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IEEE Recommended Practice for

Applying Low Voltage Circuit Breakers Used in Industrial and Commercial Power Systems

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IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems

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Abstract: Information is provided for selecting the proper circuit breaker for a particular application. This recommended practice helps the application engineer specify the type of circuit breaker, ratings, trip functions, accessories, acceptance tests, and maintenance requirements. It also discusses circuit breakers for special applications, e.g., instantaneous only and switches. In addition, it provides information for applying circuit breakers at different locations in the power system, and for protecting specific components. Guidelines are also given for coordinating combinations of line-side and load-side devices.

Keywords: circuit breakers, circuit breaker evaluation, insulated case, insulated-case circuit breakers, low-voltage circuit breaker, low-voltage power circuit breaker, low-voltage protection, low-voltage protection device, molded case, molded-case circuit breaker, overcurrent protection, power circuit breaker, rating, testing

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Introduction

This introduction is not part of IEEE Std 1015-2006, IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems.

This introduction provides an engineer a comprehensive reference source to aid in deciding what type of low-voltage circuit breaker to use for a particular application, and how to apply the circuit breaker. This recommended practice includes a comparison between the standards of low-voltage power circuit breakers and molded-case circuit breakers so that an engineer can make better, more informed choices. Pertinent tables have been extracted from other standards to provide the basis for the selection and application guidelines. In addition, specific application examples are provided.

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Ruth Whitaker
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IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems

Chapter 1
Overview

1.1 Scope

This recommended practice provides information for selecting the proper circuit breaker for a particular application. This recommended practice helps the application engineer specify the type of circuit breaker, ratings, trip functions, accessories, acceptance tests, and maintenance requirements. It also discusses circuit breakers for special applications, e.g., instantaneous only and switches. In addition, it provides information for applying circuit breakers at different locations in the power system and for protecting specific components. Guidelines are given for coordinating combinations of line-side and load-side devices. Acceptance testing and maintenance guidelines are provided so that reliable operation can be verified and maintained.

This recommended practice does not cover the selection and application of circuit breakers such as marine circuit breakers and definite purpose circuit breakers.

1.2 Two classifications of breakers

There are two main classifications of low-voltage circuit breakers: molded-case circuit breakers and low-voltage power circuit breakers. Within the molded-case circuit breaker classification, there is another type of circuit breaker called the insulated-case circuit breaker. The construction and characteristics of these three types will be discussed. Throughout the balance of this recommended practice, these devices will be referred to as follows:

- MCCB: molded-case circuit breaker
- ICCB: insulated-case circuit breaker
- LVPCB: low-voltage power circuit breaker

Each one of these circuit breakers has different design characteristics and, in many cases, different application requirements.

This recommended practice compares the different types of circuit breakers so that the power systems engineer can decide which one is best suited for a particular application. In addition, it discusses ratings, such as overload, short-time, and interrupting capabilities. Protection requirements depend on the circuit breaker location in the power system as well as the type of equipment that is being protected. Examples for different types of equipment and circuit locations are discussed in this recommended practice.

MCCBs are tested and rated in accordance with UL 489-2002.[1] Their current-carrying parts, mechanisms, and trip devices are completely contained within a molded case of insulating material. The cover and base of smaller MCCBs are designed so that the MCCBs cannot be opened for maintenance purposes. The main contacts of MCCBs cannot be removed; however, some MCCBs are available with field-installable accessories. MCCBs are available in stationary or plug-in construction with circuit-breaker enclosures that can be flush or surface mounted. They are available in a large number of continuous-current and interrupting ratings. The smaller continuous-current ratings are equipped with thermal-magnetic or magnetic only trip units. Larger sizes are also available with thermal-magnetic or electronic (static) trip devices.

ICCBs are also tested and rated in accordance with UL 489-2002. As with MCCBs, ICCB current-carrying parts, mechanisms, and trip units are contained within a molded case of insulating material. The case is designed so that it can be opened for inspection of contacts and arc chutes and for limited maintenance. Most manufacturers offer designs that permit replacement of accessories, and some designs permit replacement of the main contacts. ICCBs are available in both stationary and drawout construction. They are generally characterized by a stored energy mechanism, larger frame sizes, and higher short-time withstand ratings than MCCBs. Electronic trip units are standard.

LVPCBs are tested and rated according to the following standards:

— ANSI C37.16-2000
— ANSI C37.17-1997
— ANSI C37.50-1989 (R2000)
— IEEE Std C37.13™ -1990
— UL 1558-1999

LVPCBs are generally characterized by physically large frame sizes, drawout construction, and the highest short-time withstand ratings of all the types of low-voltage circuit breakers. When the circuit breaker is removed from its enclosure, the current-carrying parts and operating parts are accessible for inspection, maintenance, and replacement purposes. Electromechanical trip units were used in the circuit breakers prior to the early 1970s. However, electronic trip units are used in new LVPCBs and are available as upgrades for older units.

1.3 Description of a molded-case circuit breaker

Figure 1-1 is a cutaway view of a typical MCCB. Letters are used to indicate the various elements of the circuit breaker, with a description listed in the legend. This typical circuit

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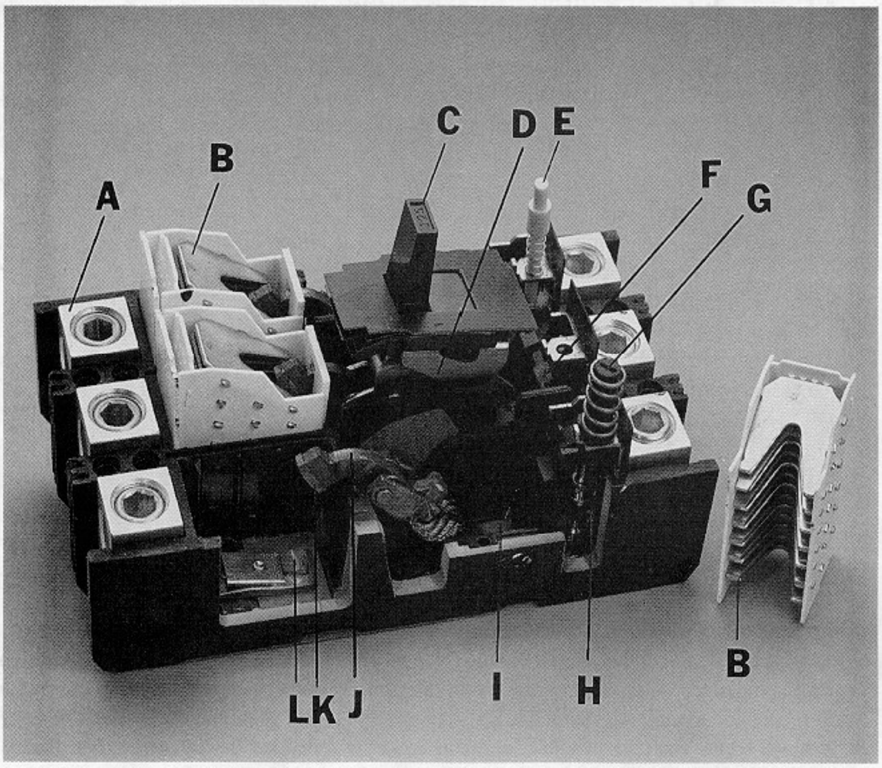
[1] Information on references can be found in 1.7.

breaker operates using an over-center toggle, quick-make-quick-break mechanism. This mechanism is operated manually to the ON (closed) and OFF (open) positions using the handle. The quick-make-quick-break action ensures that the speed at which the breaker contacts are open or closed is independent of the speed at which the handle is moved. This toggle mechanism is also trip-free, which means that the circuit breaker cannot be prevented from tripping by holding or locking the handle in the ON position. When the circuit breaker trips open automatically, the handle will assume either an intermediate position between ON and OFF or the OFF position. If the handle moves to the intermediate position, it must be manually moved slightly past the OFF position to reset the mechanism. Instructions for resetting a particular circuit breaker after it trips should be marked on the circuit breaker and/or indicated on the equipment where the circuit breaker is installed.

1.4 Description of a low-voltage power circuit breaker

Figure 1-2 is a view of a partially disassembled, manually operated, drawout LVPCB. The open construction permits access to the circuit-breaker parts for maintenance and parts replacement. Numbers are used to indicate the various elements of the circuit breaker. A description of each element is listed in the legend. The following description of the operation of the circuit breaker starts with the open position. The circuit breaker condition “open” is indicated on the face of the circuit breaker. To close the circuit breaker, a spring mechanism must be charged. The springs are charged by pulling down and releasing the manual spring charging handle. The spring condition “charged” is indicated on the face of the circuit breaker. The circuit breaker is manually closed by depressing the close (push-to-close) hood. The circuit breaker condition “closed” is indicated on the face of the circuit breaker. The circuit breaker is opened manually by depressing the open (push-to-trip) lever or automatically by the operation of the trip unit.

The drawout circuit breaker has three separate positions: “CONNECT,” “TEST,” and “DISCONNECT.” A racking crank is used to move the drawout circuit breaker to each position in the circuit breaker compartment. The circuit breaker's contacts are only connected to the external power circuit in the connected position. If the circuit breaker is closed in the TEST position, there is no effect to the external power circuit. Interlocking prevents moving a closed circuit breaker between these positions or closing it in other than the CONNECT or TEST position. Further interlocking prevents inserting circuit breakers of the wrong frame size into a compartment. Primary disconnects and optional secondary disconnects automatically complete the power circuit in the CONNECT position and control circuits in the CONNECT and TEST positions, respectively.



LEGEND

A.	Wire connector	G.	Instantaneous trip level adjustment
B.	De-ionizing arc stack	H.	Electro-magnet
C.	Handle	I.	Bimetal
D.	Operating mechanism	J.	Moving arm
E.	Test trip actuator	K.	Moving contact
F.	Common-trip bar	L.	Stationary contact

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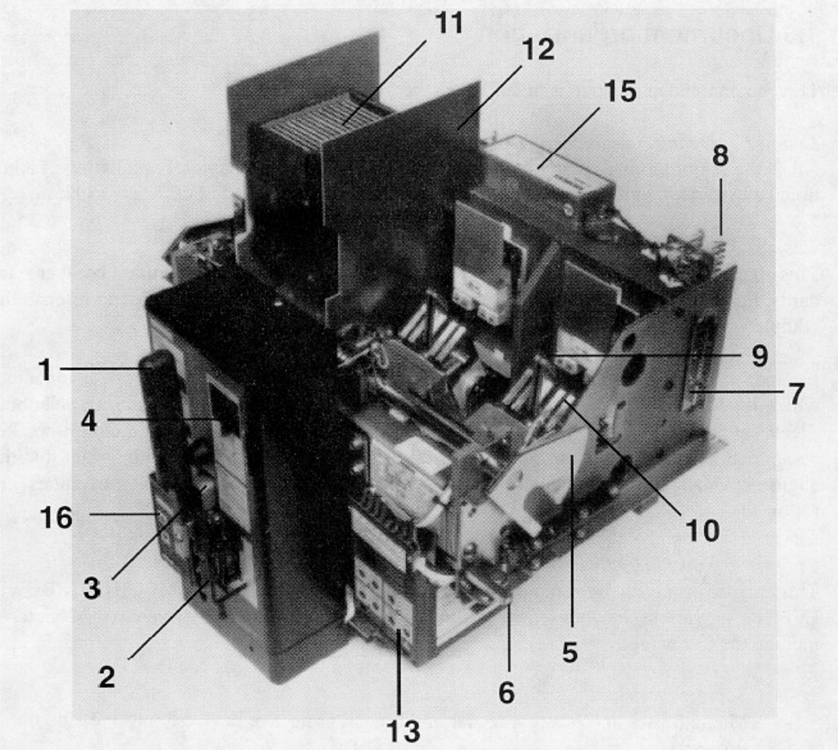
Figure 1-1—Cutaway view of a typical MCCB



LEGEND

1. Manual spring charging handle
2. Open (push-to-trip) lever
3. Close (push-to-close) hood
4. Racking crank access opening & interlock
5. Racking (drawout) mechanism
6. Drawout interlocks
7. Breaker frame size interlock
8. Primary disconnect finger assembly
9. Main contacts
10. Arcing contacts
11. Arc chute
12. Interphase barrier
13. Electronic overcurrent trip device
14. Current sensors (on rear—not shown)
15. Voltage sensor (optional)
16. Breaker display unit (current, voltage, and power measurements) (optional)

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Figure 1-2—Low-voltage ac power circuit braker-drawout type (shown partially disassembled to show internal features)

1.5 Document organization

This recommended practice is organized in the following manner:

Chapter 2: Definitions, acronyms, and abbreviations

All of the major terms used in this recommended practice are defined in this chapter. For a listing of additional electrical definitions, refer to *The Authoritative Dictionary of IEEE Standards Terms* [B1][2] and IEEE Std C37.100™-1992.

Chapter 3: Rating and testing

This chapter summarizes the application requirements of recognized low-voltage circuit breaker standards. For more details on a particular application, the engineer is encouraged to refer to the complete standard for amplification and a more complete discussion.

By understanding the differences in standards, an engineer can make a better decision about which type of breaker should be used for a particular application. In addition, Section 110.3(B) from the National Electrical Code® (NEC®) (NFPA 70-2005) requires that a circuit breaker be applied according to the information listed in the standards. Thus, it is important that the engineer know and understand the standards so that proper application procedures are followed.

Chapter 4: Specific applications

This chapter provides a systematic procedure for selecting and applying MCCBs, ICCBs, and LVPCBs at various locations in a power system. The applications covered in Chapter 4 are as follows:

- Service entrances
- Mains (buses and busway, feeder and branch protective devices, and line-side transformers)
- Bus ties
- Feeders and branch circuits (cable and busway)
- Circuit breakers in series combinations
- Motors (individual and grouped)
- Transformers
- Capacitors and capacitor banks
- Generators
- Switchboards and panelboards
- Motor control centers and starters

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[2] The numbers in brackets correspond to those of the Bibliography in 1.8.

Chapter 5: Selective coordination of low-voltage circuit breakers with other protective devices

This chapter explains how to coordinate different combinations of devices and provides typical settings. Conflicting objectives normally occur between protection and selective coordination. The objective of protection is to minimize the damage by removing the overload or short circuit as quickly as possible. However, the objective of selective coordination is to disconnect a minimum amount of equipment from the power system. Coordination is obtained by selecting the appropriate type of circuit breaker, trip characteristics, and trip settings so that only the circuit breaker closest to the overload or short-circuit condition clears the problem.

To obtain selective coordination over the entire range of available short-circuit current, delayed operation of the line-side circuit breaker is necessary to allow the load-side circuit breaker to clear a fault. The additional time delay of the line-side device can increase the extent of the damage to circuit components. However, it is often necessary to make a compromise in protection to obtain coordination, within the limits of the National Electric Code (NFPA 70-2005) and ANSI protection requirements. Coordination between devices is often sacrificed when continuity of service and/or equipment damage and associated cost are not critical.

Chapter 6: Fused and special-purpose circuit breakers

This chapter discusses application of the following special-purpose circuit breakers:

- Instantaneous trip only
- Mine duty
- Current limiting
- Molded-case switch
- Integrally fused
- Circuit breaker and ground fault circuit interrupters
- Arc-fault circuit interrupters
- Supplementary protectors

Chapter 7: Acceptance and maintenance requirements.

This chapter is divided into the following two time periods:

- Acceptance testing that should be performed *before* placing a circuit breaker into service
- Maintenance guidelines that should be followed *after* a circuit breaker is placed into service

Acceptance testing and maintenance are required to ensure that the circuit breaker will perform satisfactorily to the full extent of the manufacturer's ratings. In addition, proper maintenance is required for continued, reliable operation. Also discussed briefly are testing and maintenance for insulated case circuit breakers, molded-case switches, and ground fault circuit interrupters. Annex 7A and Annex 7B provide sample data record sheets for recording circuit breaker test information and results.

A circuit breaker may be damaged during shipment, or defective components may be present; therefore, acceptance testing should be performed prior to placing it in service. Acceptance testing of circuit breakers is the initial testing on a breaker before it is placed into service to verify that the circuit breaker will perform properly. This chapter provides instructions for performing and documenting test results. Some acceptance test criteria discussed are insulation resistance, electrical operations at selected settings, mechanical operation, and auxiliary functions. Acceptance test data sheets are provided.

Maintenance procedures are important to power system reliability and safety. Proper maintenance will improve confidence that the circuit breakers will operate properly when called on to interrupt an overload or fault condition. The operating performance of a circuit breaker may deteriorate with time due to contamination by pollutants in the atmosphere, excessive use, or lack of operation for a prolonged duration. Welding in the main contact may occur during a short circuit if the contacts are in a deteriorated condition due to excessive use. In addition, the performance characteristics of other components in the breaker, such as contact pressure springs, may be degraded for some other reason such as overheating. This chapter discusses proper maintenance procedures and schedules that should be followed to maintain reliable operation.

1.6 Summary

This recommended practice identifies the differences between the two classifications of low-voltage circuit breakers and provides information for selecting the best one for a particular situation. In addition, this recommended practice gives information for applying circuit breakers at different locations in the power system and for protecting specific components. Guidelines are also given for coordinating combinations of line-side and load-side devices. Acceptance testing and maintenance guidelines are given so that reliable operation can be verified and maintained.

1.7 Normative references

The following referenced documents are indispensable for the application of this recommended practice. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI C37.16-2000, American National Standard Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors-Preferred Ratings, Related Requirements, and Application Recommendations.[3]

ANSI C37.17-1997, American National Standard for Trip Devices for AC and General Purpose DC Low Voltage Power Circuit Breakers.

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[3] ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

ANSI C37.50-1989 (R2000), American National Standard for Switchgear-Low-Voltage AC Power Circuit Breakers Used in Enclosures-Test Procedures.

IEEE Std C37.13-1990 (R1995), IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.[4, 5]

IEEE Std C37.100-1992, (R2001) IEEE Standard Definitions for Power Switchgear.

NFPA 70-2005, National Electrical Code® (NEC®).[6]

UL 489-2002, Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures.[7]

UL 1558-1999, Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

1.8 Bibliography

[B1] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition. New York: Institute of Electrical and Electronics Engineers, Inc.

[B2] IEEE Std 141™-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants *(IEEE Red Book™)*.

[B3] IEEE Std 242™-2001, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems *(IEEE Buff Book™)*.

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[7] UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

Chapter 2
Definitions, acronyms, and abbreviations

2.1 Definitions

For the purposes of this document, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B1][1] should be referenced for terms not defined in this clause.

2.1.1 adjustable: (as applied to circuit breakers) A qualifying term indicating that the circuit breaker can be set to trip at various values of current, time, or both, within a predetermined range. [adapted from the National Electrical Code® (NEC®) (NFPA 70-2005)] [2]

2.1.2 alarm switch: An auxiliary switch that actuates a signaling device upon the automatic opening of the circuit breaker with which it is associated.

2.1.3 auxiliary switch: A switch that is mechanically operated by the main switching device for signaling, interlocking, or other purposes.

NOTE—Auxiliary switch contacts are classified as a, b, aa, bb, LC, etc., for the purpose of specifying definite contact positions with respect to the main device.[3]

2.1.4 available short-circuit current: (at a given point in a circuit) The maximum current that the power system can deliver through a given circuit to any negligible-impedance short circuit applied at the given point, or at any other point that will cause the highest current to flow through the given point. *See also:* **prospective fault current**.

2.1.5 circuit breaker: A device designed to open and close a circuit by nonautomatic means, and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating. [adapted from the NEC] *Syn:* **low-voltage circuit breaker**.

2.1.6 continuous load: A load where the maximum current is expected to continue for 3 hours or more. [adapted from the NEC]

2.1.7 coordination: The selection and/or setting of protective devices to provide protection of system components and to provide selectivity when a short circuit or other abnormality occurs.

2.1.8 current-limiting circuit breaker: A circuit breaker that does not use a fusible element and that when operating within its current-limiting range limits the let-through I^2t

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[1] The numbers in brackets correspond to those of the bibliography in 2.4.

[2] Information on references can be found in 2.3.

[3] Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

to a value less than the I^2t of a 1/2 cycle wave of the symmetrical prospective current. (adapted from UL 489-2002) *See also:* **current-limiting overcurrent protective device.**

2.1.9 current-limiting overcurrent protective device: A device that, when interrupting currents in its current-limiting range, reduces the current flowing in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device were replaced with a solid conductor having comparable impedance. (adapted from the NEC) *See also:* **current-limiting circuit breaker**.

2.1.10 drawout-mounted circuit breaker: An assembly of a circuit breaker together with a supporting structure so constructed that the breaker is supported and can be moved between the main circuit connected and the disconnected positions without unbolting connections or mounting supports. The stationary portion of the drawout assembly includes self-supporting primary circuit terminals and may include an interlocking means that permits movement of the breaker between the main circuit connected and the disconnected positions only when the breaker contacts are in the open position. (adapted from UL 489-2002)

2.1.11 dynamic impedance: The arc impedance introduced into a circuit by the opening of the circuit-breaker contacts during current interruption. (adapted from NEMA AB 1-1993)

2.1.12 electrical operator: A controlling device that is used to open, close, and reset a circuit breaker. (adapted from UL 489-2002)

NOTE—The term *motor operator* is sometimes used when the operating device is a motor.

2.1.13 electronic trip unit: A self-contained portion of a circuit breaker that senses the condition of the circuit breaker electronically and that actuates the mechanism that opens the circuit breaker contacts automatically.

NOTE—Where the term *electronic trip unit* is used in this book, the alternate terms *solid state trip unit* and *static trip unit* are commonly used in literature.

2.1.14 frame: As applied to circuit breakers, that portion of an interchangeable trip unit circuit breaker remaining when the interchangeable trip unit is removed. (adapted from UL 489-2002)

2.1.15 frame size: A term applied to a group of circuit breakers of similar physical configuration. Frame size is expressed in amperes and corresponds to the largest ampere rating available in the group. The same frame size designation may be applied to more than one group of circuit breakers. (adapted from UL 489-2002)

2.1.16 ground-fault delay: An intentional time delay in the tripping of a circuit breaker when a ground fault occurs. (adapted from NEMA AB 1-1993)

2.1.17 ground-fault pickup: The nominal value of the ground fault current at which the ground fault delay function is initiated. (adapted from UL 489-2002)

2.1.18 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. (adapted from the NEC)

2.1.19 I^2t: An expression related to the energy available as a result of current flow, meaningful only for adiabatic conditions. With respect to circuit breakers, the expression refers to the I^2t between the initiation of fault current and the clearing of the circuit. The defining equation is $I^2t = I^2(t)\ dt$ over the stated period, in units of amperes-squared seconds. (adapted from UL 489-2002)

2.1.20 instantaneous pickup: The nominal value of current at which an adjustable circuit breaker is set to trip instantaneously. (adapted from UL 489-2002)

2.1.21 instantaneous trip: (as applied to circuit breakers) A qualifying term indicating that no delay is purposely introduced in the tripping action of the circuit breaker. (adapted from the NEC)

2.1.22 instantaneous-trip-only circuit breaker: A circuit breaker intended to provide short-circuit protection only. Although acting instantaneously under short-circuit conditions, instantaneous trip breakers shall be permitted to include a transient damping action to ride through initial motor transients. (adapted from UL 489-2002)

2.1.23 insulated-case circuit breaker (ICCB): A circuit breaker that is assembled as an integral unit in a supporting and enclosing housing of insulating material and with a stored energy mechanism.

2.1.24 integrally-fused circuit breaker: A circuit breaker in which coordinated fuses are connected in series with the release (trip) elements of the circuit breaker and are mounted within the housing of the circuit breaker. (adapted from NEMA AB 1-1993)

2.1.25 interrupting rating: The highest current at rated voltage that a device is intended to interrupt under standard test conditions. (adapted from the NEC)

2.1.26 inverse time: (as applied to circuit breakers) A qualifying term indicating that there is purposely introduced a delay in the tripping action of the circuit breaker, which delay decreases as the magnitude of the current increases. (adapted from the NEC)

2.1.27 Ip: *See:* **peak current**.

2.1.28 long-time delay: An intentional time delay in the overload tripping of an adjustable circuit breakers inverse time characteristic. (adapted from UL 489-2002)

2.1.29 long-time pickup: The current at which the long-time delay function is initiated. (adapted from UL 489-2002)

2.1.30 low-voltage power circuit breaker (LVPCB): A mechanical switching device, capable of making, carrying, and breaking currents under normal circuit conditions and making and carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short circuit. Rated 1000 V ac or below, or 300 V dc and below, but not including molded-case circuit breakers. (adapted from IEEE Std C37.100™-1992)

2.1.31 molded-case circuit breaker (MCCB): A circuit breaker that is assembled as an integral unit in a supporting and enclosing housing of insulating material. (adapted from UL 489-2002 and IEEE Std C37.100-1992)

2.1.32 molded-case switch: A device designed to open and close a circuit by nonautomatic means, assembled as an integral unit in a supportive and enclosed housing of insulating material. *Syn:* **nonautomatic switch** (deprecated). (adapted from UL 489-2002 and UL 1087-1993)

2.1.33 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. (adapted from the NEC) *See also:* **overload**.

2.1.34 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. (adapted from the NEC) *See also:* **overcurrent**.

2.1.35 panelboard: A single panel or group of panel units designed for assembly in the form of a single panel, including buses and automatic overcurrent devices, and equipped with or without switches for the control of light, heat, or power circuits; designed to be placed in a cabinet or cutout box placed in or against a wall, partition, or other support; and accessible only from the front. (adapted from the NEC) *See also:* **switchboard**.

2.1.36 peak current: The maximum instantaneous current that flows in a circuit, designated Ip. (adapted from UL 489- 2002)

2.1.37 peak let-through current: The highest current flowing in the circuit after the inception of the fault that the circuit breaker and the protected system must withstand, expressed as an instantaneous rather than a root-mean-square (rms) value.

2.1.38 pickup: The root-mean-square (rms) current at which a circuit breaker tripping function is initiated. (adapted from NEMA AB 1-1993)

2.1.39 prospective fault current: The current that would flow during a short circuit if the circuit breaker and the wires used for its connection were replaced by a solid conductor of negligible impedance. (adapted from UL 489-2002) *See also:* **available short-circuit current**.

2.1.40 rated short-time withstand current: **(A)** The maximum root-mean-square (rms) total current that a circuit breaker can carry momentarily without electrical, thermal, or mechanical damage or permanent deformation. The current shall be the rms value, including the dc component, at the major peak of the maximum cycle as determined from the envelope of the current wave during a given test time interval. (adapted from IEEE Std C37.100-1992) **(B)** That value of current assigned by the manufacturer that the device can carry without damage to itself, under prescribed conditions. (adapted from NEMA AB 1-1993) *Syn:* **withstand rating; short-time rating**.

2.1.41 rating plug: An interchangeable module of an electronic trip unit that, together with the sensor, sets the current rating range of the circuit breaker. For example, a 1200 A frame may contain an 800 A sensor, fixing the maximum rating that can be configured for the unit at 800 A adjustable by the following kind of settings. By installing a 600 A rating plug, the adjustable rating is correspondingly 600 A multiplied by the long-time pickup adjustment [i.e., the long-time pickup may be adjusted to "0.9," and the ampere rating or setting is (0.9 × 600 A) = 540 A]

2.1.42 release: A device, mechanically connected within the circuit breaker, that initiates the tripping function of a circuit-breaker. (adapted from NEMA AB 1-1993)

2.1.43 root-mean-square (rms) sensing: A term commonly used to indicate the sensing of root-mean-square (rms) value current rather than instantaneous or peak values, as by a circuit-breaker trip unit.

2.1.44 selective coordination: *See:* **coordination; selectivity**.

2.1.45 selectivity: A general term describing the interrelated performance of relays and breakers and other protective devices; complete selectivity being obtained when a minimum amount of equipment is removed from service for isolation of a fault or other abnormality. (adapted from IEEE Std C37.100-1992) *See also:* **coordination**.

2.1.46 sensor: (as applied to a circuit-breaker with an electronic trip unit) A current sensing element such as a current transformer within a circuit-breaker frame. The sensor will have a current rating less than or equal to the frame size and will provide the sensing function for a specific group of current ratings within the frame size.

2.1.47 series rating: The interrupting rating of a tested combination of a line-side (main) overcurrent protective device and a load-side (branch) circuit-breaker in which the interrupting rating of the combination is greater than the interrupting rating of the branch circuit-breaker. The interrupting rating of the series combination does not exceed the interrupting rating of the main overcurrent protective device. *Syn:* **series-connected rating**.

NOTE—See *UL Recognized Component Directory,* 2002 [B2].

2.1.48 setting: (of a circuit breaker) The value of current, time, or both at which an adjustable circuit-breaker is set to trip. (adapted from the NEC)

2.1.49 short circuit: An abnormal connection (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential. (adapted from IEEE Std C37.100-1992)

2.1.50 short-time current: The current carried by a device, an assembly, or a bus for a specified short-time interval. (adapted from IEEE Std C37.100-1992) *See also:* **rated short-time withstand current; short-time rating**.

2.1.51 short-time delay: An intentional time delay in the tripping of a circuit-breaker that is above the overload pickup setting.

2.1.52 short-time delay phase or ground trip element: A direct-acting trip device element that functions with a purposely delayed action (measured in milliseconds). (adapted from IEEE Std C37.100-1992)

2.1.53 short-time pickup: The current at which the short-time delay function is initiated. (adapted from UL 489- 2002)

2.1.54 short-time rating: A rating applied to a circuit breaker that, for reason of system coordination, causes tripping of the circuit breaker to be delayed beyond the time when tripping would be caused by an instantaneous element. (adapted from UL 489-2002) *See also:* **rated short-time withstand current; short-time current**.

2.1.55 shunt trip device: A trip mechanism energized by a source of voltage that may be derived either from the main circuit or from an independent source. (adapted from UL 489-2002)

2.1.56 stored-energy operation: Operation by means of energy stored in the mechanism before the completion of the operation and sufficient to complete it under predetermined conditions. (adapted from IEEE Std C37.100-1992)

2.1.57 switchboard: A large, single-panel, frame or assembly of panels on which are mounted, on the face, back, or both, switches, overcurrent and other protective devices, buses, and usually instruments. Switchboards are generally accessible from the rear as well as from the front and are not intended to be installed in cabinets. (adapted from the NEC) *See also:* **panelboard**.

2.1.58 switchgear: A general term covering switching and interrupting devices and their combination with associated control, metering, protective and regulating devices; also, assemblies of these devices with associated interconnections, accessories, enclosures, and supporting structures used primarily in connection with the generation, transmission, distribution, and conversion of electric power. (adapted from IEEE Std C37.100-1992)

2.1.59 transient recovery voltage (TRV): The voltage transient that occurs across the terminals of a pole of a switching device upon interruption of the current. (adapted from IEEE Std C37.100-1992)

2.1.60 tripping: The opening of a circuit breaker by actuation of the release mechanism. (adapted from UL 489- 2002)

2.1.61 trip unit: A self-contained portion of a circuit breaker that actuates the mechanism that opens the circuit-breaker contacts automatically. (adapted from UL 489- 2002)

NOTE—The terms *trip device* and *tripping device* are used in literature as alternative terms for trip unit.

2.1.62 undervoltage trip device: A trip mechanism that causes a circuit-breaker to open automatically if the voltage across the terminals of the trip coil falls below a predetermined value. (adapted from UL 489- 2002) *Syn:* **undervoltage release**.

2.1.63 withstand current: *See:* **rated short-time withstand current**.

2.1.64 withstand rating: *See:* **rated short-time withstand current**.

2.1.65 zone selective interlocking: A function provided for rapid clearing while retaining coordination. The function is a communication interconnection between the electronic trip units of two or more circuit breakers connected in series on multiple levels. By means of intercommunication between the short-time delay and/or ground fault elements, the one nearest the fault trips with minimum time delay while signaling the supply-side circuit-breaker(s) to delay for a predetermined period. *Syn:* **zone interlocking; selective interlocking.**

2.2 Acronyms and abbreviations

2.2.1 40 °C: Designates a circuit-breaker that is acceptable for use in ambient temperatures up to 40 °C.

2.2.2 AIC: Amperes interrupting capacity. Maximum current a protective device is capable of interrupting, namely, its interrupting rating. May be found in manufacturer's literature. Also see **AIR**.

2.2.3 AIR: Amperes interrupting rating. Shortened term marked on some small circuit breakers with the interrupting rating.

2.2.4 CTL: A Class CTL circuit breaker, because of its size or configuration in conjunction with the physical means provided in Class CTL panelboards, prevents more circuit-breaker poles from being installed than the number for which the assembly is designed and rated. A Class CTL panelboard is a circuit-limited lighting and appliance panelboard as referenced in Sections 408.14 to 408.16 of the NEC. Both half-size and full-sized circuit breakers may be installed.

2.2.5 HACR: Heating, air conditioning, and refrigeration. Designates compliance with the special requirements of Section 430-53(C)(3) of the NEC, as listed for group installation for use with heating, air conditioning, and refrigeration equipment. A circuit breaker with this marking is suitable only for use with equipment marked to indicate that an HACR circuit breaker is acceptable.

2.2.6 HID: High-intensity discharge. Indicates construction suitable for switching high-intensity discharge lighting loads.

2.2.7 SWD: Switching duty. Designates compliance with requirements for circuit breakers used as switches on fluorescent lighting circuits as indicated in Section 240-83(D) of the NEC.

2.3 Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEEE Std C37.100-1992 (R2001), IEEE Standard Definitions for Power Switchgear.[4]

NEMA AB l-1993, Molded Case Circuit Breakers and Molded Case Switches.[5]

NFPA 70-2005, National Electrical Code®(NEC®).[6]

UL 489-2002, Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures.[7]

UL 1087-1993, Molded-Case Switches.

UL Molded-Case Circuit Breaker Marking Guide, 1996.

2.4 Bibliography

[B1] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition. New York: Institute of Electrical and Electronics Engineers, Inc.

[B2] *UL Recognized Component Directory,* 2002.

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[4] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08855- 1331, USA (http://standards/ieee.org/).

[5] NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http:// global.ihs.com/).

[6] NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (http://www.nfpa.org/).

[7] UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

Chapter 3
Rating and testing

3.1 Relevance of rating and testing

This chapter provides information on rating and testing of circuit breakers that will be helpful to electrical engineers in choosing low-voltage circuit breakers for an application. Ratings assigned to circuit breakers are determined by the testing done to prove their design capabilities. Therefore, a discussion of the testing requirements of the different classes of circuit breakers is fundamental to understanding their capabilities.

Other influences, such as the National Electrical Code® (NEC®) (NFPA 70-2005),[1] industry practices, and environmental considerations can also affect circuit-breaker choices. These are also discussed in areas where they relate to testing requirements. Application considerations such as choosing the type of trip unit, the type of time-current-characteristic, and the continuous current and interrupting ratings to satisfy coordination requirements are the subjects of other chapters of this book.

3.2 The ideal circuit breaker

The ideal circuit breaker (not realizable) would have no internal impedance and would carry current with no voltage drop when closed, and therefore, the circuit breaker would not produce any heat during operation. It would interrupt any overcurrent it was called on to interrupt without experiencing contact erosion, and structurally, it would be able to withstand the pressure and heat of interruption and the magnetic forces produced by the flow of fault current through it. Its connectors would be firmly attached to the circuit-breaker terminals and would hold the external circuit conductors in place regardless of the amount of fault current flow. It would provide perfect electrical isolation of the load from the normal system voltage when open, and it would be able to provide these functions indefinitely regardless of the environment.

3.3 The practical circuit breaker

Circuit breakers do not, of course, perform exactly in the fashion described in 3.2. They have internal impedance, and therefore, they develop a small voltage drop while carrying current. The product of the resistive voltage drop and the current is a measure of power loss, which is manifested as heat in the circuit breaker during normal operation. The consequence is that practical circuit breakers warm up during operation.

When properly applied within their ratings and when they are in good operating condition, practical circuit breakers can interrupt any overcurrent that occurs in the circuit in which they are applied. They can do this without undue contact erosion and can withstand the pressure and heat of interruption as well as the magnetic forces produced by fault current.

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[1] Information on references can be found in 3.43.

The process of interruption will not damage the operating mechanism, trip unit, or supporting frame. As their contacts do experience some erosion, they can only perform a limited number of switching and interrupting operations without maintenance. Circuit breakers that cannot be maintained should be replaced whenever wear and tear reaches certain limits. Properly sized and properly torqued connectors attached to the circuit breaker terminals can hold conductors firmly in place. That is, the connectors must fit the circuit breaker terminals, the connectors must be compatible with the conductor material (AL or CU or AL/CU), and the conductor stranding and compression must be compatible with the connector.

Circuit breakers can provide adequate disconnecting capability to isolate the load from recovery voltage transients, surges, and normal voltage, and they can provide adequate service.

3.4 Basic circuit-breaker selection criteria

The selection of a circuit breaker, for any given duty, is ultimately based on an assessment of its ability to perform the following basic functions:

a) To carry the required current without overheating (i.e., it should have the correct current rating)
b) To switch and isolate or disconnect the load from the source at the given system voltage (i.e., it should have the correct voltage rating)
c) To interrupt any abnormally high operating current or short-circuit current likely to be encountered during operation (i.e., it should have the correct interrupting rating)
d) To be able to perform these functions over an acceptably long period of time under the operating and environmental conditions that will actually prevail in the application (i.e., it should have the correct mounting provisions, enclosure, and operating endurance and have the required accessories for operation in the environment in which it is applied)

The degree to which a circuit breaker can satisfy these requirements is a measure of its applicability for a function. A circuit breaker's rating indicates these capabilities to the user because rating is established by proof testing. Hence, an understanding of how a circuit breaker is tested and given its rating will give insight into its applicability for any function.

3.5 The role of industry standards

The primary vehicle for ensuring commonality in performance among circuit breakers of the same rating produced by different manufacturers is a product standard. Standards represent the consensus of manufacturers, testing organizations, users, and others about what a given product should be able to do. Standards establish the design tests that each manufacturer must perform and pass to claim a rating and to be in compliance with that standard. Some standards include requirements for periodic follow-up testing that, in effect, continues to sample the capabilities of newly manufactured circuit breakers. This testing assures that they maintain the capabilities of their product ratings. Standards also provide for monitoring the quality of the materials used in the construction of circuit breakers and the quality of the workmanship in the manufacturing process.

As stated, standards requirements for the different classes of circuit breakers establish a basis for minimum performance. Circuit breakers may prove by test to perform better than their product ratings indicate, but they can never be permitted to perform worse. The user, however, may never assume that a circuit breaker can perform better than its rating indicates and should realize that there are manufacturing variations among mass-produced products. The levels of performance required by the standards for the minimum acceptable performance of different classes of circuit breakers will be the primary references in the discussion that follows.

3.6 The role of safety and industry codes

Safety and industry code requirements have evolved over the years. These codes reflect experience in actual application over the years. The Occupational Safety and Health Act (OSHA) [B12][2] is the primary legal safety code in the United States, and the NEC is the primary safety code for installations. The NEC is often made part of state and local law, but to be effective, it must be accepted by the authority having jurisdiction. However, it can be ignored by local bodies and it can be modified. Other safety standards are the National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2-2007) [B1] sponsored by the IEEE, NFPA 70B-2002 [B10], and NFPA 70E-2004 [B11]. Industry practices vary between industries and may vary from location to location in the same industry. The NEC and other industry codes for application may either make use of available circuit-breaker product features or they may influence the development of them. The feature of the sealable cover over the trip adjusting mechanism of a circuit breaker, described later, indicates how code provisions can affect product design and installation economics.

3.7 Comparison of testing requirements

In most cases, a meaningful one-to-one comparison of test procedures will not be possible. It will be seen that tests of different types of circuit breakers differ, and without the exact testing, comparisons of the severity of tests can only be made subjectively. There are also some local differences in interpretation of the requirements of the NEC and other specific industry safety codes that make them also somewhat subjective. Only consideration and evaluation of the whole set of application requirements will permit a confident selection of a type of circuit breaker to be made. This chapter addresses many of the details that should be evaluated.

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[2] The numbers in brackets correspond to those of the bibliography in 3.44.

3.8 Circuit-breaker classes and types

For low-voltage circuit protection in the United States, circuit-breaker designs and tests are based on the requirements of three standards organizations: the American National Standards Institute (ANSI), the Underwriters Laboratories (UL), and the National Electrical Manufacturers Association (NEMA). The two classifications of circuit breakers these organizations define are as follows:

— Molded-case circuit-breaker class

— Low-voltage power circuit-breaker class

Three types of circuit breakers are based on the two classifications above. The classifications lend their names to the first two of the three types, whereas the third type, derived from the molded-case circuit-breaker class, is known as an insulated-case circuit breaker. The three types of circuit breakers are as follows:

— Molded-case circuit breakers (MCCBs)

— Low-voltage power circuit breakers (LVPCBs)

— Insulated-case circuit breakers (ICCBs)

Some salient features of these types of circuit breakers are as follows.

MCCBs, as a class, are those tested and rated according to UL 489-1994 and whose current-carrying parts, mechanisms, and trip devices are completely contained within a molded case of insulating material. MCCBs are available in the widest range of sizes, from the smallest (15 A or less) to the largest (6000 A) and with various interrupting ratings for each frame size. They are characterized generally by fast interruption short-circuit elements. With electronic trip units, they can have limited short-delay and ground-fault sensing capability. Virtually all MCCBs interrupt fast enough to limit the amount of prospective fault current let-through, and some are fast enough and limiting enough to be identified as current-limiting circuit breakers. MCCBs are not designed to be field maintainable.

ICCBs are also rated and tested according to UL 489-1994. However, they use characteristics of design from both the power and molded-case classes. They are of the larger frame sizes, fast in interruption, but normally not fast enough to qualify as current-limiting circuit breakers. ICCBs also use electronic trip units and can have short-time ratings and ground-fault current sensing. They use stored energy operating mechanisms similar to those designed for LVPCBs, and their design is such that they are partially field maintainable.

LVPCBs are rated and tested to satisfy ANSI C37 standard requirements and are used primarily in drawout switchgear. They are generally characterized as being the largest in physical size. They have short-time ratings, but they are not fast enough in interruption to qualify as current-limiting. LVPCBs are designed to be maintainable in the field.

The ANSI C37 series of standards were jointly developed by IEEE and NEMA and apply to LVPCBs. UL 489-1994 was developed by the Underwriters Laboratory in consultation with manufacturers and users, and it applies to ICCBs and MCCBs.

3.9 Generalized application considerations

Relative to the physical details of design and application, MCCBs are most often applied fixed mounted; however, drawout mechanisms have been designed for some of the largest ones and plug-in mechanisms have been designed for some of the smaller ones. Larger MCCBs are designed to use interchangeable trip units. They can be either thermal-magnetic trip units using bimetallic overload elements and electromagnetic overcurrent trips or they can be electronic trip units incorporating electrical analog or digital logic circuits to calculate current levels and initiate tripping functions. They usually derive operating power from current sensors mounted in the circuit breakers themselves.

ICCBs are used primarily in fixed mounted switchboards, but because of their size and weight, they are frequently mounted using drawout mechanisms. ICCBs are designed primarily to use interchangeable state-of-the-art electronic trip units.

While considering the merits of maintainability in circuit breakers, it is well to remember that although MCCBs and ICCBs are not designed to be field maintainable, they are designed to have relatively high endurance capabilities that should be evaluated in any application.

LVPCBs are always used in enclosures and because of their large size and weight are essentially always applied in drawout construction. Fixed mounting is an option rarely used. Drawout mechanisms not only minimize the work required in circuit breaker installation and maintenance, but they also facilitate rapid changeout, which minimizes system downtime. It is especially important when the circuit breaker to be changed out is a main and a building or plant shutdown is necessary to change it. Drawout mechanisms also facilitate the performance of regular field inspection and maintenance services.

LVPCBs can use a variety of trip units. Some of the latest versions of electronic trip units they use are also used in large MCCBs and ICCBs. Significant differences in the total operating times of different circuit breakers using the same types of trip units are accounted for in specific time-current curves (TCCs) published for the different circuit-breaker and trip unit combinations.

3.10 References on rating and application

For new equipment, the latest version of standards should always be used for circuit-breaker information. For older equipment, the version of the standards that was in effect when the circuit breaker was manufactured should be referenced.

Preferred ratings and application recommendations for LVPCBs are given in ANSI C37.16-1997. Standards for low-voltage ac power circuit breakers used in enclosures are given in IEEE Std C37.13™-1995, and test procedures for LVPCBs used in enclosures are given in ANSI C37.50-1989. Application factors are discussed in the IEEE C37.20™ standards. LVPCBs are generally UL Listed and can be UL Labeled. Ratings and test procedures for MCCBs and ICCBs are found in UL 489-1994. Other *IEEE Color Books*® complement this book, offering a complete and comprehensive source of application information for all three types of circuit breakers.

3.11 Endurance considerations

Table 3-1, Table 3-2, and Table 3-3 summarize some specific mechanical and electrical endurance test parameters. The information in these tables is taken from ANSI C37.50-1989 and UL 489-1994. These standards do not lend themselves to one-to-one comparison. The tests or test conditions are different. It is necessary to make subjective judgments to determine which test procedure might be more severe than another.

Although choices may be made by subjective judgment of test procedures, an alternative method is to follow established practices that have a history of long-term successful performance. Fortunately, information on these practices is often available in the engineer's own facility, and if it is not, references such as IEEE Std 493™-1990 [B9], which discusses reliability in general and contains sets of data that can be of assistance in decision making, can be consulted. The comments in this chapter may be sufficient to resolve some questions on evaluation, but sometimes they may be sufficient only to indicate a direction for further, more detailed engineering investigation.

Other aspects of application, such as the size or weight of a circuit breaker, or its physical placement in a building or facility, spares availability or its maintenance requirements, and not factors directly pertaining to electrical rating and testing, can have an impact on the selection.

Table 3-1—Circuit-breaker endurance test parameters[a]

Parameter	UL-489-1994	ANSI C37.50-1989
Enclosure	Smallest individual or open if mounted on metal plate	Minimum dimension test enclosure
Current	Rated	Rated
Voltage	100–105% Rated	100–105% Rated max (254 V, 508 V, or 635 V)
Power factor (ac)	0.75–0.80	0.85 max
Time constant (dc)	Not defined	Not covered
Frequency	48–62 Hz	48–72 Hz
Ambient	Not defined	Not defined
Ground fuse	30 A	30 A or 10 AWG (copper)

[a] Reprinted from: “Panel Discussion on Application of Molded-Case Circuit Breakers” [B13].

Table 3-2—Endurance test operations[d]

Preferred frame sizes for MCCBs and ICCBs (A)	Number of cycles of operation			
	Per min[a]	With current	Without current	Total
50	6	6000	4000	10 000
100	6	6000	4000	10 000
125	5	4000 [b]	4000	8000 [b]
150	5	4000 [b]	4000	8000 [b]
200	5	4000	4000	8000
225	5	4000	4000	8000
400	4	1000	5000	6000
600	4	1000	5000	6000
800	1	500	3000	3500
1200	1	500	2000	2500
1600	1	500	2000	2500
2000	1	500	2000	2500
2500	1	500	2000	2500
3000	1 [c]	400	1100	1500
4000	1 [c]	400	1100	1500
5000	1 [c]	400	1100	1500
6000	1 [c]	400	1100	1500

[a] For circuit breakers rated more than 800 A, the endurance test may, at the option of the manufacturer, be conducted in groups of 100 load operations. No-load operations may be conducted between groups of load operations at the option of the manufacturer.

[b] Where tests are required on samples having ratings of 100 A or less, 250 V or less, the number of operations shall be the same as for the 100 A frame.

[c] Rate of operation: 1 cycle/min for first 10 operations; thereafter in groups of 5, at 1 cycle/min, with an interval between groups that is agreeable to all concerned.

[d] Reprinted from: Table 19.1 of UL 489-1994.

Table 3-3—Circuit-breaker mechanical/electrical endurance test comparison,[f]

Frame size (A)	Minimum operation rate cycles/hour		Number of operating cycles[e]							
			Between servicing[b]		With current		Without current		Total	
	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989
100	360	—	See Footnote c	—	6000	—	4000	—	10 000	—
150	300	—	See Footnote c	—	4000	—	4000	—	8000	—
225	300	30	See Footnote c	2500	4000	4000	4000	10 000	8000	14 000
400	240	—	See Footnote c	—	1000	—	5000	—	6000	—
600	240	30	See Footnote c	1750	1000	2800	5000	9700	6000	12 500
800	60	30	See Footnote c	1750	500	2800	3000	9700	3500	12 500
1200	60	—	See Footnote c	—	500	—	2000	—	2500	—
1600	60	30	See Footnote c	500	500	800	2000	3200	2500	4000
2000	60	30	See Footnote c	500	500	800	2000	3200	2500	4000

Table 3-3—Circuit-breaker mechanical/electrical endurance test comparison[f] *(continued)*

Frame size (A)	Minimum operation rate cycles/hour		Number of operating cycles[e]							
			Between servicing[b]		With current		Without current		Total	
	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989
2500	60	—	See Footnote c	—	500	—	2000	—	2500	—
3000	See Footnote a	30	See Footnote c	250	400	400	1100	1100	1500	1500
4000	See Footnote a	30	See Footnote c	250	400	400	1100	1100	1500	1500
5000	See Footnote a	30	See Footnote c	250	400	400	1100	1100	1500	1500

[a] First 10 at 60/h; thereafter in groups of 5 at 60/h with interval between as acceptable to all.
[b] Servicing means adjusting, cleaning, lubricating, and tightening.
[c] Servicing not permitted.
[d] May be conducted in groups of operations provided at least one group is not less than 120.
[e] Tests on same breaker—sequence not defined.
[f] Reprinted from: ANSI C37.50-1989 and UL 489-1994.

3.12 Circuit-breaker voltage rating considerations

MCCBs, ICCBs, and LVPCBs use the same standard nominal system voltages of 600 V, 480 V, and 240 V. However, MCCBs and ICCBs have additional rated voltages of 120 V, 120/240 V, 277 V, 347 V, 480Y/277 V, and 600Y/347 V, and LVPCBs have maximum voltages. A few comments on these considerations can be very instructive.

First, for MCCBs and ICCBs, the nominal voltage levels are maximum "not to exceed" voltages, whereas LVPCBs, on the other hand, have assigned "maximum" voltages of 254 V ac, 508 V ac, and 635 V ac. Second, the slash marks (/) between some voltage ratings have significance to circuit-breaker design, application, and testing. NEC 240.83 refers to straight and slash voltage marking in a fine print note (FPN), which is quoted as follows:

> A circuit breaker with a straight voltage marking, e.g., 240 V or 480 V, may be applied in a circuit in which the nominal voltage between any two conductors does not exceed the circuit breaker's voltage rating; except that a two-pole circuit breaker is not suitable for protecting a 3-phase corner-grounded delta circuit unless it is marked 1-phase/3-phase to indicate such suitability.
>
> A circuit breaker with a slash rating, e.g., 120/240 V or 480Y/277 V, may be applied in a circuit in which the nominal voltage to ground from any conductor does not exceed the lower of the two values of the circuit breaker's voltage rating and the nominal voltage between any two conductors does not exceed the higher value of the circuit breaker's voltage rating.

Voltage is a sensitive factor in interruption, and circuit-breaker voltage rating is a significant factor in applications. That significance can be seen most readily in that different interrupting ratings are assigned to the same circuit breaker at different system voltages. The ratings are proven in testing.

Because of the benefits and associated limitations of different types of grounding systems, testing of slash voltage-rated circuit breakers is different from the testing of straight voltage-rated circuit breakers. IEEE Std 142™-1991 [B6] discusses grounding considerations in detail. Slash voltage-rated circuit breakers take advantage of the fact that the power system neutral is fixed at ground potential. Table 3-4 indicates the various tests required of MCCBs and ICCBs as a function of the different numbers of poles of the circuit breaker and the different voltage ratings to be applied. More detail on the tests and the circuits they are performed in follows. Table 3-4 emphasizes the significant difference in testing required for circuit breakers to be rated with a straight voltage and those to be rated with a slash voltage. The NEC FPN is an excellent reminder of the significance of voltage rating.

See Figure 3-1 for test circuit details.

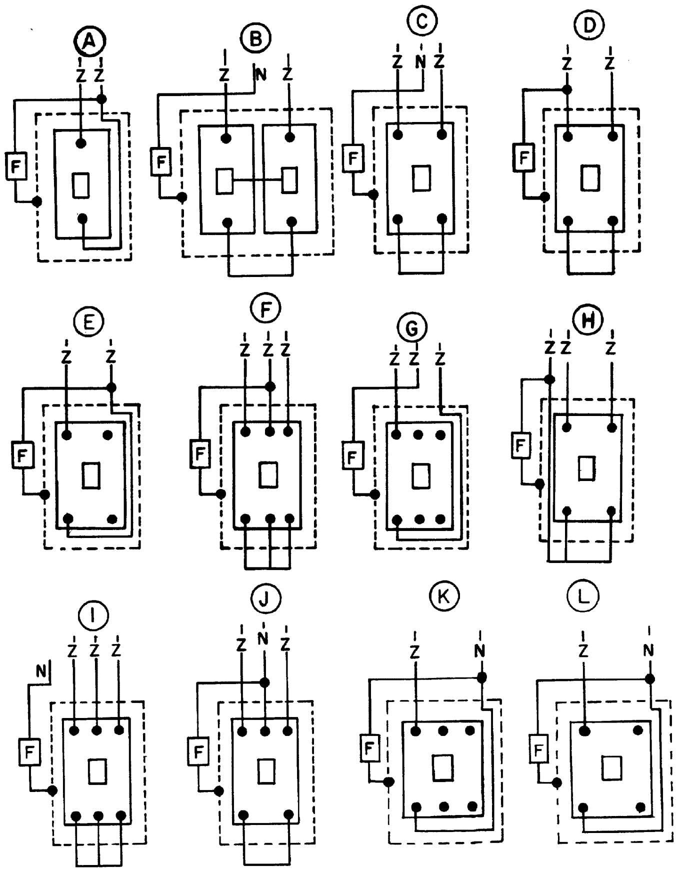
For insulation testing, LVPCBs, MCCBs, and ICCBs are subjected to a 2200 V ac dielectric withstand voltage test, or an equivalent dc test, when new.

Table 3-4—MCCB and ICCB interrupting ability operations [a, b]

Poles	Frame rating	Circuit-breaker ac voltage rating	Letters indicate diagram in Figure 21.1 of UL 489-1994						Total number of operations
			Operations of each pole			Common operations			
—	—	—	O	CO	O	O	CO	O	—
—	—	—	—	—	—	—	—	—	—
1	All	120, 240, 277, 347, 480, or 600	A	A	A	—	—	—	3
1	All	120/240 (tested in pairs)	—	—	—	B	B	B	3
2	All	240, 480, or 600	E	E	—	D	—	—	5
2	All	120/240	—	—	—	C	C	C	3
2	0–1200 A	480Y/277 or 600Y/347	L	L	—	C	—	—	5
2	All	1ϕ—3ϕ	E	E	—	H	—	—	5
3	0–1200 A	240, 480, or 600	G	G	—	F	—	—	7
3	1201–Up	240, 480, or 600	G	G	—	F	—	—	7
3	All	120/240	—	—	—	J	J	J	3
3	0–1200 A	480Y/277, 600Y/347	K	K	—	I	—	—	7
3	1200–Up	480Y/277, 600Y/347	K	K	—	I	—	—	7

[a] For the 125/250 V dc rating, the number of operations is the same as for the 120/240 V ac rating. For the 250 V dc rating, the number of operations is the same as for the 240 V ac rating.

[b] Reprinted from: Table 22.1 of UL 489-1994.



N — Neutral
Z — Limiting Impedance
F — 30 A "ground" Fuse — Enclosure

Reprinted from: Figure 22.1 of UL 489-1994.

Figure 3-1—Interrupting ability test ability diagrams

3.13 Frequency rating and considerations

In the United States, MCCBs, ICCBs, and LVPCBs are all basically rated for 60 Hz operation. Whenever they are capable of being applied at other frequencies, they are marked to indicate those other frequencies. For operation at any frequency not specifically indicated as applicable, the manufacturer should be consulted. Sometimes no changes are required in performance specifications. Sometimes it may simply be necessary to recalibrate a circuit-breaker trip unit for operation at the new frequency. Other times, for application at both lower or higher frequencies or for dc, a different trip unit may have to be used or the circuit breaker may have to be de-rated. Occasionally, application of a given circuit breaker might have to be absolutely prohibited at another frequency or dc.

At higher frequencies, the phenomena of eddy currents and skin effect have significance. They affect circuit-breaker components such as the primary current-carrying conductors or the iron cores of sensors and/or accessory devices. The extent of their effects on operation determines whether a given circuit breaker can be de-rated for use or cannot be used at all at higher frequency. At lower frequencies or dc, the method of current sensing may dictate whether a given circuit breaker can or cannot be used. Obviously, a circuit breaker using transformer action for current sensing in its trip unit cannot be used for dc applications.

3.14 Temperature considerations

Temperature affects circuit-breaker operation in that below some limiting low temperature, mechanism operation will not be reliable due to possible freezing of condensation inside the circuit breaker, freezing of lubricants, and/or mechanical interference effects caused by changes in physical dimensions of components. Also, physical properties of materials may change. With extreme cold, some materials might tend toward brittleness. Temperature also affects circuit-breaker operation in that above some limiting high temperature, the mechanism operation will not be reliable because the physical or electrical strength limits of some materials may be reduced to marginal levels. Some materials can begin to melt, and the useful life of insulation will be seriously reduced. Each of these factors should be considered in detail by the circuit-breaker designer and taken into account by the application engineer.

Total temperatures to which some insulating materials in LVPCBs may be subjected are listed in Table 3-5. These data are used by circuit-breaker designers. Users of circuit breakers need only ensure that operation of the complete equipment will take place within the maximum and minimum limiting ambient temperatures.

The standard operating ambient temperature range for MCCBs and ICCBs is –5 °C to +40 °C (23 °F to 104 °F). The standard operating ambient temperature range for LVPCBs is also –5 °C to +40 °C (23 °F to 104 °F), but IEEE Std C37.20.1™-1993 permits the temperature of the cooling air surrounding the enclosure of low-voltage switchgear to be within the range of –30 °C to +40 °C (–22 °F to +104 °F).

Since circuit breakers applied in temperatures outside their operating ranges may malfunction, the user should provide the operating conditions required to keep the temperature surrounding the assemblies and circuit breakers in their safe operating range. Sometimes it will mean that space heaters are required inside an enclosure to prevent condensation. Other times, special enclosures will be required not only for temperature control, but also possibly for environmental protection against contamination by particulate matter, liquids, or gas vapors. When extreme cold or hot ambient conditions are possible, the addition of separate heating or air cooling systems is necessary.

Table 3-5—Limits of temperature in circuit-breaker components [c]

	Limit of temperature rise over air surrounding enclosure (°C)	Limit of total temperature (°C)
Class 90 insulation	50	90
Class 105 insulation	65	105
Class 130 insulation	90	130
Class 166 insulation	115	155
Class 180 insulation	140	180
Class 220 insulation	180	220
Circuit-breaker contacts, conducting joints, and other parts (except the following)	85	125
Fuse terminals	See Footnote a	See Footnote a
Series coils with over class 220 insulation or bare	See Footnote a	See Footnote a
Terminal connections	55	95

[a] No specified limit except not to damage adjacent parts.

[b] Terminal connection temperatures are based on connections to bus in low-voltage metal-enclosed switchgear. If connections are made to cables, recognition must be given to possible thermal limitations of the cable insulation and appropriate measures must be taken.

[c] Source: IEEE Std C37.13-1995.

Sometimes forced ventilation alone can be sufficient to transfer enough heat to maintain an acceptable temperature, and therefore, the use of increased forced air flow rather than the addition of air cooling equipment can be of economic advantage. When ventilating fans are used to establish current-carrying capability, it should be remembered that the current-carrying capability so obtained is now dependent on the operation of the fans, and fan performance may need monitoring.

Any necessary separate heating or air cooling equipment that is required for an application should be provided in the system design. It should be kept in mind that this equipment can be costly, can be heavy, and will occupy space. However, to obtain design life operation of switchgear and circuit breakers, ambient temperature limitations should be observed.

3.15 Enclosure considerations

All circuit breakers are fully rated for operation in free air at their listed maximum ambient temperature. All LVPCBs are applied in enclosures and all are fully rated for operation in their design enclosures with maximum design ambient temperature. LVPCBs are therefore said to be 100% rated. Some MCCBs are also 100% rated.

The requirements for 100% rating of MCCBs are given in paragraph 19.25 of UL 489-1994. Parts of some pertinent details concerning 100% rating are as follows:

a) "A circuit breaker may be rated for continuous operation at 100% of its ampere rating if it (1) is of a frame size rated 250 A or more or a multi-pole type of any ampere rating and rated higher than 250 V..."

b) The candidate circuit breaker is tested for compliance with the 100% rating criteria in "an enclosure that is representative of the smallest enclosure with which the circuit breaker is likely to be used."

c) For compliance, "The temperatures of the insulating materials used in the circuit breaker shall not exceed the limits for the material involved," and "The temperature rises (1) where connections are made to external bus bars, when bus bars are used; or (2) on a wiring terminal at a point to which the insulation of a wire is brought up... shall not exceed 60 °C (140 °F)..."

When the total terminal temperature in contact with insulation is 90 °C (194 °F), then a 90 °C (194 °F) rated conductor should be used. The minimum enclosure size for 100% rated application of MCCBs is indicated on the instruction sheet furnished with the circuit breaker and on the circuit breaker nameplate.

MCCBs that are not 100% rated are capable of operation in an enclosure at their rated maximum temperature at 80% of their free air current rating. Effective de-rating to 80% in application results from NEC rules stating that (1) the circuit must be wired for and the rating of the overload device shall not be less than the noncontinuous load plus 125% of the continuous load and that the circuit must be wired for 125% of full load ampacity, and (2) the circuit breaker must be applied according to the ampacity of the circuit. NEC Section 215.3, Exception #1 points out that the circuit-breaker rating should not be less than the non-continuous load plus 125% of the continuous load. Even with all continuous load, this results in the circuit breaker effectively being applied at no more than 80% of conductor ampacity or 80% of its own free air current rating.

NEC rules account for the application of 100% rated MCCBs by stating that

> Where the assembly, including the over current devices protecting the feeder(s), is listed for operation at 100 percent of its rating, the allowable ampacity of the feeder conductors shall be permitted to be not less than the sum of the continuous load plus the noncontinuous load.

Because circuit breakers are tested and rated to account for these factors, engineers should be aware of all aspects of the application and installation environment and specify circuit breakers tested to satisfy all of them.

3.16 Cable, wire, and conductor considerations

The type, size, strand configuration, and compression of cable or wire conductor intended to be connected to a circuit breaker is an important application consideration and should satisfy at least two size requirements. First, the NEC requirement for load-carrying ability states that feeder conductors shall have sufficient ampacity to supply the load served. Rules of the NEC should be followed to establish the minimum acceptable wire size for the circuit. Second, if the 75 °C rated wire size of Table 3-6 is not used for the circuit, then it should be used in the last 4 ft of the circuit to satisfy the circuit breaker requirements. To satisfy voltage drop requirements, the circuit conductors might be sized a little larger, but they must always be able to fit into the circuit breaker connectors. They can never be sized a little smaller. Circuit-breaker conductors also serve as conductive heat sinks for the circuit breaker. It is for the heat sinking requirement that the conductors should have a minimum cross-sectional conductor area equal to the cross-sectional conductor area of the 75 °C (167 °F) rated wire specified in Table 3-6 for a given terminal current. The wire insulation temperature rating should, of course, match the application.

Even though MCCBs are designed to operate in a 40 °C (104 °F) maximum ambient, the operating ambient temperature is not always 40 °C (104 °F). UL 489-1994 allows for the surface of conductor insulation to rise 35 °C (rise 63 °F) above the normal ambient, which might be 25 °C (77 °F), a common normal room temperature, giving a total temperature of 60 °C (140 °F). With the maximum permissible rise of 50 °C (90 °F rise) on the terminals during temperature test, and again with a 25 °C (77 °F) ambient, the total temperature would be 75 °C (167 °F). These numbers are the basis for the 60 °C or 75 °C or 60 °C/75 °C conductor insulation ratings specified for the conductors used with MCCBs rated 125 A or less. For MCCBs rated greater than 125 A, the 75 °C conductor insulation rating is normal (called rated wire). When an MCCB is 100% rated, the maximum permissible terminal temperature rise during test is 65 °C (117 °F rise). When added to a 25 °C (77 °F) ambient, the total is 90 °C (194 °F). UL 489-1994 rules require that if the terminal temperature rise during 100% rating test exceeds 50 °C (90 °F rise), then the circuit breaker should be marked "For use with 90 °C (194 °F) wire and the wire size." The nameplate, in that case, would be marked accordingly.

Designers may want to use smaller, higher temperature rated wire. The application engineer should remember that when 90 °C (194 °F) insulated conductor is specified for a given ampacity, the cross-sectional area of the metal conductor inside the 90 °C (194 °F) rated insulation will generally be smaller than the cross-sectional area of the normal 75 °C (167 °F) rated conductor that was used to proof test the circuit breakers. If it is smaller, it will not be able to provide sufficient heat sinking capacity for normal circuit-breaker performance and should not be used. Therefore, conductors connected to circuit breakers should always have a cross-sectional area equal to at least that of the 75 °C (167 °F) rated conductor specified for the application.

A properly sized conductor, in addition to having sufficient ampacity, will also be stranded to satisfy the requirements of the circuit-breaker terminals or connectors. It will have a sufficient cross section to adequately heat sink the circuit breaker, it will be insulated for the temperature conditions existing in all spaces through which it will pass, and it will be able to withstand fault-interrupting forces and temperature changes without experiencing inordinate damage. Circuit breakers are tested with a rated conductor to prove these capabilities. Therefore, the rated wire size is sufficient for normal operation.

Many operating problems with circuit breakers start at the terminals. Therefore, all connectors used to connect conductors to circuit breakers at both the line side and the load side should be properly matched for size, material, and temperature rating, and it should always be confirmed that they fit the circuit-breaker terminals, that they are clean, properly coated with anti-oxidants when required and that they are torqued properly when installed. The connectors should be able to firmly hold the conductors in place against the forces that are imposed on them during short circuits. Standard interruption tests prove they can. It may be necessary to rope-tie conductors into place in some cases. When this approach is necessary, instruction sheets describe how it is to be done. The number of strands making up stranded conductor is an important factor in how well connectors can hold conductors against magnetic forces. See Table 8 of Chapter 9 of the NEC for a listing of normal conductor stranding to be used for circuit-breaker wiring, and see the notes below that table. The NEC requires stranding for conductors of size 8 AWG and larger.

Note that very flexible, finely stranded conductor, sometimes called welding cable, should not be used unless the connector is designed for it because the fine stranding is difficult or impossible to constrain under some standard terminal clamps. Sometimes the fine strands squeeze out from under the clamp, gradually loosening the connection. At the other extreme, conductors with fewer strands, but not compressed, can sometimes be tightly held with the first tightening, but as the conductor goes through heat expansion and contraction cycles or if the conductor is forced to move physically, the strands can rearrange themselves under the clamp, again resulting in a loose connection. Nothing could be worse for a circuit breaker. The higher resistance of loose conductors generates excess heat with rated current flow. The connectors specified by the manufacturer of the circuit breaker should be used because they are the ones used in proof testing. For more information on connectors and conductors, the interested reader is referred to the UL 486 series of standards on connectors (UL 486A-1991 [B14], UL 486B-1991 [B15], UL 486C-1991 [B16], UL 486D-1993 [B17], and UL 486E-1994 [B18]).

These factors affect circuit-breaker operating temperature and are as important as ampacity. They are taken into account in the design and proof testing of circuit breakers.

As referred to previously, UL 489-1994 requires in paragraph 49.30 that

> A circuit breaker, circuit breaker frame or interchangeable trip unit rated 125 A or less shall be marked as being suitable for 60 °C(140 °F), 75 °C (167 °F) only or 60/ 75 °C (140/167 °F) wire.

The UL listed wire size and type should be used. Table 3-6 lists “rated wire sizes” for the various terminal currents or circuit currents. For proper circuit-breaker application, these wire sizes are a necessity. They are the sizes used in proof testing of circuit-breaker designs.

Table 3-6—Terminal current and conductor size [d]

Terminal current (A)[a]	Copper conductor			Aluminum or copper-clad aluminum conductor		
	No. of conductors	Size (AWG or kcmil)		No. of conductors	Size (AWG or kcmil)	
		60 °C	75 °C		60 °C	75 °C
15 or less	1	14	14	1	12	12
20	1	12	12	1	10	10
25	1	10	10	1	10	10
30	1	10	10	1	8	8
40	1	8	8	1	6	8
50	1	6	6	1	4	6
60	1	4	6	1	3	4
70	1	4	4	1	2	3
80	1	3	4	1	1	2
90	1	2	3	1	1/0	2
100	1	1	3	1	1/0	1
110	1	1	2	1	—	1/0
125	1	1/0	1	1	—	2/0
150	1	—	1/0	1	—	3/0
175	1	—	2/0	1	—	4/0
200	1	—	3/0	1	—	250
225	1	—	4/0	1	—	300
250	1	—	250	1	—	350
275	1	—	300	1	—	500
300	1	—	350	1	—	500
325	1	—	400	2	—	4/0
350	1	—	500	2	—	4/0
400	2	—	3/0	2	—	250
	1[c]	—	500	1[c]	—	750
450	2	—	4/0	2	—	300
500	2	—	250	2	—	350
550	2	—	300	2	—	500
600	2	—	350	2	—	500
700	2	—	500	3	—	350

Table 3-6—Terminal current and conductor size *(continued)*[d]

Terminal current (A)[a]	Copper conductor			Aluminum or copper-clad aluminum conductor		
	No. of conductors	Size (AWG or kcmil)		No. of conductors	Size (AWG or kcmil)	
		60 °C	75 °C		60 °C	75 °C
800	3	—	300	3	—	400
1000	3	—	400	4	—	350 600
1200	4 3	—	350 500	4	—	500
1400	4	—	500	5	—	500
1600	5 4	—	400 600	5	—	600
2000	5	—	400 600	6	—	600
2500	8 7 6	—	400 500 600	8 7 9	—	600 750 500
3000	9 8 7	—	400 500 600	10 9 8	—	500 600 750
4000	12 11 10	—	400 500 600	13 12 11	—	500 600 750
5000[b]	15 13 12	—	400 500 600	16 15 13	—	500 600 750
6000[b]	18 16 15	—	400 500 600	19 18 16	—	500 600 750

[a] For a terminal current other than that indicated, the next higher rating is to be used (e.g., if rated 35 A, enter at 40 A).

[b] Circuit breakers rated at more than 4000 A are to be considered as being bus- or cable-connected unless indicated otherwise in marking.

[c] See 13.19 of UL 489-1994.

[d] Reprinted from: Table 9.1 of UL 489-1994.

Maintenance personnel should remember that when a fault occurs, the conductors should be inspected for damage, and all damaged components should be repaired or replaced before reclosing the circuit breaker.

In summary, all conductors intended to be connected to circuit breakers should start with the size of the 75 °C conductor used to establish their rating. They should

a) Be rated to carry the required maximum full-load current.

b) Be large enough to limit voltage drop to an acceptable application level.

c) Be large enough to withstand circuit-breaker fault interruption let-through current.

d) Be small enough to fit into the circuit-breaker connectors where they can be held tightly in place during a fault.

e) Be insulated for the rated system voltage.

f) Be of the correct stranding and construction to permit proper torquing.

g) Have an insulation temperature rating and composition suitable for the total application.

h) Be coated with the proper anti-oxidant whenever required, i.e., aluminum conductor terminations.

Testing with wire confirms these considerations.

3.17 De-rating for ambient temperature

MCCBs, ICCBs, and LVPCBs all should be de-rated for their current-carrying capacity when operated in ambient temperatures above their rated maximum. The manufacturer of the circuit breaker should be consulted for the applicable de-rating information for a particular unit. There are formulas for calculation of current de-rating that are based on simplifying assumptions and empirical factors. These formulas should be used with discretion.

For LVPCBs and ICCBs, formula 8.4.1 of IEEE Std C37.20.1™-1993 can be used to determine a continuous-load current capability based on actual ambient temperature, as shown in Equation (3.1):

$$I_a = I_r\left[\frac{\theta_{max} - \theta_a}{\theta_r}\right]^{1/2.0} \tag{3.1}$$

where

I_a is the allowable de-rated current (A) (never to be more than two times I_r)

I_r is the rated continuous current (A)

θ_{max} is the allowable hottest spot total temperature = (θ_r + 40 °C)

θ_a is the actual ambient temperature (°C) expected

θ_r is the allowable hottest spot temperature rise (°C) at rated current

The specifying engineer should always refer to the manufacturer for the best possible guidance in de-rating.

For MCCBs using bimetallic overload trips, it is best to consult the manufacturer's temperature de-rating tables for the particular circuit breaker of interest because different bimetallic pairs operate at different temperatures. Obviously, trip mechanism designs and calibration methods can vary. However, the following general guidelines can be used to make rough estimates of expected thermal performance capability. Assuming temperature rise proportional to current squared, and taking the ratio of a known condition to an unknown condition, de-rated current can be solved as shown in Equation (3.2):

$$I_2 = I_1\sqrt{(T_2 - A_2)/(T_1 - A_1)} \tag{3.2}$$

where

T_1 is the circuit breaker bimetallic element temperature, or the total terminal temperature for electronically tripped circuit breakers (°C) at rated current of I_1 amperes with rated ambient temperature A_1 °C

T_2 is assumed to remain approximately the same as T_1, not being too much affected by the practical difference in ambient temperatures

A_2 is the new ambient temperature (°C)

I_2 is an estimate of the current the circuit breaker is likely to be able to carry in an ambient temperature of A_2 °C

Equation (3.2) does not take into account any built-in compensation and as suggested can even be used to estimate thermal de-rating of electronically tripped circuit breakers by using the total terminal temperature for T_1 and T_2. For example, assuming a 50 °C (90 °F) terminal rise over a 40 °C (104 °F) ambient for a total temperature of 90 °C (194 °F) gives $T_1 = T_2 = 90$ °C (194 °F) for rough estimating. The engineer should know the internal temperatures more accurately to reproduce manufacturer's de-rating data, but in the absence of manufacturer's data, Equation (3.2) gives some guidance.

It should be remembered that the properties of the materials used in the construction of circuit-breaker components determine the maximum limiting temperature allowable for any given circuit breaker, and they therefore determine the amount of de-rating necessary for any given over-temperature condition. Temperature limitations on current transformers, for example, can be more restrictive than limitations on the circuit breaker. And the properties of materials used in different circuit breakers can be different even when circuit breakers are similar in rating.

3.18 Circuit-breaker humidity limitations

The effect of humidity on any circuit breaker is a function of temperature. NEMA AB 1-1993 sets an operating limit on relative humidity in clean air at a level of not more than 50% at a maximum temperature of 40 °C. However, it recognizes that a higher level of as much as 90% relative humidity at a lower temperature of 20 °C could be satisfactory as long as consideration is given to the fact that moderate condensation is possible.

The detrimental effects of condensation are multiplied when water-soluble contaminants can also be present inside an enclosure. NEMA standardized enclosure types are available for various application conditions. When condensation is known to be possible in the application area, the circuit-breaker enclosures should at least be equipped with space heaters intended to prevent internal condensation by heating the air a small amount and allowing gravity to keep the internal air in motion.

3.19 Circuit-breaker altitude limitations

The altitude of an installation is important because, as altitude increases, atmospheric pressure and air density decrease. The reduced insulation and heat transfer properties of less dense air require that circuit breakers be de-rated for voltage withstand and current-carrying capacity as a function of altitude, assuming the temperature remains constant. But temperature typically goes down with an increase in altitude so current de-rating tends to be compensated for, to some degree, naturally. However, voltage withstand capability is essentially unaffected by lower temperature, so a voltage correction factor for altitude is applied.

MCCBs and ICCBs should be de-rated for voltage, current-carrying capacity, and sometimes interrupting capacity, when applied at or above 1830 m (6000 ft) above mean sea level.

LVPCBs should be de-rated when applied at or above 2000 m (6600 ft) above mean sea level. Table 3-7, taken from IEEE Std C37.13-1995, lists the specific altitude rating correction factors for LVPCBs. The manufacturers of MCCBs and ICCBs should be consulted for specific information on de-rating for altitude. Please note that altitude correction factors for LVPCBs and Metal-Enclosed Switchgear are under review with the IEEE Switchgear Committee at the time of this printing, and the correction factors stated in this standard should be used with caution.

Table 3-7—Altitude rating correction factors[a]

Altitude		**Rated continuous current**	**Rated voltage**
(ft)	**(m)**		
6600 and below	2000 and below	1.00	1.00
8500	2600	0.99	0.95
13 000	3900	0.96	0.80
NOTE—Values for intermediate altitudes may be derived by linear interpolation.			

[a] Source: Table 4 of IEEE Std C37.13-1995.

There are few test sites in the world where actual altitude testing can be performed, and simulated altitude test facilities are few and far between. Instead, test voltage levels adjusted for the normal altitude conditions of the manufacturing site are used to test insulation integrity, and if necessary, rules based on theory and confirmed by experience are applied to answer practical interruption performance questions. The theoretical guidelines established for this purpose have proven to be quite satisfactory in application.

3.20 Circuit-breaker ampere rating

MCCB ampere ratings are characterized by a very wide range, starting with the smallest single-pole lighting circuit breakers and ending with ratings shared by the largest LVPCBs. ICCB ampere ratings tend to be toward the high end of the MCCB range. LVPCB ampere ratings overlap a wide range of both MCCB and ICCB ratings, with the smallest power circuit-breaker ratings in the neighborhood of a few hundreds of amperes.

Within a circuit-breaker frame size, whenever trip units are interchangeable, the trip unit chosen determines the ampere rating of a particular circuit breaker. The trip units may be magnetic-only, thermal-magnetic, or electronic. In recent years, specialized high-technology trip units have been designed in packages that make them suitable for application in a number of the larger frame size circuit breakers of all three types.

3.21 National Electrical Code considerations

Article 240 of the NEC, entitled "Overcurrent Protection," gives guidance to the application engineer and the circuit-breaker designer. Section 240-4 of the NEC states that "Conductors, other than flexible cords and fixture wires, shall be protected against overcurrent in accordance with their ampacities as specified in Section 310-15...." Circuit-breaker tests with wire and bus prove that circuit breakers can protect conductors. Standard wire ampacities are therefore of interest to the systems engineer and the circuit-breaker designer when deciding on ampere ratings. Since the circuit breaker should protect the conductors, the choice of circuit breaker and conductor are related. When circuit breakers have trip units that fit into a single large frame, the following NEC consideration can be important to the circuit-breaker and trip unit choice.

> The ampere rating of a circuit breaker is described in NEC 240.6, which lists the standard ampere ratings to be considered and further states in part (B) 'The rating of adjustable-trip circuit breakers having external means for adjusting the current setting (long-time pickup setting), not meeting the requirements of 240.6(C), shall be the maximum setting possible. This ruling could affect project economics were it not for part (C) to the rule. Without part (C), the rule would require wiring to be for the maximum circuit breaker trip level instead of for the maximum load current.

The exception to the rule, Part (C), states that "A circuit breaker(s) that has restricted access to the adjusting means shall be permitted to have an ampere rating(s) that is equal to the adjusted current setting (long-time pickup setting). Restricted access shall be defined as located behind one of the following:

1) Removable and sealable covers over the adjusting means
2) Bolted equipment enclosure doors
3) Locked doors accessible only to qualified personnel"

This exception gives the circuit-breaker design engineer and the power system design engineer some latitude to affect power system economics. A simple feature like the provision of a sealable cover for the circuit-breaker trip unit will allow a larger frame circuit breaker to be applied on a smaller ampacity circuit with the correct overload ampere trip setting. This feature makes it possible to keep the conductor size proportional to the circuit ampacity, thereby reducing the cost of the circuit conductors required, and it makes possible the realization of economic benefits in commonality in the type of circuit breakers used and in the stocking of spares. Circuit-breaker testing with different trip units make this possible.

NEC rules apply to all types of circuit breakers and are consistent with the primary purpose of these rules and the exception (i.e., to protect the wire or bus and to do so safely); all circuit breakers are tested with rated wire or bus. This safety code provision recognizes the efficacy of circuit-breaker test methods and offers the benefits of this demonstrated circuit-breaker capability to users.

3.22 Preferred current ratings

The preferred frame sizes for MCCBs and ICCBs are listed in the first column of Table 3-2. Frame sizes for LVPCBs are listed in column 5 of Table 3-8 and Table 3-9. It is from these lists that circuit-breaker frame sizes are chosen. Table 3-10 indicates the preferred ratings for LVPCBs that are integrally fused and use instantaneous direct-acting phase trip elements.

Table 3-8—Current ratings for low-voltage ac power circuit breakers with instantaneous direct-acting phase trip elements [c]

Line no.	System nominal voltage (V)	Rated maximum voltage (V)	Insulation (dielectric) withstand (V)	Three-phase short-circuit current rating (symmetrical A)[a]	Frame size (A)	Range of trip-device current ratings (A)[b]
	Col 1	**Col 2**	**Col 3**	**Col 4**	**Col 5**	**Col 6**
1	600	635	2200	14 000	225	40–225
2	600	635	2200	22 000	600	40–600
3	600	635	2200	22 000	800	100–800
4	600	635	2200	42 000	1600	200–1600
5	600	635	2200	42 000	2000	200–2000
6	600	635	2200	65 000	3000	2000–3000
7	600	635	2200	65 000	3200	2000–3200
8	600	635	2200	85 000	4000	4000
9	480	508	2200	22 000	225	40–225
10	480	508	2200	30 000	600	100–600
11	480	508	2200	30 000	800	100–800

Table 3-8—Current ratings for low-voltage ac power circuit breakers with instantaneous direct-acting phase trip elements *(continued)*[c]

Line no.	System nominal voltage (V)	Rated maximum voltage (V)	Insulation (dielectric) withstand (V)	Three-phase short-circuit current rating (symmetrical A)[a]	Frame size (A)	Range of trip-device current ratings (A)[b]
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6
12	480	508	2200	50 000	1600	400–1600
13	480	508	2200	50 000	2000	400–2000
14	480	508	2200	65 000	3000	2000–3000
15	480	508	2200	65 000	3200	2000–3200
16	480	508	2200	85 000	4000	4000
17	240	254	2200	25 000	225	40–225
18	240	254	2200	42 000	600	150–600
19	240	254	2200	42 000	800	150–800
20	240	254	2200	65 000	1600	600–1600
21	240	254	2200	65 000	2000	600–2000
22	240	254	2200	85 000	3000	2000–3000
23	240	254	2200	85 000	3200	2000–3200
24	240	254	2200	130 000	4000	4000

[a] Ratings in this column are root-mean-square (rms) symmetrical values for single-phase (two-pole) circuit breakers and three-phase average rms symmetrical values of three-phase (three-pole) circuit breakers. When applied on systems where rated maximum voltage may appear across a single pole, the short-circuit current ratings are 87% of those values. See 5.6 of IEEE Std C37.13-1995.

[b] For preferred trip-device current ratings, see Table 22 of ANSI C37.16-1997. Note that the continuous-current-carrying capability of some circuit-breaker trip device combinations may be higher than the trip device current rating. See 10.1.3 of IEEE Std C37.13-1995.

[c] Reprinted from: Table 1 of ANSI C37.16-1997.

Table 3-11 lists standard ampere ratings taken from NEC Section 240-6.

Circuit-breaker manufacturers design trip units for the various preferred ampere levels spanned by different frame sizes. All circuit breakers are tested with the various trip units installed to demonstrate both their time-current tripping characteristics and the circuit breaker's interrupting capability with that trip unit installed. The ability of a circuit breaker to protect rated cable or bus is demonstrated simultaneously because the test circuit is made up of a specified size bus or wire of "rated wire size." See the individual manufacturer's literature for available trip unit ampere ratings.

Table 3-12 lists the preferred trip-device current ratings or settings for LVPCBs.

Table 3-9—Preferred current ratings for LVPCBs without instantaneous direct-acting phase trip elements (short-time-delay element or remote relay)[d]

Line no.	System nominal voltage (V)	Rated maximum voltage (V)	Insulation (dielectric) withstand (V)	Three-phase short-circuit current rating or short-time current rating (symmetrical A)[a, b]	Frame size (A)	Range of trip-device current ratings (A)[c] Setting of short-time-delay trip element		
						Minimum time band	Inter-mediate time band	Maximum time band
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8
1	600	635	2200	14 000	225	100–225	125–225	150–225
2	600	635	2200	22 000	600	175–600	200–600	250–600
3	600	635	2200	22 000	800	175–800	200–800	250–800
4	600	635	2200	42 000	1600	350–1600	400–1600	500–1600
5	600	635	2200	42 000	2000	350–2000	400–2000	500–2000
6	600	635	2200	65 000	3000	2000–3000	2000–3000	2000–3000
7	600	635	2200	65 000	3200	2000–3200	2000–3200	2000–3200
8	600	635	2200	85 000	4000	4000	4000	4000
9	480	508	2200	14 000	225	100–225	125–225	150–225
10	480	508	2200	22 000	600	175–600	200–600	250–600
11	480	508	2200	22 000	800	175–800	200–800	250–800
12	480	508	2200	42 000	1600	350–1600	400–1600	500–1600
13	480	508	2200	50 000	2000	350–2000	400–2000	500–2000

Table 3-9—Preferred current ratings for LVPCBs without instantaneous direct-acting phase trip elements (short-time-delay element or remote relay)[d] *(continued)*

Line no.	System nominal voltage (V)	Rated maximum voltage (V)	Insulation (dielectric) withstand (V)	Three-phase short-circuit current rating or short-time current rating (symmetrical A)[a, b]	Frame size (A)	Range of trip-device current ratings (A)[c] Setting of short-time-delay trip element		
						Minimum time band	**Inter-mediate time band**	**Maximum time band**
	Col 1	**Col 2**	**Col 3**	**Col 4**	**Col 5**	**Col 6**	**Col 7**	**Col 8**
14	480	508	2200	65 000	3000	2000–3000	2000–3000	2000–3000
15	480	508	2200	65 000	3200	2000–3200	2000–3200	2000–3200
16	480	508	2200	85 000	4000	4000	4000	4000
17	240	254	2200	14 000	225	100–225	125–225	150–225
18	240	254	2200	22 000	600	175–600	200–600	250–600
19	240	254	2200	22 000	800	175–800	200–800	250–800
20	240	254	2200	42 000	1600	350–1600	400–1600	500–1600
21	240	254	2200	50 000	2000	350–2000	400—2000	500–2000

Table 3-9—Preferred current ratings for LVPCBs without instantaneous direct-acting phase trip elements (short-time-delay element or remote relay)[d] *(continued)*

Line no.	System nominal voltage (V)	Rated maximum voltage (V)	Insulation (dielectric) withstand (V)	Three-phase short-circuit current rating or short-time current rating (symmetrical A)[a, b]	Frame size (A)	Range of trip-device current ratings (A)[c] Setting of short-time-delay trip element: Minimum time band	Inter-mediate time band	Maximum time band
	Col 1	**Col 2**	**Col 3**	**Col 4**	**Col 5**	**Col 6**	**Col 7**	**Col 8**
22	240	254	2200	65 000	3000	2000–3000	2000–3000	2000–3000
23	240	254	2200	65 000	3200	2000–3200	2000–3200	2000–3200
24	240	254	2200	85 000	4000	4000	4000	4000

[a] Short-circuit current ratings for breakers without direct-acting trip devices, opened by a remote relay, are the same as those listed here.

[b] Ratings in this column are rms symmetrical values for single-phase (two-pole) circuit breakers and three-phase average rms symmetrical values of three-phase (three-pole) circuit breakers. When applied on systems where rated maximum voltage may appear across a single pole, the short-circuit current ratings are 87% of these values. See 5.6 of IEEE Std C37.13-1995.

[c] For preferred trip-device current ratings, see Table 22 of ANSI C37.16-1997. Note that the continuous-current capability of some circuit-breaker trip-device combinations may be higher than the trip-device current rating. See 10.1.3 of IEEE Std C37.13-1995.

[d] Reprinted from: Table 2 of ANSI C37.16-1997.

Table 3-10—Preferred ratings for LVPCBs integrally fused with instantaneous direct-acting phase trip elements[f]

Line No.	Circuit-breaker frame size (A)[a]	Rated maximum voltage (V)[b]	Insulation (dielectric) withstand (V)	Three-phase short-circuit current rating (symmetrical A)[c]	Range of Continuous-current rating (A)	
					Range of trip-device current ratings (A)[d]	Maximum fuse rating[e]
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6
1	600	600	2200	200 000	125–600	24
2	800	600	2200	200 000	125–800	24
3	1600	600	2200	200 000	200–1600	24

[a] Two circuit-breaker frame ratings are used for integrally fused circuit breakers. The continuous-current rating of the integrally fused circuit breaker is determined by the rating of either the direct-acting trip device or the current-limiting fuse applied to a particular circuit-breaker frame rating, whichever is smaller.

[b] Listed values are limited by the standard voltage rating of the fuse.

[c] Ratings in this column are rms symmetrical values for single-phase (two-pole) circuit breakers and three-phase average rms symmetrical values of three-phase (three-pole) circuit breakers. When applied on systems where rated maximum voltage may appear across a single pole, the short-circuit current ratings are 87% of these values. See 5.6 of IEEE Std C37.13-1995.

[d] For preferred trip-device current ratings, see Table 22 of ANSI C37.16-1997. Note that the continuous-current-carrying capability of some circuit-breaker trip-device combinations may be higher than the trip-device current rating. See 10.1.3 of IEEE Std C37.13-1995. Lower rated trip-device current ratings may be used when the fuse size is small or the available current is low, or both. Consult the manufacturer.

[e] Fuse current ratings may be 300 A, 400 A, 600 A, 800 A, 1000 A, 1200 A, 1600 A, 2000 A, 2500 A, and 3000 A. Fuses are of the current-limiting type.

[f] Reprinted from: Table 17 of ANSI C37.16-1997.

Table 3-11—Standard ampere ratings for inverse-time circuit breakers[a]

15	70	225	1000
20	80	250	1200
25	90	300	1600
30	100	350	2000
35	110	400	2500
40	125	500	3000
45	150	600	4000
50	175	700	5000
60	200	800	6000

[a] Reprinted from: Section 240-6 of the NEC.

Table 3-12—Preferred trip device current ratings or settings for LVPCBs (in amperes)[a, b, d]

40	225	1000
50	250	1200
70	300	1600
90	350	2000
100	400	2500
125	500	3000/3200
150	600	4000
175	800	5000 [c]
200		6000

[a] Where these exact ratings are not available in solid-state trip devices, they may be closely approximated by the pickup setting of the long-time delay element.

[b] See Tables 1, 2, 8, and 17 of ANSI C37.16-1997 for range of trip-device current ratings by circuit-breaker frame size.

[c] These values are for dc circuit breakers only.

[d] Reprinted from: Table 22 of ANSI C37.16-1997.

3.23 Load effects

Continuous-current ratings required of circuit breakers can be affected by the characteristics of the loads being served. Harmonics in nonlinear loads and high, short-time inrush loads like those of tungsten filament lamps and premium-efficiency motors and transformers at startup can affect the circuit-breaker contacts or trip circuit logic. These load effects are applicable to all circuit breakers both in their thermal effect on the circuit breaker and in their effect on the functioning of instantaneous trip units. Tungsten filament lamp rating, heating and air conditioning rating (HACR), and high-intensity-discharge (HID) rating, for example, are specially tested load ratings. NEC rule changes allow for higher instantaneous trip levels for premium-efficiency motors.

3.24 The effect of nonlinear loads on circuit breakers

Although capacitor banks do not generate harmonic currents, they are low-impedance sinks for power system harmonic currents. Regardless of where the harmonic currents originate, if they flow into a capacitor bank, they do so by flowing through the associated circuit breaker or fuse controlling the capacitor bank. Modern drives and controls using electronic power-switching devices generate harmonic currents that propagate throughout the power system as a function of the impedances of the various paths. To provide adequate thermal protection for capacitor banks, circuit-breaker trip units should be able to respond adequately to rms power regardless of harmonic content. For more information on the subject of harmonics, the reader is referred to IEEE Std 519™. Bimetallic thermal elements respond to rms directly through the heat produced in them, and newer electronic trip units have been designed with sampling algorithms to provide rms current sensing in the presence of harmonics. For more information on capacitor bank applications in particular, refer to NEMA CP 1-2000.

Resistance welding applications can also generate harmonics. Rapid rises in current followed by sharp cutoffs constitute non-sinusoidal current waveform during a welding operation. The nominal load level is the average of the rms peaks and valleys over a period of time. The duty cycle of a process, even with sinusoidal waveform, can also affect the required circuit-breaker rating. Refer to Article 630 III of the NEC for discussion about resistance welding applications. Load nonlinearity can affect circuit breakers through trip-unit sensitivity to current peaks as well as through circuit-breaker component heating. Test procedures do not currently include provisions to account for nonlinear load effects, but as such loads continue to proliferate, the effects of nonlinearity can be expected to become more noticeable on the power system and ultimately engineers can expect to be required to take them into account in testing procedures.

Many modern microprocessor-based signal processing trip units include a heating memory algorithm based on preceding current level history so they can take into account the heating effect of that current flow as do bimetallic elements and real utilization devices. With these capabilities, they can very adequately protect power circuits feeding nonlinear loads.

At this time there is no commonly accepted specification of a test waveform that microprocessor trip units should be able to sample and accurately quantify. However, circuit-breaker manufacturers have done extensive development testing to provide assurance that their digital sampling algorithms will work to the degree that they specify in their technical literature.

3.25 The effect of high inrush loads

If loads are cycled on and off or up and down in level or if motor plugging[3] is involved in an application, the current rating and type of circuit-breaker trip unit should be chosen carefully. It may be necessary to consult the manufacturer of any type of circuit breaker for guidance under these conditions. Large inrush current with potentially high offset peaks and longer duration high continuous-current flows accompanies these operations, making them unlike normal motor starting duty, and these operations may occur more frequently in a process. The response of the circuit-breaker trip unit to these higher currents and offsets and their heating effect on the circuit breaker should be evaluated. Such effects are considered in circuit-breaker overload testing.

3.26 Overload testing of circuit breakers

MCCBs, ICCBs, and LVPCBs are tested to interrupt overload current at 600% of rated current a given number of times. ICCB and MCCB minimum overload test current is 150 A. See Table 3-13 and Table 3-14. Table 3-15 and Table 3-16 summarize the overload testing parameters and indicate data for comparison.

The definitions of overcurrent and overload in Article 100 of the NEC can be helpful in understanding short-circuit interrupting and overload testing. It is important not to confuse these terms.

> *Overcurrent.* "Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload (see definition), short circuit, or ground fault."
>
> *Overload.* "Operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated capacity which, when it persists for a sufficient length of time, would cause damage or overheating. A fault, such as a short circuit or ground fault, is therefore not an overload."

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[3] Motor plugging is the process of reversing the polarity of dc motors or reversing the phase-rotation of ac motors and applying power to rapidly stop or change the speed and/or direction of the motor's coupled load.

Table 3-13—Overload test operations for MCCBs and ICCBs[a, h]

Number of operations			
Frame size (A)	**Close and open manually[b, c, d]**	**Close manually, open automatically**	**No. of cycles of operation/min**
50	35	15	6
100	35	15	6
125	60 [e]	— [e]	5
150	50 [e]	— [e]	5
200	50	—	5
225	50	—	5
400	50 [c]	—	4 [f]
600	50 [c]	—	4 [f]
800	50 [c]	—	1 [f]
1200	50 [c]	—	1 [f]
1600	50 [c]	—	1 [f]
2000	25 [c]	—	1 [f]
2500	25 [c]	—	1 [f]
3000	28 [g]	—	1 [g]
4000	28 [g]	—	1 [g]
5000	28 [g]	—	1 [g]
6000	28 [g]	—	1 [g]

[a] The operation may be performed by a machine simulating manual operation.

[b] If the test sample trips during manual operation, it is still considered manual operation.

[c] At the option of the manufacturer, the adjustable instantaneous response of a circuit breaker rated 400 A or more may be adjusted to less than the maximum position.

[d] The minimum closed time shall be one cycle, unless the sample trips.

[e] In the case of a multiple breaker without a common trip, rated at more than 100 A, 35 cycles of operations are to be made manually and 15 are to be made automatically as covered in 16.10 of UL 489-1994.

[f] Operations may be conducted in groups of 5, with 15 min maximum between groups.

[g] Three operations at 600% of current rating at the rate of 1 cycle/min, followed by 25 operations at 200% of current rating at the rate of 1 cycle/min may be conducted in groups of 5 with 15 min maximum between groups.

[h] Reprinted from: Table 16.1 of UL 489-1994.

Table 3-14—Overload switching requirements for low-voltage ac power circuit breakers[a]

Line no.	Circuit-breaker frame size (A)	No. of make-break operations
	Col 1	Col 2
1	225	50
2	600	50
3	800	50
4	1600	38
5	2000	38
6	3000	N/A
7	3200	N/A
8	4000	N/A

[a] Reprinted from: Table 3 of ANSI C37.16-1997.

Table 3-15—Overload performance test parameters[a, f]

Frame size (A)	Min operation rate (cycle/h)		No. of operating cycles					
			Opening manually		Opening automatically		Total	
	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989[b, c]	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989
100	360	—	35	—	15	—	50	—
150	300	—	50	—	—	—	50	—
225	300	60	50	50	—	—	50	50
400	240 [d]	—	50 [a]	—	—	—	50	—
600	240 [d]	60	50 [a]	50	—	—	50	50
800	60 [d]	60	50 [a]	50	—	—	50	50
1200	60 [d]	—	50 [a]	—	—	—	50	38
1600	60 [d]	—	50 [a]	38	—	—	50	38
2000	60 [d]	—	25 [a]	38	—	—	25	38
2500	60 [d]	—	25 [a]	—	—	—	25	—
3000	60 [d]	—	28 [a, e]	N/A	—	—	28	N/A

Table 3-15—Overload performance test parameters[a, f] *(continued)*

Frame size (A)	Min operation rate (cycle/h)		No. of operating cycles					
			Opening manually		Opening automatically		Total	
	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989[b, c]	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989
4000	60[d]	—	28 [a, e]	N/A	—	—	28	N/A
5000	60[d]	—	28 [a, e]	N/A	—	—	28	N/A

[a] At option of manufacturer, adjustable instantaneous may be set at less than maximum.
[b] Must carry current a minimum of one cycle.
[c] Circuit opened by separately operated shunt trip device.
[d] Operations may be in groups of 5 with 15 min maximum.
[e] Three operations at 600% followed by 25 at 200%.
[f] Reprinted from: “Panel Discussion on Application of Molded-Case Circuit Breakers” [B13].

Table 3-16—Overload test parameters[a]

Parameter	UL 489-1994	ANSI C37.50-1989
Enclosure	Smallest individual	Min dimension test enclosure
Current (ac) (dc)	6 × rated 6 × rated	6 × rated
Voltage	100–105% rated	100–105% rated max (254 V, 508 V, or 635 V)
Power factor (ac)	0.45–0.50	0.5
Time constant (dc)	3 ms min	Not covered
Frequency	48–62 Hz	48–72 Hz
Ambient	Not defined	Not defined
Ground fuse	30 A	30 A fuse or 10 AWG (copper)

[a] Reprinted from: "Panel Discussion on Application of Molded-Case Circuit Breakers" [B13].

3.27 Forced-air cooling of LVPCBs

In the case of LVPCBs, forced-air cooling may be used as an option to obtain additional continuous-current-carrying capacity. Although a system might be intentionally designed to use forced-air cooling, it is most likely that this approach would be decided on as a backup contingency only because the ability of the circuit breakers to carry the required load current in this mode depends on the operation of the air-moving fans. The reliability of the fans becomes a most important factor in the overall reliability of the circuit-breaker system.

Obviously, testing is necessary to prove the current-carrying capability of a circuit breaker with forced-air cooling because modeling of air flow and heat transfer inside circuit breakers and enclosures is a difficult process at best and unexpected failure of a system can have unacceptable consequences. If forced-air cooling seems to be required or of advantage, the engineer should see 10.1.3.1 of IEEE Std C37.13-1990 for a detailed discussion of the factors to be considered and discuss the matter further with the manufacturer.

3.28 Short-circuit interrupting rating

Short-circuit interrupting rating addresses the ability of a circuit breaker to interrupt the actual flow of fault current in a circuit having a given prospective fault-current level and to protect the conductors connected to the circuit breaker. The circuit-breaker interrupting rating is now given on a symmetrical rms ampere basis. At one time it was given in asymmetrical amperes. The symmetrical short-circuit interrupting rating of the circuit breaker takes into account the initial current offset due to the circuit X/R ratio. The value of the standard X/R ratio is used in the test circuit, and its effect is therefore included in the interrupting rating. For unfused LVPCBs, the implicit value of X/R is 6.6 (15% power factor), whereas for fused LVPCBs, it is 5.0 (20% power factor). For MCCBs and ICCBs, the implicit value of X/R used in the test circuit varies with the short-circuit current rating of the circuit breaker, having a maximum value of 4.898 (20% power factor). See IEEE Std 399™-1990 [B7] for a more detailed discussion of short-circuit studies.

One benefit of rating circuit breakers on a symmetrical current basis is that the symmetrical short-circuit interrupting ampere level required for an application can be calculated much easier. Ohms Law or any other method of circuit analysis can be used. The *IEEE Violet Book*™ (IEEE Std 551™-2006) [B9] will discuss different methods for calculating short-circuit currents. Circuit-breaker evaluation is then made on the basis of the application circuit X/R ratio as compared with the test circuit X/R ratio. Tables of X/R facilitate the evaluation.

Short-circuit testing is done to ensure that a given frame size circuit breaker is capable of withstanding the heat and forces of a short-circuit interruption and that it can protect the conductors connected to it. The standards require proof testing of a circuit breaker's ability to interrupt bolted faults. When a circuit breaker of a given ampere rating is chosen for an application, its interrupting rating is chosen to be equal to or greater than the calculated short-circuit symmetrical current of the supply system at the point where the circuit breaker is to be connected to the supply system. The current calculated for this condition is called the prospective fault current. The actual fault current can never reach this level because there is always additional impedance added between the point of circuit-breaker connection to the supply bus and the load side of the circuit breaker. The connections and the circuit-breaker impedance are between those points.

The short-circuit interruption testing specified in standards takes this into account in different ways. For more discussion of the fault calculation process and the effect of fault impedance on the results, see IEEE Std 141™-1993 [B4]. For details on the differences in testing, several standards should be reviewed. Generally, for LVPCB testing details, see ANSI C37.50-1989, and for MCCBs and ICCBs, see UL 489-1994.

The short-circuit current interrupting rating of a circuit breaker is that value of symmetrical short-circuit current that would flow in the circuit where the circuit breaker is to be connected for test. This test prospective fault current is actually a measured value of current to ensure that the proper test conditions exist. The X/R ratio in the prospective test current circuit is set to the value specified for it in the applicable circuit-breaker standard. The circuit breaker is tested to prove that it is able to safely interrupt the fault current that actually flows from this circuit during the test.

The short-circuit current interrupting requirement for a circuit breaker to be applied in a practical system is called the prospective fault current for that system and is the value of symmetrical short-circuit current mathematically calculated for that system at the point of circuit-breaker application. The process of determining whether the circuit-breaker rating is sufficient to interrupt the prospective application circuit fault current is called circuit-breaker evaluation. More discussion of the circuit-breaker evaluation process follows.

3.29 Fault-current calculation considerations

Short-circuit application duty requirements for circuit breakers are calculated the same way for all types of circuit breakers. As all circuit breakers are now rated on a symmetrical current basis, the initial step is an Ohm's Law solution of the symmetrical three-phase circuit. The short-circuit interrupting duty requirement for a circuit breaker is taken to be the short-circuit capacity of the power system at the point in the power system where the circuit breaker is to be connected. As discussed, it leads to conservative results because neither connection impedance, circuit-breaker impedance, fault-circuit impedance, nor arc impedance is taken into account in this calculation. Furthermore, and better from the point of view of consistency, the results of the Ohm's Law system study calculations are essentially the same no matter which engineer does the calculation (provided commonly accepted power system data are used). Finally, any correction needed to account for fault-circuit power factor less than the value used for testing (or for X/R ratio greater than that used for testing) is applied. This is most often done by multiplying the fault current by a multiplying factor that is a function of the system X/R. A separate discussion of the effects of X/R ratio follows in this chapter. The *IEEE Violet Book* (IEEE Std 551-2006) [B9] will be an excellent reference for further study of the process of calculation.

3.30 Circuit-breaker interrupting ratings

Recognized current interrupting ratings for MCCBs and ICCBs are listed in Table 3-17. The preferred short-circuit interrupting ratings of LVPCBs are listed in Table 3-8, Table 3-9, and Table 3-10. Circuit breakers are designed with the goal of achieving one of these ratings.

Table 3-17—Current interrupting ratings for MCCBs and ICCBs—rms symmetrical or dc amperes[a]

7500	25 000	65 000
10 000	30 000	85 000
14 000	35 000	100 000
18 000	42 000	125 000
20 000	50 000	150 000
22 000	—	200 000

[a] Reprinted from: Table 67.1 of UL 489-1994.

MCCBs and ICCBs are tested in the prospective fault test circuit by connecting the circuit breaker on test in place of the shorting bus links used for test-circuit calibration. The connections are made with lengths of rated wire or bus in accordance with UL 489-1994. The prospective current source or test laboratory source remains as set during calibration. Power factor values for the test circuit are as given in Table 3-18.

Table 3-18—Test-circuit power factor for testing MCCBs and ICCBs[a]

Test circuit (A)	Power factor
10 000 or less	0.45–0.50
10 001–20 000	0.25–0.30
Over 20 000	0.15–0.20

[a] Reprinted from: Table 22.4 of UL 489-1994.

LVPCBs can be included in the prospective current test circuit when that circuit is being calibrated for testing. However, they usually are not. Shorting links are used to complete the test circuit for calibration, and when the circuit is calibrated, the circuit breaker to be tested is connected into the prospective circuit to replace the short-circuiting links. Tests are then performed to satisfy one of the preferred short-circuit interrupting ratings given in Table 3-8, Table 3-9, and Table 3-10.

3.31 Single-pole fault interruption testing

Single-pole, maximum line-to-line voltage testing is done at the theoretical maximum single-phase fault-current level of 87% of maximum bolted three-phase fault current on all LVPCBs. Some MCCBs are tested similarly except at full-rated voltage that is equal to their maximum voltage. Other MCCBs are single-pole tested in a similar manner at the same full-rated voltage but at a reduced fault-current level. Table 3-19[4] and Table 3-20 show the test current values used. Refer to IEEE Std 242™-1991 [B6] for more discussion of single-pole considerations.

3.32 Circuit-breaker evaluation in standards for testing

Voltage, symmetrical short-circuit current magnitude, and circuit X/R ratio as seen from the point of circuit-breaker connection to the power system are the factors that should be known to evaluate a circuit breaker. If a circuit breaker has not been tested to ANSI or UL testing standards, it may be very difficult or impossible to evaluate. Because a circuit breaker is applied according to its rating, the method of testing that was used to establish that rating must be known in order to be able to do evaluation. If a circuit breaker's interrupting capability cannot be evaluated, it should not be applied.

Current IEC practices and standards do not directly correspond to the practices and standards in use in North America for single-pole duty, thermal response, or grounding. This can make it very difficult at best to make comparison evaluations between domestic and IEC circuit-breaker capabilities. UL 489-1994 and ANSI C37.50-1989 short-circuit

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[4] Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

testing procedures and parameters are tabulated for reference in Table 3-21, Table 3-22, and Table 3-23 of this chapter. These tables show how the differences between procedures can complicate direct comparison.

Table 3-19—Available current in test circuits[c]

Frame rating	Individual pole short-circuit test values			
	Two-pole circuit breaker		Three-pole circuit breaker	
	Amperes	Voltage	Amperes	Voltage
100 A max 250 V max	5000	L–L[a]	4330	L–L
100 A max 251–600 V delta	10 000	L–L	8660	L–L
101–800 A delta voltage	10 000	L–L	8660	L–L
800 A max 480 Y/277 V or 600 Y/347 V	10 000	L–N[b]	10 000	L–N
801–1200 A delta voltage	14 000	L–L	12 120	L–L
801–1200 A 480 Y/277 V or 600 Y/347 V	14 000	L–N	14 000	L–N
1201–2000 A delta voltage	14 000	L–L	14 000	L–L
2001–2500 A delta voltage	20 000	L–L	20 000	L–L
2501–3000 A delta voltage	25 000	L–L	25 000	L–L
3001–4000 A delta voltage	30 000	L–L	30 000	L–L
4001–5000 A delta voltage	40 000	L–L	40 000	L–L
5001–6000 A delta voltage	50 000	L–L	50 000	L–L

NOTE 1—Individual poles of multipole MCCBs are tested at short-circuit levels indicated in this table for all values of multipole interrupting ratings. These tests are in addition to multipole tests.

NOTE 2–These are minimum test values for certification to UL 489-1994. They are not marked ratings and are printed here to aid the system designer who may need them for single-phase short-circuit analysis. Single-pole circuit breakers are tested at values equal to their interrupting rating.

[a] L–L = line-to-line voltage applied.
[b] L–N = line-to-neutral voltage applied.
[c] Reprinted from: Table 22.2 of UL 489-1994.

Table 3-20—Short-circuit current tests[a]

Test	Duty cycle	Type of test (no. of phases)	Rated maximum voltage	Current
1	O-15 s C-O	3	635	I_1
2	O-15 s C-O	3	508	I_2
3	O-15 s C-O	3	254	I_3
4	O-15 s C-O	1	635	0.87 I_1
5	O-15 s C-O	1	508	0.87 I_2
6	O-15 s C-O	1	254	0.87 I_3
7	O	3	635	I_1
8	O-15 s C-O	3	635	I_8
9	O	1	600	174 000
10	O+t+C-O	3	600	200 000
11	O	3	600	See 3.9.2.3 of ANSI C37.50-1989
12	O	3	600	See 3.9.2.4 of ANSI C37.50-1989

NOTE 1—O is the opening operation; C-O is close-open; t is the time necessary for the test procedures, including replacement of fuses and resetting of the open-fuse trip device; I_1 is the rated short-circuit current at rated maximum voltage of 635 V; I_2 is the rated short-circuit current at rated maximum voltage of 508 V; I_3 is the rated short-circuit current at rated maximum voltage of 254 V (see Table 1 of ANSI C37.16-1997); I8 is the rated short-circuit current at rated maximum voltage of 635 V (see Table 2 of ANSI C37.16-1997).

NOTE 2—Tests 1 and 2 are to be performed with opposite terminals energized (e.g., if upper terminals are used for test 1, then lower terminals are used for test 2, and vice versa).

NOTE 3—Test 2 is to be performed in sequence II given in Table 1 of ANSI C37.50-1989, using a circuit breaker equipped with the minimum-rated continuous-current electromechanical over current trip device for the circuit-breaker frame size being tested.

NOTE 4—Tests 4, 5, and 6 may be performed on the same circuit breaker, one test per pole.

NOTE 5—For tests 9 and 10, the current is in rms symmetrical amperes.

NOTE 6—For tests 11 and 12, see the appropriate sections of ANSI C37.50-1989.

NOTE 7—At the option of the manufacturer, test 11 may be omitted if the total clearing time of the maximum fuse is equal to or less than the minimum total clearing time of the circuit-breaker element, at the short-circuit test current value. If the circuit breaker's time current characteristic data are for the maximum clearing time, subtract 0.016 s to obtain a value for the minimum total clearing time of the circuit-breaker element.

[a] Reprinted from: Table 3 of ANSI C37.50-1989.

Table 3-21—MCCB and ICCB short-circuit test summary[a]

	Test no.	Tested in sequence no.	Duty cycle	No. of poles being tested	Max rated vol-tage	Actual test current rms symmetrical kA Frame rating (A)										
						100[b]	100[b]	225[b]	600[b]	800[b]	1200[b]	1600[b]	2000[b]	2500[b]	3000[a]	4000[a]
Standard tests	1	Z	O-CO	1	250	4.3	—	—	—	—	—	—	—	—	—	—
	2	Z	O-CO	1	600	—	8.6	8.6	8.6	8.6	12.1	14	14	20	25	30
	3	Z	O-CO	1	600	—	8.6	8.6	8.6	8.6	12.1	14	14	20	25	30
	4	Z	O-CO	1	600	—	8.6	8.6	8.6	8.6	12.1	14	14	20	25	30
	5	Z	O	3	250	5	—	—	—	—	—	—	—	—	—	—
	6	Z	O	3	600	—	10	10	10	10	14	—	—	—	—	—
	7	Z	O-CO	3	600	—	—	—	—	—	—	20	25	30	35	45
	8	Y	O-CO	3	240	1.5	—	—	—	—	—	—	—	—	—	—
	9	Y	O-CO	3	600	—	3	3	6	10	14	20	25	30	35	45

	Test no.[c]	Duty cycle	No. of poles	Trip rating	Actual test current
High I/C tests	A[b]	O-CO	3	Maximum	Same as maximum interrupting capacity (I/C) rating
	B[b]	O-CO	3	Maximum	I/C rating at maximum voltage rating
	C[b]	O-CO	3	Maximum	I/C at maximum kVA rating
	D[b]	O-CO	3	Maximum	Maximum I/C rating

[a] Reprinted from: “Panel Discussion on Application of Molded-Case Circuit Breakers” [B13].

[b] All tests at each rating in sequence Z must be successfully passed with a single breaker

[c] Each test may use a new breaker.

Table 3-22—LVPCB short-circuit test summary[a]

Test no.	Tested in sequence no.	Duty cycle	No. of poles	Rated max voltage	Actual test current rms symmetrical kA						
					Frame rating (A)						
					225	**600**	**800**	**1600**	**2000**	**3000**	**4000**
1	I	O-CO	3	635	14	22	22	42	42	65	85
2	II	O-CO	3	508	22	30	30	50	50	65	85
3	II	O-CO	3	254	25	42	42	65	65	85	130
4	II	O-CO	1	635	12.2	19.1	19.1	36.5	36.5	56.6	74
5	II	O-CO	1	508	19.1	26.1	26.1	43.5	43.5	56.6	74
6	II	O-CO	1	254	21.8	36.5	36.5	56.6	56.6	74	113.1
7	III	O	3	635	14	22	22	42	42	65	85
8	IV	O-CO	3	635	14	22	22	42	42	65	85
NOTE—Any of the above tests may use a different breaker provided that the test sequence in progress is completed with the same breaker.											

[a] Reprinted from: “Panel Discussion on Application of Molded-Case Circuit Breakers” [B13].

Table 3-23—UL and ANSI short-circuit test parameters[a]

Parameter	**UL 489-1994**	**ANSI C37.50-1989**
Enclosure	Smallest individual	Min dimension test enclosure
Current	Per Table 5 of UL 489-1994	Per Table 5A of ANSI C37.50-1989
Voltage	100-105% rated	100–105% rated max (254 V, 508 V, or 635 V)
Power factor (ac)	10 000 or less 0.45–0.50 10 001–20 000 0.25–0.30 Over 20 000 0.15–0.20	0.15 max
Time constant (dc)	10 000 or less 3 ms Over 10 000 8 ms	Not covered
Frequency	48–62 Hz	48–72 Hz
Ambient	Not defined	Not defined
Ground fuse	30 A	30 A or 10 AWG (copper)

NOTE 1—Random closing employed.

NOTE 2—Time interval between interrupting operations: 2 min to 1 h maximum.

NOTE 3—Cotton test during each test to 0.010 in diameter rod entry test must be passed.

[a] Reprinted from: “Panel Discussion on Application of Molded-Case Circuit Breakers” [B13].

Field testing by manual methods often produces results that are not in agreement with the manufacturer's tests and are not accurate indicators of circuit-breaker performance. It is difficult to justify a high-quality test setup anywhere except at a manufacturing facility, so differences between factory and field test results should be expected. Offset in the test current wave invalidates results.

When testing, it is always important to make sure the trip unit installed is the one represented by the referenced specifications or time-current curves. Interchangeable trip units often look similar but may be different. MCCBs, for example, may have thermal-magnetic trip units or electronic trip units. If they have electronic trip units, the electronic trip units may be peak sensing or rms sensing and they may or may not include ground-fault tripping provisions. Furthermore, newer electronic trip units feature built-in test provisions that are easy to operate and can even be operated in a no-trip mode while the circuit breaker is under light load.

An alternative to using the built-in provisions, secondary or primary current injection methods can be employed using external test equipment. Current injection tests, of course, require the circuit breaker to be taken out of service. Thermal overload trip units using bimetallic sensors respond to the rms value of the current flowing through them and their heaters. Electronic overload trip units may be either peak sensing or rms sensing depending on their internal circuit design. That is, they can be designed to respond to the peak value of the current flowing through them or to the rms value of current flow. The engineer should always keep these factors in mind when evaluating alternative circuit-breaker and trip-unit choices.

The response of a bimetallic trip unit on circuit breakers will be different if the energy input to the trip unit as a whole is different. For example, if only one pole is carrying current, then only one bimetallic element is being heated and pressing on the trip bar, and in general, a slightly longer trip time should be expected. This fact is indicated by the single-pole test characteristic printed above the long-time, time-current curve on typical circuit-breaker data sheets. The shorter time characteristic below it is indicative of performance, per standards, with equal current flow in all poles. See the time-current characteristic curves in Chapter 4.

Instantaneous electromagnetic pickup (tripping) in thermal-magnetic circuit breakers is in fact a function of peak current flow even though the abscissa of the time-current curve is labeled in rms amperes. The reason is because the magnetic flux and the force the magnetic flux produces in the operating mechanism of the trip unit is a function of current alone, not power. In like manner, a peak-sensing electronic trip unit can respond with a trip to a single current surge or spike that reaches the circuit trip level. Even electronic trip units using rms sensing algorithms can be triggered to produce an override instantaneous trip if a current surge or spike large enough to activate the override is experienced. The override trip is an independent instantaneous trip set near the circuit-breaker withstand level that overrides the electronic logic trip unit to cause the circuit breaker to open without delay at very large fault levels. Therefore, circuit-breaker application evaluations should take into account not only the salient features of the test specifications cited above, but also the requirements and characteristics of the circuit-breaker trip unit and the circuit breaker itself. Every aspect of circuit-breaker design, circuit operation, and system maintenance can affect overall operational performance.

3.33 Blow-open contact arms

Most MCCBs achieve high interrupting rating levels because they are designed to use the fault current to drive tripping action. Within the limits of rating, it can be generalized that the larger the fault-current flow, the greater the driving force and the quicker the trip and interruption. Most MCCBs trip and interrupt fast enough to limit the peak and I^2t let-through of fault current. Some satisfy the requirements of current-limiting circuit breakers as defined in Chapter 2. LVPCBs, on the other hand, trip only after their trip units initiate a mechanism release. Then fault current can contribute driving force.

If an MCCB is claimed to be current limiting, UL 489-1994 requires that the peak current and I^2t be tabulated for the threshold of current limiting, the maximum interrupting level, and at least one point in between. A curve to present these data is usually drawn and published for user reference. Such a tabulation and curve are not required for circuit breakers not claimed to be current-limiting.

3.34 Circuit breaker useful life

It is prudent to replace any MCCB that has interrupted, at most, two faults at rated maximum current. The reason is that the MCCB short-circuit proof test consists of an "O-t-CO" sequence, which means that in proof testing of the circuit-breaker design and in periodic follow-up testing thereafter, the circuit breaker is required to open a fault from an initially closed position (corresponding to the "O" operation), then after a period of time (t) to reset is allowed, to be closed into a maximum fault and trip open for a second time (corresponding to the "CO" operation). This process demonstrates a circuit breaker's ability to perform at least two maximum-level fault interruptions, with the second at least a little worse than the first. No maintenance of the circuit breaker on test is permitted between interruptions.

The problem, of course, is that fault-current levels are not usually monitored. It is difficult and expensive to tell whether a fault was a maximum fault, and in general, low-voltage system faults tend to be less than maximum. Therefore, circuit-breaker inspections should be performed according to a plan developed to suit the application. NEMA AB 4-2001 should be referenced for MCCB and ICCB field inspection and maintenance.

LVPCBs go through similar short-circuit test cycles, but it is generally not said that LVPCBs need to be replaced after a given number of fault interruptions because they can and should be inspected for wear and damage and they should be refurbished or repaired as required after interrupting faults and before being restored to service. The fact that LVPCBs can even be maintained between tests emphasizes the maintainability feature of their design and further distinguishes them from MCCBs and ICCBs. See note (3) of Table 1 of ANSI C37.50-1989 for some specific detail on LVPCB testing. Maintenance is necessary if continued reliable service is to be expected.

3.35 Considerations on interrupting duty and maintenance

As discussed in 3.34, one problem associated with the implementation of good system operating and maintenance procedures is that it is generally difficult to determine whether a fault that has occurred was a maximum-level or bolted fault. Another factor is that without inspection, the actual condition of any circuit breaker cannot be known. Time and money must be spent to implement both procedures. Some new digital microprocessor-based trip units store fault-current magnitude data, both phase and ground, in memory when a trip occurs and that data can be read at the time of inspection, which helps the engineer determine the seriousness of a trip condition.

For the ultimate in reliability, the engineer should assume that the fault could have damaged any of the circuit elements, including the conductors, and a complete inspection of the circuit is required. MCCBs, ICCBs, and LVPCBs should be inspected in proportion to the required reliability of their service and as a minimum in observance of the recommendations given in standards and instruction leaflets. For a detailed discussion of MCCB inspection procedures, see NEMA AB 4-2001 in particular, and for a detailed discussion of circuit-breaker reliability in general, see IEEE Std 493-1990 [B8]. LVPCB, MCCB, and ICCB maintenance and inspection procedures can be found in the instruction leaflets and documentation furnished by circuit-breaker manufacturers. These documents should be read by system operating personnel upon receipt of the equipment, and they should be kept on file for future reference. Maintenance personnel should incorporate pertinent practices and procedures into their own maintenance policies. The benefits of proof testing can be lost if inspection and maintenance policies are not implemented.

3.36 Integrally fused devices

Integrally fused LVPCBs and MCCBs with inverse time or instantaneous automatic tripping have interrupting capacities much greater than those of unfused circuit breakers of corresponding frame sizes, and they are intended primarily for overcurrent and/or short-circuit protection of high-capacity electrical circuits. When applied on high short-circuit current capacity systems, the effects of the let-through characteristics of the fused circuit breakers on the connected equipment should be considered. The presence of the current-limiting fuse as part of the fused circuit breaker does not necessarily imply that the connected equipment can adequately withstand these effects.

It should be noted that fused circuit breakers do not generally have any current-limiting effect until the current associated with the fault exceeds the current-limiting threshold of the fuse. When fuses of relatively low continuous-current rating and relatively low peak let-through current rating are selected to give protection to downstream equipment, there is increased likelihood that they will open at currents much below the circuit-breaker element short-circuit current rating. If the full coordination study for the protection of connected equipment is made known to the manufacturer, then the best combination of direct-acting trip devices and fuses may be selected. Non-optimum combinations can lead to needless fuse opening. In no case should combinations of trip devices and fuses that are not approved by the manufacturer be installed.

Where fuses of different manufacture are being considered for the same system, the characteristics of all fuses and circuit breakers in the system should be evaluated because both the melting time current characteristics and the peak let-through currents of a given fuse rating may vary substantially between manufacturers. Only fuses that have been proof tested with the circuit breakers should be used.

3.37 Series-connected rating

A series connection of circuit breakers can be of economic advantage in an application only if full selectivity in coordination is not required. In the strictest interpretation, domestic series combinations are also restricted to use in circuits where there is no motor loading on any branch circuit breakers. However, there are differences of opinion about this restriction in the United States and in other parts of the world. For example, IEEE Std C37.13-1990 does not even consider the fault-current contribution of motors 50 hp and less, and for a large part of the rest of the world, IEC 781 (1989) [B2] indicates that the contribution of asynchronous motors to the short-circuit current can be disregarded if the sum of the motor contribution is less than 1% of the initial symmetrical short-circuit current.

Sometimes it is erroneously thought that series combinations are at a disadvantage with regard to coordination as compared with fully rated systems. The fact is that even fully rated circuit breakers with instantaneous trips will not “coordinate” once the fault level exceeds both circuit breakers’ instantaneous trip levels. An IEC viewpoint extends this concept somewhat by definition of the term “discrimination,” which recognizes that energy is required to cause a circuit breaker to trip and even though the straight vertical lines and flat horizontal segments commonly used to describe the magnetic trip range of a circuit breaker are drawn, there is some range of overlap of these zones where tripping of both circuit breakers does not occur. The process of discrimination defines these areas so they can be added to the range of selectivity indicated by the time-current curves. The interested reader should refer to IEC 947-2 (1995) [B3] for more detail. Because there are enough opportunities to make series rating an advantage to users, series ratings and listings have been established by the UL and are recognized in the NEC.

Series connection of MCCBs, where the branch or downstream circuit breaker has an interrupting rating less than the calculated fault duty at its point of connection in the power circuit, is permitted only when the series combination has been proven to be safe by actual interruption testing. Domestically, a series combination is recognized for series application by a third-party organization such as the UL.

Series ratings should not be confused with the older domestic calculated cascade ratings discussed in 3.38. It should be noted that the IEC uses the term *cascade* to describe its series rated and tested circuit-breaker combinations and the term *discrimination* to describe the ability of a load-side series-connected circuit breaker to actually coordinate with a line-side circuit breaker over some portion of their indicated mutual instantaneous trip range. Fundamentally, series ratings are proven by test, whereas the no longer valid cascade arrangements of the past were determined by calculation procedures that are no longer accepted as generally adequate.

> NEC 110.22 acknowledges that manufacturers can establish series combination ratings and it requires that equipment enclosures "...shall be legibly marked in the field...Caution—Series Rated System" to indicate that the rules for series application were utilized to design this part of the power distribution system.

This marking becomes part of the application. NEC 240.86 on overcurrent protection also acknowledges the use of series ratings and the requirements for marking. UL 489-1994 (in paragraph 41, Circuit Breakers Connected in Series) outlines the test connections and procedures required for proof of series combination ratings.

Series rating of two circuit breakers makes it possible to apply the two in series, as one device, with the interrupting rating being the series rating of the combination. In summary, it is not permissible to calculate series ratings because accurate and sufficiently uncomplicated methods for doing so have not been identified at this time.

3.38 Cascade arrangement

Previously, in practice, there was a circuit-breaker arrangement known as a *cascade arrangement* in which circuit breakers were essentially applied in series. However, the adequacy of the cascade arrangement was determined by calculation, not by testing, and the calculation methods have since been determined to be generally inadequate. As the cascading method does not include verification by testing, it is no longer a recommended procedure for applying circuit breakers. UL 489-1994 does not address the subject of cascade arrangements generally for MCCBs, whereas IEEE Std C37.13-1990 specifically states that it is no longer a recommended procedure for LVPCBs. If coordination considerations will permit the application of a series combination, then only tested and listed series combinations of circuit breakers can be applied and the markings of equipment discussed above should be employed. Otherwise, fully rated circuit breakers should be applied at all locations in the circuit with interrupting ratings equal to or greater than the evaluated prospective fault current at the point of application.

3.39 Short-time rating

Short-time ratings are not covered in MCCB standards, because generally MCCBs are designed to trip and interrupt high-level faults without intentional delay. However, newer electronic trip units usable with some MCCBs are able to use the capabilities of some of these circuit breakers to implement short-delay tripping. ICCBs generally do have short-time capability because their closing and tripping mechanisms are more like those of LVPCBs, not designed to blow open, and they generally have more current withstand capability. LVPCBs are designed to have "making current" capability and "short-time" capability and can withstand the short-time duty cycle test. They are designed to be tripped by a shunt trip device.

For an unfused LVPCB, the rated short-time current is the designated limit of available (prospective) current at which it shall be required to perform its short-time current duty cycle of two periods of 0.5 s current flow separated by a 15 s interval of zero current at rated maximum voltage under the prescribed test conditions. This current is expressed as the rms symmetrical value of current measured from the available current wave envelope at a time one half-cycle after short-circuit initiation.

Unfused LVPCBs shall be capable of performing the short-time current duty cycle with all degrees of current asymmetry produced by three-phase or single-phase circuits having a short-circuit power factor of 15% or greater (X/R ratio of 6.6 or less). Preferred short-time current ratings are shown in Table 3-9.

No test is defined in the standards for the circuit breaker element of a fused circuit breaker.

3.40 Circuit-breaker evaluation for X/R ratio or short-circuit power factor

LVPCBs in general are evaluated for short-circuit interrupting capability on a first-half-cycle basis. As indicated, MCCBs can sometimes operate so quickly that they function in a current-limiting mode, which means they operate to limit short-circuit current before the first current peak is reached. As the peak current is a function of the offset of the rms symmetrical current wave, which is in turn a function of the power factor or the X/R ratio of the circuit, the fact that (1) LVPCBs are tested with an X/R ratio of 6.6 and (2) MCCBs and ICCBs are tested with X/R ratios of 6.6 to 4.89, 3.8 to 3.18, and 1.98 to 1.75, depending on interrupting rating, means they have to be evaluated differently. See Table 3-18 for a listing of the power factor ranges from which the MCCB and ICCB X/R ratio ranges are derived.

If a circuit has an X/R ratio less than the value used for proof testing a given circuit breaker, then no adjustment in that circuit breaker's interrupting rating is required and the circuit breaker can be evaluated by direct comparison of its short-circuit interrupting current rating with the calculated Ohm's Law symmetrical short-circuit fault-current calculation. Another way of understanding that statement is to understand that an increase in the short-circuit interrupting capability of a circuit breaker may never be claimed by virtue of a mathematical calculation alone.

On the other side of the X/R inequality, if the calculated value of the short-circuit X/R ratio is greater than the value used to test the circuit breaker, then the interrupting duty requirement of that application has to be increased by multiplying the calculated symmetrical short-circuit current magnitude by a multiplying factor (MF) greater than one, which is equal to the ratio of the offset peak of the calculated circuit divided by the offset peak of the test circuit. This means that the offset current for the calculated fault is greater than the offset current of the circuit-breaker test circuit and that the circuit breaker should therefore have the capability to interrupt MF times the calculated Ohm's Law value of the symmetrical short-circuit current when applied in that circuit.

Looking at this from the point of view of de-rating the circuit breaker instead of up-rating the short-circuit current, it could be said that the circuit-breaker rated interrupting capacity should be de-rated by a factor equal to the reciprocal of MF (or 1/MF) because the peak fault current with this larger X/R condition is greater than the peak current of the circuit-breaker test circuit.

In summary, the calculated Ohm's Law symmetrical short-circuit current can be multiplied by an MF to indicate the true interrupting requirement of the circuit, or the short-circuit interrupting rating of the circuit breaker can be de-rated by multiplying its short-circuit interrupting rating by (1/MF) to indicate the circuit breaker's capacity to interrupt current on the new higher X/R basis. Both approaches are commonly used. See Table 3-24 and Table 3-25 for multiplying factors.

Table 3-24—Selection of short-circuit current multiplying factor for LVPCBs[a]

System short-circuit power factor (%)	System X/R ratio	Multiplying factor for calculated short-circuit current	
		Factors for unfused circuit breakers	Factors for fused circuit breakers
20	4.9	1.00	1.00
15	6.6	1.00	1.07
12	8.27	1.04	1.12
10	9.95	1.07	1.15
8.5	11.72	1.09	1.18
7	14.25	1.11	1.21
5	20.0	1.14	1.26

[a] Source: Table 3 of IEEE Std C37.13-1995.

3.41 Single-pole interrupting capability and power system design considerations

For the rated X/R condition, every three-pole circuit breaker intended for use on three-phase circuits is able to interrupt a bolted single-phase fault. Obviously, it should have this capability because single-phase faults not only cannot be prevented from occurring on three-phase systems, but also they are probably the most likely to occur.

When interrupting a single-phase, line-to-line fault in a three-phase circuit, there are two circuit-breaker poles in series performing the interruption with line-to-line voltage impressed across the two poles in series. Theoretical maximum single-phase prospective fault current is therefore 87% of the full three-phase bolted fault current. This interrupting duty is less severe than for a three-phase interruption test where the first pole to open can have a maximum of one and one-half times peak phase voltage impressed across that pole alone and the theoretical maximum three-phase prospective fault current is by definition 100%. Therefore, three-phase interruption tests also prove single-phase interrupting capability of three-pole circuit breakers.

However, if the three-phase power system is corner grounded, then a single-line-to-ground fault on the load side of the circuit breaker will result in single-phase fault current flowing through only one pole of the circuit breaker, but with line-to-line voltage impressed across that one pole. A review of the test specifications referenced will show that all LVPCBs are tested to prove single-pole interrupting capability at the 87% current level with maximum line-to-line voltage impressed across that one pole (see Table 3-20). But not all MCCBs and ICCBs receive the same 87% current, full line-to-line voltage single-pole test. All MCCBs and ICCBs are tested for single-pole performance at rated line-to-line voltage, but some are tested at lower than 87% of maximum fault-current level. As in all applications, it is necessary to calculate the interrupting requirement of the circuit and to apply a circuit breaker with the required interrupting rating. See Table 3-19 for the different individual levels.

Table 3-25—Selection of short-circuit current multiplying factor for MCCBs and ICCBs[a]

Power factor (%)	X/R ratio	Interrupting rating (A)		
		10 000 or less	10 001 to 20 000	Over 20 000
		Multiplying factor		
4	24.98	1.62	1.37	1.23
5	19.97	1.59	1.35	1.22
6	16.64	1.57	1.33	1.20
7	14.25	1.55	1.31	1.18
8	12.46	1.53	1.29	1.16
9	11.07	1.51	1.28	1.15
10	9.95	1.49	1.26	1.13
11	9.04	1.47	1.24	1.12
12	8.27	1.45	1.23	1.10
13	7.63	1.43	1.21	1.09
14	7.07	1.41	1.20	1.08
15	6.59	1.39	1.18	1.06
16	6.17	1.38	1.17	1.05
17	5.80	1.36	1.15	1.04
18	5.49	1.35	1.14	1.02
19	5.17	1.33	1.13	1.01
20	4.90	1.31	1.11	1.00
21	4.86	1.31	1.11	1.00
22	4.43	1.28	1.09	1.00
23	4.23	1.27	1.08	1.00
24	4.05	1.26	1.06	1.00

Table 3-25—Selection of short-circuit current multiplying factor for MCCBs and ICCBs[a] *(continued)*

Power factor (%)	X/R ratio	Interrupting rating (A)		
		10 000 or less	10 001 to 20 000	Over 20 000
		Multiplying factor		
25	3.87	1.24	1.05	1.00
26	3.71	1.23	1.04	1.00
27	3.57	1.22	1.03	1.00
28	3.43	1.20	1.02	1.00
29	3.30	1.19	1.01	1.00
30	3.18	1.18	1.00	1.00
35	2.68	1.13	1.00	1.00
40	2.29	1.08	1.00	1.00
45	1.98	1.04	1.00	1.00
50	1.98	1.04	1.00	1.00

[a]Source: IEEE Std 242-1986 [B6].

Figure 3-1 shows the circuit connections for the tests of one-, two-, and three-pole MCCBs tabulated in the operations columns of Table 3-3. From these connections, the different connections used for straight voltage rated, slash voltage rated, and single-pole tests can be seen. It is therefore necessary to treat MCCB applications in corner-grounded systems differently from applications of LVPCBs. Generally, the circuit-breaker manufacturer should be consulted whenever corner-grounded system applications are involved.

For a wider perspective on this situation, IEC rated circuit breakers are not required to receive regular single-pole tests. The single-pole interrupting capacity aspect of performance is addressed in Appendix C of IEC 947-2 (1995) [B3] only for "... multi-pole circuit breakers intended for use on phase-earthed systems..." and then only at a prospective current "... equal to 25% of the ultimate rated short-circuit breaking capacity...."

Outside the situations of application in a corner-grounded system or double jeopardy on improperly operated, ungrounded, or high-resistance grounded systems, which require the occurrence of simultaneous bolted faults on the line side and the load side of a circuit breaker to get even the possibility of 87% current, single-pole interrupting capability has not been a major application factor worldwide over the last half-century. Circuit-breaker sales literature notes cover the intentional corner-grounded system application contingency by noting that if the power system is corner grounded, then the purchaser should contact the factory for application assistance.

Power system design engineers should first determine the type of power system to be used with due consideration for its practical implementation, which means that if power systems are to be designed to be operated ungrounded or with high-resistance grounding, then it should be specified that they should be operated in accordance with the operating procedures set forth for such systems. For more detailed discussion on power system design considerations and their operation, the interested reader is referred to IEEE Std 141-1993 [B4].

3.42 Applying ac thermal-magnetic molded-case circuit breakers using their UL 489 dc rating

Under the provisions of UL 489-1994, (the standard upon which the designs of molded-case circuit breakers are based), some thermal magnetic molded-case circuit breakers can have dc ratings assigned. When dc ratings are assigned to these molded-case circuit breakers, the dc voltage levels and their corresponding interrupting ratings are indicated on the circuit breaker faceplate, on the circuit breaker's time-current-curves (TCCs) and on circuit breaker data sheets. Just as ac interrupting ratings differ with voltage rating, different DC interrupting ratings apply at different dc voltage levels and the dc interrupting ratings are subject to de-rating for application voltage as is done for ac circuit applications.

Obviously, dc current interruption is different from ac current interruption. Alternating sinusoidal short-circuit fault current usually passes through zero magnitude at least twice each cycle. These zero crossings are helpful in the ac interrupting process. DC short-circuit fault current does not normally go through a zero value. It is best characterized as a unidirectionally increasing exponential current approaching a limiting value. To interrupt dc current, the circuit breaker must produce all of the physical effects required to reduce the dc current to zero magnitude and thereafter maintain an open circuit.

As there is no difference in the heating ability of effective rms ac current and dc current, the long-time trip characteristic or the thermal trip characteristic of a thermal-magnetic circuit breaker is the same for ac and dc. This finding means that the thermal part of the TCC remains the same for both ac and dc applications. It is only in the instantaneous trip region where the current waveforms are different that a correction factor must be applied. The characteristic curve shape remains the same, but the abscissa current magnitude value changes. For that reason, it is simple and economical to state the correction factor for current magnitude in this range of the TCC and not to complicate the presentation with another set of abscissa values. How to deal with this difference is addressed by circuit-breaker manufacturers in application notes or on the circuit-breaker TCC and on data sheets.

3.42.1 Consequences of the difference between instantaneous ac symmetrical rms current and dc current for instantaneous trip

The magnetic trip devices in thermal-magnetic circuit breakers that initiate an instantaneous trip operate on magnetic force produced by the instantaneous fault current itself. Here, the difference between instantaneous dc current and instantaneous ac rms current for the same numerical value must be taken into account. The theoretical instantaneous peak magnitude of a sine wave of current is larger than its rms value by a factor of $\sqrt{2}$ .Therefore, the amount of dc current required to produce the same amount of magnetic force as the peak of the indicated ac rms sine wave current must be $\sqrt{2}$ times as large. The abscissa of the ac TCC is uniformly scaled in units of symmetrical rms ac amperes or ac per-unit current. Therefore, a correction to the abscissa current values in the instantaneous trip area, but not in the thermal trip area, must be made for a dc application. This correction is a current magnitude-multiplying factor. But, it is not a variable multiplying factor like those shown in Table 3-25 for ac applications. The current multiplying factor for the dc instantaneous trip area is a constant value of, or near to, $\sqrt{2}$ or approximately 1.4. Circuit-breaker manufacturers may indicate the value they prefer to be used in a note on the TCC or in application data.

3.42.2 Similarities and differences between ac and dc circuit-breaker evaluation

AC circuit breaker evaluation uses calculation of the ratio of circuit reactance to circuit resistance or the ratio X/R to determine an ac fault-current multiplying factor for application. Table 3-25 lists ac short-circuit current multiplying factors for a set of circuit ratios of X/R. Similarly, dc circuit-breaker evaluation uses calculation of the ratio of circuit inductance to circuit resistance, L/R, but a current multiplying factor is not determined from this ratio. With the prospective dc short-circuit current magnitude satisfactory, the L/R ratio is a determining criterion for dc circuit-breaker evaluation.

In pure dc circuits where the sources are batteries or constant voltage dc generators, the prospective ultimate short-circuit current is simply E/R, where E is the dc source voltage and R is the dc circuit resistance. Short-circuit current rises exponentially toward this prospective peak at a rate proportional to the L/R time constant. But, where dc power is derived through rectifiers connected to an ac circuit, the ratio of X/R in the ac part of the circuit can affect the dc prospective current magnitude. Transient offset current in the ac part of the circuit can be carried through the rectifier to increase the dc prospective current during the transient period. The dc prospective current in that case also has a transient peak. The net result is that the effect of the X/R ratio of the ac side of the rectifier circuit can affect the magnitude of the dc prospective fault current. The amount of increase and the duration of current offset depends on several factors. If the rectifier is controlled electronically and is very fast, the controller can have an affect on both the dc current magnitude and/or its duration. If the rectifier is not electronically controlled, then the impedance of the rectifier devices can affect the magnitude. If the rectifier solid-state devices are fused, then the fuse characteristics can become a consideration. Therefore, the effect of the ac part of the circuit and the rectifier must be considered to determine the dc prospective current when applying a circuit breaker for rectifier dc applications.

In effect, the L/R ratio, which is the dc circuit time-constant, serves to relate the dc interrupting conditions to the ac interrupting conditions associated with the ac rms sinusoidal current indicated on the abscissa of the ac time-current-curve. It takes into account the difference in current wave shape and clearing energy dissipation. The L/R time-constant has units of seconds, and the limiting values for application are as follows. For application of MCCBs designed per UL 489-1994, which have interrupting current ratings less than 10 000 A, the circuit L/R time-constant must be equal to or less than 3 ms, 0.003 s. For those circuit breakers having rated interrupting currents equal to or greater than 10 000 A, the circuit L/R time-constant must be equal to or less than 8 ms, 0.008 s.

Most thermal-magnetic molded-case circuit breakers blow open under fault conditions. They usually interrupt fast enough to limit the maximum fault current but usually not enough to satisfy the definition of a current limiting circuit breaker. By virtue of their impedance and blow-open speed of interruption, they never let the prospective current level be reached. (Their *rating* is based on prospective current, however.) In ac operation, they typically interrupt current flow between a quarter-cycle in time (approximately 4.2 ms at 60 Hz) and a half-cycle in time (approximately 8.3 ms at 60 Hz). The dc time-constant limitation relates the "fair wear and tear" of contacts and arc chutes associated with the ac interruption to dc interruption. Many of the more common dc circuit-breaker applications are in control circuits where the power source is a bank of batteries and a charger. In these circuits, in addition to having the charger also contributing to fault current, the dc circuit time-constant can vary over a wide range, possibly exceeding 8 ms. In those cases, a more specific purpose circuit breaker is required. Summarizing, for dc application of thermal-magnetic MCCBs within their standard design constraints, the dc voltage and interrupting ratings must be satisfied and the time-constant of the circuit must satisfy the time-constant constraint for the circuit-breaker interrupting current rating. No fault current magnitude-multiplying factor is applied due to the L/R ratio.

3.42.3 DC circuit connections

A very practical aspect of the application of molded-case circuit breakers in dc circuits is the question about how to connect them into the circuit. There are different possibilities for connection for one, two, three, and possibly four-pole circuit breakers.

a) For single-pole circuit breakers, there is no question. When applicable, one pole interrupts the circuit, and with only that one conductor open, both sides of the load cannot be totally isolated from the source.

b) With two-pole circuit breakers, one pole in each side of the dc circuit puts two contacts in series for interruption, and when both contacts are open, they isolate both sides of the load totally from the source. With both contacts in one side of the circuit, they, like single-pole circuit breakers, can interrupt fault current, but they will not totally isolate both sides of the circuit from the source when they are open.

c) Whenever a standard three-pole or possibly a four-pole circuit breaker is used in a dc circuit application, there are the choices of using one, two, three, or all four poles (circuit breaker contacts) in series. The UL requires the use of two contacts for two-pole circuit breakers and three contacts for three-pole circuit breakers. Usually, the manufacturer indicates the minimum number of poles required for the voltage and interrupting rating. If only two poles of a three-pole circuit breaker are sufficient for interruption, the connection is like the two-pole circuit breaker case, but the manufacturer may specify which two poles should be used. Whenever three or four poles are to be used in series, a close local connection from one pole of the circuit breaker to another is probably required. Hardware to make the short local connection between poles neat and convenient may be available from the circuit-breaker manufacturer. The user should refer to the manufacturer's literature for details on dc application. As arbitrary as the connection might seem, there is a possibility that the manufacturer may want pole currents to be flowing in a given direction through the circuit breaker for magnetic field considerations. It is therefore advisable to check the manufacturer's literature before planning the connection.

3.42.4 Trip unit differences for dc application

Many standard ac thermal-magnetic molded-case circuit breakers lend themselves readily to application in dc circuits. But some of the more recently designed molded-case circuit breakers can use different kinds of trip units. If the trip unit installed in a given molded-case circuit breaker is not a thermal-magnetic trip unit, it may not be suitable at all for use in dc circuits. Therefore, special care must be taken when applying molded-case circuit breakers on dc.

An optionally available ac electronic trip unit will most likely not function properly when subjected to constant dc current, and it should not be expected to respond effectively to transient dc current changes either. Electronic trip units are made specifically for dc circuit breakers. They incorporate special sensors for dc current. Their electronic trip circuits are designed to accept dc signals. Their TCC characteristic shapes are generally very much like those of ac electronic trip units. That is, the trip characteristics will most often be composed of straight-line segments that indicate computed electronic decision making, not thermal or magnetic force responses. Also, the units of measure on the abscissa of their TCCs will be given directly in dc amperes.

3.43 Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI C37.16-1997, American National Standard Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors—Preferred Ratings, Related Requirements, and Application Recommendations.[5]

ANSI C37.50-1989 (R2000), American National Standard for Switchgear—Low-Voltage AC Power Circuit Breakers Used in Enclosures—Test Procedures.

IEEE Std C37.010™ -1979 (R1988), IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.[6, 7]

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[5] ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[6] The IEEE standards or products referred to in this chapter are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

IEEE Std C37.13™ (1990 and 1995 versions), IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

IEEE Std C37.20.1™-1993, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

NEMA AB 1-1993, Molded Case Circuit Breakers, and Molded Case Switches.[8]

NEMA AB 4-2003, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications.

NEMA CP 1-2000, Shunt Capacitors.

NFPA 70-2005, National Electrical Code® (NEC®).[9]

UL 489-1994, Molded-Case Circuit Breakers and Circuit-Breaker Enclosures.[10]

3.44 Bibliography

[B1] Accredited Standards Committee C2-2007, National Electrical Safety Code® (NESC®).[11]

[B2] IEC 781 (1989), Application guide for calculation of short-circuit currents in low-voltage radial systems.[12]

[B3] IEC 947-2 (1995), Low-voltage switchgear and controlgear—Part 2: Circuit-breakers.

[B4] IEEE Std 141-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*™).

[B5] IEEE Std 142-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (*IEEE Green Book*™).

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[7] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

[8] NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http:// global.ihs.com/).

[9] NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (http://www.nfpa.org/).

[10] UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http:// global.ihs.com/).

[11] The NESC is available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

[12] IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http:// www.ansi.org/).

[B6] IEEE Std 242-1986 (R1991), IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (*IEEE Buff Book*™).

[B7] IEEE Std 399-1990, IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (*IEEE Brown Book*™).

[B8] IEEE Std 493-1990, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (*IEEE Gold Book*™).

[B9] IEEE Std 551-2006, IEEE Recommended Practice for Calculating AC Short-Circuit Currents in Industrial and Commercial Power Systems (*IEEE Violet Book*).

[B10] NFPA 70B-2002, Electrical Equipment Maintenance.

[B11] NFPA 70E-2004, Electrical Safety Requirements for Employee Workplaces.

[B12] Occupational Safety and Health Act (OSHA), U.S. Department of Labor, published in the *Federal Register.*[13]

[B13] "Panel Discussion on Application of Molded-Case Circuit Breakers," *1991 IEEE IAS Annual Meeting,* Dearborn, MI.

[B14] UL 486A-1991, Wire Connectors and Soldering Lugs for Use with Copper Conductors.[14]

[B15] UL 486B-1991, Wire Connectors for Use with Aluminum Conductors.

[B16] UL 486C-1991, Splicing Wire Connectors.

[B17] UL 486D-1993, Insulated Wire Connectors for Use with Underground Conductors.

[B18] UL 486E-1994, Equipment Wiring Terminals for Use with Aluminum and/or Copper Conductors.

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[13] The Federal Register is available from the Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082, USA (http://www.access.gpo.gov/).

[14] UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

Chapter 4
Specific applications

4.1 Scope

This chapter describes the systematic procedures for determining the type, rating, and protective characteristics of low-voltage circuit breakers applied for specific purposes. The three types of circuit breakers are as follows:

- Low-voltage power circuit breakers (LVPCBs)
- Molded-case circuit breakers (MCCBs)
- Insulated-case circuit breakers (ICCBs)

Specific circuit applications discussed in this chapter are as follows:

a) Service entrance
b) Main circuit breakers
c) Tie circuit breakers
d) Feeder and branch circuit breakers:
    1) Cables
    2) Busway
    3) Switchgear, switchboards, panelboards, or motor control centers (MCCs)
    4) Motors
    5) Generators
    6) Capacitors
    7) Transformers

4.2 Selection considerations

Selection considerations should include the following:

a) Compliance with nationally recognized regulations and standards such as the National Electrical Code® (NEC®) (NFPA 70-2005),[1] and those from the Occupational Safety and Health Administration (OSHA), Underwriters Laboratories (UL), American National Standards Institute (ANSI), and National Electrical Manufacturers Association (NEMA), where applicable, along with any local codes or safety requirements. In addition, IEEE standards contain useful application information for various types of systems. These standards include IEEE Std 141™-1993 for industrial plants, IEEE Std 241™-1990 for commercial systems, and IEEE Std 242™-2001 for protection and coordination of electrical systems.
b) Special or unusual requirements imposed by characteristics of the electrical power source.

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[1] Information on references can be found in 4.12.

c) Special or unusual requirements resulting from load characteristics.

d) Interconnected system performance objectives with respect to selective fault clearing.

e) Unusual operating conditions.

f) Special requirements for personnel safety.

g) Type of equipment in which the circuit breaker is mounted (individual enclosure, panelboard, switchboard, MCC, metal-enclosed switchgear).

It is recognized that the type of facility (industrial plant, continuous process, commercial building, hospital, etc.), as well as economics, facility operating and maintenance philosophies and capabilities, and standardization programs may influence the selection process described, with particular effect on the type of circuit breaker being applied. Such aspects are, by necessity, excluded from consideration in this chapter.

Service conditions that differ from those described in Section 2 of ANSI C37.13-1990, Section 4 of ANSI C37.14-1992, and NEMA AB 3-2001 are beyond the scope of this chapter.

4.3 Selection approach for application requirements

This chapter covers the application of standard-purpose low-voltage circuit breakers in specific applications. Special-purpose circuit-breaker applications are covered in Chapter 6.

4.4 Selection approach for electrical ratings

4.4.1 System voltage

Circuit breakers are rated by voltage class and should be applied only to system voltages within their ratings. System voltage is a determining factor of the circuit-breaker interrupting rating. MCCBs have either straight voltage ratings or slash voltage ratings. Refer to 3.12. Circuit breakers with slash voltage ratings, such as 480Y/277 V or 120/240 V, may be applied only on solidly grounded neutral systems as shown in Figure 4-1 and Figure 4-2. Circuit breakers with straight ratings, and all LVPCBs, can be applied on ungrounded as well as on grounded systems.

4.4.2 System grounding

Most circuit breakers are rated for application on low-voltage systems that are solidly grounded WYE, high-resistance grounded WYE, ungrounded DELTA, and center-grounded DELTA. Circuit breakers are also available for corner-grounded DELTA. A brief description/discussion is provided for each of these various power system configurations and MCCB requirements are indicated in Figure 4-3, Figure 4-4, Figure 4-5, Figure 4-6, and Figure 4-7 as follows:

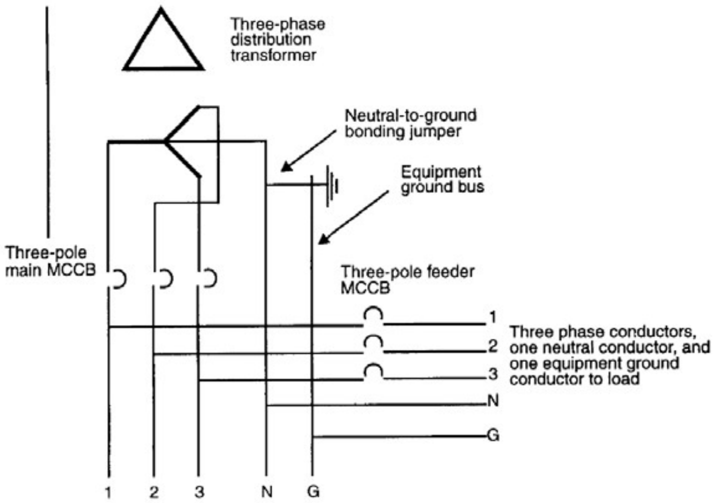

Figure 4-1—480Y/277 V power system

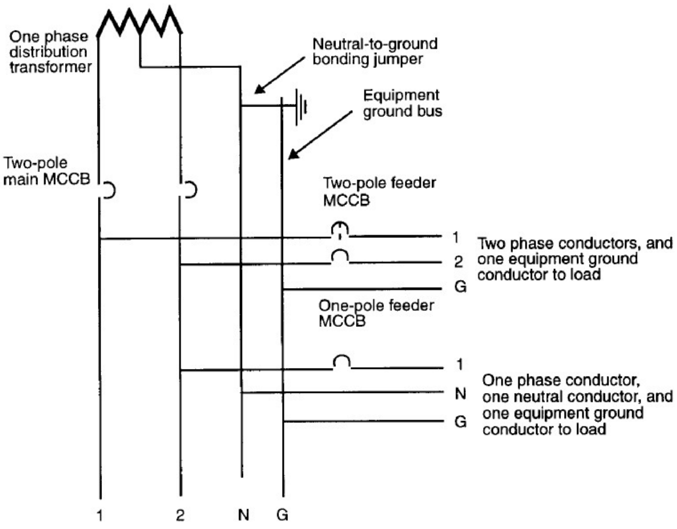

Figure 4-2—120/240 V power system

NOTE—Additional information on “Ratings and Testing” that may be useful for these applications are indicated in Chapter 3 of this recommended practice.[2]

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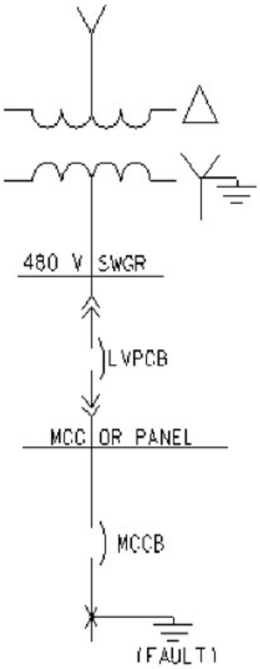
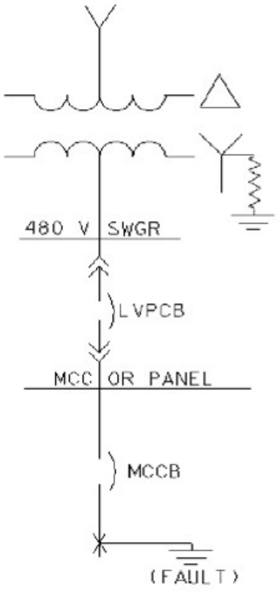
[2] Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.



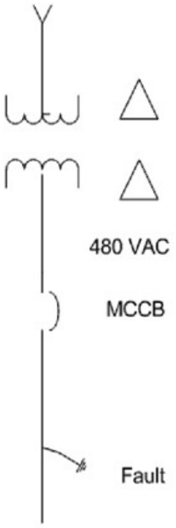
This solidly grounded WYE system is the most common in North America. This system is typically delta connected on the primary and wye connected on the secondary with the neutral solidly connected to ground. The grounded neutral conductor carries the single phase or unbalanced three-phase current. A single line-to-ground or line-to-neutral fault is the kind of fault that would involve an individual circuit-breaker pole interruption in this system. For a four-wire 480 Y/277 V system, the voltage across each pole would be limited to 277 V during the time the circuit breaker is interrupting the fault. The individual pole interrupting capability of a MCCB for this system is its marked interrupting rating. In other words, an individual pole of a three-pole MCCB with a 65 kA interrupting rating @ 480 V in a 480 Y/277 V system is capable of interrupting a single-phase fault of 65 kA @ 277 V, which is 0.577 or 58% of 480 V. This same principle holds for a MCCB connected to a 208 Y/120 V system.

Figure 4-3—480 Y/277 or 208 Y/120 VAC solidly grounded systems



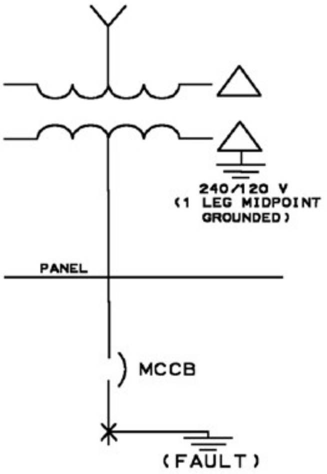
The high-resistance grounded WYE system is used in process plants as a means to minimize the overall impact of a possible ground fault that may occur on the system. In this case, a resistor is connected between the transformer secondary neutral connection and the ground. The magnitude of the ground resistance is chosen to limit the ground fault current to be equal to or slightly greater than the charging current of the system, thus reducing possible transient overvoltages. This permits plant operations to continue during first ground fault conditions until an appropriate outage can be scheduled to clear the fault. Consideration should be given in using this type of grounding system for a possible second ground fault occurring on another phase before the first fault is cleared, resulting in a phase-to-ground-to-phase fault that is not limited by the neutral grounding resistor. When the second phase-to-ground fault occurs, it is possible to impress full line-to-line voltage across one pole of the MCCB. Many MCCBs are rated 65 KA for application where the available short-circuit current of a three-phase bolted fault is at that level. However, a MCCB with a straight voltage rating and a frame rating between 100 and 800 A will have an individual pole short-circuit test at 8.7 KA at line-to-line voltage. Only MCCBs with a straight voltage rating may be applied in this type of system. Relays are available that will alarm on the first fault and trip on the second fault in time to prevent burndowns. For additional application details concerning high-resistance grounding, please refer to the *IEEE Buff Book*™.

Figure 4-4—480 Y/277 VAC High-resistance grounded system



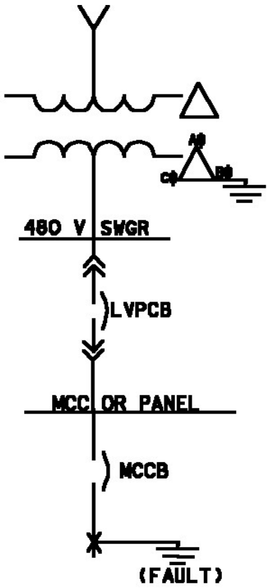
For an ungrounded delta system, we have a system that is actually grounded through the system capacitance. As a result, a small amount of capacitance current will flow during a line-to-ground fault. This application is very similar to the high-resistance grounded system. The first phase-to-ground fault must be detected and cleared promptly before a second ground fault occurs on another phase. Arcing ground faults on a large ungrounded system can result in excessive transient overvoltages. As indicated for the high-resistance grounded system, single pole interrupting capability must be considered for this system as the second ground fault can impress full line-to-line voltage on one pole of the MCCB. Only MCCBs with a straight voltage rating may be applied in this type of system.

Figure 4-5—480 VAC ungrounded delta system



This mid-point grounded 240/120 V system has been used by utilities to provide three-phase, four-wire service comprising three-phase 240 VAC and one-phase 120 VAC power. The voltage-to-ground from the high leg (the leg of the delta opposite the ground) is 208 V. The voltage-to-ground from the other two legs is 120 V. The circuit breaker must, in this case, be rated for 240 VAC rather than for 120/240 VAC. Circuit breakers rated 120 or 120/240 VAC are suitable for use on the legs with the center ground. The three-pole 240 V MCCB should have a single pole interrupting rating capable of interrupting the available short-circuit current at 208 V. Only MCCBs with a straight voltage rating may be applied in this type of system.

Figure 4-6—240/120 VAC mid-point grounded system



The corner grounded delta system is also used. Overcurrent protection is not required in the grounded phase [(phase) B)]. However, when a phase-to-ground fault occurs, the full line-to-line voltage is applied to the individual poles of a MCCB that are connected to the ungrounded phases [(phase) A and-(phase) C].

The use of corner-ground delta power system configurations requires special consideration in the use of MCCBs. In this case, the maximum short-circuit current for an individual pole shall be limited to 87% of the breaker's interrupting rating at full line-to-line voltage. This requires that the circuit breaker should be applied with an available fault current no higher than the tested values of current indicated in Table 3-19 unless it has been specially certified at a higher interrupting rating for application on the corner-grounded system.

Figure 4-7—480 VAC corner-grounded delta system

When selecting the type of circuit breaker for use on low-voltage, solidly grounded systems of more than 150 V to ground, the use of integral ground-fault trip elements should be considered. Ground-fault tripping is recommended for some applications, and it is required by the NEC for certain service entrance and feeder applications (refer to 230.95, 215.10, and 240.13 of the NEC).

Ground-fault trip elements may also be used on high-resistance grounded and ungrounded systems, but they will not operate for the first ground fault. However, if a second ground fault occurs in a different phase in the system, they will provide backup protection, which is more sensitive than the phase elements.

4.4.3 System frequency

Applications on systems other than 60 Hz should be checked with the manufacturer. Refer to 3.13. Systems rated 50 Hz may require special calibration of the trip device.

Circuit breakers with thermal-magnetic trip devices that are directly heated can generally be applied to power systems with a frequency up to 120 Hz without derating. Application of these circuit breakers above 120 Hz will result in increased eddy currents and iron losses, which cause greater heating within the thermal trip elements. To avoid this potential problem, the circuit breaker should either be calibrated for the specific frequency, be derated accordingly, or both. The amount of derating depends on the frame size and current rating as well as the system frequency.

Some thermal-magnetic circuit breakers rated 600 A, and many thermal-magnetic circuit breakers with higher current ratings, have a transformer-heated bimetal and are suitable for 60 Hz maximum. They require special calibration for 50 Hz.

Circuit breakers with electronic trip devices receive their signals from current transformer type sensors and are calibrated for 60 Hz applications.

4.4.4 Continuous-load current

4.4.4.1 Continuous current rating or setting

The continuous-load current of a circuit determines the minimum conductor size. The trip rating or setting of the circuit breaker should be selected to protect the load and/or conductor. The trip rating or setting of the various types of circuit breakers is established as follows:

a) Thermal-magnetic trip units of MCCBs may be non-interchangeable. MCCBs containing these trip units are available in many current ratings up to the frame size of the circuit breaker. The circuit-breaker rating is the trip rating.
b) Thermal-magnetic trip devices of ICCBs and LVPCBs may be interchangeable and are available in many current ratings up to the frame size of the circuit breaker. These units may be changed in the field. The trip rating of the circuit breaker depends on the trip unit installed.
c) Electronic trip units, available on MCCBs, ICCBs, and LVPCBs, use current sensors with ratings equal to or less than the continuous current rating of the circuit breaker. Rating plugs may be used to increase the range of settings. The trip unit provides an adjustable range of settings equal to or less than the sensor or plug rating. The sensor rating, plug rating (if applicable), and current setting selected from the adjustment range (if applicable) determine the trip setting of the circuit breaker.

The load current should not exceed the continuous-current rating or setting for "100% rated" circuit breakers, which includes all LVPCBs as well as ICCBs and MCCBs that are specifically rated and labeled for 100%. Other ICCBs and MCCBs may be applied at only 80% of the circuit-breaker rating for non-interchangeable trip type, 80% of the trip unit rating for interchangeable trip type, or trip setting of adjustable trip type.

4.4.4.2 Ambient temperature and altitude

Derating of the circuit breaker's continuous current at higher ambient temperatures, humidity, or altitudes than rated conditions should be checked in 3.17 through 3.19.

4.4.4.3 Harmonics

Circuit breakers with trip devices that use rms sensing are most suited to applications where harmonics are known to be a problem. Peak sensing units react to the peak value of the distorted wave shape, which does not correspond to the effective heating value of the current.

4.4.5 Available short-circuit current

4.4.5.1 Interrupting rating

The interrupting rating of a circuit breaker is the highest current at rated voltage that it is intended to interrupt under standard test conditions. Refer to Section 100 from the NEC, and 3.30 of this recommended practice.

The symmetrical interrupting rating of the circuit breaker shall exceed the calculated available short-circuit current at the point of application. The available short-circuit current includes contributions from all utility sources, plant generation, and connected motors. The interrupting rating of the circuit breaker is specific for the voltage at which it is applied. Refer to Table 3-8 and Table 3-9 for standard interrupting ratings of the various types of low-voltage circuit breakers at different system voltages. Consult the manufacturers for ratings of specific circuit breakers, because some are available with interrupting ratings higher than the minimum rating required by ANSI C37.16-2000. A short-circuit study is required to determine the magnitude of three-phase and single-phase short-circuit current at various points in the system. The procedure for performing short-circuit studies is provided in IEEE Std 141-1993, IEEE Std 241-1990, and IEEE Std 242-2001. The calculated symmetrical short-circuit currents should be reviewed with respect to the expected system short-circuit X/R ratio or associated short-circuit power factor, because the interrupting rating of the circuit breaker is based on a specific maximum X/R ratio. This is described in 3.42.

To obtain selective coordination over the entire short-circuit current range, LVPCBs may be applied without instantaneous trip elements. When applied without the instantaneous trip element, the interrupting rating is the same as the short-time rating, as shown in Table 3-9.

LVPCBs may be applied without integral trip units. In such cases, they are generally applied with separate overcurrent relays and tripped using a shunt trip device. In these applications, it is important to use the short-time rating rather than the interrupting rating, as shown in Table 3-9. The short-time current is defined as the current at a maximum clearing time of 0.5 s at rated short-circuit per Table 4 of ANSI C37.17-1997.

When high interrupting ratings and/or current limiting capabilities are needed, current-limiting MCCBs or integrally fused MCCBs and fused LVPCBs may be used as a design option. Refer to Chapter 6.

4.4.5.2 Series-connected rating

The series-connected rating is a UL recognized interrupting rating for a combination of line-side and load-side MCCBs. The load-side circuit-breaker interrupting rating may be less than the rating of the combination as shown in Figure 4-8. UL recognized series combinations of fuses and MCCBs also exist (refer to the UL Recognized Component Directory [B1]).[3]

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[3] The numbers in brackets correspond to those of the bibliography in 4.13.

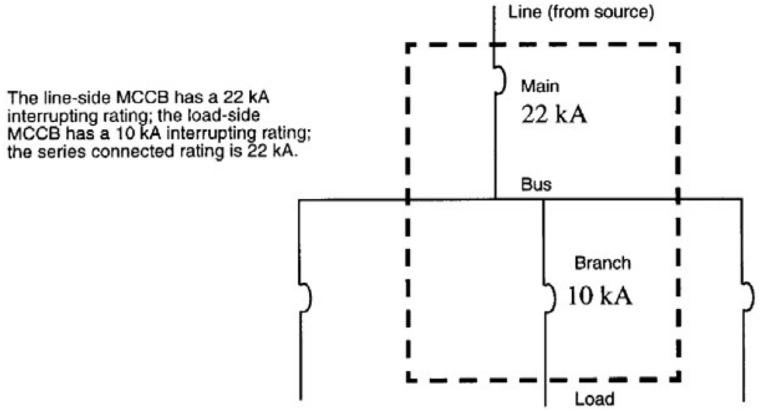

Figure 4-8—Series-connected rating

Equipment containing MCCBs, such as switchboards, panelboards, and residential service entrance equipment, must be tested and assigned a UL short-circuit rating when based on the rating of the series combination of circuit breakers used (tests may cover other main overcurrent protective devices).

Protective device series ratings are not limited to devices located in the same enclosure, such as panelboard main and branch circuit breakers. They can be located in different equipment, such as a residential metering distribution panelboard circuit breaker and a load-side residential load center, or a line-side switchboard and a load-side panelboard. Equipment will have rating labels that show short-circuit ratings when protected by series-connected rated line-side devices.

The load-side circuit breaker of a series combination must be located in equipment that is listed and marked for use with series-connected ratings that include that circuit breaker.

Series-connected ratings for each manufacturer's equipment using series combinations of MCCBs are established by that manufacturer with testing witnessed by UL and the Canadian Standards Association (CSA). A series-combination should not use different manufacturers' circuit breakers, even though the manufacturers have similar designs, because no testing has been done to verify a series-connected rating.

The principal benefit of series ratings is the cost savings realized by using load-side circuit breakers whose interrupting rating is less than the available short-circuit current. However, there are disadvantages. The following should be considered when applying circuit breakers in a series combination:

a) One disadvantage of series combination is loss of selective coordination at high-fault currents. A fully rated system might be arranged to avoid tripping the main circuit breaker for a feeder short circuit, but the series combination requires both the main and the feeder circuit breakers to trip when the available short-circuit current is above the instantaneous trip of the main circuit breaker. This is