the wave length for the median frequencies found in this type equipment. The two essential requirements are bolted-down *stringers* (the lateral supporting braces installed between supporting pedestals) and suitably plated (tin or zinc) members so that low-resistance pressure connections can be made. It is important that all metal components of the floor structure be in good electrical contact with each other. This might require using bolts and clamps along with a copper or aluminum bonding conductor.

Some supporting structures are marketed in which the removable floor tiles lock onto the supports by gravity but it has not been demonstrated that the contact has a low enough resistance and is free from intermittent contact as people move about or loads are moved across the floor. The bolted down horizontal stringers (braces) with pressure-type spring washers or springs in the assembly have been shown to be highly suitable for the purpose.

Experience has shown that it is unnecessary that lift-out floor panels make a low-resistance contact with the supporting network of stringers. The plastic or synthetic rubber cushions or molded edging upon which the panels rest have been found to be adequate to drain static electricity from the panel if any should accumulate. A resistance as high as 20,000 megohms under 20 percent relative humidity or higher will satisfy this requirement.

Once the signal reference grid has been established in the IT room, the various IT units can each be connected to the grid by a flat braided copper strap. The connection should be made from each IT unit, preferably at a point near where the equipment grounding conductor is connected, to the nearest intersection of the signal reference grid. The strap should be no longer than necessary and should have few bends and very little loop or sag to minimize the impedance at high frequency. In addition, the effectiveness of the reference grid is improved if it is solidly connected to the power supply for the IT equipment by a very short strap.

If the IT equipment manufacturer does not subscribe to the philosophy of connecting the IT equipment to the grid at multiple locations, the stray capacitance between the IT equipment and the raised floor reference grid will still help reduce voltage differences between grounded parts of the IT equipment.

High Frequency Effects in Equipment Grounding Conductors

Avoiding resonances at radio frequencies has become more important as the frequencies of digital signal circuits have increased beyond the 3 to 10 MHz clock repetition rate. Resonance occurs when the length of a conductor and the frequency of the alternating current are in tune. This is the principle of tuning a radio transmitting tower or antenna for maximum resonance and maximum radiation.

At frequencies slightly below and above resonance, the partial resonance still increases the impedance so it is ineffective as a constant potential conductor such as that needed as a good ground reference. Good engineering practice requires that a conductor any longer than 1/20 of a wavelength cannot be counted upon to equalize voltages between its ends. This amounts to only 1.34 m (4.4 ft) at 10 MHz.

The significance of this is that unless conductors can be limited to less than 1.2 m to 1.5 m (4 to 5 ft) in length, conventional grounding techniques with single-point grounds might not be effective for signal and noise frequencies up to 10 MHz. At higher frequencies and longer length of conductors, other techniques are needed to avoid resonance.

The use of multipoint grounding and short conductors appears to be the simplest and most reliable method for dealing with signals over 10 MHz in frequency (see figure 18.7). If bypass capacitors are installed instead of bonding straps, it is possible to make a conductor shield appear to be grounded at frequencies where the capacitors have very low impedance. At low frequencies, they carry very little current so the same system can have the characteristics of a single-point ground at power frequencies and other low frequencies. A signal reference grid is an effective way to ground systems and equipment installed in computer rooms.

Establishing a Single-Point Ground Reference

Deciding whether to use single-point grounding or multipoint grounding typically depends on the frequency range of equipment. Single-point grounding is typically applied to analog circuits with signal frequencies up to 300 kHz, while digital circuits with signal frequencies in the MHz range should utilize multipoint grounding.

The concept of single-point grounding is similar to the concept of equipotential bonding used in swimming pools (see figures 18-8). The intent is to maintain potential (voltage) differences among various IT equipment as low as possible. It should be noted that single-point grounding includes a set of bonding conductors that are in addition to the required equipment grounding conductors (sometimes referred to as *safety grounds*).

Single-point grounding should never be installed instead of the required equipment grounding conductors.

Single-point-grounding conductors are often connected from all equipment to an auxiliary (enhanced) grounding electrode in the vicinity of IT equipment. Requirements for auxiliary grounding electrodes are provided in 250.54. However, a bonding conductor must be installed from this auxiliary grounding electrode to the grounding electrode system for the electrical system. The auxiliary grounding electrode must never be isolated from the electrical system grounding electrode or be permitted to serve in place of the equipment grounding conductors (safety grounds). This clearly violates the installation instructions for equipment that is listed by a qualified electrical testing laboratory.

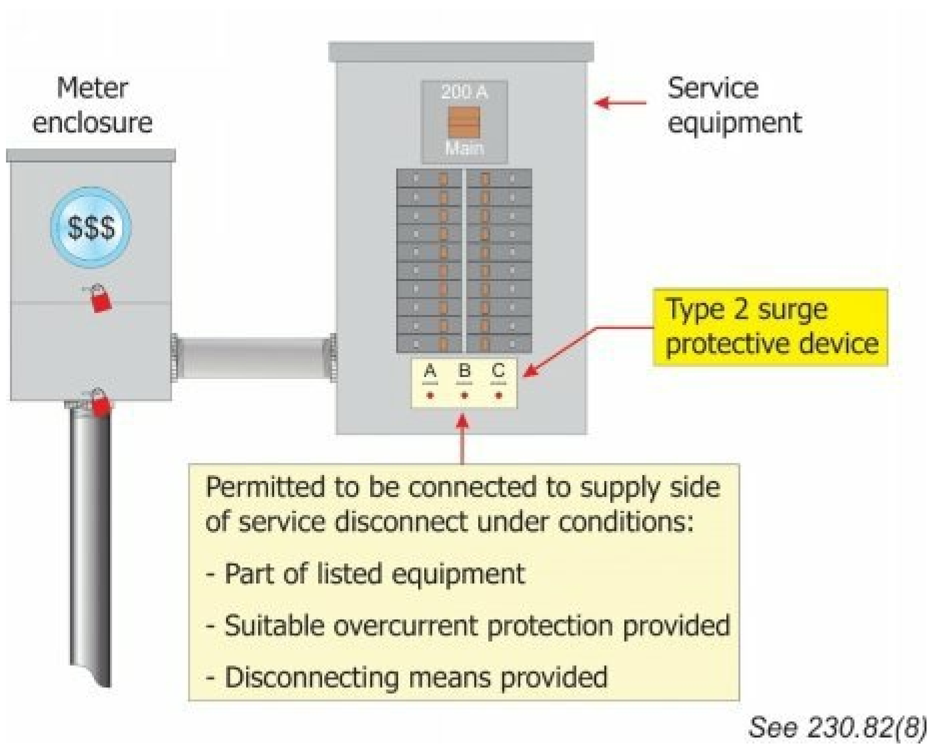


Figure 18.9 Surge protective device (SPD) component of a panelboard

Surge Protection

The term *surge arrester* is defined in Article 100 as “a protective device for limiting surge voltages by discharging or bypassing surge current; it also prevents continued flow of follow current while remaining capable of repeating these functions.” Rules for installing surge arrestors over 1000 volts can be found in Article 280. They are permitted to be installed either at the service equipment or on the load side of the service equipment. Surge arresters must be made inaccessible to other than qualified persons unless listed for installation in accessible locations.

Surge arresters are of several basic types with different characteristics serving different functions in different ways. When used in combination in a coordinated manner, they provide protection by limiting overvoltage, reducing stress and unnecessary failures in components and reducing component failures in equipment caused by surges.

Two types of surge arresters become conductive when their threshold voltage is exceeded. The first type becomes and stays conductive until the current is reduced to zero such as when an alternating current passes through zero as it changes in amplitude and direction. The second type becomes conductive when its voltage threshold is exceeded but returns to its open circuit state as soon as the voltage drops below its threshold.

Pellet type and gas discharge type arresters are typical of the first type of surge arresters. They are usually capable of handling very high currents because the voltage drop through them becomes very low when they are conducting. However, if a weak, short duration impulse of a millisecond triggers the arrester, the shunting action would essentially short circuit the line for at least half of a cycle or possibly longer. The transient caused by shorting the power conductor can be greater than the event that triggered it.

The second type, typical of nonlinear insulating material, becomes conductive when voltage gradients exceed their threshold values. Some semiconductors in an avalanche mode exhibit similar characteristics not unlike Zener diodes. Metal oxide varistors or MOVs are marketed and widely used for arresting surges. These are constructed of an amorphous oxide material and exhibit these characteristics. Other types of surge arrestors of a silicon solid-state device are marketed which perform similar functions.

Surge arresters divert surge currents rather than absorb them. They are connected from ungrounded terminals in service equipment or panelboard to the ground terminal. Other common connection points include power conditioning equipment, the line and load side of transformers, motor generators and uninterruptible power supplies (UPS) systems.

There are risks associated with these devices, and they must be installed in compliance with manufacturer’s installation instructions. Some devices can discharge flaming materials when they fail and must be mounted in suitable enclosures. The devices should be connected to the protected equipment with short conductors not more than 300 mm (1 ft) or so in length.

Some depth of technical understanding of surge voltages, the nature of traveling pulse waves, their reflection and diversion is needed for proper selection of surge arresters and the locations where they are most likely needed and can be most effective. In general, they are most likely needed wherever current in an inductive circuit element can be interrupted. They also might be useful where long cable leads interconnect widely separated systems as in different buildings or parts of a system within a very large building. Surge arresters are often installed at entrances of power and communications cables into a building to divert lightning and power switching surges before they reach IT equipment, power conditioning equipment or air-conditioning equipment.

Surge Protective Devices

Surge protective devices (SPDs) are available as stand-alone equipment or as a recognized component of listed equipment, such as switchboards or panelboards (see figure 18.9). Surge arresters rated 1 kV or less and surge protective devices are covered in Article 285 (see photo 18.6).

Photo 18.6 Typical three-phase surge protective device (SPD)

The term *surge protective devices* (SPDs) is defined in Article 100 as "A protective device for limiting transient voltages by diverting or limiting surge current; it also prevents continued flow of follow current while remaining capable of repeating these functions and is designated as follows:

- Type 1: Permanently connected SPDs intended for installation between the secondary of the service transformer and the line side of the service disconnect overcurrent device.
- Type 2: Permanently connected SPDs intended for installation on the load side of the service disconnect overcurrent device, including SPDs located at the branch panel.
- Type 3: Point of utilization SPDs
- Type 4: Component SPDs, including discrete components, as well as assemblies.

Unlike surge arresters, surge protective devices (SPDs) are required to be listed per 285.5. They are not permitted on ungrounded systems, impedance grounded systems, or corner-grounded systems, unless listed for this use. According to 285.4, "where used at a point on a circuit, the SPD (surge arrester or TVSS) shall be connected to each ungrounded conductor." For other than receptacle-type devices, SPD (surge arrester or TVSS) must be marked with their short-circuit current rating and are not permitted to be installed at any point on the electrical system where the available fault current is in excess of that rating (see photos 18.6 through 18.8).

Installation requirements for SPDs are located in Part II of Article 285 and *Code* rules for connecting SPDs are provided in Part III of the article.

Photo 18.7 Surge protective device (SPD) labels

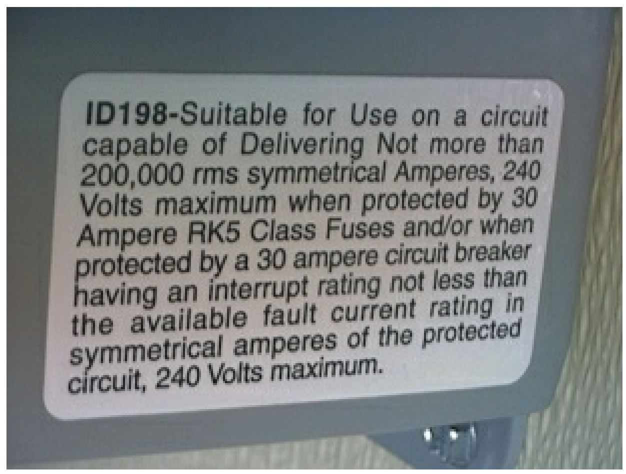


Photo 18.8 Surge protective device (SPD) labels showing short-circuit rating

Harmonic Currents

Harmonics in the power source voltage to IT equipment can interfere with the proper operation of some IT equipment internal regulators. It can also create extra losses, excessive ground leakage current in line filters, and couple unwanted signals into low signal level conductors.

Harmonic currents are produced by equipment classed as being a nonlinear load. The term *nonlinear load* is defined in Article 100 as, "A load where the wave shape of the steady-state current does not follow the wave shape of the applied voltage." An informational note following the definition indicates that "electronic equipment, electronic/electric-discharge lighting, adjustable-speed drive systems, and similar equipment may be nonlinear loads." The power supplies in information technology equipment often are switching mode power supplies and are nonlinear loads. This nonlinear load can cause several problems in the electrical supply system including overloading of neutral conductors and creating excessive heat in transformers.

Harmonic currents appear as reflected waveforms that distort the basic sine wave produced and provided by the electric utility. These reflected waves are multiples of the fundamental root frequency (60 Hz) sine wave. The odd multiples, such as the 3rd (180 Hz), 5th (300 Hz), 7th (420 Hz) add to the distortion of the sine wave and will appear as a single distorted waveform on an oscilloscope.

When the load current of IT units is distorted and contains harmonics, they interact with the power source impedance to create voltage drops at the harmonic currents that can be present. Line voltage distortion from this cause is the result of IT load characteristics interacting with the power source impedance. It is not correctable at the power source except to the extent that the source impedance can be reduced at each harmonic frequency by filters. Capacitors in parallel with the load can help but can cause unwanted resonance at specific frequencies.

Engineers will often specify K-rated transformers for IT installations. These transformers are designed to handle, without failure, the extra heat produced in the windings by the harmonic currents. K-rated transformers are available with ratings from K-4 through K-20. In addition, design engineers often specify oversize neutrals to handle the extra nonlinear load without excessive voltage drop or heating.

[1–8] NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA, © 2016)

[-9] IEEE Std 1100-2005, *IEEE Recommended Practice for Powering and Grounding Electronic Equipment*. For more detailed information on Grounding and Bonding requirements for Information Technology Equipment see FIPS 94 *Guidelines on Electrical Power for ADP Installations* and *FIPS Federal Information Processing Standards* Publication

[10] Burke, Thomas M., "Listing Requirements for ITE Installed in Computer Rooms," *IAEI News*, Volume 73, Number 1, January/February 2001, p. 11.

Review Questions

1. Which of the following articles in the *NEC* specifically cover electrical requirements for information technology equipment ____?

    1. Article 250
    2. Article 645
    3. Article 725
    4. Article 800

2. The grounding requirements for information technology equipment in Article 250 apply ____.

    1. to the entire installation
    2. unless amended in Article 90
    3. unless amended in Article 250
    4. unless amended in Article 645

3. The wiring methods permitted in Article 645 for information technology equipment are permitted to be used ____.

    1. only where all the conditions of 645.4 are complied with
    2. for computer room equipment located in dedicated spaces
    3. for interconnection of peripheral equipment in open office spaces
    4. provided a disconnecting means is located at exit doors

4. Power systems derived within listed information technology equipment that supply information technology systems _____.

    1. are considered separately derived systems and must be grounded
    2. are considered separately derived systems but are not required to be grounded
    3. are not considered separately derived systems
    4. are considered Uninterruptible Power Systems (UPS)

5. Currents that introduce noise or data errors in electronic equipment _____.

    1. are considered a design flaw and are corrected as desired
    2. are considered an unavoidable event in computer operation
    3. are not considered objectionable currents
    4. are not considered in design of systems

6. Which of the following sections in Article 250 generally requires that the grounded (often a neutral) conductor not be connected to ground past the service ____?

    1. 250.20
    2. 250.24(A)(5)
    3. 250.30(B)(2)
    4. 250.66

7. Which of the following statements most accurately describes an effective ground-fault current path?

    1. Earth is not considered an effective path
    2. Low-impedance circuit
    3. Adequate current-carrying capacity
    4. All of the above

8. The terms *safety ground* and *clean ground* ____.

    1. are defined in NFPA 70
    2. are defined in NFPA 75

3. are information technology industry jargon
4. all of the above

9. Grounding IT equipment using a single connection only to “local” grounding means such as a ground rod rather than using the “safety” equipment grounding conductor ______.

1. is never permitted
2. is a design choice
3. is permitted to solve “dirty ground” problems
4. is not likely to create a shock or electrocution risk

10. Which of the following statements is true regarding isolated grounding receptacles or equipment _____?

1. They are permitted to be installed only where necessary.
2. An insulated equipment grounding conductor is required.
3. The equipment grounding conductor can pass through one or more panelboards, wireways, boxes, or other enclosures.
4. All of the above.

11. The insulated equipment grounding conductor for isolated grounding receptacles or equipment is permitted to terminate at which of the following locations?

1. Source of the separately derived system if it supplies the branch circuit
2. The computer room disconnecting means
3. The local grounding electrode near the computer room
4. None of the above

12. To reduce “ground loops” which of the following actions is sometimes taken?

1. Single point grounding
2. Insert a balun coil
3. Fiber optic cables
4. All of the above

13. Advantages of establishing an equipotential plane in IT equipment rooms include which of the following _____?

1. Low impedance return path for RF (radio frequency) noise currents
2. Containment of electromagnetic (noise) fields between their source (cables and similar) and the plane
3. Increasing filtering effectiveness of contained electromagnetic fields
4. All of the above

14. A *signal reference gri*d is permitted to _____.

1. replace the equipment grounding conductor of the branch circuit
2. overlay the equipment grounding conductor of the branch circuit
3. be used in addition to the equipment grounding conductor of the branch circuit
4. any of the above

15. Signal reference grids are typically constructed of which of the following materials or in which method _____?

1. Copper or aluminum strips
2. 4 AWG copper or aluminum conductors
3. The metal structure for the raised floor
4. All of the above

16. Which of the following statements about high frequencies in computer room circuits is or are true _____?

1. Digital signal circuits have increased beyond the 3 to 10 MHz clock repetition rate.
2. Resonance occurs when the length of a conductor and the frequency of the alternating current are in tune.
3. Good engineering practice requires that that a conductor any longer than 1/20th of a wavelength cannot be counted upon to equalize voltages between its ends.

4. All of the above.

17. Which of the following statements about single point grounding in computer rooms is or are true ____?

1. The intent is to maintain potential (voltage) differences among different IT equipment as low as possible.
2. Single-point grounding is typically applied to digital circuits with signal frequencies up to 300 kHz.
3. Single point grounding includes a set of bonding conductors that replace the equipment grounding conductors.
4. Supplementary grounding electrodes are permitted to be isolated from the electrical system grounding electrode.

18. Which of the following statements about surge arrestors and surge protective devises (SPDs) is NOT true ____?

1. Surge arresters protect equipment by absorbing excessive voltages.
2. Surge arresters installed on circuits of more than 1000 volts shall be made inaccessible to unqualified persons.
3. Surge protective devices are required to be listed.
4. There are 4 types of surge protective devices (SPDs).

19. Which of the following statements about harmonic currents and nonlinear loads is NOT true ____?

1. Nonlinear loads can cause several problems in the electrical supply system including over loading neutral conductors and creating excessive heat in transformers.
2. Harmonic currents appear as reflected wave forms that distort the basic sine wave produced and provided by the electric utility.
3. The even multiples of the sine wave, such as the 2nd (120 Hz), 4th (240 Hz), 6th (360 Hz) are the most troublesome harmonic currents.
4. Engineers often specify oversize neutrals to handle the extra nonlinear load without excessive voltage drop or heating.

20. Power distribution units (PDUs) that are used for information technology equipment shall be permitted to contain multiple panelboards provided that the PDU is ___________ equipment listed for information technology application.

1. utilization
2. accessible
3. special
4. organization

21. Where information technology equipment is installed in a critical operations data system in compliance with 645.10(B), a procedure shall be __________________ that controls the cessation of the air circulation within the room or zone.

1. permitted
2. engineered
3. documented
4. approved by the AHJ

⏚ Chapter 19
Low-Voltage and Intersystem Grounding and Bonding

Objectives to understand

- Grounding and bonding for low-voltage circuits and systems
- Low-voltage motor control circuits
- Intrinsically safe circuits and systems
- Purpose of an intersystem bonding termination
- Communication cable grounding and bonding
- Bonding electrodes of different systems
- Radio and TV antennas
- Amateur transmission and receiving stations
- CATV systems
- Network-powered broadband communications systems
- Premises-powered broadband communications systems

The general requirements for grounding of low-voltage circuits and systems less than 50 volts are covered in 250.20(A). Typical low-voltage systems falling into this category can include motor control circuits, Class 1, 2, or 3 circuits, and remote control or signaling circuits, such as low-voltage circuits for electric door release equipment or doorbell circuits.

The *Code* requires these systems to be grounded under any of the following conditions:

> "Where supplied by transformers, if the transformer supply system exceeds 150 volts to ground."[1] A low-voltage ac system must be grounded if it is supplied by a transformer secondary that is supplied on the primary side with a voltage exceeding 150 volts from the ungrounded conductors to ground. Where the primary circuits for these transformers are supplied from a grounded system, there will be measurable voltages from any of the phase (ungrounded) conductors to ground (earth) or grounded metal parts.
>
> "Where supplied by transformers, if the transformer supply system is ungrounded."[2] A secondary system must also be grounded where the transformers for these circuits or systems are supplied on the primary side by an ungrounded system, such as by an ungrounded 480-volt or 240-volt power system. These systems are not required to be grounded by 250.20(B).
>
> "Where installed outside as overhead conductors."[3]

When the conductors are installed as overhead conductors outside of buildings, the previously mentioned low-voltage systems or circuits must be grounded. These would include, but are not limited to, signal circuits, fire alarm, and other control circuits or systems. This is primarily due to the possible exposure to lightning.

Where low-voltage circuits or systems do not fall into the requirements of 250.20(A) as outlined above, grounding these systems is optional. In other words, these types of systems or circuits could be operated ungrounded with no grounded conductor for the system or circuit supplied by the secondary and where the transformer secondary is intentionally not grounded.

Low-Voltage Motor Control Circuits

Low-voltage motor control circuits are required to be grounded if any of the conditions in 250.20(A)(1) or 250.20(A)(2) exist.

Motor controllers and combination motor control units are often supplied with control-circuit transformers that are factory grounded on the secondary of the low-voltage side by the manufacturer (see photo 19.1). If the motor control circuits are field-installed and wired, then grounding may or may not be required, depending on the voltage or characteristics of the circuit on the primary side of the control circuit transformer. The determining factors for grounding a low-voltage motor control circuit on the secondary of the transformer are if it is supplied on the primary by a circuit derived from an ungrounded system, or if the primary is supplied by a circuit that exceeds 150 volts between any of the primary conductors to ground. The requirements for motor control circuits are located in Part VI of Article 430.[4]

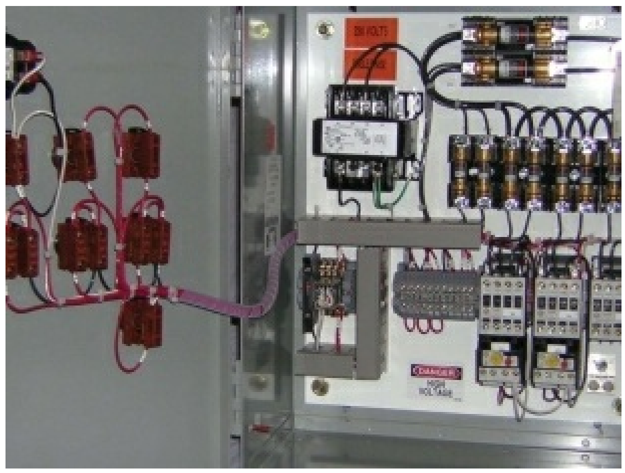


Photo 19.1 Factory-grounded secondary of control circuit transformer in motor controller center

The definition of control circuit was revised and relocated to Article 100 in the 2014 *NEC*. The revised definition, that would apply for all control circuits including motor control circuit is “The circuit of a control apparatus or system that carries the electric signals directing the performance of the controller but does not carry the main power current.” The requirements for motor control circuits include overcurrent protection, physical protection, disconnecting means, and that control circuit transformers be installed in an enclosure. Section 430.72(C)(1) through (C)(5) includes the overcurrent protection requirements for the control circuit transformers. Section 430.72(C)(1) specifically provides that motor control circuit transformers supply “a Class 1 power-limited circuit, Class 2, or Class 3 remote-control circuit complying with the requirements of Article 725, protection shall comply with Article 725.”

Other Signaling Circuits

Low-voltage signaling circuits are required to be grounded circuits or systems if either 250.20(A)(1) or (2) applies. For example, the circuit is supplied by a transformer that has a primary voltage of 480 volts single-phase and steps the voltage down for the signal circuit to 24 volts AC for a horn or bell annunciation. Low-voltage signaling circuits are commonly used for doorbell installations in dwelling units. Generally, the voltage for these door chime circuits is usually less than 24 VAC and the systems are ungrounded since they are supplied from a 120-volt circuit on a grounded system.

Intrinsically Safe Systems and Circuits

Branch circuits that supply intrinsically safe systems must include an equipment grounding conductor as covered in 250.118. The equipment grounding conductor is used for grounding the metal enclosure(s) and other metal parts and equipment of the system.

Article 504 of the *Code* includes the requirements for intrinsically safe systems, and 504.50 and 504.60 cover the grounding and bonding requirements for these systems.

Section 504.50(A) requires "intrinsically safe apparatus, associated apparatus, cable shields, enclosures, and raceways, if of metal, shall be connected to the equipment grounding conductor." A control drawing is required for these systems to provide specific information and instructions. These control drawings include grounding and bonding information critical to the integrity of the intrinsically safe system or circuit(s). Supplementary bonding to the grounding electrode may be needed for some associated apparatus (Zener diode barriers, for example) if specified in the control drawing. Additional information relative to these systems can be found in ANSI/ISA RP 12.06.01-2003, Recommended Practice for Wiring Methods for Hazardous (Classified) Locations Instrumentation --Part 1: Intrinsic Safety.

It is not uncommon for the required control drawing(s) to specify a grounding electrode conductor connection for these systems in addition to connection to an equipment grounding conductor. Usually, terminals for both of these conductors are located within the system enclosure or control panel. If a grounding electrode is required, then one of the electrodes in 250.52(A) must be used. The choice of which grounding electrode(s) must be used is governed by the same provisions specified in 250.30(A)(4) for separately derived systems. The electrode must be "The building or structure grounding electrode system shall be used as the grounding electrode for the separately derived system. If located outdoors, the grounding electrode shall be in accordance with 250.30(C)." The size of this grounding electrode conductor is generally specified by the manufacturer's control drawing.

Where shielded conductors or cables are used, shields shall be grounded in accordance with the required control drawing. The bonding requirements for metallic enclosures and raceways enclosing intrinsically safe systems or circuits in hazardous locations must be in accordance with any of the methods that are suitable for the bonding on the line side of a service.

Section 250.100 indicates that "regardless of the voltage of the electrical system, the electrical continuity of non-current-carrying metal parts of equipment, raceways, and other enclosures in any hazardous (classified) location as defined in 500.5, 505.5, and 506.5, shall be ensured by any of the bonding methods specified in 250.92(B) (2) through (B)(4). One or more of these bonding methods shall be used whether or not the equipment grounding conductor of the wire type is installed."

Sections 501.30, 502.30, and 503.30 also provide additional requirements for grounding and bonding requirements in hazardous locations. Bonding must be extended and maintained for all intervening raceways and enclosures from the hazardous location all the way to the applicable service or separately derived system (see chapter fifteen for more detailed information on bonding requirements in hazardous locations).

The Purpose of Intersystem Grounding and Bonding

Intersystem grounding and bonding requirements serve a few important purposes [see figure 19-1]. The systems and circuits covered in *NEC* Chapter 8 must be grounded (to earth) and bonded to the electrical power distribution systems for the building or structure.

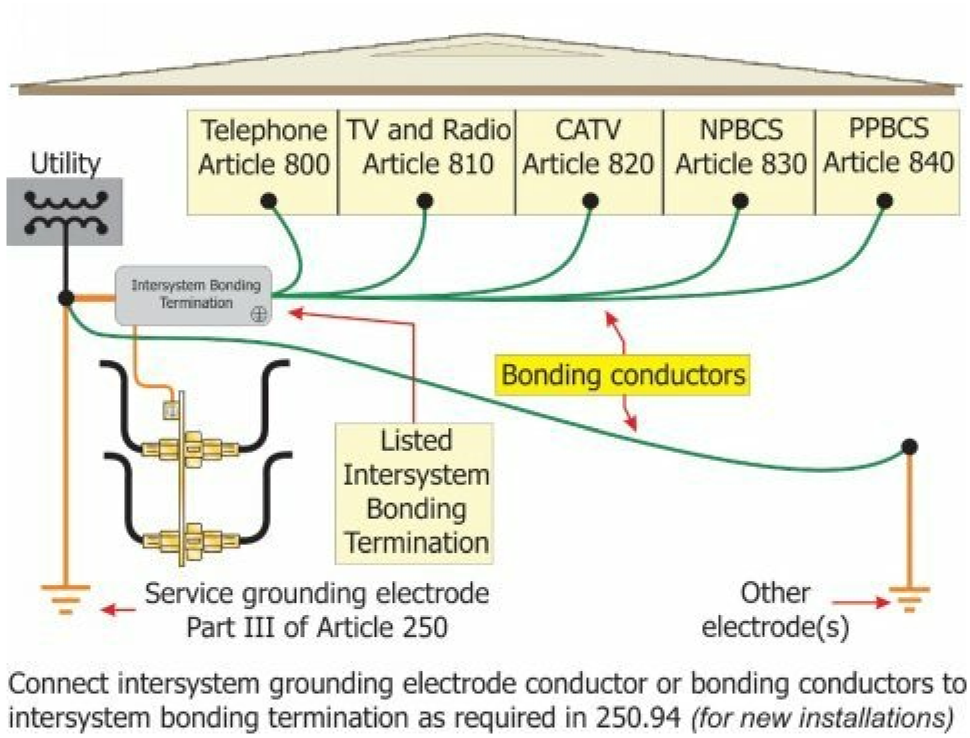


Figure 19.1 Intersystem grounding electrodes (bond together and connect to intersystem bonding termination)

By providing the connection to a grounding electrode, the systems and circuits are afforded reasonable protection from spike and surge currents and also brief elevated potentials due to lightning strikes. Bonding the electrodes of the systems listed in *NEC* Chapter 8 to the grounding electrode system for the electrical system(s), as required by the *NEC*, of the building or structure limits the potential differences during normal operation and during surge or spike events and the effects of lightning discharges into the earth at close proximities. Bonding the electrodes of the two different systems together also limits the potential differences and shock hazards that could result from isolated grounding (earthing) electrode connections.

The *NEC* is specific in Articles 800, 810, 820, 830, and 840 about grounding electrodes to be used with these systems. Each article requires an effective bonding connection to the electrical power grounding electrode(s) system with a minimum 6 AWG copper conductor. This means that where items such as satellite dishes, TV antennas, radio antennas, and the like are installed at any occupancy, electrodes are required; and the electrode must be the same electrode used by the electrical service or system. All grounding electrodes that are installed must be bonded to the building grounding electrode system.

The grounding and bonding for these systems, although referred to as intersystem grounding and bonding, is usually not the grounding of the particular system itself. Part II of Article 250 is specifically titled Circuit and System Grounding. Section 250.20 specifies systems required to be grounded, systems permitted to be grounded, and systems not permitted to be grounded.

Intersystem Bonding Termination

The requirements for safety of communications systems, antenna systems, CATV and radio systems, and network-powered broadband communications systems are located in *NEC* Chapter 8 entitled Communications Systems. Section 250.94 includes the requirements for intersystem bonding and grounding of these communications systems (see figures 19.2 and 19.3).

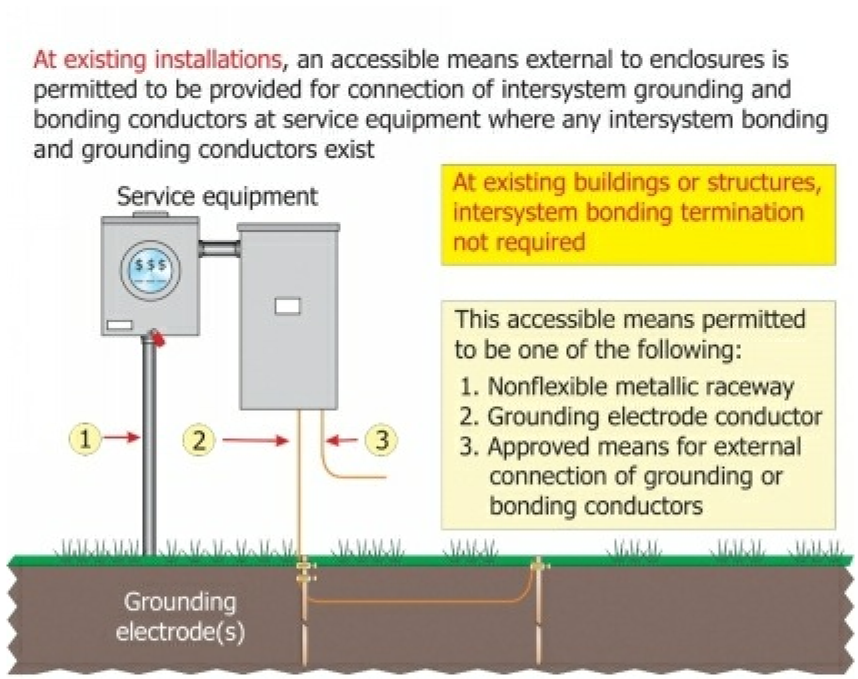


Figure 19.2 Intersystem bonding termination

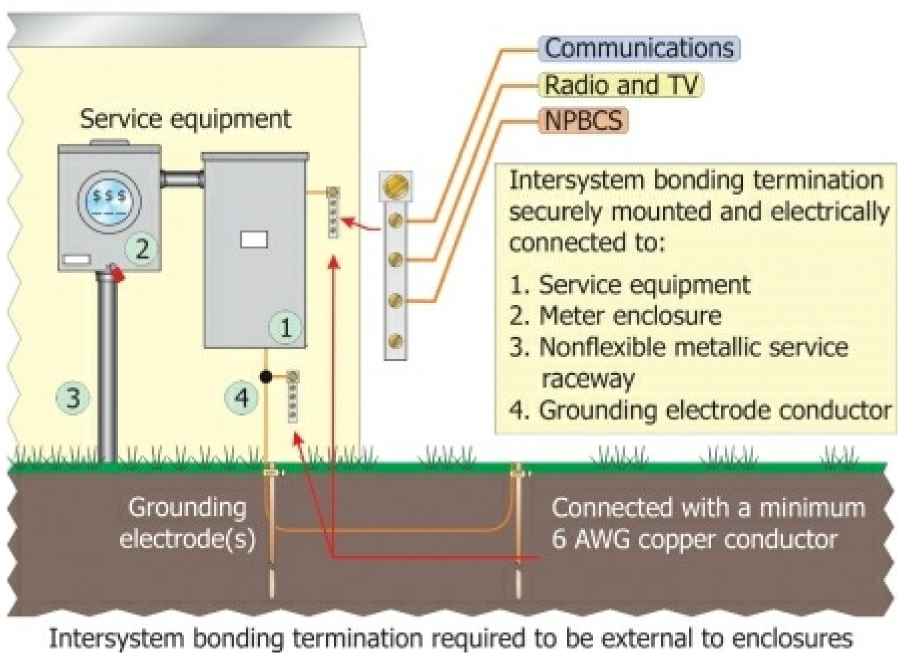


Figure 19.3 Bonding of other systems at existing building (250.94, Exception)

An intersystem bonding termination is required to be provided external to service equipment and at the disconnecting means for additional buildings or structures supplied by a feeder or branch circuit. There is an exception to 250.94 that permits not installing the interservice bonding termination at outbuildings that might have power supplied, such as a shed, that are not likely ever to be provided with a communications system. The intersystem bonding termination is required to have provisions for connecting not less than three intersystem bonding conductors and shall be so installed that it does not interfere with opening service or metering equipment enclosures or the disconnect enclosures at the outbuilding [250.94(A)(3)] (see figure 19.3).

The systems that the *Code* points to here are low-voltage (limited energy) systems and frequency signals or communications circuits and systems.

These systems are not normally grounded as power systems in accordance with 250.20, where one conductor of the system or service is intentionally grounded. The grounding and bonding requirements for these communications systems provide safety from shock hazards and fire hazards and, in addition, provide important equipment and system/circuit protection from damaging surges or dips in the normal electrical supply. The following definitions are still applicable to the installations of these voice, data, and video (VDV) systems.

Photo 19.2 Communications system grounding electrode conductor connected to intersystem bonding termination

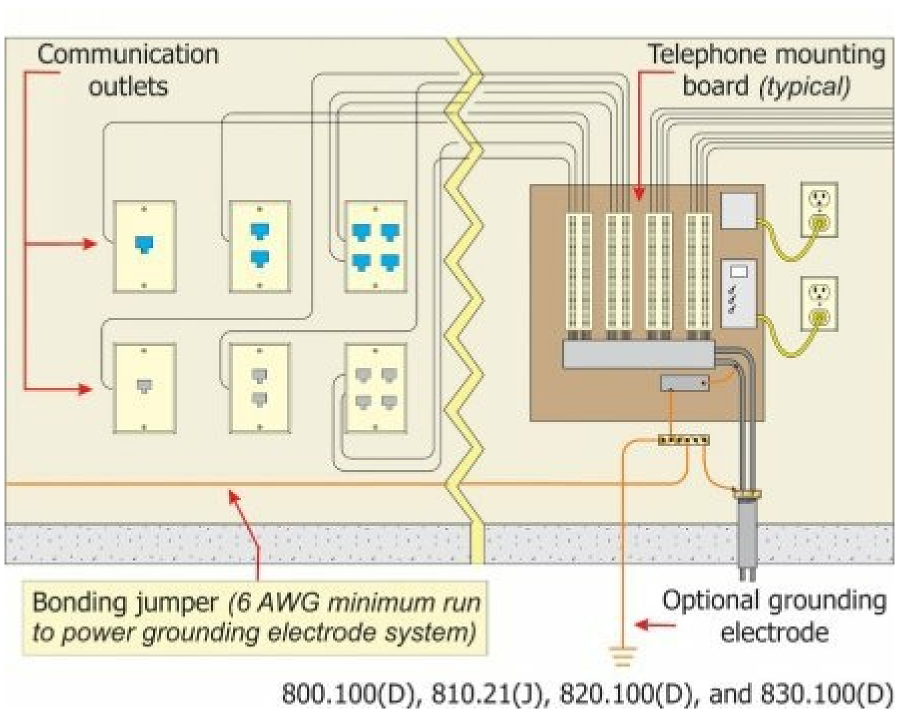


Figure 19.4 Communications systems grounding and bonding

Definitions

Grounding Electrode Conductor. “A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or a point on the grounding electrode system.” [5]

Bonded (Bonding). “Connected to establish electrical continuity and conductivity.” [6]

Bonding Conductor or Jumper. “A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected.” [7]

Intersystem Bonding Termination. “A device that provides a means for connecting intersystem bonding conductors for communications systems to the grounding electrode system.”

A major change occurred in the 2011 *NEC* cycle that deleted the term and definition grounding conductor since it was very close to the definition of grounding electrode conductor. In completing its work *Code* Panel 16 found that the term grounding conductor had been improperly used from its definition and revised text accordingly to either identify the conductor as a grounding electrode conductor or as a bonding conductor.

Article 800, Communications Circuits, covers telephone, telegraph (except radio), outside wiring for fire alarm and burglar alarm, and similar central station systems; and telephone systems not connected to a central station system but using similar types of equipment, methods of installation, and maintenance for such circuits and systems. Grounding and bonding requirements for communications systems are found in Part IV and specifically in 800.100 and 800.106.

> “Insulation. The bonding conductor or grounding electrode conductor shall be listed and shall be permitted to be insulated, covered, or bare.
>
> “Material. The bonding conductor or grounding electrode conductor shall be copper or other corrosion-resistant conductive material, stranded or solid.
>
> “Size. The bonding conductor or grounding electrode conductor shall not be smaller than 14 AWG. It shall have a current-carrying capacity not less than the grounded metallic sheath member(s) and protected conductor(s) of the communications cable. The bonding conductor or grounding electrode conductor shall not be required to exceed 6 AWG.
>
> “Length. The primary protector bonding conductor or grounding electrode conductor shall be as short as practicable. In one- and two-family dwellings, the primary protector bonding conductor or grounding electrode conductor shall be as short as practicable, not to exceed 6.0 m (20 ft) in length”[8](see figures 19.5 and 19.6).

This grounding also serves as a discharge path for lightning strikes and other events that work to raise potentials on these systems. By keeping the length of the bonding conductor or grounding electrode conductor as short as practicable, the effectiveness of the bonding conductor or grounding electrode conductor to provide a low-impedance path to ground to dissipate lightning and other surge events is established.

The exception to 800.100(A)(4) reads, “In one- and two-family dwellings where it is not practicable to achieve an overall maximum primary protector bonding conductor or grounding electrode conductor length of 6.0 m (20 ft), a separate communications ground rod meeting the minimum dimensional criteria of 800.100(B)(3)(2) shall be driven, the primary protector shall be connected to the communications ground rod in accordance with 800.100(C), and the communications ground rod shall be connected to the power grounding electrode system in accordance with 800.100(D).” In this case, the electrode for the communications system is to be installed and bonded to the service grounding electrode system with a bonding jumper sized not smaller than 6 AWG copper (see figures 19.5 and 19.6).

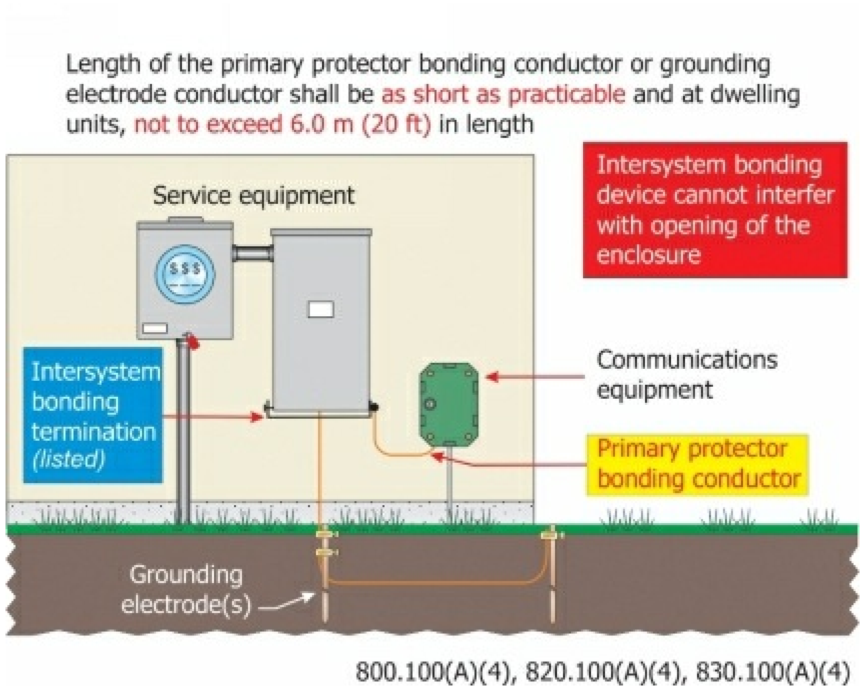


Figure 19.5 Length of bonding conductor or grounding electrode conductor for cable and primary protector (dwellings)

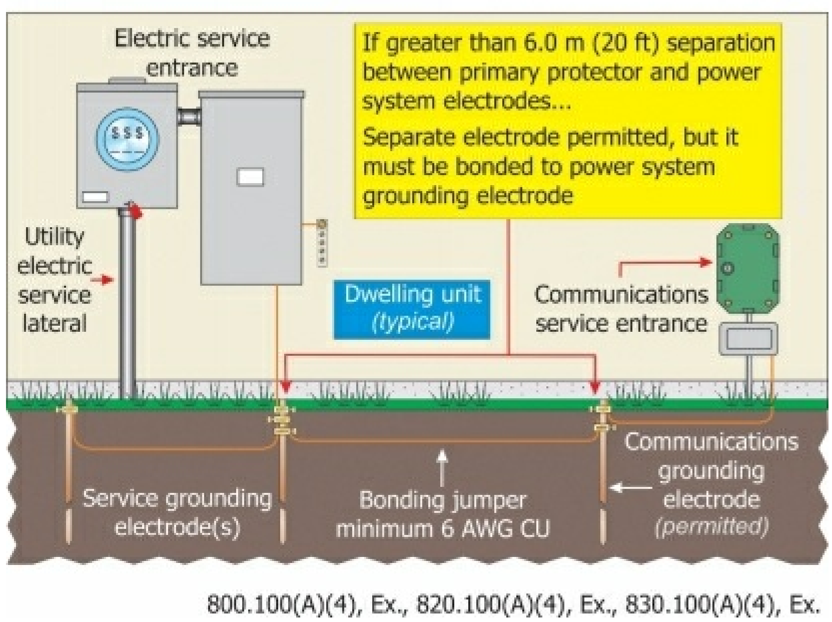


Figure 19.6 Length of bonding conductor or grounding electrode conductor for cable and primary protector (dwellings). The exception permits bonding of separate electrodes together.

Section 800.100(A)(5) also requires that “the bonding conductor or grounding electrode conductor shall be run to the grounding electrode in as straight a line as practicable.” Section 800.100(A)(6) has the provisions for physical protections and part of this section includes the requirement of where the bonding conductor or grounding electrode conductor is installed run in a metal raceway, both ends of the raceway shall be bonded to the contained conductor or to the same terminal or electrode to which the bonding conductor or grounding electrode conductor is connected.

The 2017 *NEC* revised the above requirements into an item “(A)” and then added a new provision as section 250.94(B). For some installations, particularly but not limited to commercial, institutional or industrial locations, the intersystem bonding termination device at the service or building disconnect may not be adequate. 250.94(B) for “Other Means” provides that, “Connections to an aluminum or copper busbar not less than 6 mm thick × 50 mm wide (1/4 in. thick × 2 in. wide) and of sufficient length to accommodate at least three terminations for communication systems in addition to other connections. The busbar shall be securely fastened and shall be installed in an accessible location. Connections shall be made by a listed connector. If aluminum busbars are used, the installation shall also comply with 250.64(A).” (see figure 19.7). This aligns with the common practice in some installations for the communication room with many systems to use a copper or aluminum bus for the purposes of grounding and bonding all the various communications equipment and connecting to the building grounding electrode system. The busbar used at a dwelling unit would also allow connection of non-communications systems where required by other *Code*s as long as the required three terminations for the communications systems are provided.

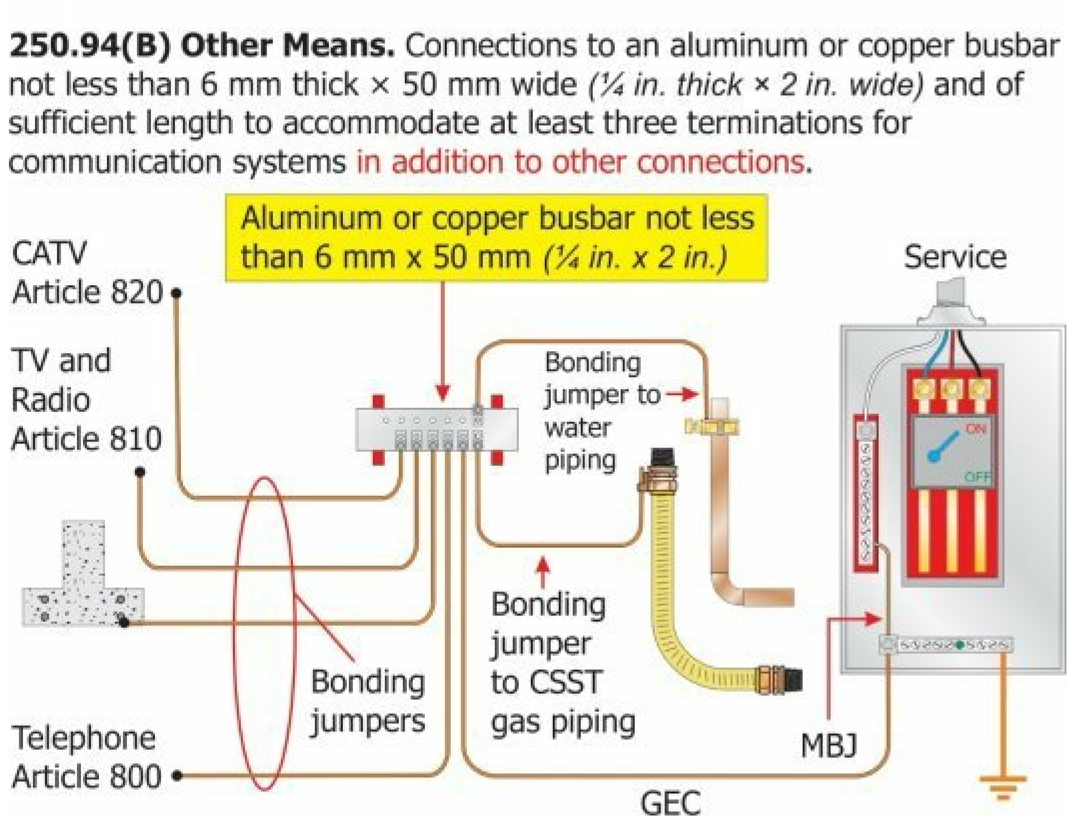


Figure 19.7 Communications systems bonding with busbar

Electrodes

For communications systems, the goal is to establish a close connection to a grounding electrode either directly or through the intersystem bonding termination. Section 800.100(B) requires provisions for connection to ground by one of three means provided in (B)(1) through (B)(3).

"(B) Electrode. The bonding conductor or grounding electrode conductor shall be connected in accordance with 800.100(B)(1), (B)(2), or (B)(3):

"(1) In Buildings or Structures with an Intersystem Bonding Termination. If the building or structure served has an intersystem bonding termination as required by 250.94, the bonding conductor shall be connected to the intersystem bonding termination."

The intersystem bonding terminations are then connected to earth through a grounding electrode conductor from the interservice bonding termination. See the definitions above and Article 100 for the definition of intersystem bonding termination. The *NEC* also specifies several acceptable points on an existing building or structure grounding electrode system where the communications system grounding electrode or grounding electrode conductor from the intersystem bonding connection can be made (see figure 19-2, 19-4 and 19.7). This preferred method eliminates distances and potential differences between the connections to earth for the two systems. Where a building or structure has no intersystem bonding termination as required by 800.100(B)(1) for new installations, Section 800.100(B)(2) requires that the bonding conductor or grounding electrode be connected as follows:

> "(2) In Buildings or Structures With Grounding Means. If an intersystem bonding termination is established, 250.94(A) shall apply.

If the building or structure has no intersystem bonding termination, the bonding conductor or grounding electrode conductor shall be connected to the nearest accessible location on one of the following:

"(1) The building or structure grounding electrode system as covered in 250.50

"(2) The grounded interior metal water piping system, within 1.5 m (5 ft) from its point of entrance to the building, as covered in 250.52

"(3) The power service accessible means external to enclosures using the options identified in 250.94(A), Exception

"(4) The nonflexible metallic power service raceway

"(5) The service equipment enclosure

"(6) The grounding electrode conductor or the grounding electrode conductor metal enclosure of the power service

"(7) The grounding electrode conductor or the grounding electrode of a building or structure disconnecting means that is grounded to an electrode as covered in 250.32.

A bonding device intended to provide a termination point for the bonding conductor (intersystem bonding) shall not interfere with the opening of an equipment enclosure. A bonding device shall be mounted on nonremovable parts. A bonding device shall not be mounted on a door or cover even if the door or cover is nonremovable.

For purposes of this section, the mobile home service equipment or the mobile home disconnecting means, as described in 800.90(B), shall be considered accessible.[9]

In buildings or structures that have no intersystem bonding termination or grounding means, an electrode is required to be installed as follows:

"(3) In Buildings or Structures Without an Intersystem Bonding Termination or Grounding Means. If the building or structure served has no intersystem bonding termination or grounding means, as described in 800.100(B)(2), the grounding electrode conductor shall be connected to either of the following:

"(1) To any one of the individual electrodes described in 250.52(A)(1), (A)(2), (A)(3), or (A)(4)

"(2) If the building or structure served has no intersystem bonding termination or has no grounding means, as described in 800.100(B)(2) or (B)(3)(1), to any one of the individual grounding electrodes described in 250.52(A)(7) and (A)(8), or to a ground rod or pipe not less than 1.5 m (5 ft) in length and 12.7 mm (1/2 in.) in diameter, driven, where practicable, into permanently damp earth and separated from lightning protection system conductors as covered in 800.53 and at least 1.8 m (6 ft) from electrodes of other systems. Steam, hot water pipes or lightning protection system conductors (lightning-rod conductors) shall not be employed as electrodes for protectors and grounded metallic members."[10]

Intersystem Grounding and Bonding at Mobile Homes

The grounding for communications systems on a mobile home generally follows the same requirements as for permanent buildings or structures. Electrically, the objectives are similar. The goal is to establish a grounding (earth) connection to eliminate differences of potential, and to provide a path into the earth to dissipate lightning strikes.

Section 800.106(A)(1) requires that "Where there is no mobile home service equipment located within 9.0 m (30 ft) of the exterior of the mobile home it serves, the primary protector grounding terminal shall be connected to a grounding electrode conductor or grounding electrode in accordance with 800.100(B)(3)."[11]

> The bonding requirements are a bit more specific for the mobile home applications.
>
> "(B) Bonding. The primary protector grounding terminal or grounding electrode shall be connected to the metal frame or available grounding terminal of the mobile home with a copper conductor not smaller than 12 AWG under any of the following conditions:
>
> "(1) Where there is no mobile home service equipment or disconnecting means as in 800.106(A)
>
> "(2) Where the mobile home is supplied by cord and plug" [12]

Articles 810, 820, and 830 include the grounding and bonding requirements for these particular installations although the system itself is usually ungrounded.

As indicated by 90.3, *NEC* Chapter 8 is not subject to the other chapters and stands alone unless specifically referenced from therein. The *Code* permits the minimum sizes of these grounding electrode (earth) conductors or bonding conductors to be smaller than normally is allowed by Chapter 2 in Article 250. The communications system bonding conductor or grounding electrode conductor is permitted to be as small as a 14 AWG. However, the bonding conductor required to connect the grounding electrode for the power distribution system to the grounding electrode for the communication system is always required to be at least a minimum size of 6 AWG copper.

Communications Cable Grounding Requirements

The metallic sheaths of communications cables entering buildings shall be grounded as close as practicable to the point of entrance or shall be interrupted by an insulating joint or equivalent device located as close as practicable to the point of entrance. If the metallic shields of the cables are grounded, they are required to be grounded by a conductor meeting the requirements of 800.100(A). This conductor is required to be copper or other corrosion resistant conductor and can be solid or stranded not smaller than 14 AWG [800.100(A)(3)]. It is important that the routing and orientation of the conductor be installed so that it will be in as straight a line as practicable. When functioning to dissipate the effects of lightning, it is important that the conductor be installed with straight lines and gradual bends. The bonding conductor or grounding electrode conductor is required to be installed in a manner so as to be protected from physical damage. This is often accomplished by installing it in a raceway. If the bonding conductor or grounding electrode conductor is installed in a metal raceway, both ends of the raceway shall be bonded to the bonding conductor or grounding electrode conductor or the same terminal or electrode to which the bonding conductor or grounding electrode conductor is connected [800.100(A)(6)]. The grounding electrode to be used shall be electrode or point of grounding connection as indicated in 800.100(B) as previously discussed in the section on electrodes.[13]

Differences of Potential

In today's world of interconnected communications, data (shielded cables) and electrical power (equipment grounding and/or neutral conductors) for these devices, bonding together all the separate electrodes will limit potential differences between them and between their associated wiring systems. If the bonding is not completed by proper bonding of the electrodes, bonding is completed by the cable shielding and equipment grounding conductors at the electronic equipment which will not perform well in surge or lightning events. Grounding electrodes of different systems or circuits that are not bonded together can present serious hazards for property and persons in general and in particular during lightning events. It is important for eliminating shock hazards to bond any installed intersystem electrodes to the power distribution system grounding electrode system.

Bonding Electrodes of Different Systems

Section 800.100(D) states that "a bonding jumper not smaller than 6 AWG copper or equivalent shall be connected between the communications grounding electrode and the power grounding electrode system at the building or structure served where separate electrodes are used."

Radio and TV Antennas

Grounding and Discharge Equipment

Masts and metal structures supporting antennas shall be grounded in accordance with 810.21. Where required, each conductor of a lead-in from an outdoor antenna shall be provided with a listed antenna discharge unit. The antenna discharge unit shall be grounded in a manner specified by 810.21.

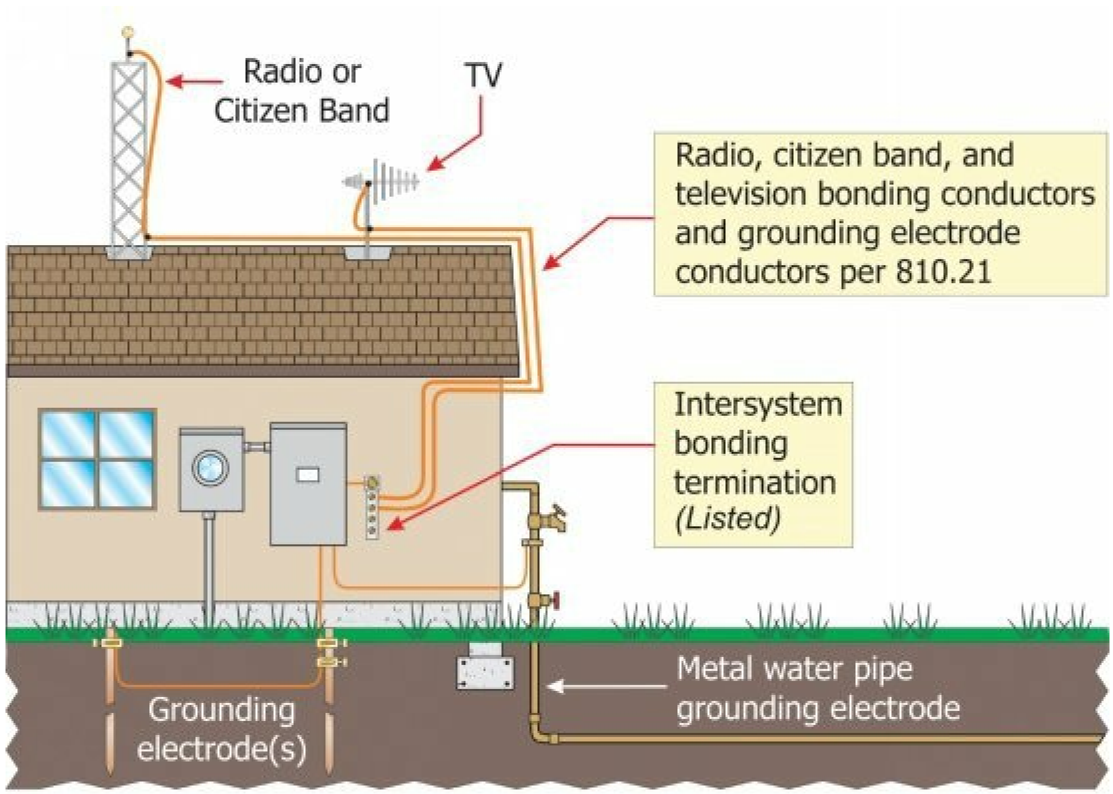


Figure 19.8 Radio, TV, and citizen band antenna systems bonding and grounding electrode conductors

Bonding Conductor or Grounding Electrode Conductor Installations

The bonding conductor or grounding electrode conductor for a radio or TV antenna system is required to be connected to an electrode or other suitable grounding connection point as specified by 810.21(F)(1) through (F)(3). These requirements are the same as the requirements for communications systems in Article 800. The size of the bonding conductors or grounding electrode conductors is a bit different, however, than the size required in Article 800.

> “(A) Material. The bonding conductor or grounding electrode conductor shall be of copper, aluminum, copper-clad steel, bronze, or similar corrosion-resistant material. Aluminum or copper-clad aluminum bonding conductors or grounding electrode conductors shall not be used where in direct contact with masonry or the earth or where subject to corrosive conditions. Where used outside, aluminum or copper-clad aluminum shall not be installed within 450 mm (18 in.) of the earth.
>
> “(B) Insulation. Insulation on bonding conductors or grounding electrode conductors shall not be required.
>
> “(C) Supports. The bonding conductor or grounding electrode conductor shall be securely fastened in place and shall be permitted to be directly attached to the surface wired over without the use of insulating supports.
>
> “(D) Physical Protection. Bonding conductors or grounding electrode conductors shall be protected where exposed to physical damage. Where the bonding conductor or grounding electrode conductor is installed in a metal raceway, both ends of the raceway shall be bonded to the contained conductor or to the same terminal or electrode to which the bonding conductor or grounding electrode conductor is connected.
>
> “(E) Run in Straight Line. The bonding conductor or grounding electrode conductor for an antenna mast or antenna discharge unit shall be run in as straight a line as practicable.
>
> “(F) Electrode. [To be covered under the subhead “Electrode” which follows.]
>
> “(G) Inside or Outside Building. The bonding conductor or grounding electrode conductor shall be permitted to run either inside or outside the building.
>
> “(H) Size. The bonding conductor or grounding electrode conductor shall not be smaller than 10 AWG copper, 8 AWG aluminum, or 17 AWG copper-clad steel or bronze.
>
> “(I) Common Ground. A single bonding conductor or grounding electrode conductor shall be permitted for both protective and operating purposes.”
>
> (J) Bonding of Electrodes. A bonding jumper not smaller than 6 AWG copper or equivalent shall be connected between the radio and television equipment grounding electrode and the power grounding electrode system at the building or structure served where separate electrodes are used.
>
> (K) Electrode Connection. Connections to grounding electrodes shall comply with 250.70. [14]

Electrode

The *Code* specifies several acceptable connection points on the building or structure grounding electrode system. This would be the preferred method, and eliminates distances and potential differences between the grounding (earthing) circuits of the two systems. Section 810.21(F)(1) requires that where the building or structure has an intersystem bonding termination, the radio and television equipment bonding conductors(s) are to be connected to the intersystem bonding termination. Where no intersystem bonding termination is present for use, Section 810.21(F)(2) requires the bonding conductor or grounding electrode conductor to be connected to the nearest accessible location on the following:

> "(1) The building or structure grounding electrode system as covered in 250.50
>
> "(2) The grounded interior metal water piping systems, within 1.52 m (5 ft) from its point of entrance to the building, as covered in 250.52 (see figures 19.8 and 19.9)
>
> "(3) The power service accessible means external to the building, as covered in 250.94
>
> "(4) The nonflexible metallic power service raceway
>
> "(5) The service equipment enclosure, or
>
> "(6) The grounding electrode conductor or the grounding electrode conductor metal enclosures of the power service.
>
> "A bonding device intended to provide a termination point for the bonding conductor (intersystem bonding) shall not interfere with the opening of an equipment enclosure. A bonding device shall be mounted on nonremovable parts. A bonding device shall not be mounted on a door or cover even if the door or cover is nonremovable" [15]

If the building or structure has no intersystem bonding termination or grounding electrode system, then connection of the bonding conductor or grounding electrode conductor is specified in 800.100(B)(3).

If the building or structure served has no intersystem bonding termination or grounding means as described in 810.21(F)(2), the grounding electrode conductor shall be connected to a grounding electrode as described in 800.100(B)(2). See 800.100(B)(3) for specific requirements.

According to 810.21(G) and (H), "the bonding conductor or grounding electrode conductor shall be permitted to run either inside or outside the building," and "shall not be smaller than 10 AWG copper, 8 AWG aluminum, or 17 AWG copper-clad steel or bronze." The connection of the bonding or grounding electrode conductor shall ultimately be made to the grounding electrode and serves both as an operational grounding connection and as a protective earthing connection for lightning and other events affecting the system and potential differences.

When installed, the separate grounding electrode for a radio or television antenna is required to be bonded to the grounding electrode system for the building. "A bonding jumper not smaller than 6 AWG copper or equivalent shall be connected between the radio and television equipment grounding electrode and the power grounding electrode system at the building or structure served if separate electrodes are used"[16] [810.21(J)]

The connection(s) to grounding electrode(s) is required to meet the requirements of 250.70 [810.21(K)] (see figure 19.9).

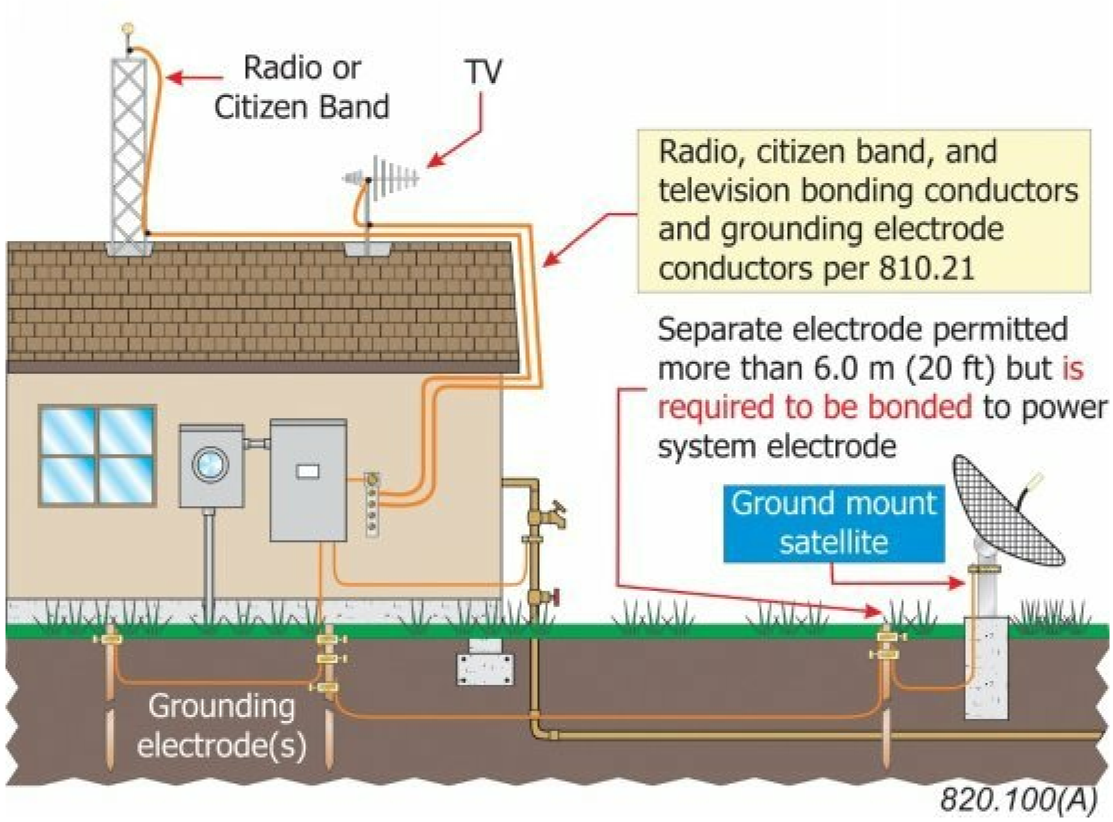


Figure 19.9 Separate electrode is required to be bonded to power system electrode.

Amateur Transmission and Receiving Stations

Lead-in antenna conductors shall be installed in such a manner that affords a degree of protection against accidental contact by personnel.

Section 810.56 requires that "lead-in conductors to radio transmitters shall be located or installed so as to make accidental contact with them difficult." Where transmitting or receiving stations are installed, "each conductor of a lead-in for outdoor antennas shall be provided with an antenna discharge unit or other suitable means that will drain static charges from the antenna system. [810.57]

> "Exception No. 1: Where the lead-in is protected by a continuous metallic shield that is grounded with a conductor in accordance with 810.58, an antenna discharge unit or other suitable means shall not be required.
>
> "Exception No. 2: Where the antenna is grounded with a conductor in accordance with 810.58, an antenna discharge unit or other suitable means shall not be required." [17]

There are two bonding conductors or grounding electrode conductors required for this specific equipment: an operating bonding conductor or grounding electrode conductor and a protective bonding conductor or grounding electrode conductor. These bonding conductors or grounding electrode conductors for amateur transmitting and receiving stations are required to be installed in accordance with 810.58(A), (B), or (C) as follows:

> **"(A) Other Sections.** All bonding conductors or grounding electrode conductors for amateur transmit-ting and receiving stations shall comply with 810.21(A) through (C).
>
> **"(B) Size of Protective Bonding Conductor or Grounding Electrode Conductor.** The protective bonding conductor or grounding electrode conductor for transmitting stations shall be as large as the lead-in but not smaller than 10 AWG copper, bronze, or copper-clad steel.
>
> **"(C) Size of Operating Bonding Conductor or Grounding Electrode Conductor.** The operating bonding conductor or grounding electrode conductor for transmitting stations shall not be less than 14 AWG copper or its equivalent." [18]

Community Antenna Television and Radio Distribution (CATV) Systems

CATV systems are usually wired with conductors that are coaxial and have shields inherent to the cable assembly. Section 820.93(A) and (B) provide similar requirements for cables entering a building or structure or terminating outside the building or structure. This section provides that the outer conductive shield of the coaxial cable shall be grounded at the building premises as close to the point of cable entrance or attachment as practicable. Where these shields are required to be grounded, selecting a grounding location to achieve the shortest practicable bonding conductor or grounding electrode conductor will help limit potential differences between CATV and other metallic systems. "Where the outer conductive shield of a coaxial cable is grounded, no other protective devices shall be required" [*NEC* 820.93 and 820.93(A) through (D)] [20] (see photo 19.3). A new section 820.49 in the 2014 *NEC* was added that requires where metallic conduit contains entrance coaxial cable, the conduit must be grounded and bonded per 820.100(B).

Photo 19.3 Coaxial cable shields grounded at point of entrance to building or structure

Where the shielded cables are grounded, they shall be bonded or grounded in a manner specified in 820.100(A) through (D) as follows:

"(A) Bonding Conductor or Grounding Electrode Conductor.

"(1) Insulation. The bonding conductor or grounding electrode conductor shall be listed and shall be permitted to be insulated, covered, or bare.

"(2) Material. The bonding conductor or grounding electrode conductor shall be copper or other corrosion-resistant conductive material, stranded or solid.

"(3) Size. The bonding conductor or grounding electrode conductor shall not be smaller than 14 AWG. It shall have a current-carrying capacity not less than the outer sheath of the coaxial cable. The bonding conductor or grounding electrode conductor shall not be required to exceed 6 AWG.

"(4) Length. The bonding conductor or grounding electrode conductor shall be as short as practicable. In one- and two-family dwellings, the bonding conductor or grounding electrode conductor shall be as short as practicable, not to exceed 6.0 m (20 ft) in length." An exception for one and two family dwellings permits the grounding electrode conductor to be connected to a separately installed electrode where the maximum distance specified cannot be achieved. In this case the separate electrode is to be installed and the electrode for the electrical service and the CATV electrode are required to be bonded together with a minimum 6 AWG copper bonding jumper as specified in 820.100(D) (see figures 19.10 and 19.11).

"(5) Run in Straight Line. The bonding conductor or grounding electrode conductor shall be run in as straight a line as practicable.

"(6) Physical Protection. Bonding conductors and grounding electrode conductors shall be protected where exposed to physical damage. Where the bonding conductor or grounding electrode conductor is installed in a metal raceway, both ends of the raceway shall be bonded to the contained conductor or to the same terminal or electrode to which the bonding conductor or grounding electrode conductor is connected.

"**(B) Electrode.** The bonding conductor or grounding electrode conductor shall be connected in accordance with 820.100(B)(1), (B)(2), or (B)(3).

"(1) In Buildings or Structures with an intersystem bonding termination. If the building or structure served has an intersystem bonding termination as required by 250.94, the bonding conductor shall be connected to the intersystem bonding termination.

"(2) In Buildings or Structures with Grounding Means. If an intersystem bonding termination is established, 250.94(A) shall apply.

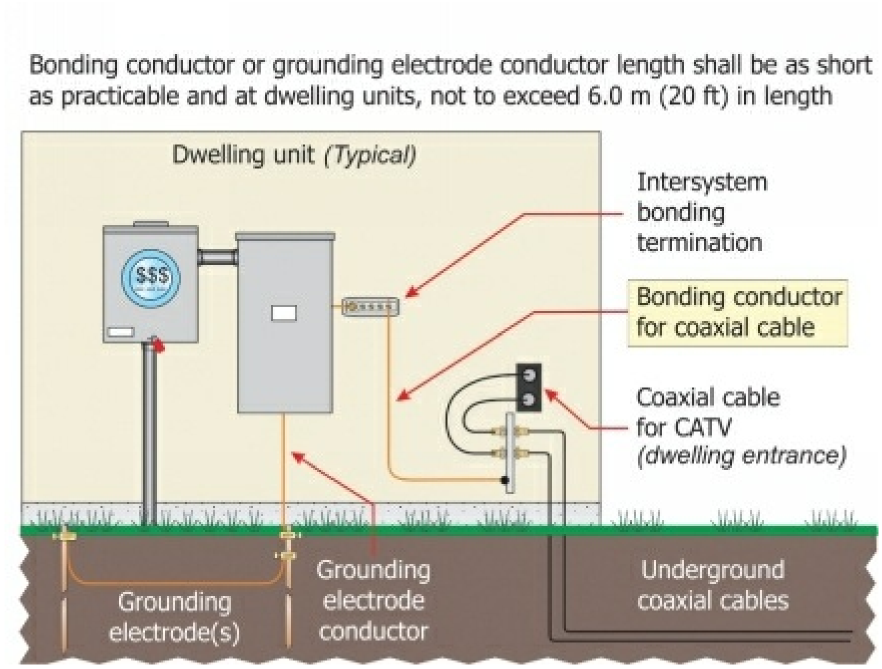


Figure 19.10 Length of bonding or grounding electrode conductor for coaxial cable systems installations. The exception permits separate electrodes but they must be bonded to the power system electrode.

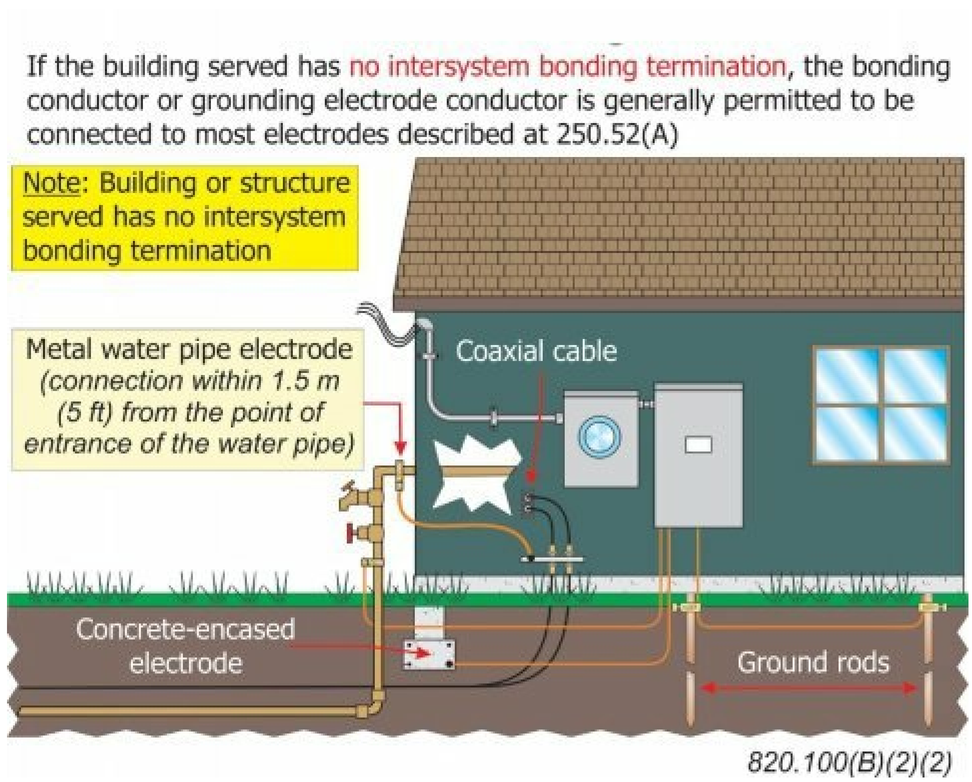


Figure 19.11 Bonding or grounding electrode conductor for CATV system at building where no intersystem bonding termination is present.

If the building or structure served has no intersystem bonding termination, the bonding conductor or grounding electrode conductor shall be connected to the nearest accessible location on one of the following:

"(1) The building or structure grounding electrode system as covered in 250.50

"(2) The grounded interior metal water piping system, within 1.5 m (5 ft) from its point of entrance to the building, as covered in 250.52

"(3) The power service accessible means external to enclosures using the options identified in 250.94(A), Exception

"(4) The nonflexible metallic power service raceway

"(5) The service equipment enclosure

"(6) The grounding electrode conductor or the grounding electrode conductor metal enclosure of the power service, or

"(7) To the grounding electrode conductor or to the grounding electrode of a building or structure disconnecting means that is connected to an electrode as covered in 250.32.

A bonding device intended to provide a termination point for the bonding conductor (intersystem bonding) shall not interfere with the opening of an equipment enclosure. A bonding device shall be mounted on nonremovable parts. A bonding device shall not be mounted on a door or cover even if the door or cover is nonremovable.

For purposes of this section, the mobile home service equipment or the mobile home disconnecting means, as described in 820.93, shall be considered accessible.

"(3) In Buildings or Structures Without an Intersystem Bonding Termination or Grounding Means. If the building or structure served has no intersystem bonding termination or grounding means, as described in 820.100(B)(2), the grounding electrode conductor shall be connected to either of the following:

"(1) To any one of the individual grounding electrodes described in 250.52 (A)(1), (A)(2), (A)(3), (A)(4); or,

"(2) If the building or structure served has no intersystem bonding termination or grounding means as described in 820.100(B)(2) or (B)(3)(1), to any of the individual grounding electrodes described in 250.52(A)(5), (A)(7), and (A) (8). Steam, hot water pipes, or lightning protection system conductors (lightning-rod conductors) shall not be employed as grounding electrodes for bonding conductors or grounding electrode conductors." [21]

Where the shields of CATV system coaxial cables are connected to grounding electrodes, they are required to be connected in accordance with 820.100(C) and (D). The "connections to grounding electrodes shall comply with 250.70." [22]

The electrode(s) of the CATV system must be bonded to the electrical service or system grounding electrode by means of a bonding jumper. Section 820.100(D) requires that "a bonding jumper not smaller than 6 AWG copper or equivalent shall be connected between the community antenna television system's grounding electrode and the power grounding electrode system at the building or structure served where separate electrodes are used." Selecting a grounding location to achieve the shortest practicable grounding electrode conductor will help limit potential differences between CATV and other metallic systems.

Network-Powered Broadband Communications Systems

A typical basic network-powered broadband communications system configuration "includes a cable supplying power and broadband signal to a network interface unit that converts the broadband signal to the component signals (see figures 19.12 and 19.13). Typical cables are coaxial cable with both broadband signal and power on the center conductor, composite metallic cable with a coaxial member(s) or twisted pair members for the broadband signal and twisted pair members for power, and composite optical fiber cable with a pair of conductors for power. Larger systems may also include network components such as amplifiers that require network power." 23

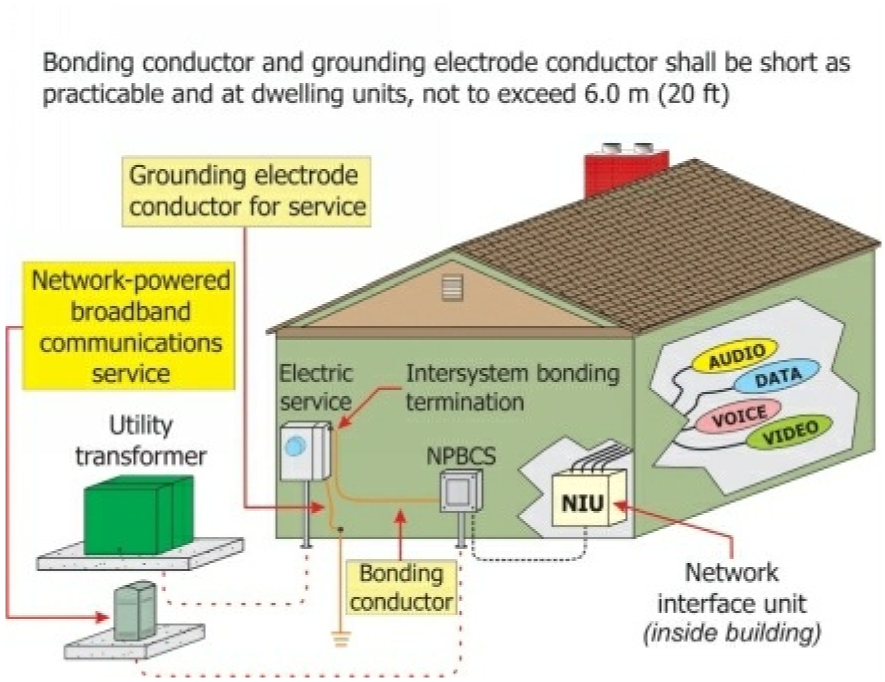


Figure 19.12 Cable network interface unit and primary protector bonding conductors connected to same electrode as power system or service. systems installations. The exception permits separate electrodes but they must be bonded to the power system electrode or service.

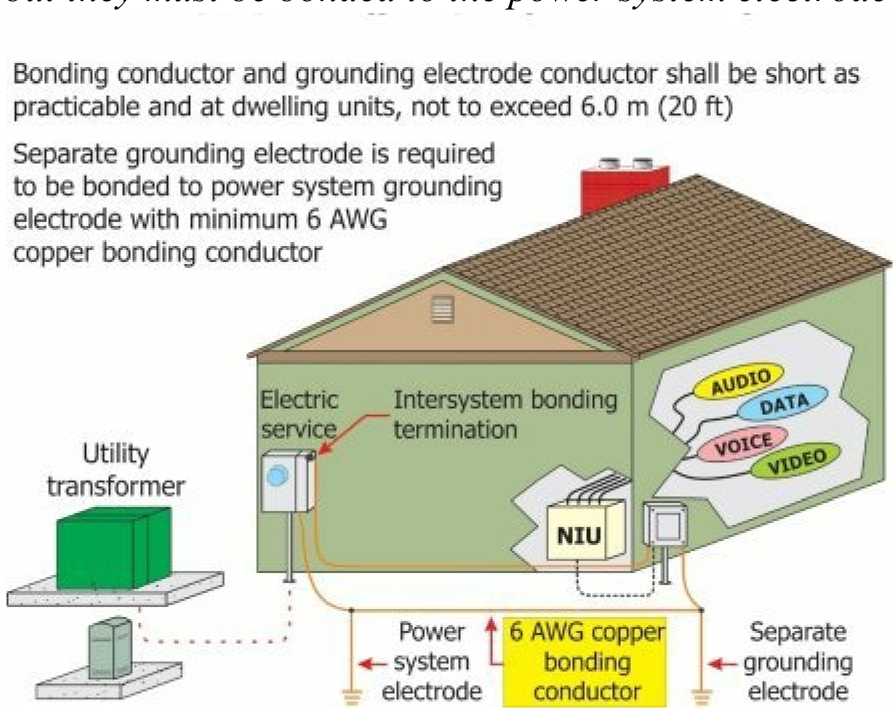


Figure 19.13 Cable network interface unit and primary protector grounding electrode connections to separate electrode that are bonded to the power system grounding electrode as required.

Section 830.100 requires that "Network interface units containing protectors, NIUs with metallic enclosures, primary protectors, and the metallic members of the network-powered broadband communications cable that are intended to be bonded or grounded shall be grounded as specified in 830.100(A) through 830.100(D)." [24] These requirements are similar to those in Articles 800, 810, and 820. The purpose of these grounding and bonding connections is also the same. The same requirement as was set in 820.49, requires that when the supply coaxial conductor is installed in "Metallic conduit containing network-powered broadband communications entrance cable shall be connected by a bonding conductor or grounding electrode conductor to a grounding electrode in accordance with 830.100(B).

The size of the bonding conductor or grounding electrode conductor for the NPBCS is required to be not "smaller than 14 AWG and shall have a current-carrying capacity not less than that of the grounded metallic member(s) and protected conductor(s) of the network-powered broadband communications cable. The bonding conductor or grounding electrode conductor shall not be required to exceed 6 AWG." [25]

Connectors, clamps, fittings, or lugs used to attach grounding electrode conductors to grounding electrodes or bonding jumpers connecting grounding electrodes to each other that are to be concrete-encased or buried in the earth shall be suitable for its application. The grounding clamps and connectors suitable for use in accordance with 250.64 are suitable as well as listed clamps for use specifically with these low-voltage/current systems.[26]

> "(B) Electrode. The bonding conductor or grounding electrode conductor shall be connected in accordance with 830.100(B)(1), 830.100(B)(2), or 830.100(B)(3).
>
> "(1) In Buildings or Structures with an Intersystem Bonding Termination. If the building or structure has an intersystem bonding termination as required by 250.94, the network-powered broadband communication systems bonding conductor shall be connected to the intersystem bonding termination.
>
> "(2) In Buildings or Structures With Grounding Means. If an intersystem bonding termination is established, 250.94(A) shall apply.

If the building or structure served has no intersystem bonding termination, the bonding conductor or grounding electrode conductor shall be connected to the nearest accessible location on one of the following:

> "(1) The building or structure grounding electrode system as covered in 250.50
>
> "(2) The grounded interior metal water piping system, within 1.5 m (5 ft) from its point of entrance to the building, as covered in 250.52
>
> "(3) The power service accessible means external to enclosures using the options identified in 250.94(A), Exception
>
> "(4) The nonflexible metallic power service raceway
>
> "(5) The service equipment enclosure
>
> "(6) The grounding electrode conductor or the grounding electrode conductor metal enclosure of the power service
>
> "(7) The grounding electrode conductor or to the grounding electrode of a building or structure disconnecting means that is grounded to an electrode as covered in 250.32.

A bonding device intended to provide a termination point for the bonding conductor (intersystem bonding) shall not interfere with the opening of an equipment enclosure. A bonding device shall be mounted on nonremovable parts. A bonding device shall not be mounted on a door or cover even if the door or cover is nonremovable.

For purposes of this section, the mobile home service equipment or the mobile home disconnecting means, as described in 830.93, shall be considered accessible.

> "(3) In Buildings or Structures Without an Intersystem Bonding Termination or Grounding Means. If the building or structure served has no intersystem bonding termination or grounding means, as described in 830.100(B)(2), the grounding electrode conductor shall be connected to either of the following:
>
> "(1) To any one of the individual grounding electrodes described in 250.52 (A)(1), (A)(2), (A)(3), or (A)(4)
>
> "(2) If the building or structure served has no intersystem bonding termination or has no grounding means as described in 830.100(B)(2) or (B)(3)(1), to any one of the individual grounding electrodes described in 250.52(A)(7) and (A)(8) or to a ground rod or pipe not less than 1.5 m (5 ft) in length and 12.7 mm (½ in.) in diameter, driven, where practicable, into permanently damp earth and separated from lightning conductors as covered in 800.53 and at least 1.8 m (6 ft) from electrodes of other systems. Steam, hot water pipes, or lightning-protection system conductors shall not be employed as grounding electrodes for protectors, NIUs, with integral protection, grounded metallic members, NIUs with metallic enclosures, and other equipment.[27]
>
> "Connections to grounding electrodes shall comply with 250.70." [830.100(C)]

A new section, 830.180, was added in the 2014 *NEC*. This new section requires grounding devices used for any grounding or bonding purposes to be listed or to be part of listed equipment.

Lightning and Other Hazards

"On network-powered broadband communications conductors not exposed to lightning or accidental contact with power conductors, providing primary electrical protection in accordance with this article helps protect against other hazards, such as ground potential rise caused by power system fault currents, and above-normal voltages induced by fault currents on power circuits in proximity to the network-powered broadband communications conductors.

"Informational Note No. 2: Network-powered broadband communications circuits are considered to have a lightning exposure unless one or more of the following conditions exist:

"(1) Circuits in large metropolitan areas where buildings are close together and sufficiently high to intercept lightning.

"(2) Areas having an average of five or fewer thunderstorm days each year and earth resistivity of less than 100 ohm-meters. Such areas are found along the Pacific coast." [28]

Bonding of Electrode Systems

Where a separate electrode is installed, it is required to bond the grounding electrode for the network-powered broadband communications system to the power system grounding electrode or electrode system for the building or structure. "A bonding jumper not smaller than 6 AWG copper or equivalent must be connected between the network powered broadband equipment grounding electrode and the power grounding electrode system at the building or structure served where separate electrodes are used." [29]

The grounding and bonding requirements for the systems covered in *NEC* Chapter 8 are important for protection against electric shock and fire, in addition to providing a level of protection from surges, spikes, dips, and lightning strikes. It is important to bond all the grounding electrodes of different systems together for safety and to comply with the minimum *NEC* rules. Effective grounding and bonding for these systems includes a connection of an equipment grounding conductor with the electrical supply circuit for grounding of the equipment.

The exception to Section 250.94 covers the requirements for intersystem grounding and bonding conductor connections at existing buildings or structures where any intersystem bonding and grounding electrode conductor connections are required by 770.93, 800.100(B), 810.21(F), 820.100(B), 830.100(B) but an intersystem bonding termination is not installed. This exception provides requirements for "an accessible means external to enclosures for connecting intersystem bonding and grounding electrode conductors shall be provided at the service equipment and at the disconnecting means for any additional buildings or structures by at least one of the following means:

"(1) Exposed nonflexible metallic raceways

"(2) Exposed grounding electrode conductor

"(3) Approved means for the external connection of a copper or other corrosion-resistant bonding or grounding electrode conductor to the grounded raceway or equipment." [30]

Grounding clamps are available that are suitable for these grounding connections, but these same grounding clamps are not permitted to be used for power distribution system grounding electrode connections unless so listed. An example would be the perforated metal-strap type grounding clamp used to connect grounding electrode conductors of these systems to the nonflexible metallic service raceways. See the UL ProductSpec, under category (KDSH).

The authority having jurisdiction would have the responsibility of approval of any provided external connecting or bonding means. The informational note indicates that "a 6 AWG copper conductor with one end bonded to the grounded nonflexible metallic raceway or equipment and with 150 mm (6 in.) or more of the other end made accessible on the outside wall is an example of the approved means covered in 250.94, Exception item (3)." [31]

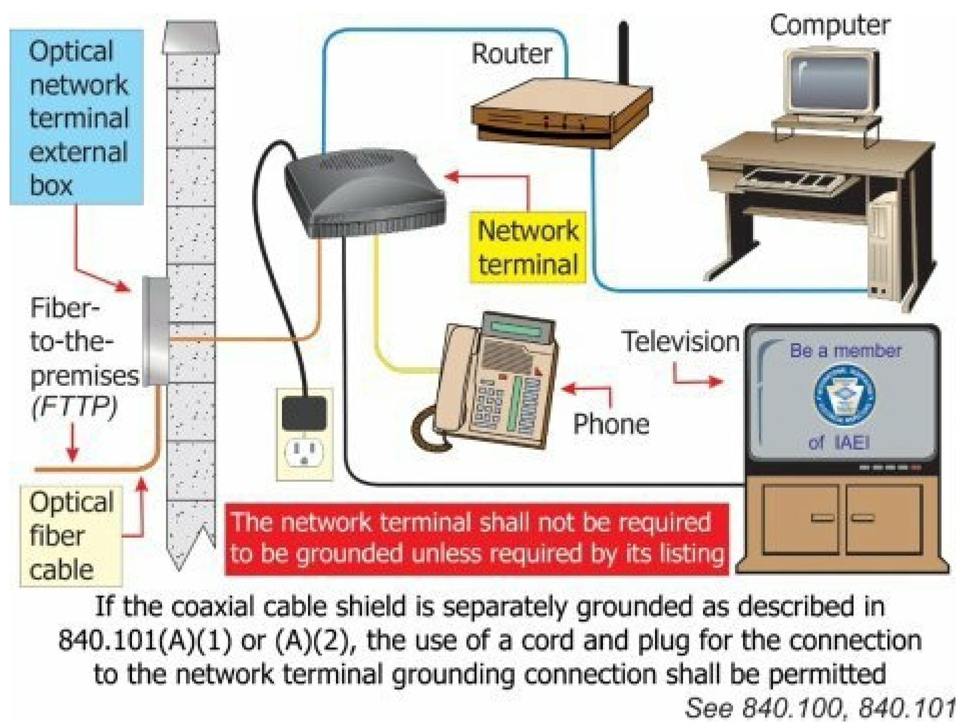


Figure 19.14 Grounding of premises-powered broadband communication systems

Premises-Powered Broadband Communications Systems

Network-powered broadband communications systems are covered in the *NEC* by Article 830. Broadband communication systems are being offered that are non-network-powered, which are covered at Article 840. “A typical basic system configuration consists of an optical fiber, twisted pair, or coaxial cable to the premises supplying a broadband signal to a network terminal that converts the broadband signal into component electrical signals, such as traditional telephone, video, high-speed Internet, and interactive services. Powering for the network terminal and network devices is typically accomplished through a premises power supply that might be built into the network terminal or provided as a separate unit. In order to provide communications in the event of a power interruption, a battery backup unit or an uninterruptible power supply (UPS) is typically part of the powering system”(see figure 19.14). Optical network units use thin-film filter technology to convert between optical and electrical signals. Thin films are thin material layers ranging from fractions of a nanometer (monolayer) to several micrometers in thickness. Electronic semiconductor devices and optical coatings are the main applications benefiting from thin-film construction.

Premises-powered broadband communications systems grounding methods are covered at Part IV of Article 840 [840.100 – 840.106]. Section 840.100 provides that “Grounding required for protection of the network terminal, conductive optical fiber cables, multipair communications cables, antenna lead-in conductors, and coaxial cables shall comply with 770.100, 800.100, 810.21 , or 820.100, as applicable.”

Section 840.101 provides specific grounding and bonding requirements where the optical network terminal and associated circuits do not leave the building or structure served. There requirements are

> “Premises Circuits Not Leaving the Building. Where the network terminal is served by a nonconductive optical fiber cable, or where any non–current-carrying metallic member of a conductive optical fiber cable is interrupted by an insulating joint or equivalent device, and circuits that terminate at the network terminal are completely contained within the building (i.e., they do not exit the building), 840.101(A), (B), or (C) shall apply, as applicable..
>
> “(A) Coaxial Cable Shield Grounding. The shield of coaxial cable shall be grounded by one of the following:
>
> “(1) Any of the methods described in 820.100 or 820.106
>
> “(2) A fixed connection to an equipment grounding conductor as described in 250.118
>
> “(3) Connection to the network terminal grounding terminal provided that the terminal is connected to ground by one of the methods described in 820.100 or 820.106, or to an equipment grounding conductor through a listed grounding device that will retain the ground connection if the network terminal is unplugged
>
> “(B) Communications Circuit Grounding. Communications circuits shall not be required to be grounded.
>
> “(C) Network Terminal Grounding. The network terminal shall not be required to be grounded unless required by its listing. If the coaxial cable shield is separately grounded as described in 840.101(A)(1) or 840.101(A)(2), the use of a cord and plug for the connection to the network terminal grounding connection shall be permitted.
>
> “Informational Note: Where required to be grounded, a listed device that extends the equipment grounding conductor from the receptacle to the network terminal equipment grounding terminal is permitted. Sizing of the extended equipment grounding conductor is covered in Table 250.122.”

Summary

The grounding and bonding requirements for voice, data, and video systems covered by *NEC* Chapter 8 are minimum requirements for safety. The *Code* includes grounding and bonding requirements for systems, circuits, and enclosures in Chapter 2, Wiring and Protection. Chapter 8 is independent from the requirements of Chapter 2, unless specifically referenced from the particular article in Chapter 8. There are requirements specified in the articles of Chapter 8 and specific requirements for grounding and bonding required for safety for these special systems. Proper grounding and bonding is essential for safety and operation of these systems. One of the most important requirements of the *Code* is to bond the electrodes or electrodes of different systems together. Failure to do so can result in shock hazards, fire hazards, and damage to electronic components of these systems. The *Code* includes the minimum requirements for personnel and building safety, this simply means that one must do at least that much to comply. It is not uncommon to see the minimum requirements of the *NEC* be exceeded relative to the grounding and bonding for these systems, but the minimum requirements must be met. For information on enhanced grounding electrodes and grounding and bonding for sensitive electronic equipment, see chapters six and eighteen of this text.

See 250.60 for use of air terminals (lightning rods), and NFPA 780, Lightning Protection Systems.

For more information relative to the applicable requirements for a listed secondary protector refer to UL 497A-2001, the Standard for Secondary Protectors for Communications Circuits.

For more information relative to determining acceptable installation practices for telecommunications systems, circuits, and equipment refer to nationally recognized standards such as ANSI/EIA/TIA 568-C-2017, Standard for Installing Commercial Building Telecommunications Cabling; ANSI/EIA/TIA 569-A-2015, Commercial Building Standard for Telecommunications Pathways and Spaces; and ANSI/EIA/TIA 570-B-2012, Residential and Light Commercial Telecommunications Wiring Standard.

[1–31] NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA, © 2016).

Review Questions

1. The conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system is a ________.

    1. equipment grounding conductor
    2. grounding electrode conductor
    3. neutral conductor
    4. grounding conductor

2. An intersystem bonding termination for connecting intersystem bonding conductors shall be provided at ________.

    1. a separately derived system
    2. the service equipment or disconnecting means for additional buildings
    3. the telephone equipment mounting board
    4. the point of entry of a cable to the building

3. The minimum size copper protective bonding conductor or grounding electrode conductor for a receiving station shall be not less than ________.

    1. 12 AWG copper
    2. 10 AWG copper
    3. 6 AWG aluminum
    4. 6 AWG copper

4. For a one-family dwelling a bonding conductor or grounding electrode conductor for a coaxial cable shall generally be as short as practicable and not exceed ________.

    1. 3.0 m (10 ft)
    2. 9.0 m (30 ft)
    3. 6.0 m (20 ft)
    4. 1.5 m (5 ft)

5. The shield of a coaxial cable shall be grounded with a bonding conductor or grounding electrode conductor not less than ________.

1. 4 AWG copper
2. 6 AWG copper
3. 14 AWG copper or other corrosion resistant material
4. 12 AWG copper

6. Where there is a grounding electrode installed for a coaxial cable antenna system that is greater than 6.0 m (20 ft) from the power grounding electrode system, there shall be a ________ bonding jumper installed between the two electrodes.

1. 4 AWG copper or equivalent
2. 8 AWG copper or equivalent
3. 6 AWG copper or equivalent
4. 12 AWG copper or equivalent

7. A grounding electrode conductor for a coaxial cable system installed on a building or structure that does not have an intersystem bonding termination shall be permitted to be connected to which of the following:

1. the building or structure grounding electrode system as covered in 250.50
2. the nonflexible metallic power service raceway
3. the service equipment enclosure
4. all of the above

8. The minimum size bonding conductor connected to a primary protector grounding terminal for a network-powered broadband communications system at a mobile home that is cord- and plug-connected shall be not less than __________.

1. 2 AWG copper
2. 4 AWG aluminum
3. 12 AWG copper
4. 10 AWG bronze

9. Where a bonding conductor or grounding electrode conductor for a communications system is installed in a ferrous metal raceway, the raceway shall be ________.

1. continuous
2. bonded to both ends of the contained conductor or to the same terminal to which the bonding conductor or grounding electrode conductor is connected.
3. rigid metal conduit
4. electrical metallic tubing

10. Where a grounding electrode conductor for network-powered broadband communications systems is connected to concrete-encased or buried electrodes the connections shall be ________.

1. accessible
2. stainless steel
3. listed for direct burial or concrete encasement
4. irreversible compression-type

11. Bonding conductors and grounding electrode conductors for overhead (aerial) network-powered broadband communications systems shall be spaced at least ________ from lightning conductors where practicable.

1. 6 m (20 ft)
2. 1.8 m (6 ft)
3. 15 m (50 ft)
4. 900 mm (3 ft)

12. A 24-volt ac system is required to be grounded where ________.

1. supplied by a transformer with a supply system of 120 volts
2. where installed as overhead conductors outside of buildings
3. where the supply system is grounded
4. where ground detectors are not installed

13. Where an intrinsically safe system is required to be connected to a grounding electrode, the electrode shall be which of the following:

1. a ground rod
2. a pipe electrode
3. the electrodes specified by 250.52(A)(1),(2),(3), and (4) where present and shall comply with 250.30(A)(4)
4. a plate electrode

14. Where shields are used with intrinsically safe systems, and the shield is part of the intrinsically safe circuit, the shield is ________.

1. not required to be grounded
2. required to be grounded
3. required to be isolated
4. required to be insulated

15. At a mobile home that is supplied by a cord- and plug-connection, the primary protector bonding conductor for a communications system is required to be connected to the ________.

1. water pipe at the sink location
2. metal frame or available grounding terminal of the mobile home
3. a ground rod
4. the panelboard enclosure in the mobile home

16. A device for premises-powered broadband communications systems that converts an optical signal into component signals, including voice, audio, video, data, wireless, and interactive service electrical, and is considered to be network interface equipment is a ________.

1. premises communication terminal
2. network terminal
3. fiber-based terminal
4. network interface terminal

17. The circuit of a control apparatus or system that carries the electric signals directing the performance of the controller but does not carry the main power current is a ________.

1. signaling circuit
2. secondary control
3. motor control circuit
4. control circuit

18. The shield of coaxial cable shall be grounded by which one of the following means?

1. a fixed connection to an equipment grounding conductor as described in 250.118
2. Connection to the network terminal grounding terminal provided that the terminal is connected to ground by one of the methods described in 820.100 or 820.106, or to an equipment grounding conductor through a listed grounding device that will retain the ground connection if the network terminal is unplugged
3. any of the methods described in 820.100 or 820.106
4. all of the above

⏚ Chapter 20
Grounding of Systems or Circuits of Over 1000 Volts

Objectives to understand

- Grounding rules for medium and high voltage (over 1000 volts)
- Services over 1000 volts
- Methods of grounding
- Use of surge arrestors
- Grounding of outdoor substations
- Stress reduction for cables

The NEC indicates that where systems or circuits of over 1000 volts are grounded, they shall comply with Article 250 plus specific rules in Part X of Article 250 (see NEC 250.180). The requirements in Part X supplement or modify other rules in Article 250.

Many medium-voltage systems in the 2.4 to 15 kV range are either low-resistance grounded or are high-resistance grounded. The only difference between low and high resistance grounding is the value of the resistor that, in turn, controls the amount of ground-fault current permitted during a ground-fault event. The other common method is to solidly ground the system, especially if it is exposed to lightning.

Medium voltage systems above 15 kV are typically either solidly grounded or ungrounded. For the ungrounded system, even though there is not an effective ground provided there is still a relationship to earth through the surge (lightning) arresters installed where outdoor lines are open and commonly subjected to lightning surges and transient overvoltages (see figure 20.1 and photo 20.1).

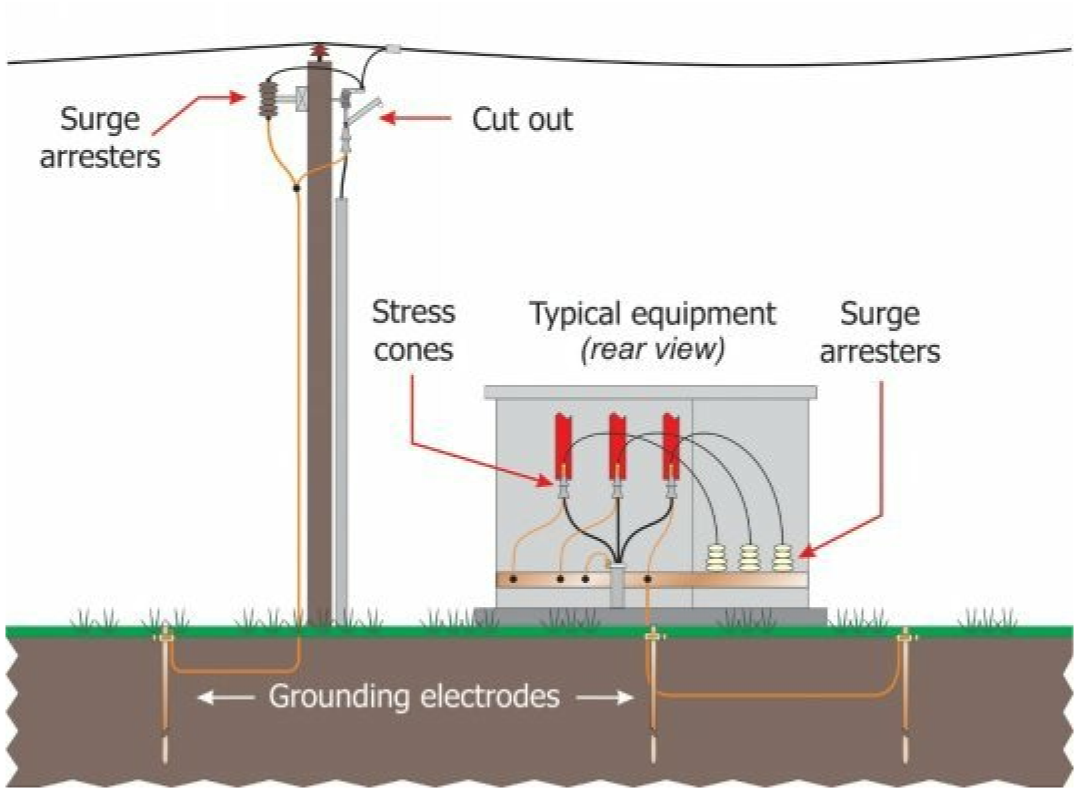


Figure 20.1 Effective grounding through surge arresters

Photo 20.1 High voltage lines typically connected to surge arresters at pole locations

Systems Rated 2400 Volts to 13,800 Volts

Grounding may be achieved through solid connections to earth or connection through a grounding impedance, typically a resistor, purposely installed in the equipment-grounding path at the source. The choice depends on available ground-fault current, the size of the system, tolerance for outages and tolerance for damage from ground faults. It is common in industrial systems to ground the neutral of systems rated 2400 volts and above through a resistor (see figure 20.2).

Figure 20.2 Typical methods of system grounding over 1000 volts

Reactance grounding (use of a reactor or grounding transformer) in this voltage range is preferred if the circuits are overhead and, thus, subject to lightning exposure, if they serve rotating machinery, and if excessive ground-fault current is not expected to develop.

Because of the higher voltage of these systems, compared to systems of 1000 volts and less, the ground-fault current levels through the earth and through the grounding electrode and grounding electrode conductor are much higher. This current may be sufficiently high so that a current transformer can be placed around the grounding electrode conductor or system bonding jumper to give a positive indication that a ground fault exists. This sensed ground fault at a protective relay is then used to clear the circuit in the event the ground fault persists over a predetermined time. This type of arrangement is very similar to the neutral ground strap type system discussed in chapter 14.

Alternatively, a more typical protection scheme uses the residual current (zero-sequence current) from the phase current transformers to the protective relays or has a zero-sequence current transformer with a ground-fault protective relay. Compare this with a system of 600 volts or less. There, the ground-fault current sensor cannot be placed satisfactorily in the grounding electrode conductor, since little ground-fault current will exist in that conductor.

Systems Rated 15,000 Volts or More

Such systems are found installed indoors and outdoors and there are some types of rotating equipment served by them such as centrifugal chillers. Usually these systems are solidly grounded, which permits the use of surge arresters rated at phase-to-ground voltage or grounded-neutral type that cost less and provide better protection from overvoltage. Just as in systems under 600 volts, these medium voltage systems will have different voltage levels for various utilization purposes. Additionally, some of the medium voltage levels are only for distribution to allow greater levels of power to be sent without having to use large conductors. As each voltage level system is created, grounding must be reestablished by some means at each voltage level as was previously described for systems of 600 volts or less.

Grounding Outdoor Substations

The grounding of outdoor substations involves not only the electrical system neutral and immediate electrical equipment enclosures but also includes grounding the fence and other supporting structures in the area. Section 250.191 requires substation grounding systems to comply with Part III of Article 250. In addition, an informational note directs the user to ANSI/IEEE 80-2013, IEEE *Guide for Safety in AC Substation Grounding*, for further reference in the design and considerations for substation grounding.

A ground bus or grid should be established extending about 900 mm (3 ft) outside the periphery of the fence. The grid should be connected to many ground rods around its periphery and, in addition, should be connected to metallic underground water piping system or other underground metallic structures where present. The ground grid should be a minimum size of 4/0 AWG copper or for higher capacity systems have a current capacity approximately 25 percent of the capacity of the system. With the known system capacity, the grid conductor rating may then be sized based on the capacity of bare conductors in free air. Copper bus is rated based on 1000 amperes per square inch. Connections from the fence and from all equipment within the fence, that is, transformer cases, steel structures, switchgear including operating mechanisms for gang-operated disconnects, and so forth, should be not less than 4/0 AWG copper nor less than 25 percent of the capacity of the secondary conductors. To be sure of having a good, permanent neutral ground, it is best to connect the neutral conductor to two points on the ground bus.

A grounding bus and connections are effective only if the mechanical construction is sound and as permanent as possible. No connection should be soldered. It is preferable to properly braze or weld all connections and to protect all cable from mechanical injury. Common practices use exothermic welding of these connections or compression connections using special tools and connectors. If metallic enclosures are used for the mechanical protection of these conductors, the enclosures should be bonded to the enclosed conductor so both are connected in parallel at both ends of the enclosure.

There is some difference of opinion as to whether the fence earth grounding should be separated from the ground grid used for the substation. If the fence is connected to the station grid and a fault occurs, the fence will be elevated above earth potential by the IZ drop from the system and ground impedance. The potential gradient formed in the earth near the fence drops off very rapidly, typically within the first few feet. Anyone contacting the fence can therefore be subjected to hazardous step-voltage or touch-voltage potentials under fault conditions.

If the fence grounding is isolated from the substation ground, then the fence will be elevated in potential from the substation ground grid, and under fault conditions anyone contacting the fence and the equipment will be subjected to that hazard.

In most substations that come under the *NEC*, the fence and equipment are close proximity; therefore, in such cases, it is best to connect the fence grounds and the substation ground grid together. The shock hazard when using a common ground for the fence and the equipment can be kept to a minimum by having the ground connection resistance as low as possible (see photo 20.2). In addition, by extending the ground grid at least 900 mm (3 ft) beyond the fence perimeter, the step-touch potential hazard is mitigated.

A new 250.194 in the 2014 *NEC* provided more prescriptive requirements for substation fences and other metal structures. This new section resolves some of the questions raised about fence location. The distance for fences or metal structures to either have their own grounding electrode system or to be connected to the substation grounding grid is 5 m (16 ft).

Metallic fences enclosing, and other metal structures in or surrounding, a substation with exposed electrical conductors and equipment are required to be grounded and bonded to limit step, touch, and transfer voltages. Where metal fences are located within 5 m (16 ft) of the exposed electrical conductors or equipment, the fence shall be bonded to the grounding electrode system with wire-type bonding jumpers. All exposed conductive metal structures (including guy wires) within 2.5 m (8 ft) vertically or 5 m (16 ft) horizontally of exposed conductors or equipment and subject to contact by persons, are also required to be bonded to the grounding electrode systems in the area. See *NEC* 250.194 for more complete details.

Ground-Fault Conductor Brought to the Service

In previous editions of the *Code*, the clear requirement for bringing the neutral conductor to the service equipment to provide the effective ground fault return path as set in 250.24(C) stopped at 1000 volts. Up until the 2014 *NEC* cycle this left a major shortcoming in the *NEC* for grounded systems over 1000 volts. Some inspection authorities were able to enforce the requirement based on 250.4(A)(5) from the performance requirements. The 2014 *NEC* established new requirements in 250.186 to cover those installations over 1000 volts. These new provisions account for the fact that sometimes the utility brings a neutral along with the circuit from the substation and sometimes they do not. The new requirement makes it clear for the *NEC* side of the installation to the service point that a wire-type conductor of suitable capacity must now be installed between the service equipment and the service point interconnection with the utility to provide the ground fault current path, just like the requirements for services 1000 volts and under. The following are the new requirements.

Grounded Systems

These new requirements at 250.186 provide prescriptive language for a grounded conductor(s) to be routed with the ungrounded conductors to each service disconnecting means where an ac system operating at over 1000 volts is grounded at any point and is provided with a grounded conductor at the service point. A main bonding jumper is required to bond the grounded conductor(s) to each service disconnecting means enclosure (see figure 20.3). This required grounded conductor shall not be smaller than the required grounding electrode conductor specified in Table 250.66 or the requirements of Table 250.102(C)(1) including notes 1 and 2 as applicable. The grounded conductor is not required to be larger than the largest ungrounded service-entrance conductor(s) when installed in a single raceway or for overhead conductors.

For ungrounded service-entrance conductors installed in parallel in two or more raceways or as overhead parallel conductors, the grounded conductors must be installed in parallel as well. The size of the grounded conductor in each raceway or overhead is to be based on the total circular mil area of the parallel ungrounded conductors in the raceway or overhead [as indicated in 250.186(A)(1)] but not smaller than 1/0 AWG.

The grounded conductor of a 3-phase, 3-wire delta service is required to have an ampacity not less than that of the ungrounded conductors. Impedance grounded neutral systems shall be installed in accordance with 250.187.

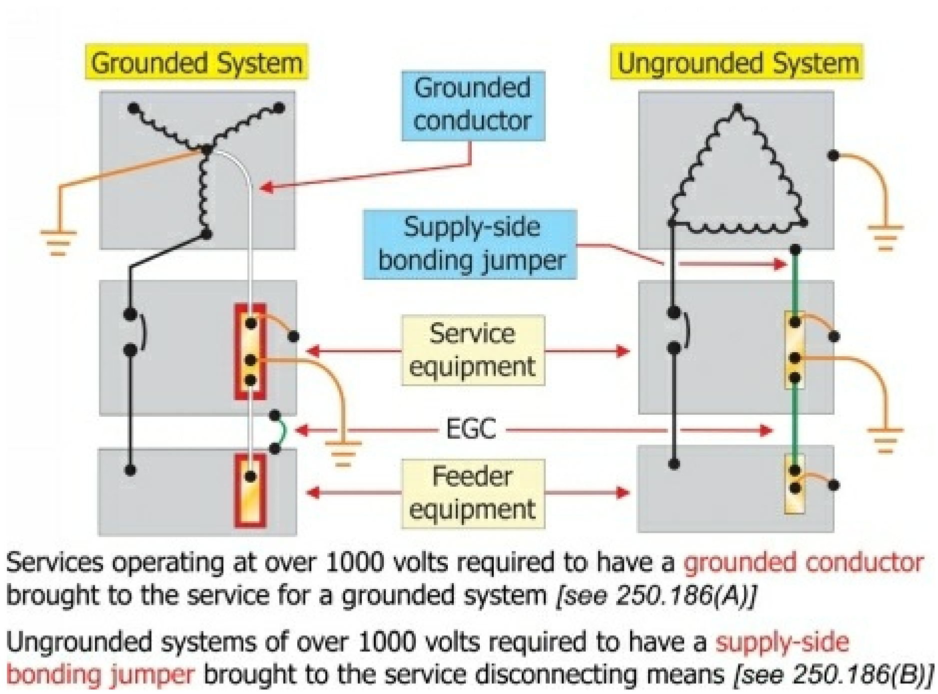


FIGURE 20.3 Ground-fault conductor brought to service equipment

Ungrounded Systems

For ungrounded systems operating at greater than 1000 volts, a supply-side bonding jumper must be routed with the ungrounded conductors to each service disconnecting means and bonded to the equipment grounding conductor terminal bar. Sizing of this supply-side bonding jumper is generally the same as described above for the grounded conductor of a grounded system. See *NEC* 250.186(A) and (B) for complete *Code* text.

Derived Neutral Systems

Section 250.182 permits a system neutral point derived from grounding transformer to be used for grounding systems over 1000 volts. The application is for ungrounded systems where there is still a need to detect and clear single phase-to-ground faults. These grounding type transformers include zigzag, wye-delta, or T-connected also known as Scott T (see figures 20.4 and 20.5). Ground-fault protection may be provided through the transformer and positive tripping can be accomplished with relatively low magnitudes of ground-fault current (see figure 20.4).

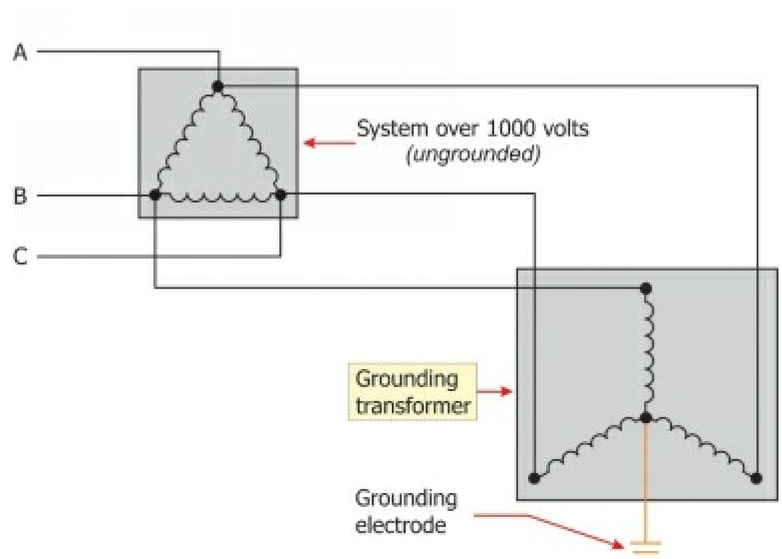


Figure 20.4 System grounding using grounding-type transformers

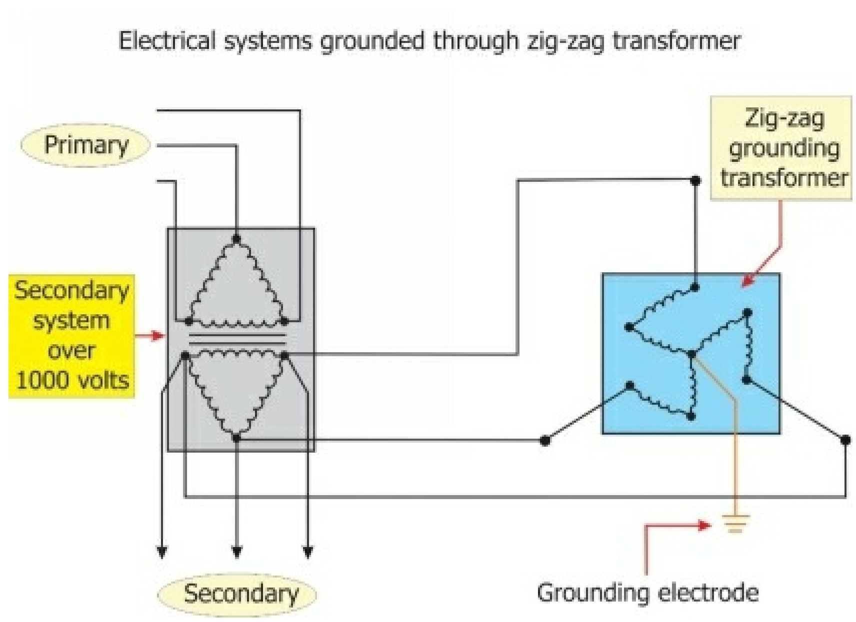


Figure 20.5 Illustrates use of a zig-zag grounding transformer for establishing a grounded system from an ungrounded system.

Solidly Grounded Neutral Systems

Section 250.184 also permits solidly grounded neutral systems and provides for two options, *single-point grounding* or *multiple-point grounding*. The neutral conductor of solidly grounded systems is generally permitted to have an insulation level of not less than 600 volts or to be bare.

Single-Point Neutral Grounded Systems

Single-point grounded neutral systems are permitted for systems of over 1000 volts, although they are less common. These are generally found where the area covered by the system is relatively small such as within one building or small campus of buildings or structures. Where a single-point grounded neutral system is used, it is permitted to be supplied from either a separately derived system or a multigrounded neutral system provided that the equipment grounding conductor of the single-point grounded system is connected to the grounded neutral point at the source (see figure 20.6).

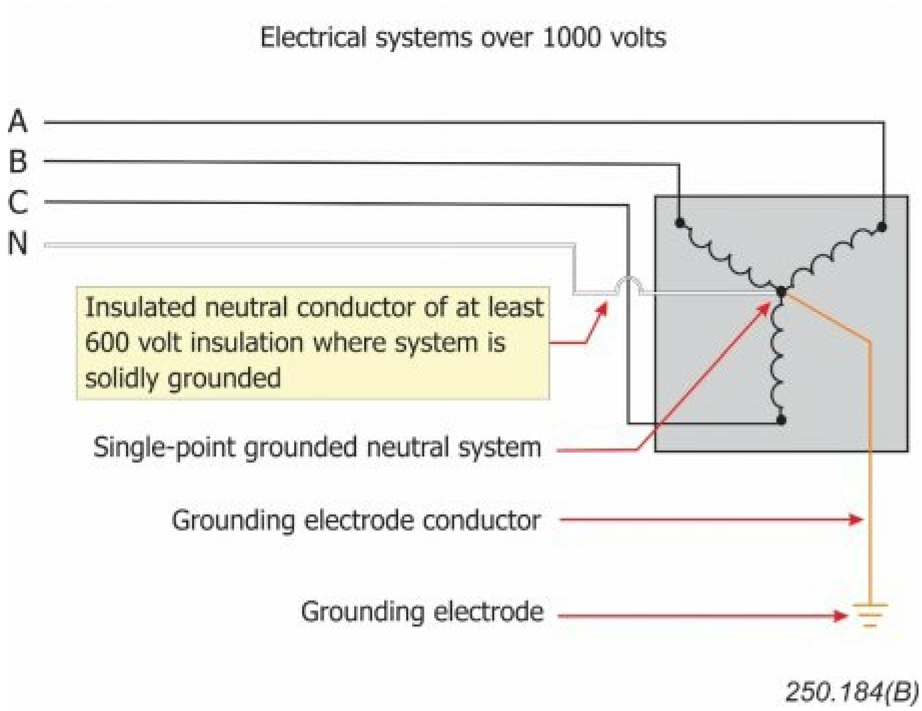


Figure 20.6 Single-point grounded neutral system

Single-point grounded neutral systems shall be installed as follows:

- They are required to have a grounding electrode that is connected to the system neutral conductor by means of a properly sized grounding electrode conductor.
- A system bonding jumper shall be installed from the system neutral to the source enclosure as well as to the grounding electrode conductor.
- An equipment grounding conductor is required at each building, structure, and equipment enclosure.
- A neutral conductor is only required where phase-to-neutral loads are supplied. The system neutral conductor is required to be insulated from the earth, except at one location (the point of grounding).

Equipment grounding conductor(s) are required to be run with the phase conductors and must meet the following conditions as well as the requirements in 250.190(C).

They:

- Are not permitted to carry continuous load
- May be bare or insulated
- Must have sufficient ampacity for fault current duty

Multigrounded Neutral Systems

Multiple-point grounding, or also known as grounding the neutral conductor at the source and at additional points along the system, is permitted under specific conditions and meeting specific requirements. (see figure 20.7).

250.184(C) states: "Where a multiple grounded neutral system is used, the following shall apply:

1. "The neutral conductor of a solidly grounded neutral system shall be permitted to be grounded at more than one point. Grounding shall be permitted at one or more of the following locations:

"a. Transformers supplying conductors to a building or other structure

"b. Underground circuits where the neutral is exposed [bare conductor]

"c. Overhead circuits installed outdoors" 1

2. "The multigrounded neutral conductor shall be grounded at each transformer and at other additional locations by connections to a grounding electrode.

3. "At least one grounding electrode shall be installed and connected to the multigrounded neutral circuit conductor every 400 m (1300 ft).

4. "The maximum distance between any two adjacent electrodes shall not be more than 400 m (1300 ft).

5. "In a multigrounded shielded cable system, the shielding shall be grounded at each cable joint that is exposed to personnel contact." 2

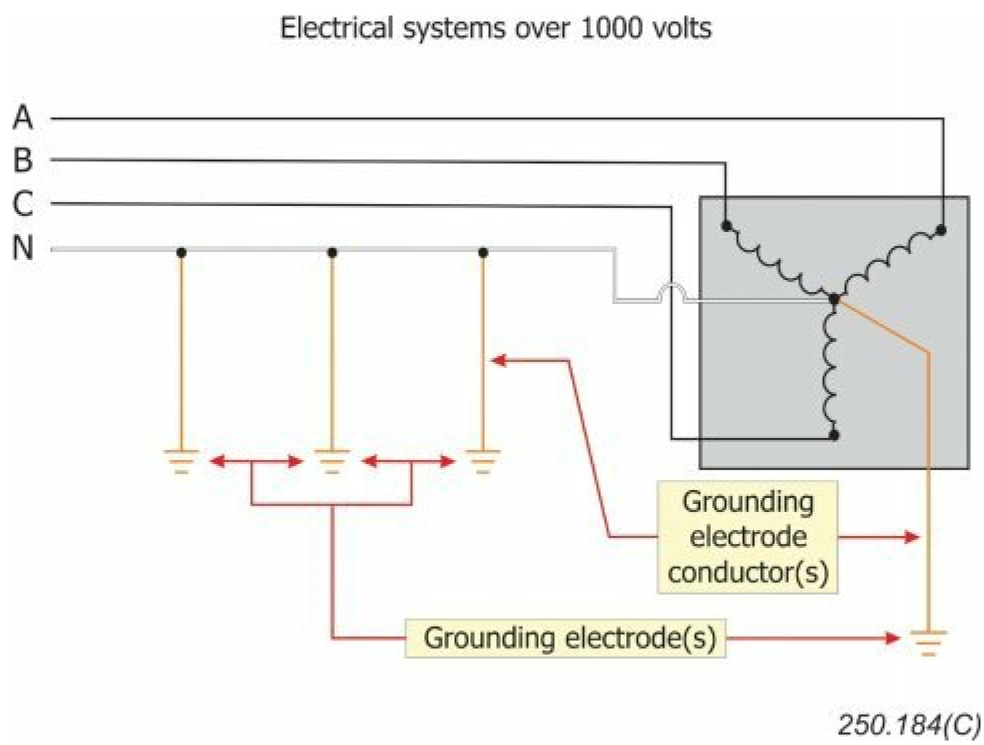


Figure 20.7 Multigrounded neutral systems

Impedance Grounded Neutral Systems

Section 250.1 permits impedance grounded neutral systems (see figure 20.8). Impedance grounding of these systems can be accomplished by reactance grounding, low-resistance grounding or high-resistance grounding. (see figure 20.2)

A significant change in the 2017 *NEC* revises the conductor insulation requirements for impedance grounded systems. Previously, the neutral conductor of an impedance grounded system was required to be fully rated for the phase to phase voltage. Under the revised text of 250.187(B), the neutral conductor is only required to be insulated for the maximum phase to neutral voltage. For example, on a 15 KV class system operating at 12.47 KV, the phase-to-neutral voltage will not be more than 7.2 KV; therefore, using 8 KV rated conductors instead of 15 KV rated conductors is permitted for the neutral.

Grounding of Systems Supplying Portable or Mobile Equipment

Special requirements apply to electrical systems that supply portable or mobile high-voltage equipment, other than substations installed on a temporary basis. The requirements are found in 250.188.

> "**(A) Portable or Mobile Equipment.** Portable or mobile equipment over 1000 volts shall be supplied from a system having its neutral conductor grounded through an impedance. Where a delta-connected system over 1000 volts is used to supply portable or mobile equipment, a system neutral point and associated neutral conductor shall be derived.
>
> "**(B) Exposed Non-Current-Carrying Metal Parts.** Exposed non-current-carrying metal parts of portable or mobile equipment shall be connected by an equipment-grounding conductor to the point at which the system neutral impedance is grounded.
>
> "**(C) Ground-Fault Current.** The voltage developed between the portable or mobile equipment frame and ground by the flow of maximum level of ground-fault current shall not exceed 100 volts. [Editor's note: This somewhat limits the shock hazard.]
>
> "**(D) Ground-Fault Detection and Relaying**. Ground-fault detection and relaying shall be provided to automatically de-energize any component of a system over 1000 volts that has developed a ground fault. The continuity of the equipment-grounding conductor shall be continuously monitored so as to automatically de-energize the circuit of the system over 1000 volts to the portable or mobile equipment upon loss of continuity of the equipment-grounding conductor.
>
> "**(E) Isolation.** The grounding electrode to which the portable or mobile equipment system neutral impedance is connected shall be isolated from and separated in the ground at least 6.0 m (20 ft) from any other system or equipment grounding electrode, and there shall be no direct connection between the grounding electrodes, such as buried pipe and fence, and so forth.
>
> "**(F) Trailing Cable and Couplers.** Trailing cable and couplers of systems over 1000 volts for interconnection of portable or mobile equipment shall meet the requirements of Part III of Article 400 for cables and 490.55 for couplers." 3

Grounding of High-Voltage Equipment

Section 250.190 generally requires grounding of all non-current-carrying metal parts of high-voltage fixed, portable, or mobile equipment including fences, housings, enclosures, and supporting structures.

The exception to this section permits normally non-current-carrying metal parts to be ungrounded if the equipment is isolated from ground and located to prevent any person who can make contact with the ground from contacting such metal parts when the equipment is energized. Many times, this is accomplished by the use of elevation.

Surge Arresters

Where surge arresters (more typically called Surge Protection Devices or SPDs) are used on secondary systems of 1000 volts or less, it is required that the connections to the service grounded conductor and to the grounding electrode conductor be as short as practicable.

Line and equipment ground connecting conductors shall not be smaller than 14 AWG copper or 12 AWG aluminum [285.26]. The SPD grounding electrode conductor shall be connected to one of the following:

- Grounded service conductor
- Grounding electrode conductor
- Grounding electrode for the service
- Equipment grounding terminal in the service equipment.[4] [285.23(B)]

The use of the first method is not applicable for an ungrounded system.

For systems over 1000 volts, if a surge arrester protects the primary of a transformer which supplies a secondary distribution system, the surge arrester grounding electrode conductor may be interconnected to the secondary neutral, provided that in addition to the connection at the arrester, the grounded conductor of the secondary has elsewhere a grounding connection to a continuous metallic underground water piping system. This applies where there is an urban type water pipe area where there are not less than four secondary connections to the underground metallic water piping system per 1.6 km (1 mile). If the above condition is met, the direct connection of the arrestor to ground (earth) may be omitted.

The grounding electrode conductor of a surge arrester also may be connected to the secondary neutral. This is true if, in addition to the direct grounding connection at the arrester, the grounding electrode conductor of the secondary system is part of a multigrounded neutral system of which the primary neutral has at least four grounding connections in each mile of line, as well as a ground at each service.

Where the secondary is not grounded to a metallic water system but uses other available electrodes, an interconnection between surge arrester grounding electrode conductor and the secondary neutral shall be made through a spark gap. The spark gap must have a breakdown voltage of at least twice the primary circuit voltage but not necessarily more than 10 kV. For a multigrounded neutral primary system with a breakdown of at least 3 KCV, there shall be at least one other ground connection on the grounded conductor of the secondary not less than 6.0 m (20 ft) away from the surge arrester grounding electrode. No other connection options between a surge arrester ground and a secondary neutral are allowed by the *Code*, except by special permission. [285.24]

Photo 20.2 Substation surrounded by a grounded chain-link fence

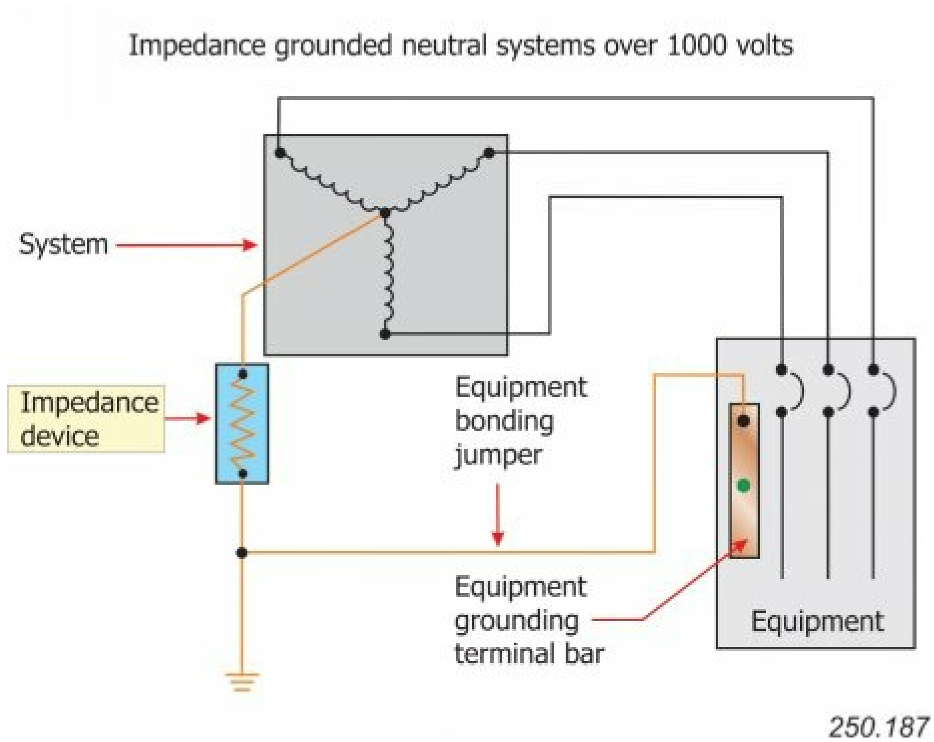


Figure 20.8 Impedance grounded neutral system

Stress Reduction Means and Cable Shielding

Medium and high-voltage cables above 2000 volts generally are required to be shielded. This shielding is usually in the form of either a conductive tape or stranded shield conductors. The purpose of the shielding is to evenly distribute voltage stresses through the insulation and bleed off to ground any capacitive voltage built up at the termination points (see photo 20-3). Section 310.10(E) addresses shielding requirements for insulated conductors operating at over 2000 volts. These conductors are required to have an ozone resistant insulation and be shielded. All metallic shields are required to be connected to a grounding electrode conductor, grounding busbar, or grounding electrode [310.10(E)] (see figures 20.9, 20.10 and 20.11).

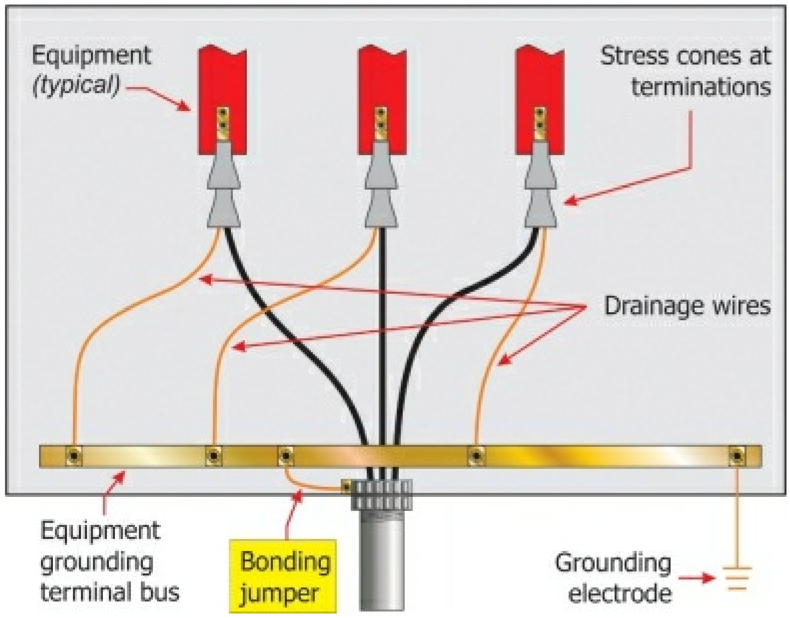


Figure 20.9 Stress reduction means (grounding of cable shielding required)

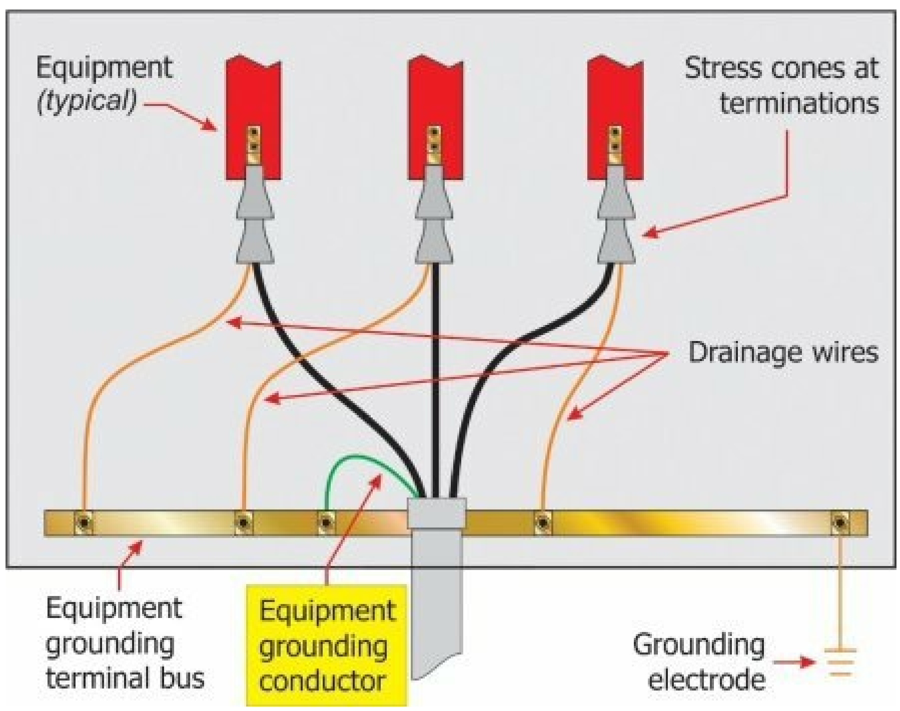


Figure 20.10 Stress reduction means (grounding of cable shielding required)

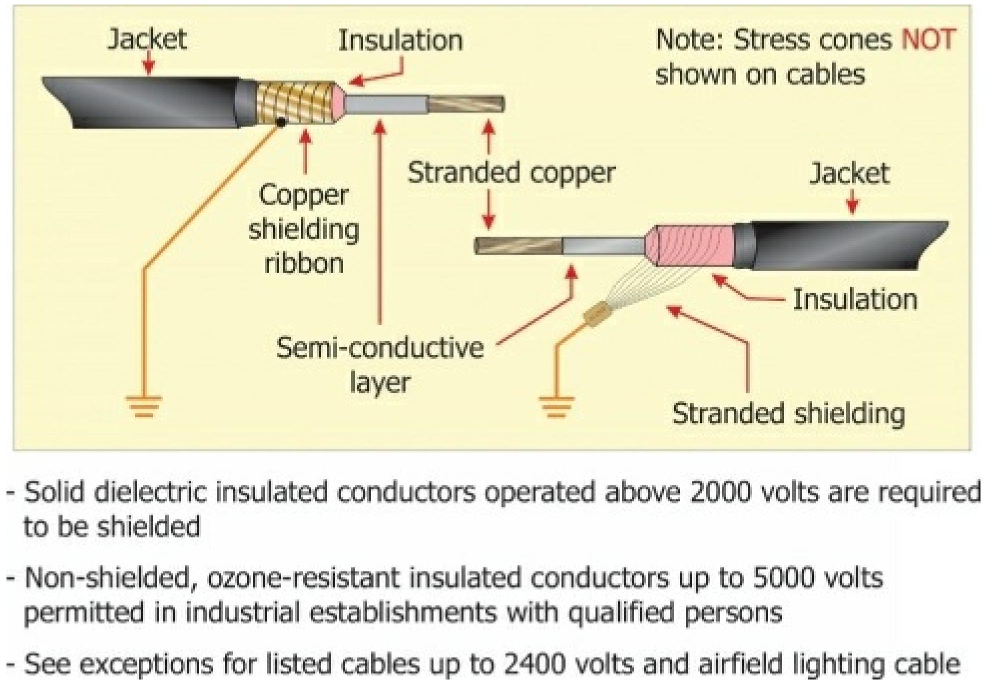


Figure 20.11 Cable shields are generally required for cables over 2000 volts. Cable shields are required to be grounded per 310.10(E).

"Exception No. 1: Nonshielded insulated conductors listed by a qualified testing laboratory shall be permitted for use up to 2400 volts under the following conditions:

"(a) Conductors shall have insulation resistant to electric discharge and surface tracking, or the insulated conductor(s) shall be covered with a material resistant to ozone, electric discharge, and surface tracking.

"(b) Where used in wet locations, the insulated conductor(s) shall have an overall nonmetallic jacket or a continuous metallic sheath.

"(c) Insulation and jacket thicknesses shall be in accordance with Table 310.104(D).

"Exception No. 2: Nonshielded insulated conductors listed by a qualified testing laboratory shall be permitted for use up to 5000 volts to replace existing nonshielded conductors, on existing equipment in industrial establishments only, under the following conditions:

"(a) Where the condition of maintenance and supervision ensures that only qualified personnel install and service the installation.

"(b) Conductors shall have insulation resistant to electric discharge and surface tracking, or the insulated conductor(s) shall be covered with a material resistant to ozone, electric discharge, and surface tracking.

"(c) Where used in wet locations, the insulated conductor(s) shall have an overall nonmetallic jacket or a continuous metallic sheath.

"(d) Insulation and jacket thicknesses shall be in accordance with Table 310.13(D).

"Informational Note: Relocation or replacement of equipment may not comply with the term existing as related to this exception.

"Exception No. 3: Where permitted in 310.10(F), Exception No. 2." 5

Internal medium voltage conductors in equipment, even over 2000 volts, such as jumpers to potential transformers, some interconnecting cables, etc., are not shielded and are investigated for proper use when the equipment is tested and evaluated to the applicable ANSI/IEEE and UL standards.

Article 490 includes grounding requirements for equipment over 1000 volts, nominal. Generally, the frames of switchgear and control assemblies are required to be grounded. "The metal cases or frames, or both, such as those of instruments, relays, meters, and instrument and control transformers, located in or on switchgear or control assemblies, shall be connected to an equipment grounding conductor or, where permitted, the grounded conductor" [490.37].[6] This can be accomplished by the mounting means to the metal enclosure or may have specific bonding jumpers installed to the equipment grounding bus.

Photo 20.3 15,000-volt cables terminated at a switch showing stress reduction means and bleed wires connected to ground (earth)

Cable Shield as Equipment Grounding Conductor

Section 250.192(C)(2) provides where the stress reduction shield on medium voltage cables can be used as an equipment grounding conductor. The primary purposes of the stress reduction shield are:

1. Provide for an equipotential ground plane surrounding the insulation so that the voltage stress through the insulation at any cross section is equal.
2. To provide a return path for an insulation fault within the cable assembly from the main conductor to the metallic insulation shield. This path would typically have a relatively high impedance due to the path through the insulation from the conductor to the metallic shield.

When the system is solidly grounded the available ground-fault current at the equipment served can be very high and most times will exceed the capacity of the insulation shield conductors to provide an adequate low-impedance ground-fault return path. Previous codes did not address this and left the design to engineers, but field experience showed that too many times a proper equipment grounding conductor was not being installed with feeders and branch circuits. Section 250.190 addresses this situation as follows:

"Grounding of Equipment.

"(A) Equipment Grounding. All non–current-carrying metal parts of fixed, portable, and mobile equipment and associated fences, housings, enclosures, and supporting structures shall be grounded.

"Exception: Where isolated from ground and located such that any person in contact with ground cannot contact such metal parts when the equipment is energized, the metal parts shall not be required to be grounded.

"Informational Note: See 250.110, Exception No. 2, for pole-mounted distribution apparatus.

"(B) Grounding Electrode Conductor. If a grounding electrode conductor connects non-current-carrying metal parts to ground, the grounding electrode conductor shall be sized in accordance with Table 250.66, based on the size of the largest ungrounded service, feeder, or branch-circuit conductors supplying the equipment. The grounding electrode conductor shall not be smaller than 6 AWG copper or 4 AWG aluminum.

"(C) Equipment Grounding Conductor. Equipment grounding conductors shall comply with (C)(1) through (C)(3).

"(1) General. Equipment grounding conductors that are not an integral part of a cable assembly shall not be smaller than 6 AWG copper or 4 AWG aluminum.

"(2) Shielded Cables. The metallic insulation shield encircling the current-carrying conductors shall be permitted to be used as an equipment grounding conductor, if it is rated for clearing time of ground fault current protective device operation without damaging the metallic shield. The metallic tape insulation shield and drain wire insulation shield shall not be used as an equipment grounding conductor for solidly grounded systems.

"(3) Sizing. Equipment grounding conductors shall be sized in accordance with Table 250.122 based on the current rating of the fuse or the overcurrent setting of the protective relay.

"Informational Note: The overcurrent rating for a circuit breaker is the combination of the current transformer ratio and the current pickup setting of the protective relay. "

The revised text now provides requirements where the grounding of equipment is accomplished through grounding electrode conductors, such as outdoor substation equipment and fences. The text also now provides the requirements for equipment grounding conductors for medium voltage systems and differentiates solidly grounded systems that will require a separate equipment grounding conductor from impedance grounded systems that may possibly use the cable shield conductors where it is documented the protective relays or fuses operate fast enough so that no damage is incurred by the metallic cable shield.

[1–6] NFPA 70, *National Electrical Code* 2017, (National Fire Protection Association, Quincy, MA, © 2016).

Review Questions

1. Many medium-voltage systems _____ to _____ are either low resistance grounded or are high resistance grounded.

    1. 5.4 – 20 kV
    2. 2.4 – 15 kV
    3. 3.3 – 17 kV
    4. 4.6 – 18 kV

2. Medium voltage ungrounded systems _____ have an earth relationship through surge arresters where the outdoor lines are open and commonly subjected to lightning surges and transient overvoltages.

    1. above 15 kV
    2. above 12 kV
    3. above 10 kV
    4. above 11 kV

3. It is common in industrial systems to ground the neutral of systems rated _____ volts and above through a resistor.

    1. 2000
    2. 2400
    3. 1800
    4. 1380

4. Medium voltage systems rated _____ volts or more may be indoors or outdoors and may have rotating equipment served by them.

    1. 10,000
    2. 12,000
    3. 15,000
    4. 13,000

5. Just as in systems under _____ volts, there will be different voltage levels for various utilization purposes regarding medium voltage systems.

    1. 1000
    2. 2000
    3. 600
    4. 1500

6. The grounding of outdoor substations is concerned with grounding the fence and other supporting structures, all equipment and conductor enclosures and the grounding of the neutral conductor. A ground bus or grid should be established extending about _____ outside the periphery of the fence.

    1. 900 mm (3 ft)
    2. 1.2 m (4 ft)
    3. 1.8 m (6 ft)
    4. 2.5 m (8 ft)

7. Cable can be sized on the basis of the capacity of bare conductor in free air and copper bus on the basis of _____ amperes per square inch.

    1. 1250
    2. 1000
    3. 1200
    4. 1300

8. Connections from the fence and from all equipment within the fence, that is, transformer cases, steel structures, switchgear including operating mechanisms for gang-operated disconnects, etc., should be not less than _____AWG nor less than _____ percent of the capacity of the secondary conductors.

1. 3/0 - 50
2. 4/0 - 25
3. 2/0 - 40
4. 1/0 - 30

9. To be sure of having a good, permanent neutral grounding connection, it is best to connect the neutral conductor to _____ points on the ground bus.

1. four
2. three
3. two
4. five

10. Impedance-grounded neutral systems are permitted and can be accomplished by all but one of the following methods:

1. reactance grounding
2. resistance grounding
3. high-resistance grounding
4. low-resistance grounding

11. Where there are not less than four secondary connections to any underground metallic water piping system per each _____, the direct grounding connection at the arrester may be omitted.

1. 0.4 km (1/4 mile)
2. 1.6 km (1 mile)
3. 0.8 km (1/2 mile)
4. 4.8 km (3/4 mile)

12. A single point grounded system shall be permitted to be supplied from which of the following?

1. a separately derived system
2. an ungrounded system
3. a high resistance grounded neutral system
4. none of the above

13. Generally, solid dielectric insulated conductors operating above ______ volts are required to have ozone-resistant insulation and are required to be shielded.

1. 5000
2. 2400
3. 2000
4. all of the above

14. For _______ grounded systems, a separate equipment grounding conductor sized per 250.122 must be installed along with the medium voltage circuit conductors.

1. high resistance
2. low resistance
3. solidly
4. impedance

15. Which of the following is NOT true for the stress relief shield of the tape drain wire type on medium voltage cables?

1. Provides an equipotential stress ground plane around the insulation
2. Provides an equipment grounding conductor path for ground-fault current
3. Provides a return path for a cable insulation fault
4. Is fixed by cable manufacturing standards and not sized per Table 250.122

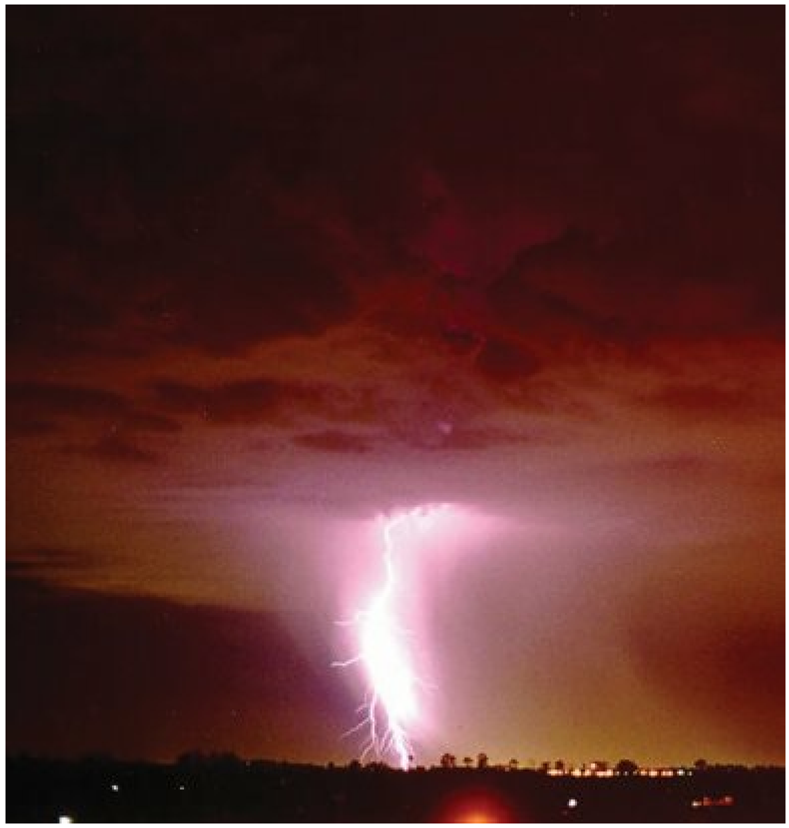
16. Metallic fences enclosing, and other metal structures in or surrounding, a substation with exposed electrical conductors and equipment shall be grounded and bonded to limit ______________________________?

1. step, touch, and transfer voltage
2. high static discharges
3. unintended loss of electricity from the substation
4. hysteresis losses

17. A new requirement makes it clear for the *NEC* side of the installation to the service point that a wire type conductor of suitable capacity must now be installed between the service equipment and the service point interconnection with the utility to provide the ________________________, just like the requirements for services 1000 Volts and under.

1. permanent disconnect
2. proper discharge pathway
3. ground fault current path
4. overvoltage surge protection

Chapter 21
Fundamentals of Lightning Protection



Objectives to understand

- Fundamentals of lightning protection systems
- Industry standards related to lightning protection systems
- Components of lightning protection systems
- Conductor sizes and installations
- Grounding network and equipotential bonding
- Quality control programs for lightning protection systems

Lightning is an atmospheric electrical discharge which may occur within a cloud, between clouds, between a cloud and earth (or items located on the earth), and sometimes in the case of very tall structures between items on or attached to the earth and the clouds.

The four basic types of cloud-to-ground lightning discharges are: (1) downward negative lightning, (2) upward negative lightning, (3) downward positive lightning, and (4) upward positive lightning. Upward negative and upward positive discharges are generally only associated with very tall structures [greater than 90 m (300 ft) tall] or objects of moderate heights located in higher elevations.[1]

The Lightning Discharge

The exact details of the process by which a cloud becomes electrically charged are not yet fully understood, but they are generally associated with charge separation resulting from the updraft of air in the center of a thunderstorm cell and the velocity of particles falling through the cloud. This is similar to the process of creating static electricity that was discussed in chapter fifteen. The growing consensus is that the primary means for the electrical charging of cumulonimbus clouds is a phenomena called the "graupel-ice mechanism."[1] In the dynamic activity within the clouds there are liquid or frozen water particles in the atmosphere called hydrometeors. These particles are classified according to the effect of gravity on them. Some particles fall rapidly as precipitation, typically at speeds of 0.3 meters per second. The other particles, called cloud particles, fall at lower speeds and can typically be considered as ice crystals. Just like with the rubbing motion of particles that form static electricity, the electrification of individual particles occurs as a result of collisions between the precipitation and cloud particles in the presence of water droplets. In general, the polarity and amplitude of charge separated during the collisions depend on several factors such as temperature, cloud water content, ice crystal size, relative velocity of the collisions, chemical contaminants in the water, and variations in size of super cooled water droplets.

Photo 21.1 Lightning striking a tree showing branching of stepped leader, streamers from objects in vicinity of the flash, luminosity of the return stoke, and the striking distance associated with the flash   Courtesy of National Geographic.

The resulting charge from this process will typically yield a net positive charge near the top of the cloud, a net negative charge below the layer of positive charge, and, often, an additional positive charge pocket at the bottom of the cloud. However, it is generally agreed that charges of both polarities often exist in any region of the cloud, just the concentration varies.

It is speculated that the lightning discharge is initiated by the emission of positive corona (the high concentration of charge that can bridge the insulation level of the surrounding air or cloud) from precipitation particles (such as raindrops) which have been deformed by strong electric fields that have been developed by this charge concentration. When the ambient electric field exceeds the electric field required to support the propagation of corona streamers, a streamer (or arc) will be developed. Should a number of these streamers occur sequentially, the resulting stronger field then becomes sufficient for further breakdown of the air dielectric. Continuation of this can result in the formation of a stepped leader as the beginning of the lightning strike. When observed, the stepped leader will be faint (not very bright) and typically heavily branched. The initial steps have lengths generally beginning at approximately 18 m (60 ft). As the stepped leader approaches the earth, these steps generally lengthen out and have fewer branches.[2]

As all this is occurring in the cloud cover, the earth and items located on the earth will develop an electrostatic charge due to the dynamic change in the charge concentration in the cloud and in the stepped leader. As the stepped leader approaches the earth, the electric field between the tip of the leader and the earth is increased. As the electric field on the earth increases, point discharge currents are produced from items on the earth, such as blades of grass, trees, poles, and structures. When the critical electric field strength is exceeded, a streamer from the earth is produced, usually from a location where the electric field is concentrated (this is similar to an arc welder as the welding lead is slowly moved toward the object being welded). When the stepped leader generated from the cloud connects to the streamer formed from the ground, a complete circuit is created and a return stroke of high energy is produced. The return stroke is the intensely luminous part of the strike where the peak transfer of current occurs. While the initial charge concentrations and stepped leaders may take some time, the actual stroke is at very high frequency and therefore the process of strokes of energy may be repeated as one or more subsequent return strokes in a single lightning flash. In subsequent return strokes, the subsequent leader (called a dart leader) is much faster and contains much less branching. The leader–return stroke process may occur once in a flash or may occur up to 26 times in a single flash.[3]

Just before connection is made, the final step of the stepped leader is often referred to as the striking distance. The striking distance is a function of the charge in the leader channel and is often characterized by the following relationship:

$$D = 10 \times I^{0.65}$$

where:

D is the striking distance in meters and

I is the peak current in the strike in kilo-amperes.

Photo 21-1 is a popular picture that was first published in *National Geographic* magazine. It is shown here as a good example of the branching of the initial stepped leader (near the top) and it provides a good example of the relative luminosity of the return stroke. The picture also provides visual documentation of the upward streamers (note the left side of the tree) produced by objects on the earth as the channel nears its final step. Finally, one can clearly see the striking distance in this flash as the channel changes from a nearly vertical path to one in a direction approximately 5 o’clock from the origin of the last step.

Definitions

To be sure we have a good understanding as this chapter goes forward, it is important to define a number of terms used when talking about designing, or inspection lightning protection systems. Some of the following terms are the same or similar to those in the *National Electrical Code*, but they have different definitions and meaning when applied to lightning protection systems. These terms and the associated definitions are from NFPA 780, the NFPA standard for lightning protection systems. The numbers provided are the definition number for the term in NFPA 780 – 2017.

"3.3.1* Air Terminal. A strike termination device that is a receptor for attachment of flashes to the lightning protection system and is listed for the purpose.

3.3.2 Bonding. An electrical connection between an electrically conductive object and a component of a lightning protection system that is intended to significantly reduce potential differences created by lightning currents.

3.3.3* Cable. A conductor formed of a number of wires stranded together.

3.3.4 Catenary Lightning Protection System. A lightning protection system consisting of one or more overhead ground wires.

3.3.7 Conductor.

3.3.7.1 ***Bonding Conductor.*** A conductor used for potential equalization between grounded metal bodies or electrically conductive objects and a lightning protection system.

3.3.7.2 ***Counterpoise Conductor.*** A bare underground electrical conductor providing an area of protection from the effects of lightning for underground raceway(s) or cable(s).

3.3.7.3 ***Down Conductor.*** A main conductor used to connect roof conductors to grounding electrodes.

3.3.7.4 ***Ground Loop Conductor.*** A main-size loop conductor installed within 12 ft (3.6 m) vertically of the base of the structure to provide a common ground potential.

3.3.7.5 ***Loop Conductor.*** A conductor encircling a structure that is used to interconnect grounding electrodes, main conductors, or other electrically conductive bodies.

3.3.7.6* ***Main Conductor.*** A conductor intended to be used to carry lightning currents between strike termination devices and grounding electrodes.

3.3.7.7 ***Roof Conductor.*** A main conductor used to interconnect strike termination devices.

3.3.10 Fastener. An attachment device used to secure the conductor to the structure.

3.3.17 Grounding Electrode. The portion of a lightning protection system, such as a ground rod, ground plate electrode, or ground conductor, that is installed for the purpose of allowing lightning current flow into the earth.

3.3.25* Lightning Protection System. A complete system of strike termination devices, conductors (which could include conductive structural members), grounding electrodes, interconnecting conductors, surge protective devices, and other connectors and fittings required to complete the system.

3.3.34 Sideflash. An electrical spark, caused by differences of potential, that occurs between conductive metal bodies or between conductive metal bodies and a component of a lightning protection system or ground.

3.3.39 Strike Termination Device. A conductive component of the lightning protection system capable of receiving a lightning strike and providing a connection to a path to ground. Strike termination devices include air terminals, metal masts, permanent metal parts of structures as described in 4.6.1.4, and overhead ground wires installed in catenary lightning protection systems.

3.3.40 Striking Distance. The distance over which the final breakdown of the initial lightning stroke to ground or to a grounded object occurs.

3.3.43 Surge Protective Device (SPD). A device intended for limiting surge voltages on equipment by diverting or limiting surge current that comprises at least one nonlinear component while remaining capable of repeating these functions.

3.3.50 Zone of Protection. The space adjacent to a lightning protection system that is substantially immune to direct lightning flashes."[5]

Purpose of a Lightning Protection System

In general, the purpose of a lightning protection system is to provide one or more points on a building or structure that will have a high probability for a lightning discharge to connect. When a strike occurs, the protection system provides a low-impedance path to a grounding electrode system that is capable of dissipating the energy in the strike into the earth swiftly and safely. Lastly, during the event the system is to minimize significant internal arcing that may result in fires or significant overvoltages that may damage internal equipment. This last part is the primary reason bonding of the lighting protection system to the metallic structural and electrical systems is critical so as to minimize potential differences during the event. Lightning protection systems meet this objective through the installation of the following subsystems:

1. Strike termination network
2. Down-conductor network
3. Grounding electrode network
4. Equipotential bonding network, and
5. Surge protection

These subsystems will be discussed in greater detail later in this chapter. Lightning protection systems cannot prevent the lightning event from occurring nor do they “attract” lightning from greater distances than the conventional calculated attractive area of a structure, but they do offer a means to dissipate the high energy levels in a controlled manner. Another way of saying this is that if lightning does strike a protected structure, the lightning protection system provides the desired point to strike and a lower impedance path to discharge and dissipate the energy into the earth.

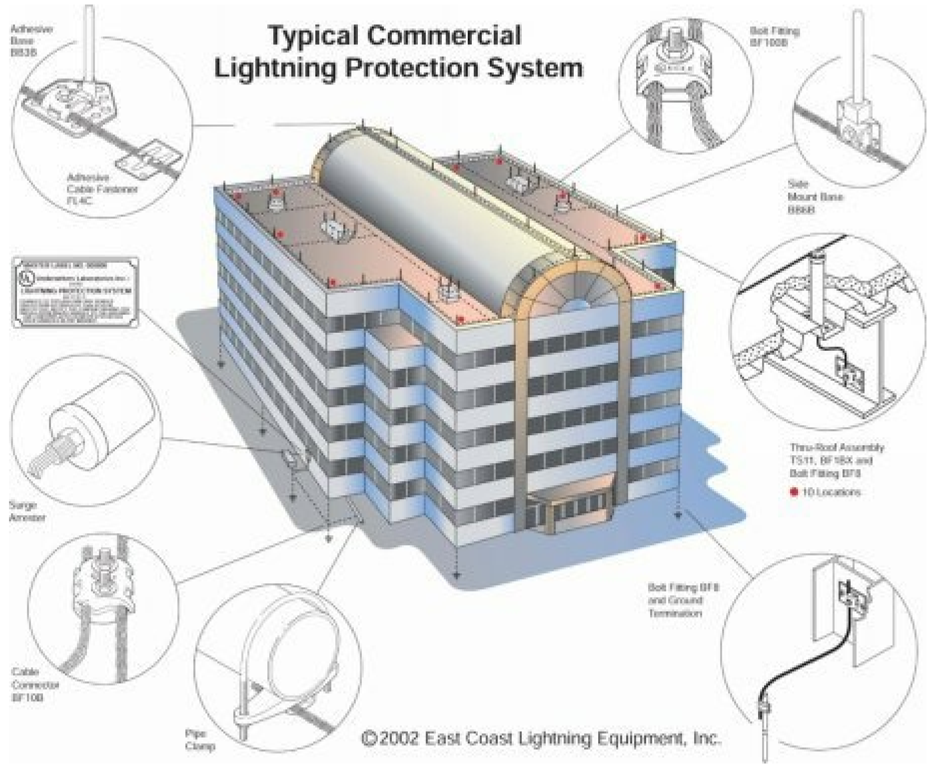


FIGURE 21.1 Example of commercial lightning protection system layout. Courtesy of East Coast Lightning Equipment of Winsted, CT

Internationally, there are different concepts and practices to approach the design of a lightning protection system and the purpose of lightning protection standards vary depending upon application. For risk-based standards, such as IEC 62305,[4] the designer is allowed to design the lightning protection system that focuses on the protection of the specific threat(s) identified by the risk assessment. For instance, if the risk assessment identified that the only threat or concern is from physical damage or fire, a system may be designed to address only this specific threat. Conversely, if the assessment identified that internal electrical systems at the site are susceptible but the structure is not susceptible to a direct strike, the lightning protection system design need only address the protection of the specific susceptible electrical equipment.

The two main lightning protection installation standards used in the United States, NFPA 780 (*Standard for the Installation of Lightning Protection Systems*) and UL 96A (*Standard for Safety Installation Requirements for Lightning Protection Systems*), are prescriptive based standards and are not considered risk-based from the individual designer's standpoint. These U.S. lightning protection standards generally describe a minimum-acceptable set of design and installation requirements which may be supplemented as necessary by the lightning protection system designer or authority having jurisdiction. The primary lightning protection standard used in the U.S., NFPA 780,[5] defines its purpose as: "to provide for the safeguarding of persons and property from hazards arising from exposure to lightning." It meets this purpose by providing specific minimum-acceptable requirements for a number of applications, such as ordinary structures, structures containing flammable vapors, heavy-duty stacks, watercraft, and alternate energy systems such as photovoltaic and wind generators. A detailed discussion on the application of NFPA 780 is provided in the following section.

NFPA 780

As stated, the principle lightning protection standard in the United States is NFPA 780 with the 2017 edition being the most recent published. It is the primary U. S. implementing document for the IEC 62305 series of documents and is referenced as providing baseline requirements in numerous specialized lightning protection documents such as those from the DOD,[6,7] DOE,[8] NASA,[9] and FAA[10] lightning protection requirements. Prior to the development of the IEC 62305 series of standards, NFPA 780 was widely used by many countries across the world as the national lightning protection standard. The scope of NFPA 780 covers traditional lightning-protection-system installation requirements for:

1. Ordinary structures
2. Miscellaneous structures and special occupancies
3. Heavy-duty stacks
4. Watercraft and
5. Structures containing flammable vapors, flammable gases, or liquids which give off flammable vapors
6. Structures containing explosive materials and
7. Wind Turbines
8. Watercraft
9. Airfield lighting circuits
10. Solar arrays

The document is not applicable to lightning-protection-system installation requirements for electric generating, transmission, and distribution systems. The document also does not cover lightning-protection-system installation requirements for early streamer emission systems or charge dissipation systems.

The layout of the document is arranged following the *NEC Style Manual* such that the administrative information is included in chapter 1. This administrative information includes the scope, purpose, requirements for the use of listed components, mechanical execution of work, maintenance requirements, and the use of metric units of measurements.

Chapter 2 provides a listing of referenced publications.

Chapter 3 contains definitions of terms used in the standard. The chapter includes definitions of official NFPA terms and terms specific to the standard. Where terms are not defined, definitions provided in the NFPA Glossary or common usages of the terms are referenced from *Merriam-Webster's Collegiate Dictionary*, 11th edition.

Chapter 4 provides the minimum requirements for the protection of ordinary structures. It provides the core of requirements on which all remaining chapters are based. It is the most important chapter in the standard as it addresses all of the key elements of a lightning protection system.

Chapter 5 provides requirements for the protection of miscellaneous structures and structures with special occupancies. Included in this chapter are protection of masts, spires, and flagpoles, metal tanks and towers, concrete tanks and silos, air-inflated structures, and guyed structures. The chapter also cautions that provisions need to be made for settling and rising of wood-framed elevators when protecting grain-, coal-, and coke-handling and processing structures.

Chapter 6 provides protection requirements for heavy-duty stacks. The chapter addresses the protection of masonry, steel-reinforced concrete and metal stacks and provides requirements above and beyond those in chapter 4 in the area of corrosion protection, strike termination device locations and materials, and the installation of fasteners.

Chapter 7 is also a principal chapter in the standard as it addresses key parameters associated with the protection of structures which may contain flammable vapors. This chapter introduces details on the concept of the use of masts and overhead ground wire lightning protection systems, even though these types of systems are listed as approved in Chapter 4. It also introduces a level of protection efficiency which exceeds that described in Chapter 4 for ordinary structures. In the case of the zone-of-protection for structures covered by Chapter 7, the rolling sphere radius is reduced from the 45 m (150 ft) striking distance specified in Chapter 4 to a 30 m (100 ft) striking distance (the rolling sphere model will be discussed later in the following section). The basic requirements of this chapter are also referenced as applicable for the baseline requirements in the informative annex on the protection of structures housing explosives.

Chapter 8 deals with the protection of structures housing explosive materials.

Chapter 9 sets the protection means for wind turbines including the protection of electrical and mechanical control systems.

Chapter 10 deals with the protection of watercraft. The basic principles associated with the protection of structures are applicable although the size and location of components are modified. Corrosion issues and the use of dissimilar metals are key issues. The zone of protection used in this application specifies the use of a 100-foot striking distance versus the 150-foot striking distance used for ordinary structures.

Chapter 11 addresses airfield lighting circuits and brings forward the counterpoise application for the airfield lighting luminaires.

Chapter 12 deals with photovoltaic arrays that might be roof-mounted or may be ground-mounted and subject to potential lightning strikes.

NFPA 780 also contains 15 informative (non-mandatory) annexes. Annex A provides explanatory material expanding on some of the specific text in the body of the standard. Annex O provides a listing of informational references. Four annexes provide explanations or discussions on items applicable to lightning protection systems. These are annexes on the principles of lightning protection systems, explanation of bonding principles, a discussion on inspection and maintenance procedures, and a discussion on grounding system measurement techniques. Two annexes provide guides, one on lightning risk assessment and one on personal safety. The remaining annexes address specific protection applications. These are protection of trees, protection for picnic grounds and open spaces, protection for livestock in fields, and protection for parked aircraft.

The Lightning Protection System

As previously discussed, the primary components of a lightning protection system are the strike termination network, down conductor network, grounding electrode network, equipotential bonding network, and providing surge protection. The definitions of terms provided earlier in this chapter will assist in understanding figure 21.1 and the discussion below. Figure 21.1 illustrates the relationship each component has with respect to a complete lightning protection system. Each of these primary components is discussed below in this section.

Strike Termination Network

Strike Termination Device Placement

We should begin by discussing the difference between the terms strike termination device and air terminal. NFPA 780 defines a strike termination device as a component of a lightning protection system that is intended to intercept lightning flashes and connect them to a path to ground. Strike termination devices include air terminals, metal masts, and permanent metal parts of structures with a thickness equivalent to no less than 5 mm (3/16 in.) thick steel and overhead ground wires. An air terminal (also called a "lightning rod") is defined as "a strike termination device that is a receptor for attachment of flashes to the lightning protection system and is listed for the purpose." The key distinction between an air terminal and other strike termination devices is that the air terminal is listed in accordance with UL 96[11] for the purpose of providing a lightning strike termination. Photo 21.2 provides examples of various configurations and materials of air terminals available to the lightning protection system designer.

All parts of a structure to be protected must be provided with strike termination devices at locations as required to ensure vulnerable parts of the structure are within a protected area or a zone of protection. NFPA 780 identifies three methods by which the placement of strike termination devices can be determined.

Protection Angle Method

The oldest method used for the determination of the protective area of a lightning-protection strike termination device is the protective angle method. The concept for this method is commonly attributed to Benjamin Franklin, but it was not until W. H. Preece[12] published the results of his experiments measuring the electric field around a vertical air terminal in 1880 that an accurate protective zone was proposed. The 1-to-1 (45 degree) protective angle proposed by Preece is still valid today for structures up to 15 m (50 ft) tall. NFPA 780 allows a 2-to-1 (60 degree) protective angle for strike termination devices at heights of 7.5 m (25 ft) or less.

Rolling Sphere Method

The most universally used method for determining the protected area of a lightning protection system is the rolling sphere method. In this method, the final striking distance of the stepped leader is modeled to serve as the radius of a sphere. It is assumed that lightning can strike any point on the surface of the sphere. Where the sphere is tangent to the earth (the far left sphere in figure 21.2 touching at grade level) and resting against a strike termination device, all space in the vertical plane between the two points of contact and under the sphere is considered to be in the zone of protection. A zone of protection is also provided in the space between strike termination devices and in the vertical plane under the sphere when the sphere is resting on two or more strike termination devices (see figure 21.2 for the spheres rolling over the structure). A striking distance of 45 m (150 ft) is used in United States lightning protection standards for ordinary applications. The striking distance is reduced to 30 m (100 ft) for structures requiring increased protection efficiency, such as structures housing flammable vapors and gases and structures housing explosives materials.

Photo 21.2 Examples of available air terminal configurations   Courtesy of East Coast Lightning Equipment of Winsted, CT

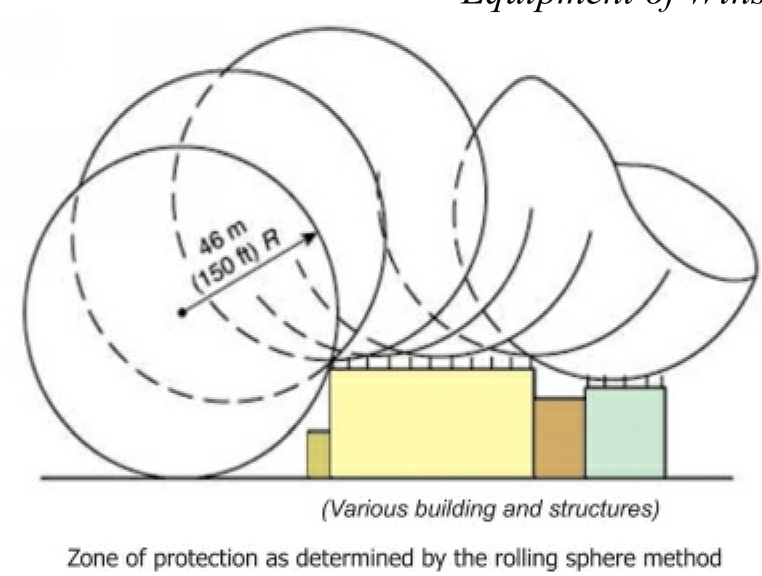


Figure 21.2   Zone of protection as determined by the rolling sphere method [from NFPA 780-2017, Figure 4.8.3.1]

Mesh Method

The lightning protection standards used in the United States do not recognize the mesh method of lightning protection for placement of strike termination devices that is recognized by IEC 62305-3[13] and well established in many European standards. It is the present position of U. S. consensus standards-making organizations that the installation of air terminals or other strike termination devices enhances the probability of a successful connection to a lighting streamer by providing a highly conductive projection into the electric field gradient that will generate a successful streamer.

The mesh method basically utilizes a grid of conductors to form a plane on the surface (roof or other part) for the lighting to connect, whereas the use of air terminals or other strike termination devices project the conductive element at least 10 inches above the protected structure. The United States lightning protection standards do recognize what will be described in this chapter as a modified mesh method that requires air terminals a minimum of 250 mm (10 in.) above the protected structure to be located along the perimeter of flat and gently sloping roofs and along the ridges of pitched roofs with roof conductors running along the perimeters or along the ridge as required to interconnect the air terminals. In addition, air terminals are required to be located within 600 mm (2 ft) of the ridge ends on pitched roofs or at edges and outside corners of flat or gently sloping roofs (see photo 21-3). The spacing between the air terminals on ridges and around the perimeter of a flat roof shall not exceed 6.0 m (20 ft) (see photo 21.4). An exception allows that air terminals projecting 600 mm (2 ft) or more above the roof of the structure may be spaced at 7.5 m (25 ft) intervals. Lastly, the "mesh" or grid is formed for flat or gently sloping roofs exceeding 15 m (50 ft) in length or width with additional strike termination devices installed. These devises shall be provided within the interior of the roof perimeter at intervals not exceeding 15 m (50 ft). This relaxed interior spacing for the center of the flat roof is due to the smaller electric field found in the center of a large flat area.

Photo 21.3 Measurement to ensure air terminal is no greater than 600 mm (2 ft) from corner of roof Courtesy of Bonded Lightning Protection of Argyle, TX

Photo 21.4 Example of air terminal spacing on roof showing air terminal spacing within 600 mm (2 ft) of the edge and at a spacing of 6.0 m (20 ft) around the perimeter
Courtesy of Lightning Prevention Systems of West Berlin, NJ

Discussions in IEC technical committee, TC81, *Lightning Protection* working group meetings have confirmed there is scientific justification for the relaxation of the air terminal placement requirements for the center of a large flat roof due to the reduction of the electric field gradient over that which will exist at corners and edges of a structure. The key to the effectiveness of this modified mesh arrangement is the location of strike termination devices where there will be greatest electric field concentration: the corners, edges, and ridges. It must be stressed that any protrusions on a flat roof (such as a vent, HVAC unit, etc., as shown in photo 21.4) must be provided with a strike termination device if it is not within the zone of protection of another device. Figure 21.3 provides an example drawing of a strike-termination device layout for a flat roof with typical protrusions in accordance with NFPA 780. With new installations for photovoltaic systems and even roof-mounted wind generation, revisions of any installed lightning protection system must be considered.

Strike Termination Devices

The strike termination network may consist of masts (remote or attached to the structure), overhead ground wires, or an arrangement of air terminals and interconnecting roof conductors located around the perimeter of flat or gently sloping roofs or along the ridges of peaked roofs. Masts may be metallic or wooden poles or they may be in the form of a metal tower. Wooden poles must be provided with an air terminal and a minimum of one down conductor. While both NFPA 780-2017 and UL 96A,[14] 13th edition, allow a single down conductor, a second down conductor is recommended. Masts will often extend up at least 12 m (40 ft) and the impedance, primarily from inductance, of a single conductor can lead to a significant voltage drop at high frequencies over the length of the conductor. This impedance and voltage drop reduces the effectiveness of the lightning protection system and could increase the damage in the event of a strike. In addition, the second conductor adds an additional level or reliability since it is possible that a single conductor can be damaged over its normal lifetime. Photo 21.5 provides an example of a wooden pole used as a terminating mast for an overhead wire lightning protection system. In addition to specific devices like air terminals or poles with conductors, metal parts of the structure having a thickness greater than 5 mm (3/16 in.) may serve as strike termination devices as long as they are properly connected to the down conductor system. As discussed in the previous paragraph, where IEC 62305-3 has been adopted in many international countries a mesh arrangement of main-sized conductors installed on a structure to serve as an approved strike termination system is also allowed. However, this mesh-type system without the use of supplementing air terminals is not recognized by United States lightning protection standards as an approved strike termination technique.

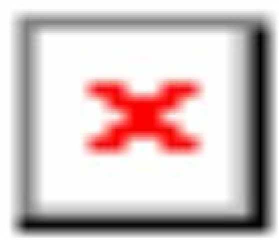


Photo 21.5 Guyed wooden mast for an overhead wire lightning protection system Courtesy of Harger Lightning Protection of Grayslake, IL

Main Conductor

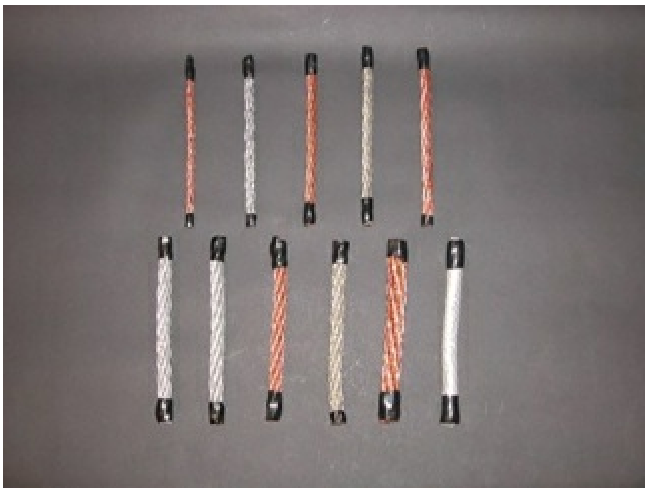
Network General

The material used for main conductors may be either copper or aluminum, depending upon the application. Since the main conductor network is generally exposed to the outdoor elements, care must be taken to minimize the probability of corrosion and contact with dissimilar metals. In no case shall a copper conductor be installed on an aluminum surface or to aluminum terminals, nor an aluminum conductor be installed on a copper surface or using copper terminals. In addition, aluminum conductors must not be used where they may come in contact with the earth. Similar to the requirements in *NEC* 250.64(A), NFPA 780, section 4.5.2 states "Aluminum materials shall not be used within 18 in. (450 mm) of the point where the lightning protection system conductor comes into contact with the earth."

NFPA 780 defines a main conductor by:

- The type of material (copper or aluminum)
- The size of each strand (in mm2 or AWG)
- Weight per specified length, (in grams per meter or lbs per 300 m (1000 ft)
- The cross-sectional area (in circular mils)

The overall height of the structure is used to size the main conductor. Ordinary buildings or structures 23 m (75 ft) or less are specified to use Class I materials, while buildings or structures over 23 m (75 ft) are to use Class II materials. If a building, like a church, has a steeple over 23 m (75 ft) but the rest of the building is less than 23 m (75 ft) then NFPA 780 allows the use of Class I materials for all except the steeple that would require Class II materials. Table 1 provides a summary of the NFPA 780-2017 requirements for a main conductor showing the difference in requirements for Class I and Class II materials. Photos 21.6 and 21.7 show examples of main-sized conductors that meet the requirements of Table 1. As can be readily seen, these cables are constructed differently than standard building wire. They need far more flexibility to accommodate the installation of the lightning protection system designed. In addition, a lightning event is at a very high frequency, and at higher frequencies the energy travels mostly over the surface of conductors and not as much in the core. Therefore, the weaves used in the production of the cables differ from standard electrical cable to make it more flexible to fit the approved connectors and fittings better and to be better conductors for lightning energy. Conductors used in a lightning protection system should be listed for the purpose in accordance with UL 96.



Photos 21.6 and 21.7 Examples of main-sized lightning protection conductors Courtesy of East Coast Lightning Equipment of Winsted, CT (photo 21-6) and Harger Lightning Protection of Grayslake, IL (photo 21-7).

Roof conductors

Generally, each strike termination device must be provided with a minimum of two paths to ground. Both NFPA 780 and UL 96A allow a single exception to this requirement for the case where a strike termination device is located below the main roof level and the length of the dead-end run is less than 4.9 m (16 ft). The dead-end run conductor must maintain a horizontal or downward routing to the nearby roof conductor or down conductor. The application of this exception is most often found in the protection of dormers.

A main conductor, properly sized, shall be used to interconnect the strike termination devices (roof conductors) and connect them to the grounding electrode network (down conductors). The routing of the main conductors shall be such that the paths from the strike termination devices are downward, horizontal, or rising, if absolutely necessary, at no more than ¼ pitch to connections with their respective grounding electrodes. No bend of a conductor shall form an included angle of less than 90 degrees, nor shall it have a radius of bend less than 200 mm (8 in.). As stated above, lightning energy is at high frequencies so any bends in the main and other conductors must not be sharp or tight. Additionally, the installation must avoid the conductors forming "U" or "V" (down and up) pockets, as sharp bends in the primary current conductor will add unnecessary inductance (impedance) to the conductor circuit. Photo 21.8 provides two examples of the proper gradual bend in the roof conductor providing a two-way path for the corner air terminal as well as the conductor used to connect the roof conductor to the through-roof connector. The through-roof connector provides the mechanism by which lightning currents can be transferred to the structural steel frame of the structure. The use of structural steel as a down conductor is discussed later in this section. It should also be noted that the air terminal in photo 21.8 is within 600 mm (2 ft) of the corner of the roof as required by NFPA 780-2017, 4.7.2.1.

NFPA 780 - Minimum Size Main Conductors

Material	Main Conductor	Thickness	Cross section area	Weight per unit length	Size of each strand
Class I	Copper cable Structure ≤ 75 ft		(29 mm^2) 57,400 cm	(278 g/m) 187 lb per 1000 ft	17 AWG
	Aluminum cable Structure ≤ 75 ft		(50 mm^2) 98,600 cm	(141 g/m) 95 lb per 1000 ft	14 AWG
	Copper solid strip Structure ≤ 75 ft	(1.30 mm) 0.051 inches	(29 mm^2) 57,400 cm		
	Aluminum solid strip Structure ≤ 75 ft	(1.63 mm) 0.064 inches	(50 mm^2) 98,600 cm		
Class II	Copper cable Structure > 75 ft		(58 mm^2) 115,000 cm	(558 g/m) 375 lb per 1000 ft	15 AWG
	Aluminum cable Structure > 75 ft		(97 mm^2) 192,000 cm	(283 g/m) 190 lb per 1000 ft	13 AWG
	Copper solid strip Structure > 75 ft	(1.63 mm) 0.064 inches	(58 mm^2) 115,000 cm		
	Aluminum solid strip Structure > 75 ft	(2.61 mm) 0.1026 inches	(97 mm^2) 192,000 cm		

Table 21.1 NFPA 780 requirements for minimum size of main conductors

Down conductors

A low-impedance path from the strike termination network, air terminals and main conductors, to the grounding electrode network is critical to the efficient operation of a lightning protection system. The function of the down conductor network is to conduct the majority of the lightning current from the strike termination network to the grounding electrode network. As discussed in earlier chapters, current will divide proportionately on all possible paths. The down conductors are the primary path but other conductive metallic paths will also have some current during the event. Even though the majority of the current will typically be divided among the installed down conductors, currents on the order of tens of thousands of amperes on a single down conductor would not be uncommon for small structures where the number of down conductors may be limited. For even a very small down conductor impedance, a significant voltage could be developed from the top of the down conductor (roof level) to the bottom of the down conductor (grounding electrode network). For this reason, significant care should be taken to minimize the impedance of the down conductor network. This is achieved by routing the down conductor as directly as possible and by minimizing bends wherever practicable. Any bends that must be included in the down conductor should be as gradual as possible and should never include a bend radius of less than 200 mm (8 in.). Photo 21.9 provides a good example of down conductor routing where a bend in the down conductor is necessary. Increasing the number of down conductors in parallel will act to both decrease the overall impedance of the down conductor network as well as decrease the current density on any one conductor.

Photo 21.9 Example of a proper down conductor bend radius   Courtesy of Guardian Equipment Company of Novi, MI

A minimum of two down conductors shall be provided for any installation from the strike termination network. Beyond this minimum, additional down conductors are required for structures having a perimeter exceeding 76 m (250 ft). A good design would ensure down conductors are added as necessary to so that the average distance between down conductors does not exceed 30 m (100 ft).

In deciding where to install them, note that down conductors must be as widely separated as practicable. The first consideration is that down conductors be located close to the corners of the structure where practicable since corners provide a higher probability of streamer development and therefore a likely point for a lightning strike. Another consideration for down conductor placement is the proximity to human traffic. Locating the down conductors in high traffic density areas is not recommended due to the higher probability of step and touch potential risks. In addition, where down conductors are located in public areas they should be protected against physical damage and consideration should also be given to utilizing a protection technique that will limit the probability of contact by humans. Other considerations influencing the specific location of down conductors are the location of strike termination devices, the direct routing of the conductors, local earth conditions, security against displacement, the location of large metallic bodies in the structure and in the earth, and the location of underground metallic piping systems.

Using the frame of a structural steel framed building as the down conductor network is encouraged. It will generally provide lower impedance than will conventional main-sized conductors due to the physical size and mass of the steel frame members and the number of members that will act as parallel conductors. In this case, the strike-termination network components will typically be connected to the frame of the structure using a through-roof connector such as the device shown in photo 21.8. The connection at the top and bottom of the structural steel frame shall be made at a contact point where the frame is cleaned to base metal using a bonding plate having a contact area of not less than 200 mm^2 (8 in.^{2}). Photo 21.10 provides an example of the interior connections to the structural steel frame from a through-roof connector. Methods allowed for connection to the structural steel are clamping, bolting or threading and tapping. Welding, brazing, or exothermic welding of the conductor directly to the structural steel is also allowed. Photo 21.11 provides an example of the installation of a bonding plate on a structural steel member at the earth level for the purpose of providing a connection between the structural steel and the grounding electrode(s).

Photo 21.10 Example of interior connections to the steel frame from the through-roof connector
Courtesy of Guardian Equipment Company of Novi, MI

It should be noted that many international standards allow the use of electrically continuous concrete reinforcing bars to serve as lightning protection system down conductors (see IEC 62305-3, 5.3.5). However, IEC 62305-3,5.3.5 recommends the use of natural components such as the concrete reinforcing bars because the large number of parallel conductors would result in a considerable drop in the maximum voltage across the down conductor network. However, this clause also states, “If electrical continuity of the natural down-conductors cannot be guaranteed, conventional down-conductors should be installed.” It is for this reason that the use of concrete reinforcing bars is not allowed in either NFPA 780 or UL 96A as a substitute for the required down conductor. NFPA 780 and UL 96A do require the interconnection (bonding) of the concrete reinforcing bars with the lightning protection system at the top and bottom for the purpose of equalizing potential during a lightning event.

Grounding Network

General

The purpose of a lightning-protection grounding network is to provide a low-impedance connection with the earth in order to dissipate the energy from the lightning currents in such a manner as to minimize the peak voltage that will appear on the lightning protection system. The grounding electrode network must also be designed to reduce to the extent possible the risk due to touch and step potentials for humans and nearby conductive structures. For a properly designed and installed lightning protection system, the largest contributor to the overall voltage that will be developed on the lightning protection system is the grounding electrode component. It follows then that a low-impedance grounding electrode network will lower the overall voltage developed and reduce the hazards due to touch potentials, internal side flashes, and the threat to internal electrical equipment.

All grounding electrodes, as well as other conductive items in contact with the earth, exhibit specific impedances with respect to remote earth. These impedances are typically characterized in terms of resistance per unit of distance, i.e., ohms per meter. As current is injected into the grounding electrode (considered a point relative to the whole earth), a voltage gradient is developed related to the injected current and earth resistance gradient. This voltage gradient is often referred to as step voltage or step potential. This step potential is a voltage across a given distance, generally the distance of an average human step. When that voltage is high enough to cause current to flow from one leg to another, then the individual is receiving a shock. In homogeneous earth, the step voltage is usually the highest where the current passing from the grounding electrode to the earth is strongest, and this is typically right at where the surface of the electrode meets the surrounding earth. The maximum potential in the soil decreases as the distance from the electrode increases, thus resulting in reduced step potential. Vertical grounding electrodes, such as ground rods, affect only a small surface area of ground surrounding them. For example, a single 3 m (10 ft) ground rod has an earth effect of a hemisphere of earth approximately 15 m (50 ft) in diameter. On the other hand, a grounding mesh network, radials, and ground ring electrode can greatly reduce the grounding electrode potential over that of a driven ground rod because of the much greater area of earth the electrode encompasses.

Many factors must be considered in the design of the optimum lightning-protection grounding electrode network. The specific design of the lightning-protection grounding electrode network may be driven by local conditions (temperature variations, soil moisture and type, local earth resistivity, and so forth) as well as the vulnerability of the structure or its contents to step potentials, ground potential rise, and the high frequency components of the lightning discharge.

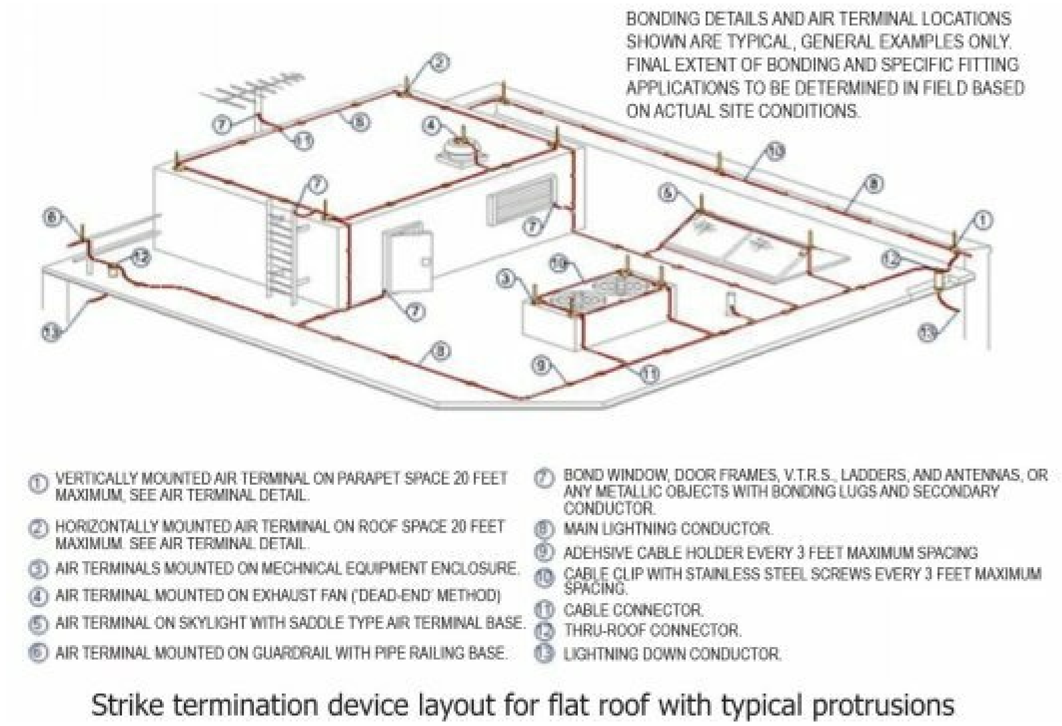


Figure 21.3 Strike termination device layout for flat roof with typical protrusions
Courtesy of Harger Lightning Protection of Grayslake, IL

Grounding electrodes

Grounding electrodes may be made of copper, copper-clad steel, or stainless steel. Each down conductor must be terminated to a grounding electrode or point on the grounding electrode system dedicated to the lightning protection system. The normal building or structure electrical or telecommunication system grounding electrodes shall not be utilized as a lightning-protection grounding electrode. However, the electrical system and communications grounding electrodes, along with all incoming or exiting metallic piping in the earth must be bonded to the lightning-protection grounding electrode system. This requirement is stated in 250.106 of the *NEC* and NFPA 780 section 4.14. Connections between the down conductors and grounding electrodes may be made by bolting, brazing, welding, or high compression connectors listed for the purpose including being listed for direct burial. Clamps suitable for direct burial may also be used. Grounding electrodes shall be installed below the frost line where possible.

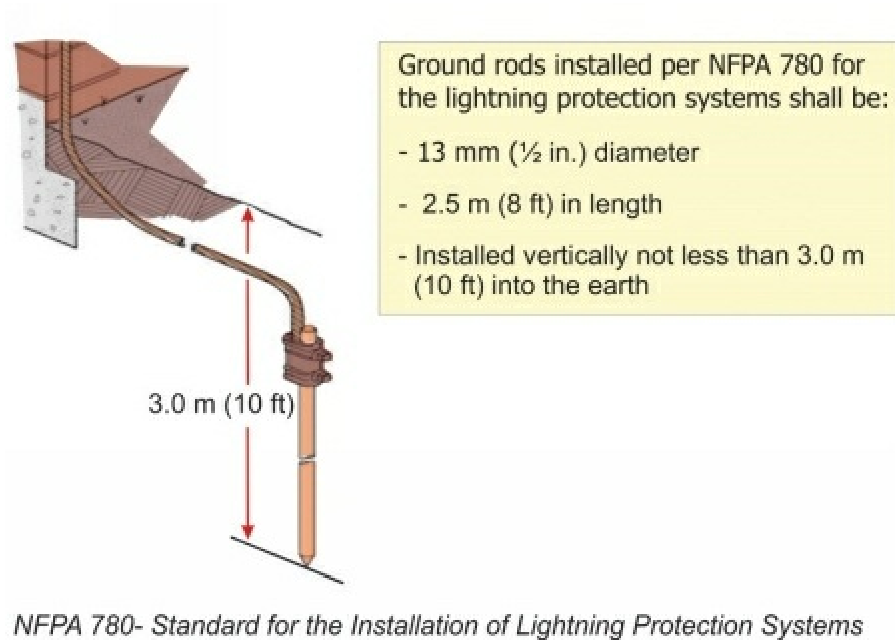


Figure 21.4 Typical single ground rod installation [from NFPA 780-2017, Figure 4.13.2.3.1)

Acceptable grounding electrodes

Grounding electrodes identified as suitable for use in lightning protection installations are ground rods, ground plate electrodes, concrete-encased electrodes, radials, and ground ring electrodes. Combinations of these devices may be used. The construction and installation requirements for each of these electrodes are similar to the requirements given in the *National Electrical Code*[15] (NFPA 70), Sections 250.52 and 250.53.

Ground rods shall be not less than 13 mm (½ in.) in diameter and not less than 2.5 m (8 ft) long. The ground rods shall extend vertically not less than 3 m (10 ft) into the earth (see figure 21.4). This is different from the *NEC* requirements that only require a 2.5 m (8 ft) ground rod to be flush with the top of the ground, where for lightning protection the same 2.5 m (8 ft) ground rod would have the top at least 600 mm (2 ft) below the surface. The earth shall be compacted and made tight against the length of the conductor or ground rod. Ground rods shall be free of paint or other nonconductive coatings. Where multiple ground rods are used to form the grounding electrode system, the separation between any two ground rods shall be at least the sum of their lengths where practicable. For example, if two 3 m (10 ft) ground rods are to be used, the spacing between then would be a minimum of 6 m (20 ft) unless it is not practical to provide that spacing.

Photo 21.11 Attachment to structural steel using a bonding plate Courtesy of East Coast Lightning Equipment of Winsted, CT

Ground plate electrodes shall have a minimum thickness of 0.8 mm (0.032 in.) and a minimum surface area of 0.18 m^2 (2 ft^2). The plate shall be buried not less than 450 mm (18 in.) below grade. Photo 21.12 provides an example of a ground plate electrode being installed.

Photo 21.12 Example of a buried copper plate grounding electrode
Courtesy of Bonded Lightning Protection of Argyle, TX

Concrete-encased electrodes are generally limited to new construction because it is necessary to ensure that the electrode was properly constructed before the concrete is poured. The electrode must be located near the bottom of a concrete foundation or footing that is in direct contact with the earth and shall be encased by not less than 50 mm (2 in.) of concrete. The encased electrode shall consist of either not less than 6 m (20 ft) of bare copper main-size conductor or at least 6 m (20 ft) of one or more steel reinforcing bars or rods not less than 13 mm (½ in.) in diameter that have been effectively bonded together by either welding or overlapping 20 diameters and wire-tying. UL 96A, 10.5.1 allows concrete-encased electrodes only when utilized in conjunction with other grounding electrodes, such as rods, plates, or ground ring electrodes. NFPA 780 allows concrete-encased electrodes as the sole grounding electrode. International lightning protection standards (IEC 62305-3, 5.4.4) indicate that concrete-encased electrodes are preferred over other grounding electrodes with the exception of the ground ring electrode.

A radial electrode system shall consist of one or more main-size conductors, each in a separate trench extending outward from the location of each down conductor. Each radial electrode shall be not less than 3.7 m (12 ft) in length and not less than 450 mm (18 in.) below grade.

A ground ring electrode is a main-sized lightning conductor encircling the structure. It shall be in direct contact with earth or it may be encased in a concrete footing at a depth below the frost line where possible but not less than 450 mm (18 in.). Photo 21.13 shows a trench being prepared for the installation of a ground ring electrode. The ground ring electrode is referred to in IEC 62305-3 as a Type B grounding system and is the preferred grounding system for all applications. Only Type B grounding systems are recommended in the international standard for installations on bare solid rock and for structures with extensive electronic systems or with high risk of fire.

Photo 21.13 Installation of a ground ring electrode
Courtesy of East Coast Lightning Equipment of Winsted, CT

Ground potential rise

Following the basic principles of Ohm's law, when an impulse current is injected onto a grounding electrode, an impulse voltage is developed. This voltage (known as a ground potential rise) will exist as long as the current is flowing. If a structure has systems that are independently grounded (systems not bonded together as required by *Code*), or the structure has unbonded metallic piping systems that are in contact with the earth, this ground potential rise could create a sufficient difference in potential to cause breakdowns through unintended paths. This could include arcing through the air, through the earth, or through conductive elements of internal systems. The result could be fire, equipment damage, and possibly human injury. This is the primary reason all the metallic elements in the earth and entering or exiting the structure at ground level must be bonded together.

As an example, consider the situation where a lightning protection system is installed with four grounding electrodes at the corners which are interconnected at the ground level and each electrode having a resistance to earth of 25 ohms. Using the IEC 62305-1 model for current division, we assume that the current associated with a direct strike would divide equally between the lightning protection grounding electrodes and the building services' grounding electrodes. For an average 40 kA (40,000 amps) lightning strike, the current in each lightning-protection grounding electrode will be

5 kA (5000 amps) (half of the total current will flow through the lightning protection system and this will then be equally divided between the four lightning protection grounding electrodes because they are of equal resistance). The result will be an estimated ground potential rise of 125 kV (125,000 volts). Let us also assume that an isolated gas line is installed in the structure sufficiently remote from the lighting-protection grounding electrode system. This lightning current and resulting ground potential rise associated with the lightning-protection grounding system will be sufficient to cause significant damage should an arc occur between the lightning-protection grounding electrode (which will be at 125 kV) and the incoming gas line, which would be at a nominal 0 volts. An alternative failure mode would be for the current path to be through the utilization equipment via the electrical service ground. Either case could create a serious problem. The solution is to ensure that all incoming and exiting conductors of the structure be bonded to a common grounding system. In this case, all of the building services would share the same potential but the majority of the current would be dissipated through the lower impedance lightning-protection grounding system. NFPA 780, 4.14 requires that all grounding electrodes and other conductive elements in the earth supplying the structure be interconnected to provide a common ground potential. This interconnection shall include lightning protection, electric service, telephone, and antenna system grounds, as well as all underground metallic piping systems. Where corrosion is an issue, the bond between the incoming piping system and the lightning-protection grounding system may be made through a spark gap.

Equipotential bonding

The previous discussion on ground potential rise justified the need to have a ground-level equipotential bonding system. An earlier section discussed the roof level conductors which would provide a roof-level equipotential bonding system. There may be some conditions where additional bonding is necessary between the roof and ground levels in the structure.

When lightning currents flow through a down conductor, a voltage is developed between the top and bottom of the down conductor as a result of the impedance of the cable. This voltage created will produce an electric field. The current flowing though the conductor will also create a magnetic field around the conductor. These electromagnetic fields can result in coupling in adjacent or nearby conductors. If the voltage difference between a lightning protection main conductor and an adjacent conductor exceeds the breakdown voltage of air, a side flash will occur. The probability of a side flash is increased for items interconnected only at the ground level and where one of the conductors, such as conduit or piping, meanders greatly through the structure or where there is a significant inductance in the circuit.

NFPA 780, 4.16.2 provides a formula in which it simplifies the calculations required to determine the probability of side flash. The formula requires a number of assumptions to get to its simplified state, but it can be accurately used to determine the need for bonding in addition to those bonds provided at the ground level. When grounded metal bodies are located within the following distance from lightning-protection network conductors, they shall be bonded to the lightning protection system:

$$D = h\,(k_m) / 6n$$

where:

D = calculated bonding distance

h = vertical distance between the bond being considered and the nearest lightning protection system bond

k_m = 1 if the flashover is through air, or 0.50 if through dense material such as concrete, brick, wood, etc.

n = a value related to the following:

- the number of down conductors that are spaced at least 7.5 m (25 ft) apart; and
- they are located within a zone of 30 m (100 ft) from the bond in question; and
- where bonding is required within 18 m (60 ft) from the top of any structure.

The value of n is given as:

n = 1 where there is only one down conductor in this zone;

n = 1.5 where there are only two down conductors in this zone;

n = 2.25 where there are three or more down conductors in this zone.

(When the bonding calculation is performed for a location below a level 18 m (60 ft) from the top of a structure, *n* is the total number of down conductors in the lightning protection system.)

For structures of 12 m (40 ft) in height or less, the value of h may be taken to be either the height of the building or the vertical distance between the nearest bonding connection of the grounded metal body to the lightning protection system and the point on the down conductor where the bonding connection is being considered.

These bonding equations are also valid for determining side flash distances from overhead ground wires or spacing of masts from a structure. For ungrounded metallic bodies, bonding is applicable only if the isolated body reduces the spacing between two grounded items (such as a window frame between a lightning protection system conductor and a water pipe).

For example, we have a building 25 m (80 ft) tall with a lightning protection system installed. There is a grounded metallic gas pipe installed vertically on an exterior wall to serve rooftop heating and cooling equipment. The down conductors are spaced 30 m (100 ft) apart and the gas pipe is located 11 m (35 ft) away from the nearest down conductor. Is a bond to the down conductor required at a point half way up the building wall?

The distance “h” from the nearest bond (roof or ground level) is 12 m (40 ft)

Km = 1

n is 1.5 as there are two down conductors within the zone of 30 m (100 ft) from the gas pipe

D= 40 * 1 / 6 * 1.5 = 1.35 m (4.44 ft)

The calculated side flash distance is 1.35 m (4.44 ft) and since the gas pipe is at a greater distance, 11 m (35 ft), a bond is not required at the point in question.

Surge protection

Surges can occur from a number of sources including lightning. Among these are direct strikes to incoming conductors (power, communication, data, and so forth), strikes near an incoming conductor, and ground potential rises as a result of a strike to or near the structure. Magnetic and capacitive coupling from a lightning strike occurring up to 450 m (1500 ft) away can induce a transient voltage surge capable of damaging electrical and electronic systems.

The protection of electrical and electronic systems within a building or structure will require that measures be taken for the protection against lightning induced electromagnetic pulses (LEMP). Measures to maintain as small a potential difference between the electrical and electronic equipment and where the lightning is being conducted are required. The first point of defense is for incoming electrical services (including data and communication services). This is normally implemented using spatial shielding and surge protective devices (SPDs). All lightning protection standards now require protection against incoming surges at a minimum. In most cases, this leads to requirements for equipotential bonding and the installation of SPDs.

The susceptibility of electrical and electronic systems can be mitigated in some cases by establishing lightning protection zones. In some cases, this may be accomplished by taking advantage of natural shielding procedures such as that provided by locating the equipment in a steel framed or steel reinforced concrete structure, by utilizing the shielding provided by the equipment's enclosure, or locating it in an equipment rack. The boundary point of the initial lightning protection zone (LPZ 1) also requires the installation of SPDs to protect the equipment. Additional lightning protection zones may be established as necessary, depending upon the sensitivity of the electronic equipment.

Prior to September 2006, UL required only a surge arrestor or a "TVSS marked for LPS" on the incoming power service to the structure in order to obtain Master Label certification. The fourth edition of UL 1449[16] now incorporates SPD (previously called surge arrestors or transient voltage surge suppressors) into a single document. The standard defines a Type 1 SPD as one that is for permanent connection and intended for installation between the secondary of the service transformer and the line side of the service-equipment overcurrent device. Type I SPDs also do not have an external overcurrent protective device. Type 2 SPDs are for permanent connection and are intended for installation on the load side of the service-equipment overcurrent device; including SPDs located at the branch circuit panel.

United States lightning protection standards agree on the surge protective device requirements to be installed at the service entrances for all power and communication supply systems. They primarily address common mode surges as a minimum, but indicate differential mode surges may need to be considered in some applications. In the case of electrical service entrances, line-to-ground and line-to-neutral modes must be protected but line-to-line protection may also be provided. For each electrical service entrance of less than 1 kV, the following is acceptable:

A surge protective device with a rated maximum discharge current of 40 kA or more complying with the IEEE C62.11, *Standard for Metal – Oxide Surge Arresters for AC Power Circuits* or the *Standard for Surge Protective Devices*. Alternatively, a SPD listed to UL 1449 that is installed on the supply or load side of the service disconnect overcurrent protection installed in accordance with NFPA 70, Articles 280 or 285 (surge arrester or Type 1 SPD).

A SPD marked for LPS application with a rated maximum discharge current of 40 kA or more, installed on the load side of the service-disconnect overcurrent protection in accordance with NFPA 70, Article 285 (Type 2 SPD)

Type 1 or Type 2 surge protective devices (SPDs) rated 20 kA or more nominal discharge current in accordance with the *Standard for Surge Protective Device*s, UL 1449, edition 3 or later, installed in accordance with NFPA 70, Article 285.

For circuits greater than 1 kV, a surge arrester with a rated maximum discharge current of 40 kA or more meeting the requirements of IEEE C62.11, *Standard for Metal – Oxide Surge Arresters for AC Power Circuits* may be used provided it is installed in accordance with the requirements of NFPA 70, Article 280.

Surge protection for all conductive signal, data, and communication lines shall be provided with a rated maximum discharge current of 10 kA or more at the point of entrance. The protection provided shall be installed in accordance with Articles 800, 810, 820, 830 or 840 (as applicable) of the *National Electrical Code* and shall comply with the *Standard for Antenna-Discharge Units*, UL 452, the *Standard for Protectors for Paired-Conductor Communications Circuits*, UL 497, and the *Standard for Protectors for Coaxial Communications Circuits*, UL 497C.

Surge protective devices should be installed in such a manner that they can be tested or monitored (as applicable). Photo 21.14 provides an example of a surge protective device installed on a service entrance and photo 21.15 provides an example of an installation for communication lines.

Photo 21.14 Installation of surge protection on incoming service
Courtesy of Erico

Photo 21.15 Installation of surge protection on communication lines at the service entry

Quality Control Programs

There are two well-recognized quality control programs in the United States for lightning-protection system installations. These are the Underwriters Laboratories (UL) Master Label program and the Lightning Protection Institute (LPI) Certified System program. Each of these programs requires the use of components listed to UL 96.[11]

UL Master Label Program

The best known of all lightning protection quality control programs is the Underwriters Laboratories Inc. (UL) Master Label Certificate program. It is well respected by numerous organizations such as many federal agencies and insurance underwriters as a program that will ensure that proper materials and workmanship were provided when the lightning protection system was installed. This service is recognized and is being provided in many countries outside of the United States and Canada. Underwriters Laboratories has been testing and certifying lightning protection equipment since 1908. In 1923, UL began issuing Master Labels for lightning-protection system installations. UL engineer Karl Klock, in a 1938 radio address, reported that in the first 15 years the service was in operation, approximately 78,000 buildings received a Master Label and that the minimal reports of failure reflected a protection efficiency of 99.9%.

UL issues Master Labels for systems by inspecting system components and checking completed installations. Components must be listed and labeled in accordance with UL 96 while installations are required to comply with UL's internationally recognized Lightning Protection Installation Standard UL 96A.[14] Where the engineering or owner's specifications dictate, UL will also provide inspection services to NFPA 780 as well as the IEC 62305-3 standard.

The program requires that installers demonstrate competence in the installation of lightning protection systems by becoming a UL Listed installer. Once the UL Listed installer completes an installation, they submit the Master Label certification application. A trained and qualified UL field representative then inspects the installation and instantly communicates the results electronically to UL and the installer. If necessary, a letter detailing any variances is issued to the installer. After variances are corrected, the installer resubmits the application for re-inspection. In some instances, system designs and variance corrections can be reviewed electronically. The UL Listed installer forwards the certificate to the premise owner/operator, and posts the certificate on the UL web site, providing proof that the lightning protection system complies with the applicable standard.[17]

Master Label certificates must be renewed every five years, or whenever the building changes structurally, or when modifications are made to the system. The UL Listed installer can repair or modify the system and arrange to have it re-evaluated by UL to determine its continued compliance with UL 96A.

LPI Certified System

The Lightning Protection Institute (LPI) also offers a certification program for lightning protection installations. Although not as well-known as the UL Master Label Certificate program, the LPI Certified System program offers an additional layer of quality control and accountability. The LPI Certified System program requires that essential inspections be performed once the lightning-protection grounding electrode system is installed, once conductors are installed (prior to being concealed if applicable), and once the roof system is completed. These inspections will be made by a LPI-certified master installer and witnessed by a representative of the owner. Upon completion, an independent inspection on the completed system will be performed either by a LPI-certified inspector or by a UL inspector and a final report on findings will be provided. When an owner receives an LPI certification for the installation, they can be assured that all aspects of the installation have been systematically scrutinized for compliance with LPI 175, NFPA 780, and UL 96A, as applicable.

NEC vs. NFPA 780

Grounding and Bonding Requirements

Little difference exists between permitted grounding electrodes identified in NFPA 70, 250.52 and those identified in NFPA 780, 4.13 with a few exceptions. One exception is that NFPA 780 allows the use of radials. Another exception is in the required burial depth and spacing of ground rods as previously discussed. The issues of the higher frequency components and higher current densities in the lightning threat warrant the need to provide a larger area covered by the grounding system to decrease the maximum potential within the earth surface developed under discharge conditions.

The primary difference between the grounding requirements identified in NFPA 70 Article 250 and NFPA 780 is in the definition of the term *grounding electrode* and some differences in the NFPA standards as to the bonding of gas lines to the lightning-protection grounding system. NFPA 70, 250.52(B), NFPA 780, and NFPA 54, 7.13.2 all agree that gas piping shall not be used as a grounding electrode. Each standard also has specific gas piping bonding requirements that derive from the scope and application of the NFPA standard.

The *National Electrical Code* defines grounding electrode as “a conducting object through which a direct connection to the earth is established.” NFPA 780 defines the term as “the portion of a lightning protection system, such as a ground rod, ground plate, or ground conductor that is installed for the purpose of providing electrical contact with the earth.” The for the purpose clause is an important distinction in the lightning protection community, as the intent is that all metallic conductors entering or exiting the structure must be interconnected with the lightning-protection grounding electrode system to eliminate the dangerous effects of ground potential rises; but the lightning-protection grounding system is designed to conduct the majority of the current into the earth.

By the definition given in the *NEC*, an underground gas line is a grounding electrode because it establishes a connection to earth the same as an underground water pipe. The key point in Section 250.52(B) is that it shall not be used for that purpose. *NEC* 250-104(B) acknowledges that gas piping “that is likely to be energized” shall be bonded to the service equipment enclosure. However, it is not clear to an electrical inspector from this text that during a direct or nearby lightning strike the gas line is likely to become energized (see the earlier discussion on ground potential rise). It is also questionable whether the bond at the service equipment enclosure is the best place to make this bond. For the purpose of lightning protection, this bond is best made at the service entrance or even directly between the gas line and the lightning protection grounding electrode system.

Summary

This chapter provides a very general overview of the principles of lightning protection and some differences as different standards are applied in different parts of the world. It is not meant to be a detailed explanation or a comprehensive installation guide for design or installation of lightning protection systems. It focuses on the installation requirements of NFPA 780 and UL 96A. While most of the users of this text are normal electrical system installers or inspectors, this chapter shows that the installation of a lightning protection system is much different from the installation of electrical service wiring. This is due to the high current densities, high rates of current rise (di/dt), and resulting mechanical forces that happen during a lightning event. For these reasons, specialized material and installation methods such as that specified in NFPA 780 and UL 96 are required and the system should only be installed by qualified personnel trained and certified in the installation of lightning protection systems (such as LPI-certified and UL listed installers).

This chapter identifies the key elements of a lightning protection system. These are the strike termination network, down conductor network, grounding electrode network, equipotential bonding network, and surge protection. It provides a description of each of these elements and provides some minimum-acceptable parameters. The text also discusses two quality control and installation inspection programs that can be utilized to ensure a lightning protection system is installed and is being maintained in accordance with established lightning protection standards.

Key principles discussed in this chapter are the differences in the definition of grounding electrodes between the *National Electrical Code* and national lightning protection standards such as NFPA 780 and UL 96A. The differences in the definition are minor on their face, but the application can lead to issues as to whether a bond to an underground pipe would constitute its use as a grounding electrode. The interconnection of underground metallic structures entering a building and all incoming system grounding electrode conductors to the lightning protection system is critical for the safe and efficient operation of the system.

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[17] http://www.ul.com/lightning

Review Questions

1. Between which of the following are lightning events likely to occur?

1. cloud-to-ground
2. cloud-to-cloud
3. between charge centers within a cloud
4. all of the above

2. The term striking distance refers to ____.

1. the distance within which an item must be bonded to the lightning protection system
2. the height of a building or structure
3. the final step of a stepped leader
4. all of the above

GIVEN: A lightning protection system cannot prevent lightning from occurring. It can only provide a mechanism by which the energy can be controlled until it can be safely dissipated into the earth.

3. Which of the following is not the purpose of a lightning protection system ____?

1. provide a high probability attachment point for a lightning strike
2. prevent lightning from occurring in the vicinity of the strike
3. provide a low impedance path to earth for the dissipation of lightning currents
4. limit internal arcing and overvoltages on electrical/electronic equipment

4. Which of the following is a part of the lightning protection system ____?

1. strike termination network
2. down conductor network
3. grounding electrode network
4. all of the above

5. Which of the following lightning protection standards allow a risk-based solution to lightning protection ____?

1. NFPA 780
2. UL 96A

3. IEC 62305
4. all of the above

6. Which of the following chapters of NFPA 780 provide the baseline requirements on which the remainder of the document is built ____?

1. Chapter 2
2. Chapter 3
3. Chapter 4
4. Chapter 5

7. NFPA 780 allows the following to act as a strike termination device ____.

1. air terminal
2. metal mast
3. structural component equivalent to 5 mm (3/16 in.) thick steel
4. all of the above

8. Which of the following standards provides the criteria for the listing of lightning protection components ____?

1. NFPA 780
2. UL 96A
3. UL 96
4. NFPA 70

9. A main-sized lightning protection conductor is used to ____.

1. interconnect air terminals
2. connect the air terminal network to the grounding electrodes
3. serve as the ground ring electrode
4. all of the above

10. The minimum bend radius of a main conductor shall not be less than:

1. 300 mm (12 in.)
2. 200 mm (8 in.)
3. 100 mm (4 in.)
4. None. There shall be no bends in main conductors

11. A lightning protection mast may be in the form of which of the following:

1. a metal pole with 5 mm (3/16 in.) cap thickness

2. wooden pole with an air terminal and two down conductors
3. metal tower
4. all of the above

12. Which of the following is not allowed by NFPA 780 as a method for determining the placement of strike termination devices ____?

1. rolling sphere method
2. protective angle
3. electric field intensification method
4. “modified-mesh” method

13. Which of the following is not allowed to be used as a strike termination device ____?

1. air terminals
2. HVAC sheet metal enclosure with less than 5 mm (3/16 in.) thickness
3. metallic structural components with a thickness of 5 mm (3/16 in.) or greater
4. all of the above

14. Which of the following is not allowed to be used as a lightning protection grounding electrode (as defined by NFPA 780) ____?

1. ground rod
2. radial electrodes
3. concrete-encased electrodes
4. underground metallic piping (such as gas or water lines)

15. Which of the following is required to be bonded to the lightning protection grounding system ____?

1. electrical service ground
2. metallic water pipe
3. gas piping
4. all of the above

16. Which of the following materials is not allowed by NFPA 780 to be used as a ground rod ____?

1. 1/2 inch bare steel rod
2. copper-clad steel ground rod
3. copper ground rod
4. stainless steel ground rod

17. Which of the following are not allowed by US lightning protection standards to be used as a lightning protection system down conductor ____?

1. main-sized conductor
2. concrete reinforcing steel
3. structural steel
4. all of the above are allowed to be used as a down conductor

18. Which of the following methods is not used by NFPA 780 to define a main-sized lightning protection conductor ____?

1. cross section area
2. weight per unit length
3. size of each strand
4. diameter

Chapter 22
Tables

The following tables are those from Article 250 of the *NEC* along with supplemental tables providing greater explanation and the basis of the *NEC* tables:

Table 22.1. *NEC* Table 250.66, Grounding Electrode Conductor for Alternating-Current Systems.

Table 22.2. Analysis of *NEC* Table 250.66 Grounding Electrode Conductor and Service Conductor Compared as to Relative Size.

Table 22.3. Comparison of Copper Grounding Electrode Conductors per *NEC* Table 250.66 When Used With and Without Steel Conduit for Physical Protection.

Table 22.4. Comparison of Aluminum Grounding Electrode Conductors per *NEC* Table 250.66 When Used With and Without Aluminum Conduit for Physical Protection.

Table 22.5. Rating of Grounding Electrode Conductors Specified in Table 250.66 and Voltage Drop under Maximum Short-Time Rating.

Table 22.6. *NEC* Table 250.102(C) Grounded Conductor, Main Bonding Jumper, System Bonding Jumper, and Supply-Side Bonding Jumper for Alternating-Current Systems.

Table 22.7. *NEC* Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceways and Equipment.

Table 22.8. Analysis of Table 250.122 of the *National Electrical Code*.

Table 22.9. *NEC* Chapter 9, Table 8 Conductor Properties.

The following tables are from the original work of Eustace Soares and then the work validating this work completed by the Georgia Institute of Technology as sponsored by the producers of metallic conduit and tubing.

Table 22-10. Maximum length of steel conduit tubing that may safely be used as an equipment grounding circuit conductor.

Table 22-11. Aluminum conduit used as an equipment grounding circuit conductor (EGC) compared with equipment grounding circuit conductors (EGC) as specified in Table 250.122 of the *National Electrical Code*.

Table 22-12. Sizes of conductor (Copper Bar) for use in the equipment grounding circuit and for the Equipment Grounding Strap for overcurrent devices from 1600 amperes through 5000 amperes.

Note: Tables 22-13 through 22-16 were derived from software (SCA) and testing developed at the Georgia Institute of Technology and sponsored by the producers of steel EMT, IMC, and rigid steel conduit. Additional information about the research and testing of steel conduit and tubing is available at www.steelconduit.org and the computer-based modeling GEMI software is available online at http://www.steelconduit.org/gemi.htm.

Table 22-13. Maximum length of conductor that may be used as an equipment-grounding circuit conductor, based on a ground-fault current of 400% of the overcurrent device rating. Circuit 122 volts to ground; 40 volts drop at the point of fault. Ambient temperature 25ºC.

Table 22-14. Maximum length of electrical metallic tubing (EMT) that may be used safely as an equipment grounding circuit conductor. Based on ground-fault current of 400% of the overcurrent device rating. Circuit 120 volts to ground; 40 volts drop at the point of fault. Ambient temperature 25ºC.

Table 22-15. Maximum length of intermediate metal conduit (IMC) that may be used safely as an equipment grounding circuit conductor. Based on ground-fault current of 400% of the overcurrent device rating. Circuit 120 volts to ground; 40 volts drop at the point of fault. Ambient temperature 25ºC.

Table 22-16. Maximum length of galvanized rigid conduit (RMC) that may be used safely as an equipment grounding circuit conductor. Based on ground-fault current of 400% of the overcurrent device rating. Circuit 120 volts to ground; 40 volts drop at the point of fault. Ambient temperature 25ºC.

Table 20-6

NEC Table 250.102(C)(1)

Grounded Conductor, main Bonding Jumper, System Bonding Jumper, and Supply-Side Bonding Jumper for Alternating-current Systems

Size of Largest Ungrounded Conductor or Equivalent Area for Parallel Conductors (AWG/kcmil)		**Size of Grounded Conductor or Bonding Jumper* (AWG/kcmil)**	
Copper	Aluminum or Copper-Clad Aluminum	Copper	Aluminum or Copper-Clad Aluminum
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250	4	2
Over 3/0 through 350	Over 250 through 500	2	1/0
Over 350 through 600	Over 500 through 900	1/0	3/0
Over 600 through 1100	Over 900 through 1750	2/0	4/0
Over 1100	Over 1750	See Notes	

Notes:

1. If the ungrounded supply conductors are larger than 1100 kcmil copper or 1750 kcmil aluminum, the grounded conductor or bonding jumper shall have an area not less than 12 ½ percent of the area of the largest ungrounded supply conductor or equivalent area for parallel supply conductors. The grounded conductor or bonding jumper shall not be required to be larger than the largest ungrounded conductor or set of ungrounded conductors.

2. If the ungrounded supply conductors are larger than 1100 kcmil copper or 1750 kcmil aluminum and if the ungrounded supply conductors and the bonding jumper are of different materials (copper, aluminum or copper-clad aluminum), the minimum size of the grounded conductor or bonding jumper shall be based on the assumed use of ungrounded supply conductors of the same material as the grounded conductor or bonding jumper, and will have an ampacity equivalent to that of the installed ungrounded supply conductors.

3. If multiple sets of service-entrance conductors are used as permitted in 230.40, Exception No. 2, or if multiple sets of ungrounded supply conductors are installed for a separately derived system, the equivalent size of the largest ungrounded supply conductor(s) shall be determined by the largest sum of the areas of the corresponding conductors of each set.

4. If there are no service-entrance conductors, the supply conductor size shall be determined by the equivalent size of the largest service-entrance conductor required for the load to be served.

*For the purpose of applying this table and its notes, the term *bonding jumper* refers to *main bonding jumpers*, *system bonding jumpers*, and *supply-side bonding jumpers*.

Table 20-9

NEC Chapter 9, Table 8 Conductor Properties

Size (AWG or kcmil)	Conductors									Direct-Current Resistance at 75°C (167°F)					
			Stranding			Overall				Copper					
	Area			Diameter		Diameter		Area		Uncoated		Coated		Aluminum	
	mm²	Circular mils	Quantity	mm	in.	mm	in.	mm²	in.2	ohm/km	ohm/kFT	ohm/km	ohm/kFT	ohm/km	ohm/kFT
18	0.823	1620	1			1.02	0.040	.823	0.001	25.5	7.77	26.5	8.08	42.0	12.8
18	0.823	1620	7	0.39	0.015	1.16	0.046	1.06	0.002	26.1	7.95	27.7	8.45	42.8	13.1
16	1.31	2580	1			1.29	0.051	1.31	0.002	16.0	4.89	16.7	5.08	26.4	8.05
16	1.31	2580	7	0.49	0.019	1.46	0.058	1.68	0.003	16.4	4.99	17.3	5.29	26.9	8.21
14	2.08	4110	1			1.63	0.064	2.08	0.003	10.1	3.07	10.4	3.19	16.6	5.06
14	2.08	4110	7		0.024	1.85	0.073	2.68	0.004	10.3	3.14	10.7	3.26	16.9	5.17
12	3.31	6530	1			2.05	0.081	3.31	0.005	6.34	1.93	6.57	2.01	10.45	3.18
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006	6.50	1.98	6.73	2.05	10.69	3.25
10	5.261	10,380	1			2.588	0.102	5.26	0.008	3.984	1.21	4.148	1.26	6.561	2.00
10	5.261	10,380	7	0.98	0.038	2.95	0.116	6.76	0.011	4.070	1.24	4.226	1.29	6.679	2.04
8	8.367	16,510				3.264	0.128	8.37	0.013	2.506	0.764	2.579	0.786	4.125	1.26
8	8.367	16,510	7	1.23	0.049	3.71	0.146	10.76	0.017	2.551	0.778	2.653	0.809	4.204	1.28
6	13.30	26,240	7	1.56	0.061	4.67	0.184	17.09	0.027	1.608	0.491	1.671	0.510	2.652	0.808
4	21.15	41,740	7	1.96	0.077	5.89	0.232	27.19	0.042	1.010	0.308	1.053	0.321	1.666	0.508
3	26.67	52,620	7	2.20	0.087	6.60	0.260	34.28	0.053	0.802	0.245	0.833	0.254	1.320	0.403
2	33.62	66,360	7	2.47	0.097	7.42	0.292	43.23	0.067	0.634	0.194	0.661	0.201	1.045	0.319
	42.41	83,690	19	1.69	0.066	8.43	0.332	55.80	0.087	0.505	0.154	0.524	0.160	0.829	0.253
1/0	53.49	105,600	19	1.89	0.074	9.45	0.372	70.41	0.109	0.399	0.122	0.415	0.127	0.660	0.201
2/0	67.43	133,100	19	2.13	0.084	10.62	0.418	88.74	0.137	0.3170	0.0967	0.329	0.101	0.523	0.159
3/0	85.01	167,800	19	2.39	0.094	11.94	0.470	111.9	0.173	0.2512	0.0766	0.2610	0.0797	0.413	0.126
4/0	107.2	211,600	19	2.68	0.106	13.41	0.528	141.1	0.219	0.1996	0.0608	0.2050	0.0626	0.328	0.100
250			37	2.09	0.082	14.61	0.575	168	0.260	0.1687	0.0515	0.1753	0.0535	0.2778	0.0847
300			37	2.29	0.090	16.00	0.630	201	0.312	0.1409	0.0429	0.1463	0.0446	0.2318	0.0707
350			37	2.47	0.097	17.30	0.681	235	0.364	0.1205	0.0367	0.1252	0.0382	0.1984	0.0605
400			37	2.64	0.104	18.49	0.728	268	0.416	0.1053	0.0321	0.1084	0.0331	0.1737	0.0529
500			37	2.95	0.116	20.65	0.813	336	0.519	0.0845	0.0258	0.0869	0.0265	0.1391	0.0424
600			61	2.52	0.099	22.68	0.893	404	0.626	0.0704	0.0214	0.0732	0.0223	0.1159	0.0353
700			61	2.72	0.107	24.49	0.964	471	0.730	0.0603	0.0184	0.0622	0.0189	0.0994	0.0303
750			61	2.82	0.111	25.35	0.998	505	0.782	0.0563	0.0171	0.0579	0.0176	0.0927	0.0282
800			61	2.91	0.114	26.16	1.030	538	0.834	0.0528	0.0161	0.0544	0.0166	0.0868	0.0265
900			61	3.09	0.122	27.79	1.094	606	0.940	0.0470	0.0143	0.0481	0.0147	0.0770	0.0235
1000			61	3.25	0.128	29.26	1.152	673	1042	0.0423	0.0129	0.0434	0.0132	0.0695	0.0212
1250	633		91	2.98	0.117	32.74	1.289	842	1.305	0.0338	0.0103	0.0347	0.0106	0.0554	0.0169
1500	760		91	3.26	0.128	35.86	1.412	1011	1.566	0.02814	0.00858	0.02814	0.00883	0.0464	0.0141
1750	887		127	2.98	0.117	38.76	1.526	1180	1.829	0.02410	0.00735	0.02410	0.00756	0.0397	0.0121
2000	1013		127	3.19	0.126	41.45	1.632	1349	2.092	0.02109	0.00643	0.02109	0.00662	0.0348	0.0106

1. These resistance values are valid ONLY for the parameters as given. Using conductors having coated strands, different stranding type, and, especially, other temperatures, change the resistance.

2. Equation for temperature change: $R_2 = R_1\ [1+a(T_2-75)]$ where: $a_{cu} = 0.00323$, $a_{AL} = 0.00330$, at 75°C.

3. Conductors with compact and compressed stranding have about 9 percent and 3 percent, respectively, smaller bare conductor diameters than those shown. See Table 5A for actual compact cable dimensions.

4. The IACS conductivities used: bare copper = 100% aluminum = 61%.

5. Class B stranding is listed as well as solid for some sizes. Its overall diameter and area is that of its circumscribing circle.

Informational Note: The construction information is in accordance with NEMA WC/70-2009 or ANSI 1581-2001. The resistance is calculated per *National Bureau of Standards Handbook 100*, dated 1966, and *Handbook 109*, dated 1972.

Table 20-10 (continued)

Maximum length of steel conduit or tubing that may safely be used as an equipment grounding circuit conductor

Conduit Trade Size In.	AWG/ kcmil	OC 75°C	Fault 500%	EMT *Length (ft)	IMC *Length (ft)	RGC *Length (ft)
2 1/2	400	300	1500	278	263	253
	400	350	1750	244	239	227
	500	350	1750	255	249	236
	500	400	2000	227	230	216
3	500	350	1750	280	262	253
	500	400	2000	251	240	231
	600	400	2000	260	248	238
	600	450	2250	235	231	220
	700	450	2250	242	237	225
	700	500	2500	221	222	209
3 1/2	600	400	2000	280	256	248
	600	450	2250	257	237	229
	700	450	2250	264	244	235
	700	500	2500	243	228	218
	750	450	2250	267	246	237
	750	500	2500	246	230	221
	900	500	2500	254	237	227
	900	600	3000	220	212	200
4	750	450	2250	277	253	245
	750	500	2500	255	236	228
	900	500	2500	264	243	234
	900	600	3000	229	216	206
	1000	500	2500	269	247	238
	1000	600	3000	233	219	210

Based on a clearing ground-fault current of 500 percent of overcurrent device rating; circuit 120 volts to ground; 50 volts drop at the arc; 30° C ambient temperature; 75°C conductor temperature. Calculated with "Steel Conduit Analysis Vs 1.2" by Georgia Institute of Technology.

* Measurement in feet

Table 20-13

Maximum length of conductor that may be used safely as an equipment-grounding circuit conductor, based on a ground-fault current of 400% of the overcurrent device rating. Circuit 120 volts to ground; 40 volts drop at the point of fault. Ambient temperature 25˚C

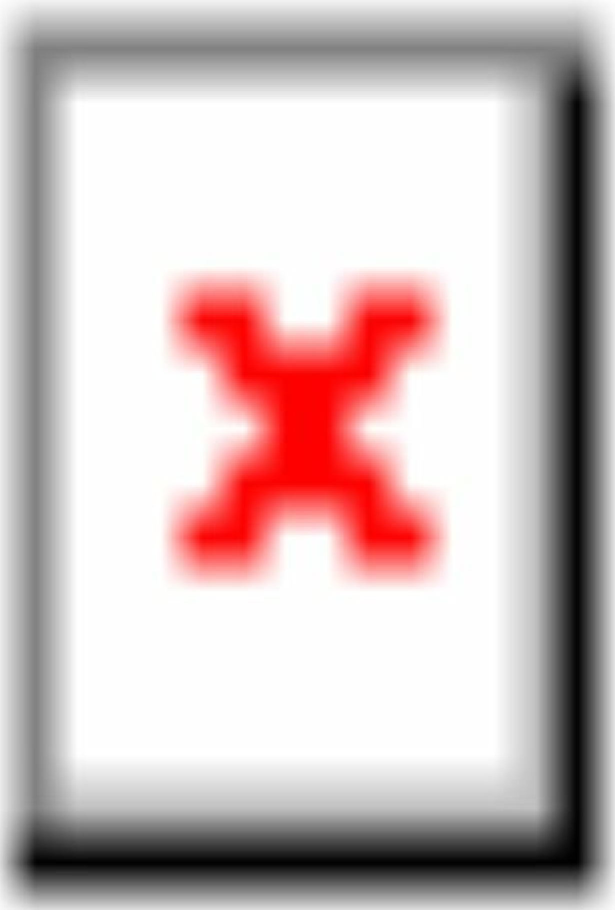
Copper Equipment Grounding Conductor AWG Size***	Copper Circuit AWG Conductors	Maximum Length of Run (in feet) using Copper Equipment Ground Conductor	**Aluminum** Equipment Grounding Conductor AWG Size***	Aluminum Circuit AWG Conductor	Maximum Length of Run (in feet) using Aluminum Equipment Grounding Conductor	**For Copper and Aluminum** Overcurrent Device Rating Amperes 75˚C**	Fault Clearing Current 400% OC Device Rating Amperes
14	14	253	12	12	244	15	60
12	12	300	10	12	226	20	80
10	10	319	8	8	310	30	120
10	8	294	8	8	232	40	160
10	6	228	8	4	221	60	240
8	3	229	6	1	222	100	400
6	3/0	201	4	250 kcm	195	200	800
4	350 kcm	210	2	500 kcm	204	300	1200
3	600 kcm	195	1	900 kcm	192	400	1600
2	2-4/0	160	1/0	2-400 kcm	163	500	2000
1	2-300 kcm	160	2/0	2-500 kcm	161	600	2400
1/0	3-300 kcm	134	3/0	3-400 kcm	131	800	3200
2/0	4-250 kcm	114	4/0	4-400 kcm	115	1000	4000
3/0	4-300 kcm	106	250 kcm	4-500 kcm	107	1200	4800
4/0	4-600 kcm	93	350 kcm	4-900 kcm	97	1600	6400
250 kcm	5-600 kcm	78	400 kcm	5-800 kcm	79	2000	8000
350 kcm	6-600 kcm	*	600 kcm	6-900 kcm	*	2500	10,000
400 kcm	8-500 kcm	*	600 kcm	8-750 kcm	*	3000	15,000
500 kcm	8-1000 kcm	*	800 kcm	8-1500 kcm	*	4000	16,000
700 kcm	10-1000 kcm	*	1200 kcm	10-1500 kcm	*	5000	20,000
800 kcm	12-1000 kcm	*	1200 kcm	12-1500 kcm	*	6000	24,000

* Calculations necessary

** 60°C for 20– and 30–ampere devices

*** Based on *NEC* Chapter 9, Table 8

Table derived from Software (SCA) and Testing developed at Georgia Institute of Technology and sponsored by the producers of Steel EMT, IMC, and rigid steel conduit.



⏚ Appendix A
Origin of Concrete-Encased Electrode

Herbert G. Ufer, in an IEEE Conference Paper, CP-61-978, describes an installation of made ground electrodes on 24 buildings in 1942, in Arizona, to meet a 5-ohm maximum value. The resistance values were checked bimonthly over an 18-year period, during which time no servicing was required.

In 1960, the maximum reading was 4.8 ohms and the minimum 2.1 ohms. The average value of the 24 installations was 3.57 ohms.

The installations used 13 mm (½ in.) steel reinforcing rods set in a concrete footing. They were at two locations in Arizona. The first was near Tucson, Arizona, which is normally hot and dry during most of the year and has an average annual rainfall of 10.91 inches. The soil is sand and gravel. The second location was near Flagstaff, Arizona, where the soil is clay, shale gumbo, and loam with small area stratas of soft limestone. The made electrodes were used, as no water piping system was available.

As a result of these installations and the 18-year test period, Mr. Ufer suggested that a 4 AWG or larger copper wire be embedded in the concrete footing of a building and that test data be compiled further to verify the effectiveness. Based on this data, CMP-5 accepted a concrete-encased electrode commonly referred to as an Ufer Ground. The concrete-encased electrode shall consist of at least 6.0 m (20 ft) of bare copper not smaller than 4 AWG encased in 50 mm (2 in.) of concrete. The original requirements for a concrete-encased electrode required the bare copper or steel reinforcing rods to be located near or at the bottom of the footing or foundation.

Appendix B
National Electrical Grounding Research Project

Beginning in 1995, the National Electrical Grounding Research Project (NEGRP) initiated a study of effectiveness of various types of buried grounding electrodes in differing geographies around the U.S. The NEGRP adopted a similar and ongoing research originated by the International Association of Electrical Inspectors, Southern Nevada Chapter (the IAEI/SNC grounding study) in 1992. During the term of the project, electrode resistance, earth resistivity, soil temperature, soils moisture and other measurements were recorded for more than twenty types of buried grounding electrodes in ten sites, situated in six geographic locations around the continental U.S. After being buried for extended periods, some electrodes at selected sites were exhumed for corrosion analysis, and observation.

One major goal of this research was to produce data and other information that would be useful to those in industry who require this to aid in the design of new systems, in the analysis of existing system performance, and in the explanation of failures of grounding electrodes.

In a report such as this, it would be preferable to state results simply and conclude facts about the features of the project; however, owing to the long-term nature of the project and the number of details evaluated, it is important to state the features of the project as many individual observations. A large amount of information was produced and many details of the project have not been fully evaluated or explored. Much can still be determined in a review of the information produced by the project.

Conductance of earth varies by location

The nature of soil varies greatly in different locations. New York, Balboa, Las Vegas and Virginia sites produced higher earth resistivity and electrode resistance results than did other sites. The earth resistivity and electrode resistance readings from the Illinois site are significantly lower in comparison to other sites. The Illinois site was situated in a water runoff area and was usually wet. Although the New York site and Nasa sites also showed evidence of water for long periods, the values of earth resistivity and electrode resistance in these two sites were always higher than Illinois.

Table 2 showing earth resistivity values covers ten years of data for each site and is arranged by minimums first, sorted in descending order.

Earth resistivity proves to be a valuable indicator of electrode performance

An apparent correlation to electrode resistance values is observed in the recorded earth resistivity data. Test pin spacing (depth of measurement) for earth resistivity proves to be a prime indicator that can be indicative of the prospective performance of electrode resistance values. Care should be taken to observe earth resistivity at pin spacings (depths) relative to the proposed electrode depths. In this project 10-foot and 20-foot pin spacings were used to obtain earth resistivity values, yet these test pin spacings produced values consistent with the reported electrode resistance. This close correlation is possibly due to the homogenous nature of the soil at lesser depths.

Earth resistivity and electrode resistance appear to be inverse to temperature

The Illinois site exhibited a clearly inverse relationship between temperature and earth resistivity (and electrode resistance) where increases in soil temperature are effectively mirrored by reductions in earth resistivity when viewed over time. In most other sites, the earth resistivity and electrode resistance similarly showed linkage to seasonal temperature variations. This factor could be important in the design and initial installation. For example, an electrode installed in summer that resulted in a 25-ohm initial value could potentially exceed this value for much of the other seasons. Except for other factors, it might also be concluded that an electrode installed in the winter that meets the ohmic design criteria would typically not venture above this ohmic value in the summer.

Of the 18 electrodes in the Balboa test site, 14 of these exceeded 25 ohms for 90% or more of the readings; electrode Types E, L and R were the exceptions. Similarly, for electrodes in the New York test site, 100% of the readings exceeded 25 ohms for 13 of the 15 electrodes in the site; the exceptions being electrodes Type L and R.

It is noted that the percentage of readings for electrode Type B, (*NEC* Section 250.52) two exceeded 25 ohms for 74% or more of the readings in four of the 10 test sites.

Electrode Type K readings exceeded 25 ohms for 75% or more of the readings at nine of the 10 test sites, with Texas readings exceeding 25 ohms for 21% of the readings.

The Illinois site had the fewest number of electrodes with readings exceeding 25 ohms. Electrodes H and K had 11% and 79% respectively that exceeded 25 ohms. This could be due to generally wet soil conditions based upon site location in a drainage field.

In the New York site, 10 of 15 electrodes exceeded 50 ohms more than 50% of the time. In the Balboa site, nine of 16 electrodes exceeded 50 ohms 50% of the time, as compared to the Illinois site where no electrodes exceed 50 ohms except for the K electrode (18%).

Although the Las Vegas Pecos and Balboa sites were in the same geographical area, the results differed greatly. In the Balboa site, nine of 18 electrodes exceeded 50 ohms more than 50% of the time; whereas in the Pecos site, only the K electrode exceeded 50 ohms 50% of the time.

It should be noted that an electrode that exceeded 50 ohms also exceeded the *NEC* 25-ohm requirement by a factor of two.

The data and observations documented under this research project support the following findings.

Site Name	Site Location	Installation Date	Removal Date
PA	Pawnee, Las Vegas, NV	May 1992	**2003**
LM	Lone Mountain, Las Vegas, NV	Jun 1992	**2004**
BA	Balboa, Henderson, NV	Aug 1992	**2001**
PE	Pecos, Las Vegas, NV	Dec 1992	**2004**
CH	Charleston, Las Vegas, NV	Dec 1992	**NA**
VA	Staunton, VA	Jun 1997	**NA**
TX	Dallas, TX	Jun 1998	**NA**
NY	Hibernia, NY	Sep 1998	**2006**
IL	Northbrook, IL	Sep 1998	**NA**
CA	Moffet Field, Mountain View, CA	Jan 2002	**NA**

Table 1 *Site Names*

Observations

Considering the national sites, the electrodes in the Illinois site exhibited the lowest resistance readings; where the New York site exhibited the highest readings. The majority of readings in New York did not meet the 25-ohm requirement of *NEC* Section 250.53(A)(2) Ex. Comparing all electrodes in each national site, E, L and R electrodes had the best results. Types S, W and X electrodes did relatively well and for most sites; where the K and G electrodes were poor performers.

Analysis limited to horizontal and vertical rod type electrodes for the Las Vegas sites showed that the vertical electrodes had lower resistance values than their horizontal counterparts. Similarly, the vertical electrodes in national sites exhibited lower resistance values, with exception of the Illinois site. For most sites, this feature appeared to be consistent.

When yearly mean electrode resistance readings were compared for the Las Vegas sites, in almost every case for every electrode, the Balboa site had the highest yearly mean readings; whereas, the Pawnee site had the lowest values. For the national sites, the yearly mean readings for all electrodes were highest in the New York site, and lowest in the Illinois and Texas sites. The B, E, F, G, H and L electrodes were occurring in Las Vegas and national sites.

The worst case results electrode resistance values were in the New York and Balboa sites. The best-case results were generally with Illinois, Pawnee, and Texas sites. Electrode resistance values are required to be lower than 25 ohms for individual rod, pipe and plate electrodes to meet *NEC* 250.53(A)(2) requirement.

Although concrete-encased electrodes per *NEC* 250.52 are not required to be lower than the 25-ohm value and may be installed without testing, the concrete-encased electrode, (Type B) exceeded the 25-ohm value in the Texas, Virginia and New York sites for the term of the project.

Temperature measurements were taken in the soil at three different depths per site. Reliability was shown in the data for all sites since there was less fluctuation in soil temperature as depth increased.

It is apparent in comparisons of data from many sites that an inverse relationship exists between earth resistivity and soil temperature. Distinct patterns can be seen in data for many of the sites. These patterns appear to be sympathetic to seasonal variations. Knowledge of this relationship could be useful in determining the suitability of an electrode.

SITES	EARTH RESISTIVITY 10 ft. Depth			EARTH RESISTIVITY 20 ft. Depth		
	MIN	MAX	AVG	MIN	MAX	AVG
NY	15378	24014	19527	11011	23363	20409
VA	7603	19533	9930	8235	15090	10269
BA	3217	31597	8736	1915	25278	11474
IL	2313	3497	2821	1896	2306	2098
TX	1563	4577	3319	1655	8158	3242
PE	766	12868	1734	306	14056	1651
CH	708	9575	2084	575	13175	2079
CA	517	4577	2763	460	9000	2118
LM	153	9000	2527	766	9506	4638
PA	77	9575	1362	613	9958	3158

Table 2 Earth Resistivity values consisting of ten years of data for each site. Arranged by minimjums first, sorted in descending order

SITE	LOCATION	SOIL
PA	Pawnee Las Vegas, NV	Water table ranging from 10 to 20 ft. generally clayey silt
LM	Lone Mountain Las Vegas, NV North Valley	Normally dry, silty, sandy clays
BA	Balboa Henderson, NV South Valley	Normally dry, rock and gravel
PE	Pecos Las Vegas, NV North Valley	Normally dry , silt and sand to 6 ft., silty clays 6 to 11 ft.
CH	Charleston Las Vegas, NV East Valley	Normally dry, sand, and gravel, surface froth
VA	Staunton, VA	Sand and silt to a depth of approximately 6 ft; silty clays 6 to 11 ft.
TX	Dallas, TX	Normally dry, sandy soil to a depth of 5 to 6 ft.; increasingly stiff sandstone to 11 ft.
NY	Hibernia, NY	Water table at 10 ft to 11 ft.; gravel, sand and clays with occasional cobbles to 11 ft. depth
IL	Northbrook, IL	Periodically covered with rainwater runoff, contains silts and clays to Illinois a depth of 11 ft.
CA	Moffet Field, Mountain View, CA	Normally dry, sand, silt with inorganic and organic clays

Table 3 *Site Descriptions*

The resistance reading for the national sites showed that Illinois had only two electrodes that exceeded 25 ohms during the term of the study. This could be due to the Illinois site being located in moist soil conditions. Most of the electrodes in the Dallas site for the term of the study were less than 25 ohms. The difference in resistance readings between the sites can be attributed primarily to earth resistivity. Soil chemistry, moisture and temperature play a part in modifying earth resistivity, thus electrode resistance, whereas corrosion and other mechanical conditions can modify electrode performance also.

Data from this research can be used to make inferences for appropriateness of electrodes to be used in similar soil conditions.

DC experiments were included in the research as a means to evaluate the effects of corrosion due to the presence of direct currents. With many of the DC electrodes in the national sites, the data showed a sharp decrease in current with time. It is assumed that this decrease is due to the corrosive effects of the DC current possibly resulting in progressively higher resistance levels between the electrode and earth ground.

Dissimilar metals experiments were included to evaluate the possibility of corrosion of electrodes caused by different metals (Zn, Cu) installed in close proximity to one another. Data was developed showing changes of resistance, mainly caused by dissimilar metals in an earth-coupled cell that could possibly produce a direct current flow and lead to accelerated corrosion. In most cases, the trendline showed a decrease in current over time, which indicates an increase of resistance between electrodes and earth due to corrosion caused by DC current from dissimilar metals located in an electrolyte (earth).

Results for the CDA® sponsored benign corrosion experiment showed that the 4/0 AWG and 500 KCM bare copper conductors backfilled with earth, Bentonite or GEM,™ received a CR of no worse than 0/1— slight superficial occurrences of corrosion, not over all surfaces. The CR rating is a method of evaluating the corrosion of electrodes exclusively in this research project.

Electrodes

TYPE	MATERIAL	LENGTH	INSTALLATION
A	No. 2 AWG stranded copper wire	15 m (50 ft.)	Centered in 12 in. of sand at 36 in. below grade measured to the conductor. Buried horizontally in sand backfill
B	No. 4 uncoated steel reinforcing bar	6 m (20 ft.)	Within, and near the bottom of a concrete foundation consisting of 12 in. by 12 in. of 2500 psi concrete. The top of the concrete was located 6 in. below grade.
C	No. 4 solid copper wire	7.5 m (25 ft.)	Centered in 6 in. by 6 in. of ERICO® Ground Enhancement Material, GEM™) located at 20 in., to the bottom of the concrete. Installed horizontally
D	No. 4 solid copper wire	7.5 m (25 ft.)	Centered in 6 in. by 6 in. of 2500 psi concrete. Located at 20 in. to the bottom of the concrete. This electrode is designed to represent the thickened edge of post tensioned concrete construction and is installed horizontally
E	Copper bonded steel rod	2.5 m (8 ft.)	5/8 in. diameter, centered in a 9 in. diameter, 9 ft. deep boring in earth, encased in ERICO® (GEM™) backfill, installed vertically.
F	Copper bonded steel rod	2.5 m (8 ft.)	5/8 in. diameter, directly buried in a trench 36 in. deep, installed horizontally.
G	Copper bonded steel rod	2.5 m (8 ft.)	5/8 in. diameter, driven vertically in earth.
H	Copper bonded steel rod	2.5 m (8 ft.)	
I	Galvanized steel rod	3 m (10 ft.)	3/4 in. diameter, driven vertically in earth.
J	Galvanized steel rod	3 m (10 ft.)	3/4 in. diameter 10 ft. directly buried horizontally at a depth of 36 in.
K	Copper grounding "pole" plate	NA	For Las Vegas sites 30 in. depth., T&B® Blackburn™ Model PBH, .025 in. thickness 7 in. wide by 7 3/8 in. long, with connection capable of up to 4 AWG stranded wire For national sites, buried at 36in., T&B® Blackburn™ GP-114, 14 in. diameter, .025 in. thickness.
L	Lyncole® XIT™, copper tube	10	Vertical chemically charged electrode assembly in an 11 ft. deep, 9 in. diameter boring.
M	Steel and concrete	NA	Arrangement designed to represent a light pole base with six each, 2 ft. long No. 4 reinforcing steel vertical, tied with 3 each No. 2 steel horizontal hoops separated 12 in., vertically in a 2 ft., deep 36 in. diameter excavation, encased in 2500 psi concrete.
N	4 AWG solid copper wire	20 Coil	20 ft. of wire rolled into a coil approximately 18 in. diameter, installed in a 2 ft. round by 2 ft. deep excavation in concrete 2500 psi.

Table 4a Electrodes

Table 4a *Electrodes*

P	Wood pole with copper grounding pole plate to 6 AWG solid copper wire	8	Approximately 18 in. diameter, with Blackburn GP-114 copper plate to 6 AWG solid copper wire grounding pole plate attached at bottom using 6 AWG solid copper wire wrapped in a spiral for 6 ft., at approximately 6 in. spacing between wraps.
Q	Copper bonded steel rod	8	1/2 in. diameter, rod installed horizontally, directly buried at 30 in. depth.
R	LEC® Chemrod	10	Vertically charged electrode assembly in an 11 ft. deep 9 in. diameter boring encased in Ground Augmentation Fill (GAF™).
S	Lyncole® XIT™	10	Horizontal chemically charged electrode assembly installed at a depth of 36 in.
T	Galvanized steel water pipe	8	3/4 in. diameter galvanized (water) pipe, driven vertically in earth.
V	4/0 AWG 7-strand copper wire	20	4/0 AWG 7-strand bare copper cable, directly buried horizontally 36 in. deep.
W	Assembly of copper bonded rods	NA	Dominion Virginia Power Co., ground cage, (proprietary) using multiple 8 ft. long, 5/8 in. diameter copper bonded rods installed vertically in a mortar backfill.
X	Stainless steel rod	8	5/8 in. diameter stainless steel ground rod driven vertically in earth.
Y	LEC® Chemrod	10	LEC® Chemrod™ charged electrode assembly installed at a depth of 36 in., encased in GAF™ backfill.
Z	Copper plated steel mesh	8	Wire mesh consisting of No. 6 copper plated steel on 4 in. centers measuring 2 ft. wide. Directly buried in earth.
AA	Copper tube	10	ERICO® Horizontal Model Chemical Electrode. Installed with backfill (GEM™)
AB	Copper tube	11	Harger® Vertical Model Chemical Electrode, installed in backfill (Ultrafill™)
AC	Copper tube	10	ERICO® Vertical Model Electrode. Installed in backfill (GEM™)
AD	Copper tube	10	Lyncole® Vertical Model Sectional Chemical. Electrode, installed in Lynconite II backfill.
AE	Copper tube	10	Lyncole® Horizontal Model Sectional Electrode, installed horizontally in Lynconite II backfill.
DCI	Rod	8	DC1A, B, and C are 5/8 in. copper bonded steel rod, installed vertically.
DC2	Pipe	8	DC2A, B, and C are ¾ in. by 8 ft. galvanized steel pipe.
DM	Rod and pipe	8	DM1A, 2A, and 3A are 5/8 in. copper bonded steel rods, installed vertically. DM1B, 2B, and 3B are ¾ in. galvanized steel pipe, installed vertically.

Table 4b *Electrodes*

Earth resistivity values are used to predict properly the performance of electrodes. Standardized testing methods such as those referenced in IEEE 81-1983 were used to determine these values. Care was taken to ensure reliability and reproducibility of readings. Even though this was done, there were a few abnormalities in the data. Nonetheless, the data for most sites show reliability through the term of the project, except for California, which showed some variability. It is known that brackish water exists below the surface of the California site. Earth resistivity was varied by location. Resistivity values for the national sites ranged from 517 to 24,014 ohm-cm. In the Las Vegas sites, the range was 30 ohm-cm to 31,597 ohm-cm. Data support the concept that a direct relationship exists between earth resistivity and electrode resistance.

Low earth resistivity or low electrode resistance values are not necessarily a product of moist soil. Each of the national sites was in different geographic locations, and, therefore, subjected to different local weather climates and soil content. Soil moisture values for the Virginia and New

York sites indicate mostly wet soil for the majority of readings while average resistivity values were higher, in the range of 9,817 and 20,424 ohm-cm for 10 ft. spacing respectively. Electrode-resistance average values were higher in the range of 39.6 ohms in Virginia to 94.6 ohms in New York.

PERCENTAGE OF MEASUREMENTS 25 OHMS OR GREATER										
TYPE	PA	LM	BA	PE	CH	VA	TX	NY	IL	CA
A	1%	7%	100%	38%	72%					
B	1%	4%	93%	5%	3%	99%	74%	100%		31%
C	50%		52%		59%					
D	5%	3%	95%	67%	87%					
E	1%	2%					2%	100%		
F	25%	2%	93%	2%		52%	1%	100%		8%
G	6%	92%	100%	52%	87%	99%	22%	100%		33%
H	3%		99%			75%		100%	11%	28%
I	1%		98%		1%					
J		2%	100%		28%					
K	80%	94%	100%	95%	97%	100%	21%	100%	79%	100%
L	40%	29%	13%		13%	15%		74%		
M	7%	68%	100%	60%	3%					
N	12%	11%	100%	88%	6%					
O	3%	12%	100%	55%						
P	3%	17%	100%							
Q	48%	44%	100%	48%	90%					
R			3%					42%		
S	2%			14%		19%		100%		
T						97%		100%		35%
V						99%	5%	100%		52%
W						4%		100%		
X						62%		100%		
Y						8%		100%		
Z						76%		100%		39%
AA										
AB										8%
AC										
AD										
AE										

ELECTRODE NOT INSTALLED IN THIS SITE

LESS THAN 25 OHMS

Table 5 Electrodes Exceeding 25 Ohms

***Table 5** Electrodes Exceeding 25 Ohms*

PERCENTAGE OF MEASUREMENTS 50 OHMS OR GREATER										
TYPE	PA	LM	BA	PE	CH	VA	TX	NY	IL	CA
A			61%	5%	13%					
B			7%			6%	1%	87%		
C	46%		7%		29%					
D	4%		11%	9%	77%			32%		
E	1%	1%						32%		
F	18%		8%			2%		95%		
G	3%	76%	97%	6%	51%	86%	1%	100%		8%
H	2%		49%			1%		100%		9%
I			1%		1%					
J			100%		5%					
K	78%	77%	100%	84%	39%	100%	3%	100%	18%	91%
L	25%	2%								
M		25%	98%	2%	3%					
N			95%	3%	3%					
O		8%	65%							
P		1%	100%							
Q	1%	4%	97%	3%	13%					
R			2%							
S								66%		
T						5%		100%		
V						17%	1%	100%		
W										
X						4%	7%	100%		
Y								13%		
Z						1%		92%		
AA										
AB										
AC										
AD										
AE										

ELECTRODE NOT INSTALLED IN THIS SITE

LESS THAN 50 OHMS

Table 6 *Electrodes Exceeding 50 Ohms*

An independent corrosion analysis was conducted for some of the grounding electrodes exhumed from sites. The analysis indicated that the majority of the grounding electrode materials performed well over the approximately ten-year exposure test except for the following:

1. loss of zinc on galvanized steel rods resulted in excessive corrosion,
2. copper-bonded steel ground rods showed minimal corrosion; however, the exposed steel at the unplated end of the ground rod was particularly vulnerable to corrosion although the average loss was minimal,
3. some electrodes filled with salts and encased in Bentonite corroded at the end of the electrode and around the weep holes by contrast to others that displayed minimal corrosion,
4. vertical electrodes in GEM ™ displayed minimal corrosion in contrast to their horizontal counterparts, and
5. there was generally insignificant corrosion of the three types of connectors—mechanical, compression, and exothermic—during the term of the study.

The project concluded in 2006 and the final report was published in mid-2007. The complete report is available through the Fire Protection Research Foundation, Quincy, Massachusetts.

Information provided by Travis Lindsey and updated to NEC-2017.

⏚ Appendix C
Metric Conversion Reference

In recognition of the global use of the metric system of measurement, IAEI has incorporated metric units into our publications in accordance with the International System of Units (SI). Metric units appear first, followed by inch-pound units in parentheses [for example, 6 m (20 ft)].

According to *NEC* 90.9(B), "Conversion from inch-pound units to SI units shall be based on hard conversion except as provided in 90.9(C)." A hard conversion changes dimensions or properties into new sizes that might or might not be interchangeable with the original measurements. In other words, the part is actually replaced by one of a different size.

In *NEC* 90.9(C), soft conversion is allowed for (1) trade sizes, (2) extracted material, (3) industry practice, and (4) safety. A soft conversion is a direct mathematical conversion that changes the description of the measurement but not the actual dimension. In other words, you can keep the same part, but express its size in metric units — the part is not replaced, it is renamed.

Colorado State University has an example that shows the difference between hard and soft metric conversion:

"For example, if an existing part is 6 inches long — 152.4 mm — it might be metricated by either

replacing the part by one that's 150 mm long (hard metric conversion), or

keeping its size unchanged at 152.4 mm but calling it a 150-mm part (soft metric conversion).

"If the latter sounds odd, not that many items' dimensions are actually nominal sizes — round numbers that aren't their exact measurements — such as lumber, where a 2 x 4 isn't really 2 by 4 inches, and pipe, where ½ inch pipe has neither an inside nor outside diameter of ½ inch."

Perhaps this explanation and the charts in this appendix will assist you in making simple conversions.

Sources:

National Electrical Code, 2017 Section 90.9

Annex C
Conversion Reference Table

U.S. Customary Unit	Existing SI Unit	Proposed SI Unit	Equivalent U.S. Unit
1/32 in.		**0.8 mm**	**0.031 in.**
0.06 in.	**1.52 mm**	**1.5 mm**	**0.059 in.**
0.0625 in.	**1.59 mm**	**1.59 mm**	**0.063 in.**
1/16 in.		**1.6 mm**	**0.063 in.**
0.090 in.	**2.29 mm**	**2.3 mm**	**0.091 in.**
1/8 in.	**3.18 mm**	**3 mm**	**0.118 in.**
¼ in.	**6.35 mm**	**6 mm**	**0.24 in.**
0.375 in.	**9.52 mm**	**9.5 mm**	**0.374 in.**
3/8 in.		**10 mm**	**0.394 in.**
½ in.	**12.7 mm**	**13 mm**	**0.51 in.**
5/8 in.	**15.87 mm**	**16 mm**	**0.63 in.**
¾ in.	**19 mm**	**19 mm**	**0.75 in.**
15/16 in.	**23.8 mm**	**24 mm**	**0.945 in.**
1 in.	**25.4 mm**	**25 mm**	**0.98 in.**
1 ¼ in.	**31.8 mm**	**32 mm**	**1.26 in.**
1 ½ in.	**38 mm**	**38 mm**	**1.50 in.**
1 ¾ in.	**44.5 mm**	**45 mm**	**1.77 in.**
1 7/8 in.		**48 mm**	**1.89 in.**
2 in.	**50.8 mm**	**50 mm**	**1.97 in.**
2 1/8 in.		**54 mm**	**2.13 in.**
2 ¼ in.		**57 mm**	**2.24 in.**
2 3/8 in.		**60 mm**	**2.36 in.**
2 ½ in.	**64 mm**	**65 mm**	**2.56 in.**
3 in.	**76 mm**	**75 mm**	**2.95 in.**
3 ½ in.		**90 mm**	**3.54 in**
3 ¾ in.		**95 mm**	**3.74 in.**
4 in.	**102 mm**	**100 mm**	**3.94 in.**
4 ½ in.		**115 mm**	**4.53 in.**
4 11/16 in.		**120 mm**	**4.72 in.**
5 in.		**125 mm**	**4.92 in.**
5 ½ in.		**140 mm**	**5.51 in.**
6 in.	**152 mm**	**150 mm**	**5.91 in.**
6 ½ in		**165 mm**	**6.5 in.**
7 in		**175 mm**	**6.89 in**
7 ½ in.		**190 mm**	**7.48**
8 in.	**203 mm**	**200 mm**	**7.87 in.**
8 ½ in.		**215 mm**	**8.46 in.**
9 in.	**229 mm**	**225 mm**	**8.86 in.**
10 in.		**250 mm**	**9.84 in.**
11 ½ in.		**290 mm**	**11.42 in.**
12 in.	**305 mm**	**300 mm**	**11.81 in.**
13 in.		**325 mm**	**12.8 in.**
14 in.		**350 mm**	**13.78 in.**

U.S. Customary Unit	Existing SI Unit	Proposed SI Unit	Equivalent U.S. Unit
15 in.	**381 mm**	**375 mm**	**14.76 in.**
16 in.	**406 mm**	**400 mm**	**15.75 in.**
17 in.		**425 mm**	**16.73 in.**
18 in.	**457 mm**	**450 mm**	**17.72 in.**
19 in.		**475 mm**	**18.7 in.**
20 in.		**500 mm**	**19.69 in.**
22 in.	**557 mm**	**550 mm**	**21.65 in.**
24 in.	**610 mm**	**600 mm**	**23.62 in.**
26 in.	**659 mm**	**650 mm**	**25.59 in.**
27 in.		**675 mm**	**26.57 in.**
30 in.	**762 mm**	**750 mm**	**29.53 in.**
36 in.	**914 mm**	**900 mm**	**35.73 in.**
38 in.		**950 mm**	**37.40 in**
40 in.	**1.02 m**	**1.0 m**	**39.37 in.**
42 in.	**1.07 m**	**1.0 m**	**39.37 in.**
44 in.		**1.1 m**	**43.30 in.**
54 in.		**1.4 m**	**55.12 in.**
96 in.	**2.44 m**	**2.5 m**	**98.43 in.**
1 ft	**305 mm**	**300 mm**	**0.98 ft**
2 ft	**610 mm**	**600 mm**	**1.97 ft**
2 ½ ft	**762 mm**	**750 mm**	**2.46 ft**
3 ft	**914 mm**	**900 mm**	**2.95 ft**
3.5 ft	**1.07 m**	**1.0 m**	**3.28 ft**
4 ft	**1.22 m**	**1.2 m**	**3.94 ft**
4 ½ ft	**1.37 m**	**1.4 m**	**4.59 ft**
5 ft	**1.52 m**	**1.5 m**	**4.92 ft**
5 ½ ft	**1.68 m**	**1.7 m**	**5.58 ft**
6 ft	**1.83 m**	**1.8 m**	**5.91 ft**
6 ft 6 in.		**2.0 m**	**6.56 ft**
6 ½ ft	**1.98 m**	**2.0 m**	**6.56 ft**
6 ft 7 in.	**2.0 m**	**2.0 m**	**6.56 ft**
7 ft	**2.13 m**	**2.1 m**	**6.89 ft**
7 ft 6 in.	**2.29 m**	**2.3 m**	**7.55 ft**
8 ft	**2.44 m**	**2.5 m**	**8.20 ft**
9 ft	**2.74 m**	**2.7 m**	**8.858 ft**
10 ft	**3.05 m**	**3.0 m**	**9.84 ft**
12 ft	**3.66 m**	**3.7 m**	**12.14 ft**
14 ft	**4.27 m**	**4.3 m**	**14.11 ft**
15 ft	**4.57 m**	**4.5 m**	**15.09 ft**
16 ft	**4.88 m**	**4.9 m**	**16.08 ft**
17 ft	**5.2 m**	**5.2 m**	**17.06 ft**
18 ft	**5.49 m**	**5.5 m**	**18.05 ft**
20 ft	**6.1 m**	**6.0 m**	**19.69 ft**
21 ft	**6.4 m**	**6.4 m**	**20.997 ft**
22 ft	**6.7 m**	**6.7 m**	**21.98 ft**
25 ft	**7.62 m**	**7.5 m**	**24.61 ft**

U.S. Customary Unit	Existing SI Unit	Proposed SI Unit	Equivalent U.S. Unit
27 ft	**8.23 m**	**8.0 m**	**26.25 ft**
30 ft	**9.14 m**	**9.0 m**	**29.53 ft**
35 ft	**10.67 m**	**11 m**	**36.09 ft**
40 ft	**12.2 m**	**12 m**	**39.37 ft**
50 ft	**15.2 m**	**15 m**	**49.22 ft**
60 ft		**18 m**	**59.06 ft**
70 ft		**21 m**	**68.9 ft**
75 ft	**23 m**	**23 m**	**75.46 ft**
80 ft	**24.4 m**	**25 m**	**82 ft**
100 ft	**30.5 m**	**30 m**	**98.43 ft**
135 ft		**41 m**	**134.48 ft**
140 ft	**42.7 m**	**42 m**	**137.76 ft**
150 ft		**45 m**	**147.65 ft**
200 ft	**61 m**	**60 m**	**196.86 ft**
1000 ft	**305 m**	**300 m**	**984.3 ft**

Answers

The references can be found on the pages in this textbook or in the 2017 *NEC* under the sections or article numbers provided.

Chapter 1 Answers

1. c. In textbook
2. d. Section 250.4(A)(1)
3. d. Section 250.4(A)(5)
4. d. In textbook
5. b. In textbook
6. a. In textbook
7. b. In textbook
8. b. In textbook
9. d. In textbook and in Article 100
10. d. In textbook
11. c. In textbook
12. c. In textbook
13. b. In textbook
14. b. In textbook
15. d. In textbook
16. a. In textbook
17. b. In textbook
18. d. In textbook, 250.1(6)
19. b. Watt's wheel/ Ohm's law - textbook

Chap. 1 - 7500 ÷ [480 x 1.73 = 830.4] = 9.03

20. d. In textbook
21. a. In textbook
22. d. In textbook, Article 100, Section 250.118 Informational Note, 250.2
23. b. In textbook, Article 100 Definition

Chapter 2 Answers

1. d. Section 250.20(A)(1)
2. b. Section 250.20(A)(2)
3. a. Section 250.20(A)(3)
4. b. Section 250.20(B)(1)
5. b. Section 250.20(B)(2)
6. c. Section 250.20(B)(3)
7. d. Section 250.21(A)(1)
8. b. Section 250.21(A)(2)
9. d. Section 250.21(A)(3), 250.21(B)(1)
10. b. Section 250.22(2), 250.21(A)(4), 517.61(A)(1)
11. d. Section 250.24(C)(4), 250.36
12. b. Section 250.20(C)
13. a. Section 250.20(C)
14. d. In textbook, Section 250.188(F)
15. d. Article 100 and in textbook
16. c. Section 250.30(A)
17. b. In textbook
18. c. In textbook
19. d. In textbook
20. d. In textbook
21. a. In textbook, 250.21(B)
22. c. In textbook
23. b. In textbook
24. d. In textbook
25. d. In textbook Sections 250.22(4), 411.6(A)
26. c. In textbook
27. a. In textbook and Section 250.4(A)(5), 250.4(B)(4)
28. b. In textbook and Section 250.21(2)
29. c. Section 250.30(A), 250.30 Informational Note No. 1
30. d. Section 250.22(5), 680.23(A)(2)
31. d. In textbook, Section 250.21

32. c. In textbook, Section 250.21(C)

Chapter 3 Answers

1. b. Article 100
2. a. Article 100
3. c. Article 100
4. a. Section 200.6(A)
5. c. Section 200.6(E), Exception No. 1
6. d. Section 200.6(B)
7. d. Section 200.6(A)
8. c. Sections 230.56, 110.15
9. d. In textbook
10. a. In textbook
11. d. In textbook
12. b. In textbook
13. d. In textbook
14. c. In textbook
15. b. In textbook
16. d. In textbook
17. c. In textbook
18. b. In textbook
19. c. Section 240.85 and Informational Note
20. d. Sections 430.36, 240.22(2)
21. a. In textbook and Section 200.6(D)
22. c. In textbook
23. b. In textbook and Article 100
24. d. In textbook and Section 200.2(B)

Chapter 4 Answers

1. c. Section 250.24(C)
2. d. Section 250.24(C)
3. a. Section 250.24(C)(1)
4. b. Section 250.24(C)(1)
5. a. Section 250.24(C)(1), Table 250.102(C)(1), Note 1
6. c. Section 250.24(C)(2)
7. c. Section 250.24(C) Exception
8. a. In textbook
9. d. In textbook
10. a. Section 250.24(A)(2)
11. d. Table 250.66
12. d. In textbook, Section 310.15(B)(7)(4)
13. d. In textbook, Section 250.24(C)(3)
14. d. Section 250.36
15. a. Section 250.170
16. b. Section 250.170, Exception No. 1
17. d. Section 250.172, Exception
18. d. In textbook and Section 250.24(C)
19. c. In textbook and Section 250.24(E)
20. a. In textbook and Section 250.66

Chapter 5 Answers

1. b. Article 100
2. a. Article 100
3. b. Section 250.2 Definition of Supply Side Bonding Jumper
4. d. Section 250.28(A)
5. b. Section 250.28(B)
6. d. Section 250.28(D), Table 250.102(C)(1)
7. d. Section 250.28(D), Table 250.102(C)(1), Note 1
8. a. Section 250.28(D), Table 250.102(C)(1), Note 1
9. d. Section 250.92(B)
10. b. Section 250.142(A)
11. c. In textbook
12. a. Section 250.102(C), Table 250.102(C)(1),
13. d. Section 250.92(B)
14. b. In textbook and Section 250.142(B) Ex. No 2
15. a. In textbook, Section 250.28(D)
16. d. In textbook and Article 100

Chapter 6 Answers

1. b. In textbook and Article 100
2. a. Article 100
3. d. Section 250.52(A)(3)
4. c. Section 250.52(A)(3)
5. b. Section 250.52(A)(4), 250.53(F)
6. a. Section 250.53(D)
7. d. Section 250.53(D)(2)
8. c. Section 250.50
9. d. Section 250.50, 250.52(A)(4)-(A)(8)
10. a. Section 250.58
11. d. Section 250.6(B)
12. b. Section 250.6(D)
13. c. Section 250.53(A)(2)
14. d. Section 250.53(A)(2) Exception (In text)
15. a. In textbook
16. d. In textbook
17. b. Section 250.60
18. b. Section 250.54 (in text)
19. d. In textbook and Section 250.52(A)(8)
20. a. In textbook and Section 250.50
21. c. In textbook and Section 250.52(A)(2)
22. c. In textbook and Section 250.52(A)(3)
23. b. In textbook

Chapter 7 Answers

1.	b.	Article 100 and in text
2.	c.	Section 250.66 and Table 250.66
3.	c.	Section 250.66 and Table 250.66
4.	a.	In textbook
5.	c.	Section 250.66 and Table 250.66
6.	c.	Section 250.66 and Table 250.66
7.	d.	In textbook
8.	d.	Section 250.66 and Table 250.66
9.	c.	Section 230.71(A)
10.	b.	Section 250.66(A)
11.	b.	Section 250.66(B)
12.	d.	Section 250.70
13.	b.	Section 250.70
14.	a.	Section 250.64(B)
15.	b.	Section 250.64(B)
16.	b.	Section 250.64(A)
17.	c.	In textbook and Section 250.68(A) Ex. No. 2
18.	a.	In textbook and Section 250.64(E)
19.	d.	In textbook and Section 250.62
20.	d.	Section 250.70(1) through (4)
21.	a.	Sections 250.30(A)(5); 250.66; Table 250.66
22.	d.	Sections 250.66 and 250.53(C)
23.	c.	Section 250.68(C)(3)
24.	b.	Section 250.166

Chapter 8 Answers

1. d. Section 250.97
2. d. Section 250.102(B), 250.8
3. d. Section 314.3, Exception Nos. 1 and 2
4. c. Section 250.148
5. b. Section 250.146(D)
6. c. Section 250.102(E)(1) and E(2)
7. d. Section 250.104(A)(1)
8. d. In textbook 250.104(B)
9. c. Section 250.104(B)
10. b. Section 250.98
11. a. Section 250.100, 250.92(B)
12. c. Section 250.122 and Table 250.122, 250.102(D)
13. c. Section 250.104(A)
14. a. In textbook and UL ProductSpec Category (QCRV), 250.92(B)
15. b. Section 250.104(A)
16. d. Section 250.104(C)
17. a. In textbook
18. c. In textbook and Section 250.146(A)
19. b. In textbook and Section 250.104(D)(2)
20. b. Section 250.146
21. d. Section 250.146(A)

Chapter 9 Answers

1. a. Article 100
2. d. In textbook and Section 250.4(A)(5)
3. c. In textbook
4. a. Section 250.122(A) and Table 250.122
5. d. Section 250.118
6. c. Section 250.118(5) and (7)
7. c. Section 250.118(6)
8. c. Section 250.120(A)
9. b. Sections 250.122(E), 240.5(B)(2)(1)
10. b. Section 250.136(A)
11. c. Section 250.122(F), 310.10(H)
12. d. Section 250.122(F) [Not permitted by *NEC*]
13. c. In textbook and Section 250.4(B)(1)
14. b. In textbook and Section 250.118(5)
15. a. In textbook and in Sections 250.118(5)(d) and 250.118(6)(e)
16. a. Section 250.54
17. c. Section 250.122(A), Table 250.122
18. d. Section 250.122(A), Table 250.122
19. a. Section 250.122(B)

Chapter 10 Answers

1. c. Article 100
2. a. Article 100
3. b. Section 250.110(1)
4. d. Section 250.110(2)
5. b. Section 250.86 Exception No. 1
6. c. Section 250.110, Exception No. 1
7. b. Section 250.110, Exception No. 2
8. d. Section 250.110, Exception No. 3
9. b. Section 250.86, Exception No. 1
10. a. Section 250.112(L)
11. d. Section 250.8
12. b. Section 250.70
13. c. Section 250.80, Exception
14. b. Section 250.24(A)(5), 250.140, 250.142
15. b. Sections 250.24(A)(5), 215.6 and 408.40
16. a. In textbook and Section 408.41
17. c. In textbook
18. d. In textbook and 250.86 Ex. No. 3

Chapter 11 Answers

1. c. In textbook, also see Chapter 1
2. b. In textbook, also see Article 100 for definition of “Ground Fault”
3. c. In textbook
4. b. In textbook
5. a. In textbook
6. b. In textbook
7. d. In textbook
8. b. In textbook Figure 11-16 (Five second withstand table)
9. a. In textbook
10. b. In textbook
11. c. In textbook, 700.32
12. a. In textbook, and in Article 100 (Definition of Coordination, Selective)

Chapter 12 Answers

1. c. Article 100
2. b. Section 250.30(A)(5) and Table 250.66
3. a. Section 250.30(A)(1)
4. c. Section 250.30(A)(4)
5. b. Section 250.30(A)(5) and (A)(6)
6. a. Section 250.58
7. d. In textbook
8. a. In textbook, 250.30, Informational Note No. 1
9. b. In textbook, 250.30(A)(1)
10. d. In textbook, 250.24(A)(5), 250.142(B)
11. a. 250.30(A)(2), 250.102(C)
12. c. 250.30(A)(3), 220.61, Table 250.102(C)(1)
13. d. Section 250.30(A)(6)(a)(1)
14. b. Section 700.7(B)
15. d. Section 250.66(A)
16. b. Section 250.30(A)(1), Article 100 Definition of Bonding Jumper, System
17. d. Section 250.30(A)(6)
18. b. Section 250.35(B)
19. d. Section 250.30(A)(8); 250.104(D)(1); Table 250.66
20. c. Section 250.30(A)(6)

Chapter 13 Answers

1. b. Article 100
2. d. Section 250.32(A) and Exception
3. b. In textbook and 250.32(B)(1)
4. a. Section 250.32(A), 250.50
5. c. Section 250.32(B)(1)
6. a. Section 250.52(A)(5)
7. c. In textbook, 250.122 and Table 250.122
8. c. Section 250.32(B)(1) Exception No. 1
9. a. Section 250.32(B)(1) Exception No. 1
10. a. Section 250.6(D)
11. a. Section 547.5(F)
12. a. Section 250.32(A) Exception
13. d. Section 250.122 and Table 250.122

Chapter 14 Answers

1. b. Section 406.4(D)(3)
2. a. Section 406.4(D)(2)
3. b. In textbook
4. a. In textbook
5. b. In textbook
6. b. In textbook
7. b. Article 100
8. b. Section 230.95
9. d. Section 230.95, Ex. No. 1, 215.10 Ex. No. 1, 695.6(G)
10. b. Section 230.95(A)
11. b. In textbook, Section 215.10 Ex. No. 2
12. c. In textbook
13. a. In textbook
14. d. Section 230.95(C)
15. c. Section 215.10
16. c. In textbook

Chapter 15 Answers

1. b. In textbook
2. b. In textbook
3. c. In textbook
4. a. Section 250.106
5. c. In textbook
6. c. Sections 501.30(A), 502.30(A) and 503.30(A)
7. d. In textbook
8. a. Sections 501.10(B)(2), 501.30(B) Exception and 250.102
9. d. In textbook 517.13(A) and (B)
10. d. Section 517.13(A)
11. d. Section 517.19(E)
12. b. Section 517.16(B)
13. d. Section 517.16(B)
14. d. Section 547.5(F)

15) d. In textbook

17. a. Section 547.10(B)
17. b. Section 547.5(G)(3)

Chapter 16 Answers

1. b. In textbook
2. c. In textbook
3. c. Section 600.7(A)(1)
4. c. Section 600.7(B)(6)
5. d. Section 600.7(B)(4)
6. b. Section 600.7(A)(3), 600.7(B)(2), 250.8
7. d. Section 600.7(B)(5)
8. d. Section 600.7(B)(1) exception
9. c. Section 680.26(B)(7), Exceptions 1 through 3
10. a. Section 680.26(B)(1)
11. b. Section 250.52(B)(3)
12. a. Section 680.23(C)
13. b. Section 680.23(B)(2)(a)
14. a. Section 680.23(B)(5)
15. a. Section 680.26(C)

Chapter 17 Answers

1. e. In textbook
2. c. In textbook
3. a. Article 100 and in textbook
4. c. In textbook
5. b. In textbook
6. c. In textbook
7. a. Definition of Separately Derived System, In textbook
8. b. In textbook
9. a. In textbook
10. b. In textbook
11. d. Section 705.6
12. b. Section 705.12(A) and (B)
13. c. Section 705.12(B)(3)(2)(a)
14. b. Section 705.12(A)
15. e. Sections 705.12(A), 705.31 and in textbook
16. d. Section 690.31(B)(1)
17. a. Section 690.41(B)
18. d. Section 692.41(C)

19 c. Section 694.40(B)

Chapter 18 Answers

1.	b.	Article 645
2.	d.	Section 645.15, 90.3
3.	a.	Section 645.1, 645.4
4.	c.	Section 645.15
5.	c.	Section 250.6(D)
6.	b.	Section 250.24(A)(5), 250.142(B)
7.	d.	Section 250.4(A)(5)
8.	c.	In textbook
9.	a.	In textbook, 250.4(A)(5), 250.54
10.	d.	In textbook, 250.146(D), 408.40 Exception
11.	a.	In textbook, 250.146(D)
12.	d.	In textbook
13.	d.	In textbook
14.	b.	In textbook
15.	d.	In textbook
16.	d.	In textbook
17.	a.	In textbook
18.	a.	In textbook
19.	c.	In textbook
20.	a.	Section 645.17
21.	d.	Section 645.10(B)(1)

Chapter 19 Answers

1. b. Article 100 Definition of Grounding Electrode Conductor
2. b. Section 250.94
3. b. Section 810.21(H)
4. c. Section 820.100(A)(4)
5. c. Sections 820.100(A)(2) and (3)
6. c. Section 820.100(D)
7. d. Sections 820.100(B)(2) and 250.94 Exception
8. c. Section 830.106(B)
9. b. Section 800.100(A)(6)
10. c. Sections 830.100(C) and 250.70
11. b. Section 830.44(G)(3)
12. b. Section 250.20(A)(3)
13. c. Section 504.50(C)
14. b. Section 504.50(B)
15. b. Section 800.106(B)
16. b. Section 840.2
17. d. In textbook, Art. 100 Definition of Control Circuit
18. d. In textbook, 840.101(A)

Chapter 20 Answers

1. b. In textbook
2. a. In textbook
3. b. In textbook
4. c. In textbook
5. a In textbook
6. a. In textbook
7. b. In textbook
8. b. In textbook
9. c. In textbook
10. b. In textbook
11. b. In textbook
12. a. In textbook, Section 250.184(B)(1)(a)
13. c. Section 310.10(E)
14. c. In textbook, Section 250.190(C)(2), (C)(3)
15. b. In textbook, Section 250.190(C)(2)
16. a. In textbook, 250.194
17. c. In textbook, 250.186

Chapter 21 Answers

1. d. In textbook
2. c. In textbook
3. b. In textbook
4. d. In textbook
5. c. In textbook
6. c. In textbook
7. d. In textbook
8. c. In textbook
9. d. In textbook
10. b. In textbook
11. d. In textbook
12. c. In textbook
13. b. In textbook
14. d. In textbook
15. d. In textbook
16. a. In textbook
17. b. In textbook
18. d. In textbook

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