**IEEE Std 516-1995**
(Revision of
IEEE Std 516-1987)

# IEEE Guide for Maintenance Methods on Energized Power Lines

**IEEE Standards Board**
Approved March 16, 1995

**Sponsor**
**Engineering in Safety, Maintenance, and Operation of Lines (ESMOL) Subcommittee of the Transmission and Distribution Committee**
**of the**
**IEEE Power Engineering Society**

**Abstract:** General recommendations for performing maintenance work on energized power lines are provided. Technical explanations as required to cover certain laboratory testing of tools and equipment, field maintenance and care of tools and equipment, and work methods for the maintenance of energized lines and for persons working in the vicinity of energized lines are included.

**Keywords:** energized, equipment, maintenance, power lines, tools.

The Institute of Electrical and Electronics Engineers, Inc. 345 East 47th Street, New York, NY, 10017-2394, USA.



ISBN 1-55937-517-5

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# Introduction

*(This introduction is not a part of IEEE Std 516-1995, IEEE Guide for Maintenance Methods on Energized Power Lines.)*

Live-line maintenance of transmission lines began in the early 1920s and developed into a major working practice as the transmission systems were expanded and the voltages increased.

In the 1950s, when the transmission line voltage exceeded 300 kV line-to-line, the use of fiberglass to replace wooden tools made a significant change in the industry. Economic conditions prohibited the construction and operation of redundant lines, and the need for live-line maintenance of transmission line increased rapidly.

During the 1950s and 1960s, several papers were written regarding the safety aspects of live-line maintenance. In the early 1970s, the IEEE Transmission and Distribution Committee recognized the need to consolidate information on live-line maintenance, and thus a task group was formed to write a guide. The task group later become the Engineering in Safety, Maintenance, and Operation of Lines Subcommittee (ESMOL).

This guide was started in the late 1970s and was published in 1986 on a trial-use basis. In 1987 the guide was released as a full-use ANSI/IEEE Standard. In 1990 the ESMOL Subcommittee started revisions to the guide to bring it up to the current state of the art and into conformance with other international standards issued in recent years.

During the original development of the guide it was not intended that the it would be used as document to establish government regulations. However, since its publication in 1986, several government regulatory agencies have used the guide in their rule making. This edition of the guide includes revisions that make it more compatible for use in governmental regulations.

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# IEEE Guide for Maintenance Methods on Energized Power Lines

## 1. Overview

### 1.1 Scope

This guide provides general recommendations for performing maintenance work on energized power lines. It is not intended to include all of the proven practical methods and procedures; however, these selected comprehensive recommendations are based on sound engineering principles, engineering safety considerations, and field experience by many utilities. Included are technical explanations as required to cover certain laboratory testing of tools and equipment, field maintenance and care of tools and equipment, and work methods for the maintenance of energized lines and for persons working in the vicinity of energized lines.

### 1.2 Purpose

The purpose of this guide is to

a) Present, in one guide, sufficient details of some of the methods and equipment presently in use to enable the performance of safe, energized-line maintenance.
b) Direct attention to appropriate standards and other documents for the acquisition of knowledge on the care and use of required tools and equipment.
c) Provide guidance for establishing a safe work area, taking into consideration the physical effects of the work area on personnel.

It is not intended that this guide should replace present proven utility practices or imply that these recommendations are superior to existing practices and, therefore, should be universally adopted as utility standards. This compilation of many accepted practices is presented specifically in the form of a guide to be used by those electric power utilities and agencies that are seeking guidance in establishing methods and procedures for maintenance of energized power lines.

### 1.3 Application

This guide, although general in scope and purpose, is specific enough to be applicable to all aspects of energized-line maintenance.

Since energized-line maintenance practices for different projects are influenced by the magnitude and nature of each project and by local conditions and circumstances, some alternative methods that have been successfully employed are presented.

The practices described provide for the safe performance of energized-line maintenance. They are based on practices of operating utilities with many years of successful experience.

The approach used in this guide is to

a) Present definitions required for clarity.
b) Indicate the engineering and other technical considerations essential to the safe performance of energized-line maintenance.
c) Provide guidance for the necessary test equipment and procedures associated with manufacturer and user acceptance, testing, and care of equipment.
d) Detail various work methods for working on or near energized lines and associated devices.

Examples of some applications under development that are not yet covered in full detail in this guide are as follows:

— Fiber optic maintenance procedures
— Effect of damaged insulators (including non-ceramic insulators)
— Influence of capacitance of a nonconductive object in the air gap
— Strength of air gaps containing a metallic object at floating potential
— Application of transient overvoltage control (e.g., metal oxide varistor, lightning arrestors, preinsertion resistors)
— Further review of insulated tools with metal components

Advancement in technology or changes in system design will probably justify modifying the minimum requirements recommended in this guide.

### 1.4 Other requirements

Requirements of federal, state, or local regulations should be observed. When any conflict exists between this guide and the rules of the owner of the line, the owner's rules should take precedence.

Familiarity with the Occupational Safety and Health Administration (OSHA) regulations Title 29, CFR 1910 and Title 29, CFR 1926 are particularly important to those preforming maintenance work on transmission and distribution facilities. While CFR 1926 rules are applicable to construction work covered by OSHA, the industry considers many of the tasks involved as maintenance work.[1]

## 2. References

This guide should be used in conjunction with the following publications. Other referenced publications also are listed in the bibliography (clause 8).

ANSI C2-1993, National Electrical Safety Code.[2]

ANSI/SIA A92.2-1990, Vehicle Mounted Elevating and Rotating Aerial Devices.

ASTM D120-87, Specification for Rubber Insulating Gloves.[3]

1. Information on references can be found in clause 2.

2. ANSI and ANSI/SIA publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

3. ASTM publications are available from the Customer Service Department, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.

ASTM D149-93a, Test Methods for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies.

ASTM D1048-93, Specification for Rubber Insulating Blankets.

ASTM D1049-93, Specification for Rubber Insulating Covers.

ASTM D1050-90, Specification for Rubber Insulating Line Hose.

ASTM D1051-87, Specification for Rubber Insulating Sleeves.

ASTM D1078-93, Test Method for Distillation Range of Volatile Organic Liquids.

ASTM F478-92, Specification for In-Service Care of Insulating Line Hose and Covers.

ASTM F479-93, Specification for In-Service Care of Insulating Blankets.

ASTM F496-93b, Specification for In-Service Care of Insulating Gloves and Sleeves.

ASTM F696-91, Specifications for Leather Protectors for Rubber Insulating Gloves and Mittens.

ASTM F711-93, Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used in Live Line Tools.

ASTM F712-88, Test Methods of Testing Electrically Insulating Plastic Guard Equipment for Protection of Workers.

ASTM F968-93, Specification for Electrically Insulating Plastic Guard Equipment for Protection of Workers.

ASTM F1236-89, Guide for Visual Inspection of Electrical Protective Rubber Products.

CSA C225-M88, Vehicle-Mounted Aerial Devices.[4]

CFR Publication 14 CFR Part 133, Rotorcraft External Load Operations.[5]

CFR Title 29, CFR 1910 Subpart R, Section 1910.137 and 1910.269 (OSHA).

CFR Title 29, CFR 1926, Subpart V (OSHA).

IEC 60-1 (1989), High-voltage testing techniques, part 1: General definitions and test requirements.

IEC 60-3 (1976), High-voltage testing techniques, part 3: Measuring devices.

IEC 60-4 (1977), High-voltage testing techniques, part 4: Application guide for measuring devices.

IEC 265-1 (1983), High-voltage switches, part 1: High-voltage switches for rated voltages above 1 kV and less than 52 kV.[6]

IEC 265-2 (1988), High-voltage switches, part 2: High-voltage switches for rated voltages of 52 kV and above.

4. CSA publications are available from the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Rexdale, Ontario, Canada M9W 193.

5. CFR publications are available from the Superintendent of Documents, US Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082, USA.

6. IEC publications are available from IEC Sales Department, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

IEC 855 (1985), Insulating foam-filled tubes and solid rods for live working.

IEC 895 (1987), Conductive clothing for live working at a nominal voltage up to 800 kV a.c.

IEC 903 (1988), Specifications for gloves and mitts of insulating material for live working.

IEC 984 (1990), Sleeves of insulating material for live working.

IEC 1057 (1991), Aerial devices with insulating boom used for live working.

IEC 1111 (1992), Matting of insulating material for electrical purposes.

IEC 1112 (1992), Blankets of insulating material for electrical purposes.

IEC 1229 (1993), Rigid protective covers for live working on a.c. installations.

IEC 1235 (1993), Live working—Insulating hollow tubes for electrical purposes.

IEC 1236 (1993), Saddles, pole clamps (stick clamps) and accessories for live working.

IEEE Std 4-1978 (W1994), IEEE Standard Techniques for High Voltage Testing (ANSI). (Refer only to the 1978 edition of this standard.)[7]

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).[8]

IEEE Std 524-1992, IEEE Guide to the Installation of Overhead Transmission Line Conductors (ANSI).

IEEE Std 524a-1993, IEEE Guide to Grounding During the Installation of Overhead Transmission Line Conductors: Supplement to IEEE Guide to the Installation of Overhead Transmission Line Conductors (ANSI).

IEEE Std 935-1989, IEEE Guide on Terminology for Tools and Equipment to Be Used in Live Line Working (ANSI).

IEEE Std 957-1995, IEEE Guide for Cleaning Insulators.[9]

IEEE Std 978-1984, (Reaff 1990) IEEE Guide for In-Service Maintenance and Electrical Testing of Live-Line Tools (ANSI).

IEEE Std 1048-1990, IEEE Guide for Protective Grounding of Power Lines (ANSI).

IEEE Std 1067-1990, IEEE Guide For In-Service Use, Care, Maintenance, and Testing of Conductive Clothing for use on Voltages up to 765 kV AC (ANSI).

IEEE Std 1070-1988, IEEE Guide for the Design and Testing of Transmission Modular Restoration Structure Components (ANSI).

IEEE P1307/D7A, March 6, 1995, IEEE Draft Trial-Use Guide for Fall Protection for the Utility Industry.[10]

7. IEEE Std 4-1978 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, tel. (303) 792-2181.

8.IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

9.As this standard goes to press, IEEE Std 957-1995 is approved but not yet published. The draft standard is, however, available from the IEEE. Anticipated publication date is August 1995. Contact the IEEE Standards Department at 1 (908) 562-3800 for status information.

10.This authorized standards project was not approved by the IEEE Standards Board at the time this went to press. It is available from the IEEE.

## 3. Definitions

This clause provides definitions for terms used in this guide. Additional terminology can be found in IEEE Std 935-1989. For terminology not listed below or in IEEE Std 935-1989, consult IEEE Std 100-1992.

**3.1 aerial device.** A vehicular mounted articulating device or telescoping boom-type personal lift device, or both, equipped with one or more buckets or a platform used to position a worker.

**3.2 aerial work.** Work performed on equipment used for the transmission and distribution of electricity, which is performed in an elevated position on various structures, conductors, or associated equipment.

**3.3 barehand work.** A technique of performing live maintenance on energized wires and equipment whereby one or more line workers work directly on an energized part after having been raised and bonded to the same potential as the energized wire or equipment. These line workers are normally supported by an insulating ladder, nonconductive rope, insulating aerial device, helicopter, or the energized wires or equipment being worked on. Most barehand work includes the use of insulating live tools.

**3.4 bonded.** The mechanical interconnection of conductive parts to maintain a common electrical potential. *Syn:* connected.

**3.5 bucket.** A device designed to be attached to the boom tip of a line track, crane, or aerial lift and used to support workers in an elevated working position. It is normally constructed of fiberglass to reduce its physical weight, maintain strength, and obtain good dielectric characteristics. *Syn:* basket.

**3.6 bypass.** *See:* **jumper.**

**3.7 capacitive current.** The component of the measured current that leads the applied voltage by 90° due to the geometrical capacitance of the tool or equipment.

**3.8 clearance.** *See:* **work permit.**

**3.9 conduction current.** The component of the measured current in phase with the applied voltage that is delivered to the volume of the tool or equipment due to the physical resistance of the material comprising the tool or equipment.

**3.10 conductive clothing.** Clothing made of natural or synthetic material that is either conductive or interwoven with conductive thread to provide mitigation of effects of the electric fields of high-voltage energized electrical conductors and equipment.

**3.11 conductor.** A wire or combination of wires not insulated from one another, suitable for carrying an electrical current. However, it may be bare or insulated. *Syn:* cable; wire.

**3.12 conductor cover.** Electrical protection equipment designed specifically to cover conductors. *Syn:* blanket; cover-up; eel; hard cover; hose; snake. *See also:* **cover-up equipment**.

**3.13 conductor grip.** A device designed to permit the pulling of a conductor without splicing on fittings, eyes, etc. It permits the pulling of a continuous conductor where threading is not possible. The designs of these grips vary considerably. Grips such as the Klein (Chicago) and Crescent utilize an open-sided, rigid body with opposing jaws and swing latch. In addition to pulling conductors, this type of grip is commonly used to tension guys and, in some cases, to pull wire rope. The design of the come-along (pocket-book, suitcase, four bolt, etc.) incorporates a bail attached to the body of a clamp that folds to completely surround and envelop the conductor. Bolts are then used to close the clamp and obtain a grip. *Syn:* buffalo; Chicago grip; come-along; Crescent four bolt; grip; Kellem grip; Klein; pocketbook; seven bolt; six bolt; slipgrip; suitcase.

**3.14 cover-up equipment.** Equipment designed to protect persons from energized parts in a specific work area. Many different types are available to cover conductors, insulators, dead-end assemblies, structures, and apparatus. Cover-up material may be either flexible or rigid.

**3.15 current-carrying part.** A conducting part intended to be connected in an electric circuit to a source of voltage. Noncurrent-carrying parts are those not intended to be so connected.

**3.16 davit.** An assembly attached to a support or assembled on a structure to provide a rigging point for rope blocks, chains, or hoists so as to manipulate various pieces of apparatus. The davit is a rigid assembly and does not swivel.

**3.17 dead.** A circuit that has been de-energized so that the circuit has been disconnected from all intended electrical sources. However, it could be electrically charged through induction from energized circuits in proximity to it, particularly when the circuits are parallel. *See also:* **de-energized.**

**3.18 dead-end.** The point at which mechanical force (primarily) and longitudinal strain is applied to a reliable support. *Syn:* anchor point, strain attachment, termination.

**3.19 de-energized.** Free from any electric connection to a source of potential difference and from electric charge; not having a potential different from that of the ground. The term is used only with reference to current-carrying parts that are sometimes alive (energized).

**3.20 distance clearance.** The minimum separation between two conductors, between conductors and supports or other objects, or between conductors and ground, or the clear space between any objects.

**3.21 dynamometer.** A device designed to measure loads or tensions. Various models of these devices are used to tension guys or sag conductors. *Syn:* clock; load cell.

**3.22 energized.** Electrically connected to a source of potential difference, or electrically charged so as to have a potential different from that of the ground. *Syn:* alive; current carrying; hot; live.

**3.23 equipotential.** An identical state of electrical potential for two or more items.

**3.24 extra-high voltage (EHV).** A term applied to voltage levels that are greater than 240 000 V.

**3.25 gin.** An assembly, which when attached to a support or assembled on a structure, provides a rigging point for rope blocks, blocks, etc., so as to manipulate various pieces of apparatus. The gin, unlike the davit, is not rigid since its boom swivels, affording greater maneuverability.

**3.26 gloving.** A method of performing live-line maintenance on energized electrical conductors and equipment whereby a worker or workers, wearing specially-made and tested insulating gloves, with or without sleeves, and using cover-up equipment while supported by the structure or insulated aerial lift equipment, work(s) directly on the energized electrical conductor or equipment.

**3.27 grounded.** Connected to earth or to some extended conducting body that serves instead of the earth, whether the connection is intentional or accidental.

**3.28 helicopter work.** A technique of using a helicopter for performing live maintenance on energized wires and equipment, whereby one or more line workers work directly on an energized part using live tools after being raised and bonded to the energized wire or equipment.

**3.29 high voltage (hv).** A term applied to voltage levels that are greater than 1000 V.

**3.30 hoist.** An apparatus for moving a load by the application of pulling force (not including a car or platform running in guides). These devices are normally designed using roller or link chain and built-in leverage to enable heavy loads to be lifted or pulled. They are often used to dead-end a conductor during sagging and clipping-in operations and when tensioning guys. *Syn:* chain hoist; chain tugger; coffin hoist; ratchet hoist.

**3.31 hold out.** Operating order, operating-order identification tag, or marker. *Syn:* hold card.

**3.32 hot.** *See:* **energized.**

**3.33 insulated tool or device.** A tool or device that has conductive parts and is either coated or covered with a dielectric material.

**3.34 insulating clothing.** Clothing made of natural or synthetic material that is designed primarily to provide insulation from an energized part or conductor.

**3.35 insulating tool or device.** 1) A tool or device designed primarily to provide insulation from an energized part or conductor. It can be composed entirely of insulating materials. Examples: conductor cover, stick, insulating tape. 2) A tool or device that has conductive parts separated by dielectric parts.

**3.36 insulator cover.** Electrical protection equipment designed specifically to cover insulators. Examples: dead-end cover, pole-top cover, ridge-pin cover. *Syn:* hood; pocketbook. *See also:* **cover-up equipment.**

**3.37 isolated.** 1) Physically separated, electrically and mechanically, from all sources of electrical energy. Such separation may not eliminate the effects of electrical or magnetic induction. 2) Not readily accessible to persons unless special means for access are used.

**3.38 jumper.** A conductive tool used to maintain electrical continuity across equipment, or a conductor that shall be opened mechanically to enable various operations of live-line work to be performed. *Syn:* bypass.

**3.39 leakage current.** A component of the measured current that flows along the surface of the tool or equipment, due to the properties of the tool or equipment surface, including any surface deposits.

**3.40 line worker.** A person qualified to perform various line-work operations, including aerial and ground work. *Syn:* lineman.

**3.41 line-work.** Various operations performed by a person on electrical facilities, including ground work, aerial work, and associated maintenance.

**3.42 live.** *See:* **energized.**

**3.43 live work.** Work on or near (e.g., part of tools being used or worker's body less than minimum approach distance) energized or potentially energized lines (i.e., grounding, live tool work, hot stick work, gloving and barehand work). *Syn:* live line work; live-line work.

**3.44 master ground.** A portable device designed to short circuit and connect (bond) a de-energized circuit or piece of equipment, or both, to an electrical ground. Normally located remote from, and on both sides of, the immediate work site. Primarily used to provide safety for personnel during construction, reconstruction, or maintenance operations. *Syn:* ground set; ground stick.

**3.45 maximum operating voltage (*V*m).** The maximum system operating rms phase-to-phase (or phase-to-ground for single phase, or pole-to-ground for dc) voltage, which is also equal to the 1 per unit (p.u.) base. For clearance calculation, the maximum operating crest phase-to-ground voltage is equal to 1 per unit (p.u.).

**3.46 minimum air insulation distance (MAID).** The shortest distance in air between electrical apparatus and/or a line worker's body at different potential. This minimum air insulation distance, with a floating electrode in the gap, is equal to or greater than the sum of the individual minimum approach distances. This is the electrical component and does not include any factor for inadvertent movement.

**3.47 minimum approach distance (MAD).** The minimum air insulation distance plus a modifier for inadvertent movement.

**3.48 minimum tool distance.** The minimum distance that must be maintained between tools and energized lines or devices.

**3.49 minimum tool-insulation distance.** The shortest permissible distance between energized electrical apparatus and any part of a worker's body or conducting object while performing live work with an insulating tool in the air gap.

**3.50 NESC.** National Electrical Safety Code, ANSI C2-1993.

**3.51 protective gap.** A gap placed between live parts and ground to limit the maximum overvoltage that may otherwise occur.

**3.52 rigging.** An assembly of material used to manipulate or support various tools and equipment in both energized and de-energized line-work.

**3.53 rope block.** A device designed with one or more sheaves, a shell, and an attachment hook or shackle, commonly used in pairs with a rope reeved through the sheaves. The primary purpose of this device is to provide mechanical advantage so as to lift or move equipment. *Syn:* **block and tackle.**

**3.54 snatch block.** A device normally designed with a single sheave, a shell, and an attachment hook or shackle. One side of the shell can be opened to eliminate the need for threading of the line. It is commonly used for lifting loads on a single line, or as a device to control the position or direction, or both, of a fall line or pulling line. *Syn:* skookum; Washington; western.

**3.55 statistical sparkover voltage.** A transient overvoltage level that produces a 97.72% probability of sparkover (i.e., two standard deviations above the 50% sparkover voltage value).

NOTE—IEC uses 90%.

**3.56 statistical withstand voltage.** A transient overvoltage level that produces a 0.14% probability of sparkover (i.e., three standard deviations below the 50% Sparkover voltage value).

NOTE—IEC uses 2%.

**3.57 stick.** A type of insulating tool used in various operations of live-line work. *Syn:* hot stick; live-line tool; pole; work pole; work stick.

**3.58 strain stick.** An insulating support tool used primarily to relieve mechanical loading at suspension and dead-end configurations so as to replace damaged insulators or hardware.

**3.59 stray current.** Currents or components that do not constitute information desired for measurement. Examples are currents due to the stray capacitance of an object to the ground plane, walls, etc.

**3.60 structure.** Material assembled to support conductors or associated apparatus, or both, used for transmission and distribution of electricity (e.g., service pole, tower).

**3.61 suspension of reclosing.** To make inoperative automatic reclosing equipment. *Syn:* hold off; hold order; hold out; live-line permit.

**3.62 tool or equipment current.** The total current delivered to the tool or equipment.

**3.63 $U_{50}$.** A transient overvoltage level that produces a 50% probability of sparkover. *Syn:* critical flashover voltage (CFO).

**3.64 ultra-high voltage (uhv).** A term applied to voltage levels that are higher than 800 000 V.

**3.65 universal stick.** A stick, or type of insulating tool, with an end to which universal tools can be attached.

**3.66 universal tool.** An accessory designed to attach to a universal stick allowing one insulated stick to be used to perform many different operations.

**3.67 work permit.** The authorization to perform work on a circuit. *Syn:* clearance, guarantee.

# 4. Technical considerations and testing

## 4.1 Introduction

The performance of live work requires the use of equipment and tools that in many cases are specific to the work operation. Development of equipment and tools is based on requirements generated from field needs and experiences related to technical considerations and safe work methods.

References or specific guidance concerning the specialized tools and equipment needed for live work are provided. These tools and devices are produced in accordance with certain standards, requirements, or performance factors, including the essential elements of laboratory electrical testing for design, certification, and acceptance testing. Other applicable test methods may also be utilized, but comparison of data between different test procedures may not be practical because of the variations in test conditions.

**Table 1—Altitude correction factor**

| Altitude | | Correction factor |
|---|---|---|
| (m) | (ft) | |
| 900 | 3000 | 1.00 |
| 1200 | 4000 | 1.02 |
| 1500 | 5000 | 1.05 |
| 1800 | 6000 | 1.08 |

| **Altitude** | | **Correction factor** |
|---|---|---|
| **(m)** | **(ft)** | |
| 2100 | 7000 | 1.11 |
| 2400 | 8000 | 1.14 |
| 2700 | 9000 | 1.17 |
| 3000 | 10 000 | 1.20 |
| 3600 | 12 000 | 1.25 |
| 4200 | 14 000 | 1.30 |
| 4800 | 16 000 | 1.35 |
| 5400 | 18 000 | 1.39 |
| 6000 | 20 000 | 1.44 |

NOTE—Multiply the distance *D* given in tables 2, 6, 7, and 8 by the indicated correction factor.

## 4.2 Basic concepts

A major part of this clause is devoted to tool and equipment current measurements for certification and acceptance purposes.

### 4.2.1 Insulating properties

Personal safety and operational security in energized-line work depend on the insulating properties of insulating materials and air.

**Table 2—Minimum air insulation distance, ac energized work**

| Voltage in kV phase-to-phase | Minimum air distance | | | |
|---|---|---|---|---|
| | phase-to-ground | | Phase-to-phase | |
| | ft | cm | ft | cm |
| 0.000–0.050[a] | Not specified | | Not specified | |
| 0.051–0.300 | Avoid contact | | Avoid contact | |
| 0.31–0.75 | 0.006 | 0.18 | 0.009 | 0.27 |
| 0.76–15.0 | 0.13 | 4 | 0.19 | 6 |
| 15.1–36.0 | 0.53 | 16 | 0.81 | 25 |
| 36.1–46.0 | 0.75 | 23 | 1.15 | 35 |
| 46.1–72.5 | 1.26 | 39 | 1.93 | 59 |
| 72.6–121 | 2.10 | 64 | 3.22 | 99 |
| 138–145 | 2.55 | 78 | 3.91 | 120 |
| 161–169 | 3.00 | 91 | 4.60 | 140 |
| 230–242 | 4.20 | 128 | 6.44 | 197 |
| 345–362 | 7.48 | 228 | 11.47 | 347 |
| 500–550 | 10.21 | 311 | 17.02 | 519 |
| 765–800 | 13.86 | 422 | 24.95 | 780 |

NOTES
1—Values are based on altitudes below 900 m. See table 1 for corrections for higher altitudes. It is not necessary to correct for atmospheric conditions.
2— Table distances do not include any factor for inadvertent movement. See 7.3 for inadvertent movement considerations.
3— Higher or lower transient overvoltage factors can occur depending on the design and operation of the system.

a. For single phase systems use voltage-to-ground.

#### 4.2.1.1 Insulating materials

Insulating materials are generally defined as a function of their electrical insulating and dielectric strength.

- — Electrical insulating materials have the property to prevent the flow of current through them.
- — Dielectric strength is the maximum potential gradient that the material can withstand without breakdown.
- — Factors affecting insulating materials include temperature, altitude, moisture, contamination, impurities, and aging.

#### 4.2.1.2 Air as insulation

The insulating characteristics of air are defined in terms of the capability of the air to withstand an electric field. The dielectric strength of air is expressed in the unit of kV per meter or an equivalent unit. The disruptive voltage is influenced by the air density, humidity, temperature, pressure, dimensions and separation of the electrodes or separation of the metal terminals, shape of the electrodes, and the time dependent characteristics of the applied voltage.

#### 4.2.1.3 Contamination—equipment

The insulating portions of aerial-lift equipment, insulating tools, and cover-up equipment should be kept free from contamination. Barehand work and work with insulating tools can be performed on dry contaminated insulators. Work on wet contaminated devices should be avoided, but can be performed with insulating tools using special precautions.

**Table 3—Transient overvoltage factors used in calculation of table 2**

| Voltage | Transient overvoltage factor (p.u.) |
|---|---|
| 362 kV and below | 3.0 |
| 500–550 kV | 2.4 |
| 700–800 kV | 2.0 |

NOTE—Higher or lower transient overvoltage factors may occur depending on the design and the operation of the system

### 4.2.2 Minimum air insulation distance

#### 4.2.2.1 General

a) Table 2 summarizes the basic electrical distances for operating voltage ranges based on the guidelines detailed in 4.2.2.2, 4.2.2.3, and 4.2.2.4. Table 2 is a general table based on the transient overvoltage factors typically found in distribution and transmission systems as shown in tables 3, 6, and 8, or when the transient overvoltage that may occur in the work area is controlled.
b) Table 7 provides the same information for dc energized work that table 6 provides for ac energized work.
c) The distances in tables 2, 6, 7, and 8 do not include any factor for inadvertent movement (ergonomic distance). For tables that include inadvertent movement, see 7.3 and tables 14 – 18.
d) For US electrical systems technical information, see [B13], which indicates that present designs provide for the transient overvoltage values, usually produced by switching, as shown in table 3 for summary of the transient overvoltage factors used in calculation of table 2.

NOTE —Tables 6 and 8 may be used when the transient overvoltage in the work area is controlled.

#### 4.2.2.2 Calculation of air insulation distances, 72 500 V and below

a) The calculation of minimum air distance for voltages below 72 500 V is based on test data from Appendix 2B of IEEE Std 4-1978 (see table 5).
b) An example of the calculations is summarized in table 4.

**Table 4—Example of detailed calculations for air gap**

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| **Maximum phase-to-phase voltage RMS, in kV** | **Overvoltage, in p.u.** | **Maximum phase-to-phase voltage RMS on a p.u. base, in kV** | **Maximum crest voltage, in kV** | **Maximum crest voltage plus 3 σ, in kV** | **Electrical withstand distance, in cm** |
| 0.30 | 3 | 0.52 | 0.73 | 0.87 | 0.070 |
| 0.75 | 3 | 1.30 | 1.84 | 2.17 | 0.174 |
| 15.0 | 3 | 25.98 | 36.73 | 43.23 | 3.723 |
| 36.0 | 3 | 62.36 | 88.17 | 103.75 | 15.944 |
| 46.0 | 3 | 79.68 | 112.68 | 132.57 | 22.733 |
| 72.5 | 3 | 125.58 | 177.60 | 208.94 | 38.258 |

NOTES

1—Col. #2. I.E.C. Technical Committee No. 78, Tools For Live Working, WG 3, Flexible Insulating Devices, along with WG 2, Rigid Insulating Devices, agreed during their Toronto meeting of June, 1990, to use a maximum transient overvoltage of 3.0 p.u., phase-to-ground, when testing tools and equipment, and to state that the 3.0 p.u. is used in their documents. Those systems having overvoltages above the 3.0 p.u. should take this limiting value into account.

2—Col. #3 $= (\text{col. \#1}) \cdot (\text{col. \#2}) \div \sqrt{3}$

3—Col. #4 $= (\text{col. \#3}) \cdot \sqrt{2}$

4—Col. #5 = (col. #4) ÷ 0.85

5—Col. #6 The basic electrical withstand (W/S) distance is determined by use of IEEE Std 4-1978, table 2 B.1, using linear interpolation between the two values that bracket the maximum overvoltage, plus 3 σ crest, of column 5. The centimeters/kilovolts for the 2 cm test has been used for the two lowest voltage ranges.

### 4.2.2.3 Calculation of air insulation distances, above 72 500–800 000 V

#### 4.2.2.3.1 General

a) In figure 1, a saturation factor is given for each voltage range. This saturation factor is derived from the transient overvoltage sparkover data. The transient overvoltage factor *T*, used in equation (1), should be correlated with characteristics of each individual application.

$$D = (C_1 C_2 + a) T \text{kV}_{\text{LG}} \quad (1)$$

where
$D$ is insulation distance, ft
$C_1$ is 0.01, or 1% of line-to-ground
$C_2$ is 1.1, composed of 1.06 for energized-line tool-to-air withstand distance ratio plus intangibles (see [B9])
$a$ is saturation factor for crest $\sqrt{2}T$ $\text{kV}_{\text{LG}}$ $\text{kV}_{\text{LG}}$voltages of 630 kV and above (see figure 1)

NOTE —Use crest voltage $\frac{(345)(\sqrt{2})(\text{overvoltage})}{\sqrt{3}}$

*T* is maximum anticipated per-unit switching surge
$kV_{LG}$ is rms system phase-to-ground kilovolts—actual

The general formula for insulating tools at all voltages becomes $D = (0.011 + a)TkV_{LG}$

b) Transient overvoltages are important in determining alternating current air insulation distances. The maximum transient overvoltage represents the maximum voltage magnitude at anytime or place on an operating line or system under consideration. When known, the maximum transient overvoltage values at the work site may be used when calculating air insulation distances. Otherwise, the values shown in table 3 should be used.
c) The configuration of electrodes influences sparkover as a function of polarity of the transient overvoltage. In usual applications for rigid insulating tools, the dry, polarity, transient overvoltage sparkover voltage is substantially above power frequency and positive-polarity values. It has been shown that the withstand curve for the conductor-tower configuration lies approximately midway between withstand curves for the rod-rod and rod-plane gaps in figure 2. These data substantiate the air insulation distance formula for air gaps, and as the derivation of air insulation distances from modified rod-gap data.
d) Air insulation distances determined by means of the formulas should not be applied without considering other relevant factors, such as inadvertent movement, conducting portions of tools, size, shapes, and position of conducting objects in the air gap.
e) The air insulation distance determined by means of the formulas should be used only at elevations below 900 m (3000 ft). Higher elevations require applicable correction factors, as indicated in table 1.
f) In determining dc pole air insulation distances, equivalents to ac line-to ground peak voltages are used.
g) The minimum air insulation distance, as given in tables 6, 7, and 8, should be maintained between an energized part and a person at ground potential, or vice versa, with an appropriate distance added for inadvertent movement. (See 7.3 for inadvertent movement distance.)

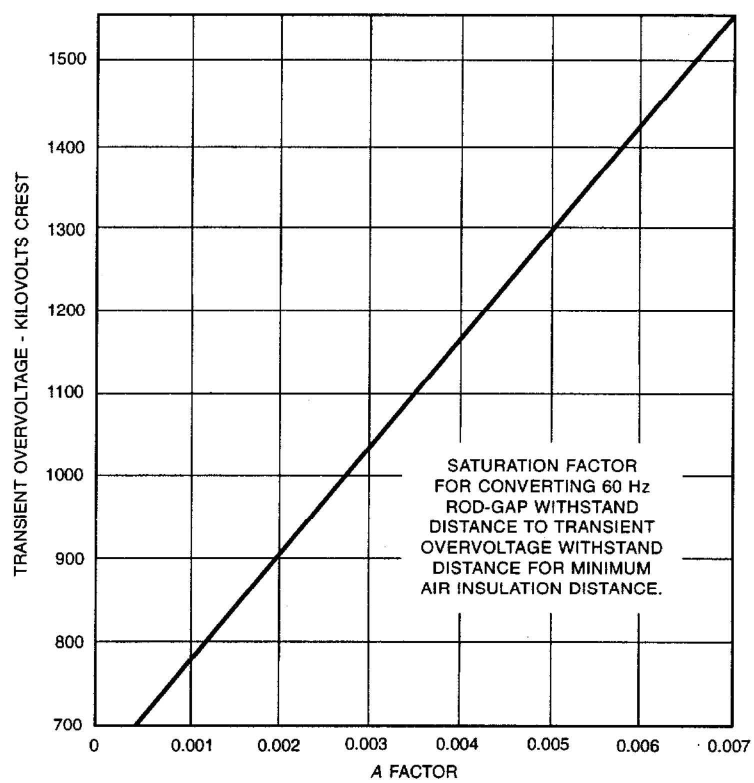


**Figure 1 — 60 Hz switching-surge saturation factor**

#### 4.2.2.3.2 Calculations

To obtain the minimum air insulation distance to energized lines or devices, the general formula is

$$D = (C_1 C_2 + a)(T)(V)$$

where

- *D* is minimum air insulation distance, ft
- $C_1$ is 0.01
- $C_2$ is 1.1, composed of 1.06 for energized-line tool-to-air withstand distance ratio plus intangibles. The 1.06 variable may be as great as 1.20 depending upon the type of insulating tool in the gap (see [B9]).
- *a* is saturation factor for transient overvoltage crest values of approximately 630 kV and above. These values are read from figure 1. However, the equations that have been fit to the curve in figure 1 provide a more convenient source for the data (see annex A).
- *T* is maximum anticipated per-unit transient overvoltage
- *V* is rms system phase-to-ground kilovolts—actual = $= \frac{\text{kV}_{\text{NOM-LL}}}{3\sqrt{2}\ \text{rms}}$

With no tool in the air gap, $C_2$ = 1.0. The general formula for the minimum air insulation distance for all voltages above 72 500 V becomes

$$D = (0.01 + a)(T)(V) \qquad (1b)$$

The evaluation of equation (1b) for the phase-to-ground voltages and transient overvoltage factors found in operating systems is summarized in table 6. See annex A for a numerical example of the derivation of live-line minimum air insulation distance using equation (1b) and figure 1.

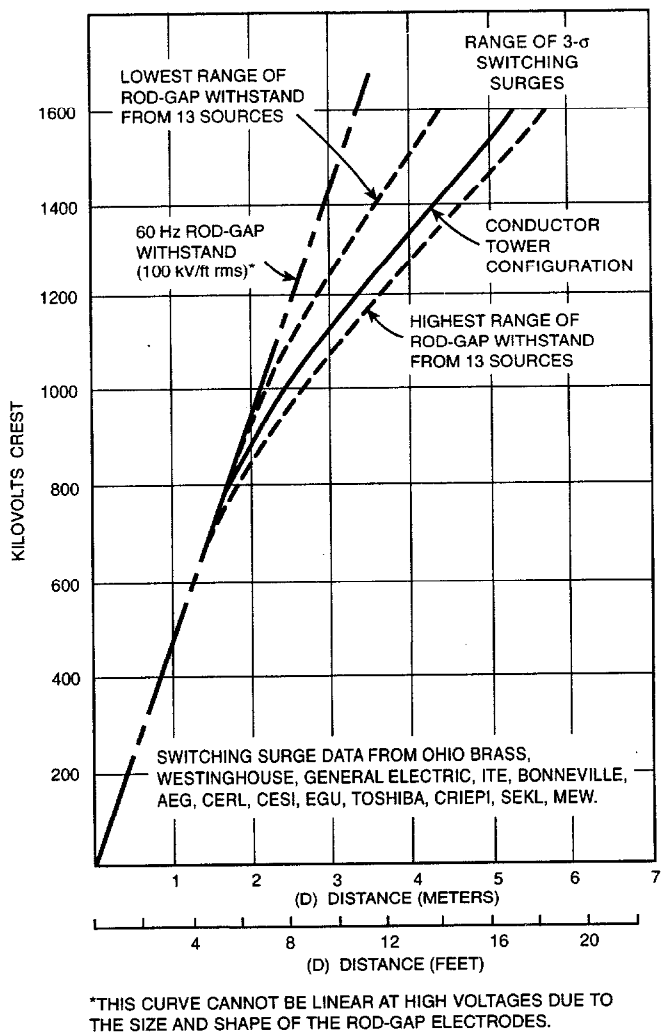


**Figure 2 — Typical withstand voltage for switching surges**

#### 4.2.2.4 Determining minimum air insulation phase-to-phase distances for energized work

Determining the minimum air phase-to-phase distance for energized work is complicated because there usually is a time displacement between the transients on the adjacent phases. The ratio of the positive and negative voltages on the two phases (electrodes) may vary. The time displacement causes the maximum voltage between phases to be less than the arithmetic sum of the magnitudes of the phase-to-ground voltages. The relationship between phase-to-ground and phase-to-phase transient overvoltage magnitudes, based upon the p.u. of system phase-to-ground crest, appears in [B5] (section 5, figure 5.2) and [B2]. The relationship given in figure 5.2 of [B5] has been converted to two formulas, as follows:

— *Phase-to-ground p.u. values of 1.5–2.0*

$$m = (Y_2 - Y_1)/(X_2 - X_1) \quad (2)$$

— *Phase-to-ground p.u. values of 2.0–3.0*

$$y = mx + b \tag{3}$$

Relationship between phase-to-ground and phase-to-phase transient overvoltage magnitude can be calculated as follows.

— Using equation (2)

| **p.u.$_{P\text{-}G}$** | **p.u.$_{P\text{-}P}$** | **p.u.$_{P\text{-}P}$/p.u.$_{P\text{-}G}$** |
|---|---|---|
| 1.5 | 1.9125 | 1.2750 |
| 1.6 | 2.2500 | 1.4063 |
| 1.7 | 2.5875 | 1.5221 |
| 1.8 | 2.9250 | 1.6250 |
| 1.9 | 3.2625 | 1.7171 |

— Using equation (3)

| **p.u.$_{P\text{-}G}$** | **p.u.$_{P\text{-}P}$** | **p.u.$_{P\text{-}P}$/p.u.$_{P\text{-}G}$** |
|---|---|---|
| 2.0 | 3.6000 | 1.8000 |
| 2.1 | 3.7000 | 1.7619 |
| 2.2 | 3.8000 | 1.7273 |
| 2.3 | 3.9000 | 1.6957 |
| 2.4 | 4.0000 | 1.6667 |
| 2.5 | 4.1000 | 1.6400 |
| 2.6 | 4.2000 | 1.6154 |
| 2.7 | 4.3000 | 1.5926 |
| 2.8 | 4.4000 | 1.5715 |
| 2.9 | 4.5000 | 1.5518 |
| 3.0 | 4.6000 | 1.5334 |

The calculation of the minimum air phase-to-phase distance is illustrated by the following example:

Example: At 362 kV: p.u.$_{\text{line-to-ground}}$ = 3.0 p.u. p.u.$_{\text{phase-to-phase}}$ = 4.6 p.u.

From table 6, 362 kV at 3 p.u., electrical distance = 7.48 ft

Electrical distances phase-to-phase = (7.48 ft)(4.6/3.0) = 11.47 ft

For a summary of the air insulation phase-to-phase distances for ac energized work, see table 9.

### 4.2.3 Physiological aspects of live-line work

#### 4.2.3.1 Electric fields

In the vicinity of an energized transmission line, an electric field exists in the space between the conductors and ground. Electric field strength is generally expressed in kilovolts per unit length.

**Table 5—Portion of table 2 B.1 from IEEE Std 4-1978: 60 Hz sparkover voltage of a 0.5 x 0.5 in square rod gap**

| Gap spacing | | kV-peak |
|---|---|---|
| cm | in | |
| 2 | 0.8 | 25 |
| 3 | 1.2 | 36 |
| 4 | 1.6 | 46 |
| 5 | 2.0 | 53 |
| 6 | 2.4 | 60 |
| 8 | 3.1 | 70 |
| 10 | 3.9 | 79 |
| 12 | 4.7 | 86 |
| 14 | 5.5 | 95 |
| 16 | 6.3 | 104 |
| 18 | 7.1 | 112 |
| 20 | 7.9 | 120 |
| 25 | 9.8 | 143 |
| 30 | 11.8 | 167 |
| 35 | 13.8 | 192 |
| 40 | 15.7 | 218 |

For example, a worker standing on the ground in the vicinity of an energized transmission line conductor, a worker on a tower or pole working on an energized conductor with live-line tools, or a worker in a bucket of an aerial lift working on an energized conductor are all within an electric field.

One of the most common manifestations of an electric field on a person is an electric shock. Such a shock may be either of two forms, transient state or steady state. A non-bonded worker assumes a potential other than that of adjacent conductive objects and the worker can receive a small perceptible shock if this conductive object is touched. The magnitude of the shock is dependent upon the orientation of the worker in the electric field and the strength of the field at power frequency. Transient shocks occur as contact is made with a conductive object at a potential different from the worker. The steady-state ac current range of the threshold-of-perception level is 0.6–1.1 mA. The let-go level is considered as having a range of 10–15 mA (see [B14]). Both types of perceptible shocks can be mitigated by either bonding or adequately shielding the worker from the electric field.

#### 4.2.3.1.1 Studies

The results of a comprehensive literature survey on the effects of electric fields on power line workers describe contrasting sets of research findings (see [B1], [B3], [B4], [B8], [B10], [B13], [B14], [B15], [B16], [B17], [B18]). Research results have failed to provide conclusive evidence that human exposure to present levels of electric fields from high-voltage overhead power lines, as normally encountered, have any harmful biological effects.

**Table 6—Minimum air insulation phase-to-ground distance, ac energized work**

| ***LL*** ***LG*** | **121 70** | | **145 85** | | **169 100** | | **242 140** | | **362 210** | | | **550 320** | | | **800 462** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***T*** | **ft** | **cm** | **ft** | **cm** | **ft** | **cm** | **ft** | **cm** | ***a*** | **ft** | **cm** | ***a*** | **ft** | **cm** | ***a*** | **ft** | **cm** |
| 1.5 | 1.08 | 33 | 1.33 | 41 | 1.50 | 46 | 2.17 | 66 | 0.0 | 3.17 | 97 | 0.3 | 4.97 | 151 | 2.5 | 8.66 | 264 |
| 1.6 | 1.17 | 36 | 1.42 | 43 | 1.58 | 48 | 2.25 | 69 | 0.0 | 3.42 | 104 | 0.6 | 5.46 | 166 | 3.0 | 9.60 | 293 |
| 1.7 | 1.25 | 38 | 1.50 | 46 | 1.67 | 51 | 2.42 | 74 | 0.0 | 3.58 | 109 | 1.0 | 5.98 | 182 | 3.5 | 10.60 | 323 |
| 1.8 | 1.33 | 41 | 1.58 | 48 | 1.83 | 56 | 2.58 | 79 | 0.0 | 3.83 | 117 | 1.3 | 6.51 | 198 | 4.0 | 11.64 | 355 |
| 1.9 | 1.33 | 41 | 1.67 | 51 | 1.92 | 58 | 2.67 | 81 | 0.0 | 4.00 | 122 | 1.6 | 7.08 | 215 | 4.5 | 12.73 | 388 |
| 2.0 | 1.40 | 43 | 1.70 | 52 | 2.00 | 61 | 2.80 | 85 | 0.0 | 4.20 | 128 | 2.0 | 7.68 | 234 | 5.0 | 13.86 | 422 |
| 2.1 | 1.47 | 45 | 1.79 | 55 | 2.10 | 84 | 2.94 | 90 | 0.0 | 4.41 | 134 | 2.3 | 8.27 | 252 | — | — | — |

| ***LL*** ***LG*** | **121 70** | | **145 85** | | **169 100** | | **242 140** | | **362 210** | | | **550 320** | | | **800 462** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***T*** | **ft** | **cm** | **ft** | **cm** | **ft** | **cm** | **ft** | **cm** | ***a*** | **ft** | **cm** | ***a*** | **ft** | **cm** | ***a*** | **ft** | **cm** |
| 2.2 | 1.54 | 47 | 1.87 | 57 | 2.20 | 67 | 3.08 | 94 | 0.1 | 4.70 | 142 | 2.6 | 8.87 | 270 | — | — | — |
| 2.3 | 1.61 | 49 | 1.96 | 80 | 2.30 | 70 | 3.22 | 98 | 0.3 | 5.01 | 151 | 2.9 | 9.49 | 290 | — | — | — |
| 2.4 | 1.68 | 51 | 2.04 | 52 | 2.40 | 73 | 3.35 | 102 | 0.6 | 5.34 | 153 | 3.3 | 10.21 | 311 | — | — | — |
| 2.5 | 1.75 | 53 | 2.13 | 65 | 2.50 | 76 | 3.50 | 107 | 0.8 | 5.87 | 173 | — | — | — | — | — | — |
| 2.6 | 1.82 | 56 | 2.21 | 67 | 2.60 | 79 | 3.64 | 111 | 1.0 | 6.01 | 163 | — | — | — | — | — | — |
| 2.7 | 1.89 | 58 | 2.30 | 70 | 2.70 | 82 | 3.76 | 115 | 1.2 | 6.36 | 194 | — | — | — | — | — | — |
| 2.8 | 1.96 | 60 | 2.38 | 73 | 2.80 | 85 | 3.92 | 119 | 1.4 | 6.73 | 204 | — | — | — | — | — | — |
| 2.9 | 2.03 | 62 | 2.47 | 75 | 2.90 | 88 | 4.05 | 124 | 1.6 | 7.10 | 215 | — | — | — | — | — | — |
| 3.0 | 2.10 | 64 | 2.55 | 78 | 3.00 | 91 | 4.20 | 128 | 1.8 | 7.48 | 228 | — | — | — | — | — | — |

*LL* = Phase-to-phase voltage in kV
*LG* = Phase-to-ground voltage in kV
*T* = Maximum anticipated per-unit transient overvoltage
*a* = Saturation factor in thousandths

NOTES

1—Distances listed are for standard atmospheric conditions.

2—Distances are based on altitudes below 900 m (see table 1). It is not necessary to correct for other atmospheric conditions.

3—Distances do not include any factor for inadvertent movement (see 7.3).

Special measurements of low-frequency acoustical noise in a high-voltage switchyard have disclosed a high level (104 dB of 120 Hz) sound. The high intensity 100 Hz or 120 Hz sounds can produce symptoms similar to those attributed to the effects of electric fields. Another possible influence is repeated spark discharges that can be attributed to electric fields (see [B1]).

#### 4.2.3.1.2 Mitigation of electric field effects on workers

Electric field effects (i.e., perceptible shocks) are readily mitigated by shielding. The electric field strength inside a conductive shield is a function of the field strength and the degree of shielding. The proximity to the line, its voltage, and the resultant strength of the electric field will determine the shielding required. When working, using barehand methods on energized lines 230 kV and above phase-to-phase, for example, the worker should have full shielding. Full shielding may also be needed at these voltage levels for other forms of live-line maintenance. Whereas, when working on or near a lower voltage line, or higher voltage line using different work methods and spacing, full shielding may not be necessary. Any sensation or discomfort experienced by the worker can serve as a useful indicator as to when shielding is desirable, and what degree of shielding is needed.

**Table 7—Minimum air insulation pole-to-ground distance, dc energized work.**

| ***LG*** | **250 kV** | | **400 kV** | | | **500 kV** | | | **600 kV** | | | **750 kV** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***T*** | **ft** | **cm** | ***a*** | **ft** | **cm** | ***a*** | **ft** | **cm** | ***a*** | **ft** | **cm** | ***a*** | **ft** | **cm** |
| 1.5 or below | 2.66 | 81 | 0.0 | 4.24 | 129 | 0.8 | 5.73 | 175 | 1.9 | 7.57 | 231 | 3.6 | 10.52 | 330 |
| 1.6 | 2.83 | 86 | 0.0 | 4.53 | 138 | 1.2 | 6.34 | 193 | 2.3 | 8.38 | 255 | 4.2 | 12.05 | 367 |
| 1.7 | 3.01 | 92 | 0.3 | 4.95 | 151 | 1.5 | 6.91 | 211 | 2.8 | 9.23 | 281 | 4.8 | 13.34 | 407 |
| 1.8 | 3.19 | 97 | 0.6 | 5.40 | 165 | 1.9 | 7.57 | 231 | 3.3 | 10.11 | 308 | 5.4 | 14.70 | 448 |

*LG* = Pole-to-ground voltage
*T*= Maximum anticipated per-unit transient overvoltage, saturation factor in thousandths

NOTES

1—If the minimum air insulation distance is used, the minimum relative humidity should be restricted to 85%.

2— Distances listed are for standard atmospheric conditions.

3—Distances are based on altitudes below 900 m (see table 1). It is not necessary to correct for other atmospheric conditions.

4—Distances do not include any factor for inadvertent movement (see 7.3).

#### 4.2.3.1.3 Forms of shielding from electric fields

a) *Conductive clothing*. Conductive clothing, comprising footwear, socks, gloves and a suit is a very effective form of shielding and is widely accepted, particularly in barehand work [IEEE Std 935-1989 and IEC 895 (1987)].

b) *Conductive screens and liners*. At extra-high voltages (EHV), conductive liners are often used in conjunction with nonconductive buckets to provide additional grading of the electric field. At lower voltages, (242 kV and below) conductive screens and liners can be used to mitigate electric field effects and, if properly employed, can be as effective as conductive clothing.

The design of the conductive liner should be in accordance with the shielding requirements of ANSI/SIA A92.2-1990.

#### 4.2.3.1.4 Work location

Note that the relative body current at a position normally employed on the tower to perform live work is higher than the values obtained with complete bucket shielding. A worker doing barehand work from a bucket provided with adequate shielding is subjected to approximately the same or less electric field as that of a counterpart working with conventional tools from the tower. The use of a conductive suit greatly reduces the exposure to the electric field in both cases as can be seen in table 8. The types of shielding employed in the comparisons in table 8 ranged from none to conductive suit through four types of screen, namely,

— Type A: Complete bucket shielding with a rear shield wall and overhead canopy
— Type B: Complete bucket shielding with a rear shield wall and no overhead canopy
— Type C: Complete bucket shielding only
— Type D: Partial bucket shielding

#### 4.2.3.2 Bonding

Bonding is used to bring personnel and conductive objects in the work area to the same potential. Conductors employed in bonding are not intended to carry line or fault current. Bond leads are used extensively during barehand work to conduct charging current and thereby eliminate transient contact shocks between the worker and conductive objects in the work area. The worker in the bucket is bonded to a conductor by a bond lead, which in turn is connected to the bucket bonding system or shielding system. The use of conductive footwear is recommended. When the worker is wearing a conductive suit, all the components of the suit should also be bonded together. These bond leads should be installed in such a way as to minimize the probability of carrying line or fault current.

**Table 8—Worker exposure and body current**

| **Position of worker** | **Type of shielding** | **Body current** | |
|---|---|---|---|
| | | **at 138 kV** | **at 345 kV** |
| On tower | None | 125 µA | 395 µA |
| In bucket | A | 70 µA | 130 µA |
| In bucket | B | 155 µA | 300 µA |
| In bucket | C | 320 µA | |
| In bucket | D | 375 µA | |
| In bucket | Suit | | 50 µA |

Worker on tower approximately 240 cm (8 ft) from conductor and 320 cm (10.5 ft) from conductor at 345 kV.
Not measured.

#### 4.2.3.3 Magnetic fields

Unlike electric fields that are present whenever a voltage is applied on a conductor, magnetic fields are present only when current flows in a conductor. Accepted shielding methods employed to mitigate the effects of electric fields are not effective in shielding a worker from magnetic fields. Researchers have also been investigating the possible long term health effects of magnetic fields on people. Research results continue to be inconclusive and no definitive evidence of health risk has been found.

### 4.2.4 Electrical properties of tools and equipment

#### 4.2.4.1 Categories of insulating materials

The basic tools and equipment used for working on or near energized electric lines or power apparatus can be divided into the following categories:

a) Personnel protective or cover-up tools and equipment, where the electric stress is applied essentially across the thickness of the tool or equipment. The dielectric strength of the tool or equipment depends on the material, and its thickness and condition. Examples are gloves, line hoses, mats, sleeves, and overshoes. Such tools and equipment are often made of natural rubber and rubber-like materials. Such tools and equipment may be flexible or rigid.
b) Support, lift, or reach-extending tools and equipment in which the electrical stress is applied essentially along the length of the tool or equipment. In the case of clean, dry tools or equipment, the dielectric strength is defined as the voltage per unit length (kilovolt/foot) of the tool or equipment. Examples are suspended or sup-

ported aerial devices, chains, ladders, platforms, poles, and ropes. Such tools and equipment are typically made of solid or hollow insulating materials in whole pieces or small sections.

#### 4.2.4.2 Current associated with personnel protective or cover-up tools and equipment

For ac excitation, this current consists of three components, as follows:

a) Capacitive current due to the insulating material comprising the tool or equipment
b) Conduction current through the volume of the tool or equipment
c) Leakage current along the surface of the tool or equipment

The conduction current is normally negligible. For clean, dry tools and equipment, the leakage current is small and the capacitive current predominates. Surface deposits may significantly increase the leakage current.

For dc excitation, the capacitive current does not exist.

#### 4.2.4.3 Current associated with support, lift, or reach-extending tools and equipment

For ac excitation, this current consists of the capacitive current and the leakage current. For clean, dry tools and equipment, the leakage current is small and the capacitive current predominates. Surface deposits can significantly increase the leakage current.

For dc excitation, the capacitive current does not exist.

#### 4.2.4.4 Application of tools and equipment

The use of tools and equipment results in a composite insulation system composed of the tool(s), equipment, and air gaps. When air gaps are involved, the resultant dielectric strength can exceed that of the tool or equipment itself, but it cannot be determined from direct addition of the material thickness and air gap sizes.

#### 4.2.4.5 Air saturation

Above 630 kV crest, the dielectric strength of an air gap with typical electrode shapes is not constant, but decreases as the gap length increases. As a result, the curve of $U_{50}$ versus gap length exhibits saturation (see figure 2).

**Table 9—Minimum air insulation phase-to-phase distance, ac energized work**

| *LL* *LG* | 121 70 | | 145 85 | | 169 100 | | 242 140 | | 362 210 | | 550 320 | | 800 462 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *T* | ft | cm | ft | cm | ft | cm | ft | cm | ft | cm | ft | cm | ft | cm |
| 1.5 | 1.88 | 57 | 2.31 | 70 | 2.60 | 79 | 3.75 | 114 | 5.48 | 167 | 6.34 | 193 | 11.05 | 337 |
| 1.6 | 2.02 | 62 | 2.45 | 75 | 2.74 | 84 | 3.90 | 119 | 5.92 | 180 | 7.68 | 234 | 13.50 | 412 |
| 1.7 | 2.17 | 66 | 2.60 | 79 | 2.89 | 88 | 4.19 | 128 | 6.21 | 189 | 9.11 | 277 | 16.14 | 492 |
| 1.8 | 2.31 | 70 | 2.74 | 84 | 3.18 | 97 | 4.47 | 136 | 6.64 | 202 | 10.58 | 322 | 18.92 | 577 |
| 1.9 | 2.31 | 70 | 2.89 | 88 | 3.32 | 101 | 4.62 | 141 | 6.93 | 211 | 12.16 | 370 | 21.23 | 687 |
| 2.0 | 2.52 | 78 | 3.06 | 94 | 3.60 | 110 | 5.04 | 153 | 7.56 | 231 | 13.83 | 422 | 24.94 | 760 |
| 2.1 | 2.59 | 80 | 3.16 | 97 | 3.70 | 113 | 5.18 | 159 | 7.77 | 236 | 14.57 | 444 | — | — |
| 2.2 | 2.66 | 82 | 3.23 | 99 | 3.80 | 116 | 5.32 | 163 | 8.12 | 246 | 15.33 | 467 | — | — |
| 2.3 | 2.73 | 83 | 3.33 | 102 | 3.90 | 119 | 5.46 | 167 | 8.50 | 256 | 16.10 | 492 | — | — |
| 2.4 | 2.80 | 85 | 3.40 | 104 | 4.00 | 122 | 5.59 | 170 | 8.90 | 272 | 17.02. | 519 | — | — |
| 2.5 | 2.87 | 87 | 3.50 | 107 | 4.10 | 125 | 5.74 | 176 | 9.30 | 284 | — | — | — | — |
| 2.6 | 2.94 | 91 | 3.57 | 109 | 4.20 | 128 | 5.88 | 180 | 9.71 | 296 | — | — | — | — |
| 2.7 | 3.01 | 93 | 3.67 | 112 | 4.30 | 131 | 5.99 | 154 | 10.13 | 309 | — | — | — | — |
| 2.8 | 3.08 | 95 | 3.74 | 115 | 4.40 | 134 | 6.16 | 157 | 10.58 | 321 | — | — | — | — |
| 2.9 | 3.15 | 97 | 3.84 | 117 | 4.50 | 137 | 6.29 | 193 | 11.02 | 334 | — | — | — | — |
| 3.0 | 3.22 | 99 | 3.91 | 120 | 4.60 | 140 | 6.44 | 197 | 11.47 | 347 | — | — | — | — |

*LL* = Phase-to-phase voltage in kV
*T* = Maximum anticipated per-unit transient overvoltage

NOTES

1—Distances listed are for standard atmospheric conditions.

2—Distances are based on altitudes below 900 m (see table 1). It is not necessary to correct for other atmospheric conditions.

3—Distances do not include any factor for inadvertent movement (see 7.3).

### 4.2.5 Protective equipment

#### 4.2.5.1 Barriers, guards, and cover-ups

Barriers, guards, and cover-ups are frequently provided for some methods of energized line work so as to prevent the worker from approaching too close to, or from contacting with, equipment that is at a potential different from the worker. When working from insulated supports, either phase-to-phase or phase-to-ground voltages should be considered as they apply. These devices are defined in clause 3. The electrical and mechanical characteristics are detailed in ASTM D1048-93, ASTM D1049-93, IEC 1111 (1992), and IEC 1112 (1992).

**Table 10—Types of tools and equipment**

| Device | Reference | Remarks |
|---|---|---|
| Aerial lifts | ANSI/SIA A92.2-1990 IEC 1057 (1991) | Latest revision Aerial devices with insulating boom used for live working |
| Rope | CSA C225-M88 | Latest revision |
| Gloves | ASTM D120-87 | Latest revision |
| Sleeves | ASTM D 1051-87 | Latest revision |
| Blankets | ASTM D 1048-93 | Latest revision |
| Hose | ASTM D 1050-90 | Latest revision |
| Hoods | ASTM D1049-93 | Latest revision |
| Hard cover-up | ASTM F968-93 | Latest revision |
| Hot sticks | ASTM F711-93 | Latest revision |
| Conductive suits | IEC 855 (1985) | Latest revision |
| Conductive footwear | IEC 855 (1985) | Latest revision |
| Stringing equipment | ANSI/IEEE Std 524-92 | Latest revision |
| Line guards | ASTM F968-93 | Latest revision |
| Couplers | ASTM F968-93 | Latest revision |
| Crossarm guards | ASTM F968-93 | Latest revision |
| Polo covers | ASTM F968-93 | Latest revision |
| Cutout covers | ASTM F968-93 | Latest revision |
| Helicopters | CFR Title 29, CFR1926 (551) | Used to lower workers |
| | CFR Title 29, CFR1910 (183) | Used raise workers to and from structures |

### 4.2.5.2 Protective gaps

A protective gap can be employed to provide worker protection by establishing a controlled sparkover path that is coordinated with the flashover voltage of the minimum approach distance. Recognizing that the protective gap at the work area may operate, these gaps are generally installed at an adjacent structure.

NOTE —If the protective gaps are placed on the structure at the work location, care must be taken to evaluate the proximity of the worker and the arc, if the gap operates.

When gaps are installed at the terminals (line ends), their ability to control the transient overvoltage level at the remote work area must be considered. Figure 3 shows a typical protective gap being installed.

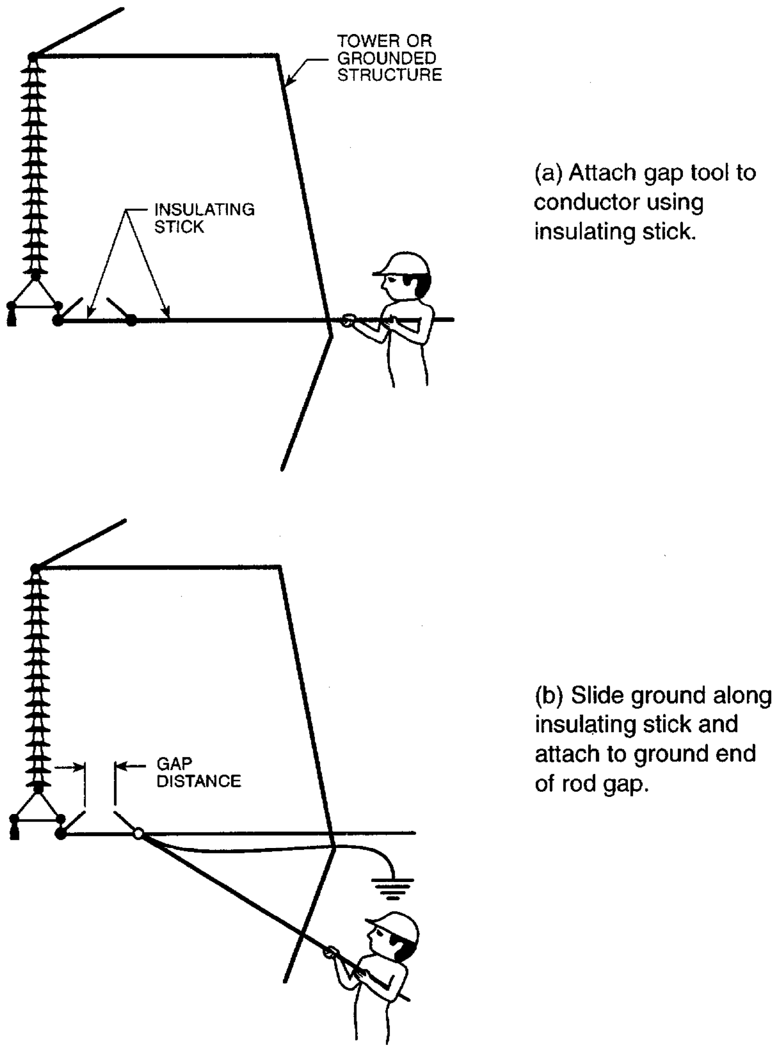


**Figure 3 — Installation of protective gap**

The key to the use of protective gaps is in establishing the statistical withstand voltage of the protective gap. The withstand and sparkover requirements of a protective gap are determined by sparkover probability test data for the particular protective gap geometry, gap distance, and conductor bundle geometry.

The 50% sparkover voltage ($U_{50}$) and the statistical withstand voltage of the protective gap are determined from the test data in [B12] and [B6].

Figure 4 illustrates the determination of the distribution of sparkovers for one gap setting. The μ value would be the 50% (critical) sparkover value. The $\mu$-3 $\sigma$ value is the withstand voltage and the $\mu$ + 2 $\sigma$ value is the sparkover voltage. The same information is illustrated in figure 5 on probability graph paper. Point A is the withstand voltage, the 50% point is the $U_{50}$, and point B is the sparkover voltage.

The setting of the withstand voltage of the protective gap is dependent upon the probability of the protective gap sparkover that the user is willing to accept. Some users may be willing to use settings very near the maximum operating voltage and accept the probability that minor transient overvoltages may cause sparkover of the protective gap and, therefore, a line outage. Each user should investigate the probability of the protective gap sparking over for their particular line or system. Each of the transient overvoltage possibilities and their anticipated magnitudes above the maximum operating voltage should be reviewed.

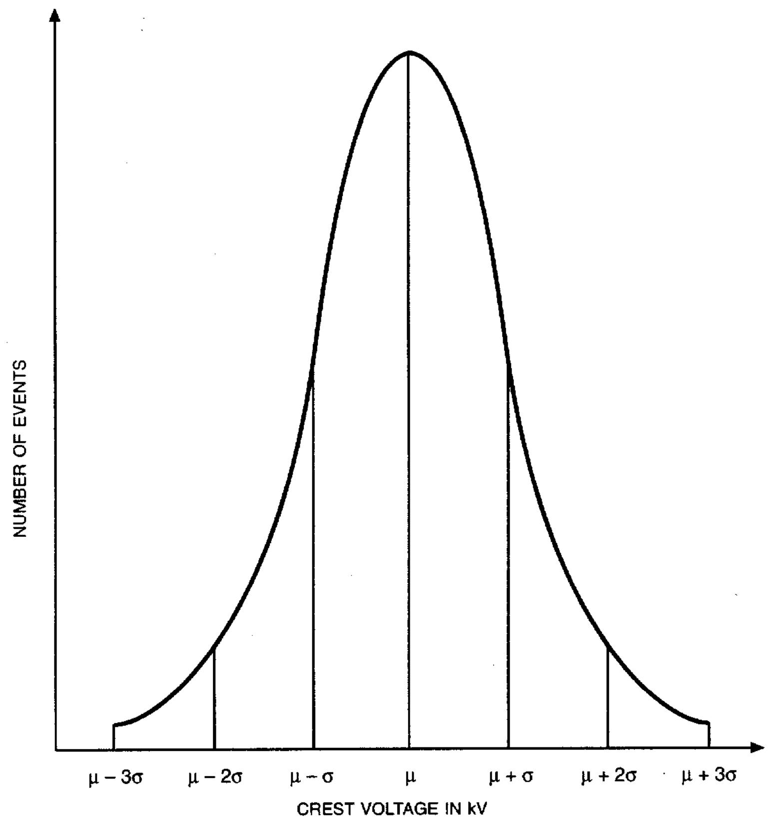


**Figure 4 — Probability density function of a single gap**

Whatever protective gap withstand voltage is selected by the user, the protective gap must spark over below the sparkover voltage corresponding to the minimum approach distance in the work area. In order to ensure this, the -3 σ withstand voltage for the minimum air insulation distance must always be equal to or greater than the +2 σ sparkover voltage of the protective gap (see figure 6). Another way to say this is that the $U_{50}$ of the minimum air distance at the work site shall be 5 σ higher than the $U_{50}$ of the protective gap (see figure 6). It is recommended that, for EHV lines or lower, a conservative or safe standard deviation of 5% be used to determine the -3 σ (i.e., 85% of $U_{50}$) and the minimum air approach distance at the work site (i.e., 110% of the $U_{50}$) of the gap, to establish the minimum air insulation approach distance.

See figure 7, point A, the -3 σ withstand voltage of the protective gap and point B, the +2σ sparkover voltage of the protective gap, which is equal to the -3 σ withstand voltage of the minimum air insulation distance at point C and the +2 σ sparkover voltage of the minimum air insulation distance at point D. Note that the two curves are displaced by a factor of 1.28 (i.e., 1.1/0.85 times the protective gap crest voltage).

With this information for several protective gap distances, both the protective gap and the reduction of the minimum approach distance can be determined as outlined in annex B.

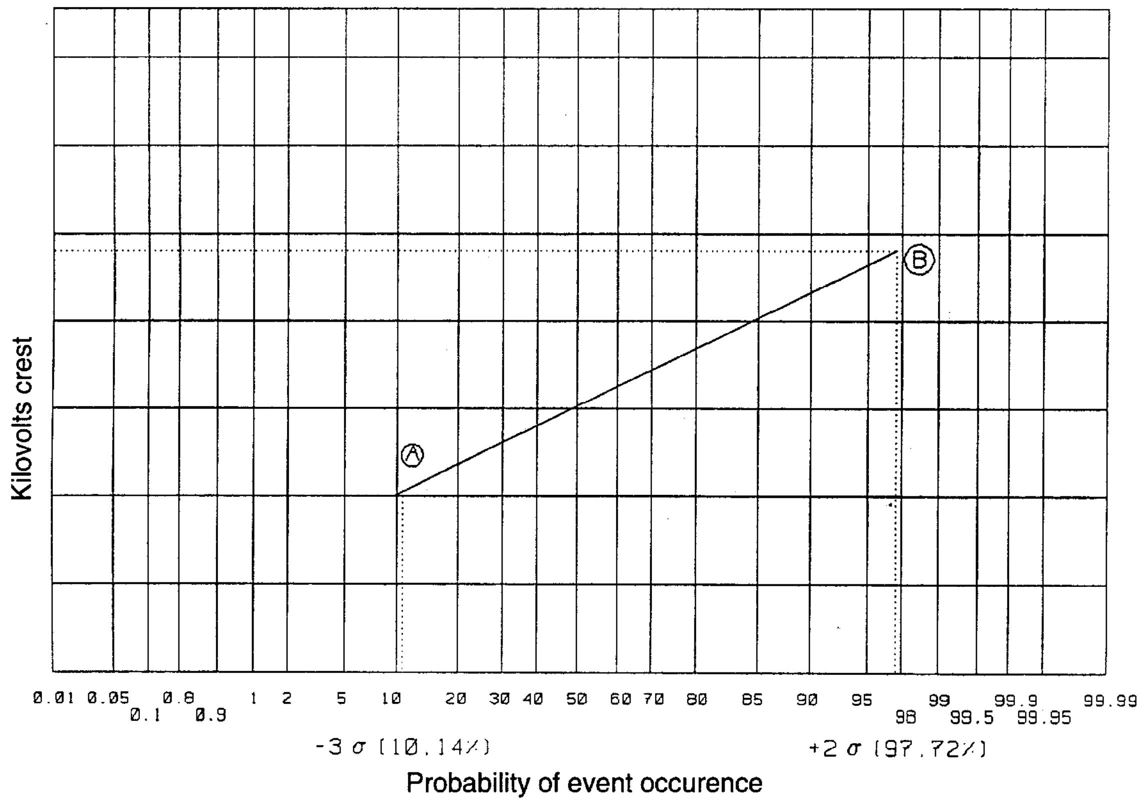


**Figure 5 — Crest voltage in kilovolts versus probability of sparkover**

## 4.3 Electrical tests

### 4.3.1 Introduction

Tables 10–12 are provided to summarize the basic and essential elements of electrical data and values that are applicable. These tables should be considered in the employment of tools, materials, and equipment in energized operations, and a series of tests should be performed (e.g., design, withstand, proof). It is recommended that the test be made with applied voltage of the same characteristics as that on which the equipment is being used. For example, if the equipment is being used on 60 Hz, the periodic withstand test should be made with 60 Hz ac. Testing with dc is at this time left to the discretion of the user.

### 4.3.2 Tool or equipment current

The preferred criterion is the measurement of tool or equipment current since this is the primary concern related to the use of the sample. Tool or equipment current measurement provides a numerical objective evaluation of the sample quality.

The range of normal current in insulating tools has been found to vary from less than 6–15 µA at an applied voltage of 100 kV across 1 ft (figure 8). Current values exceeding these values may indicate deterioration of insulating qualities.

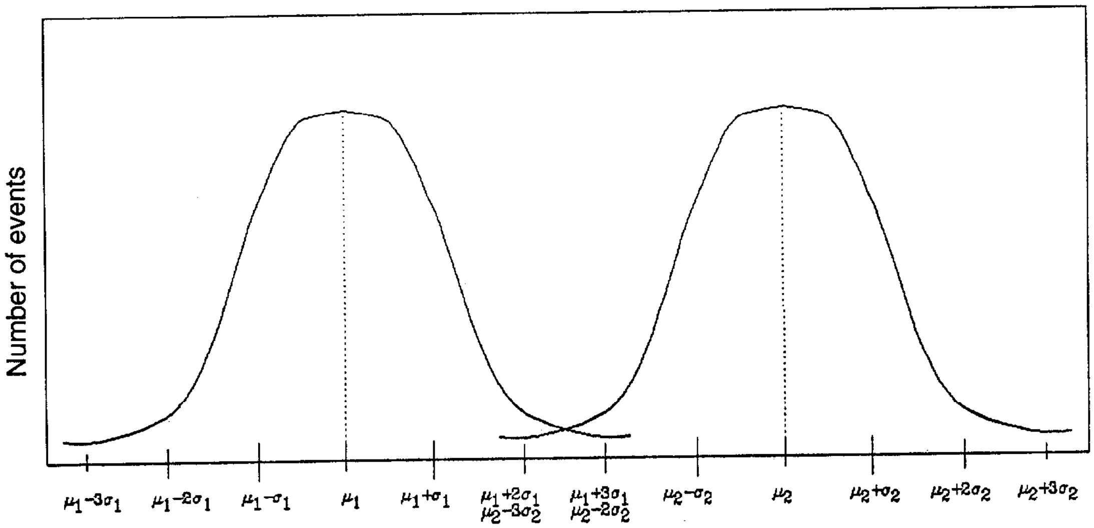


**Figure 6 — Coordinated probability density functions of two gaps**

**Table 11—Acceptance test references**

| **Tool, equipment, or device** | **Standard or other** | **Remarks** |
|---|---|---|
| **Acceptance test** | | |
| **Cover-up equipment** | | |
| **Flexible material** | | |
| Glove | ASTM D 120-87 | Latest revision |
| Insulator hoods | ASTM D 1049-93 | Latest revision |
| Line hose | ASTM D 1050-90 | Latest revision |
| Sleeves | ASTM D1051-87 | Latest revision |
| Blankets | ASTM D 1078-93 | Latest revision |
| **Rigid material** | | |
| All | ASTM F968-93] | Latest revision |
| Inspection | | |
| Visual—rubber pallets | ASTM F1236-89 | Latest revision |

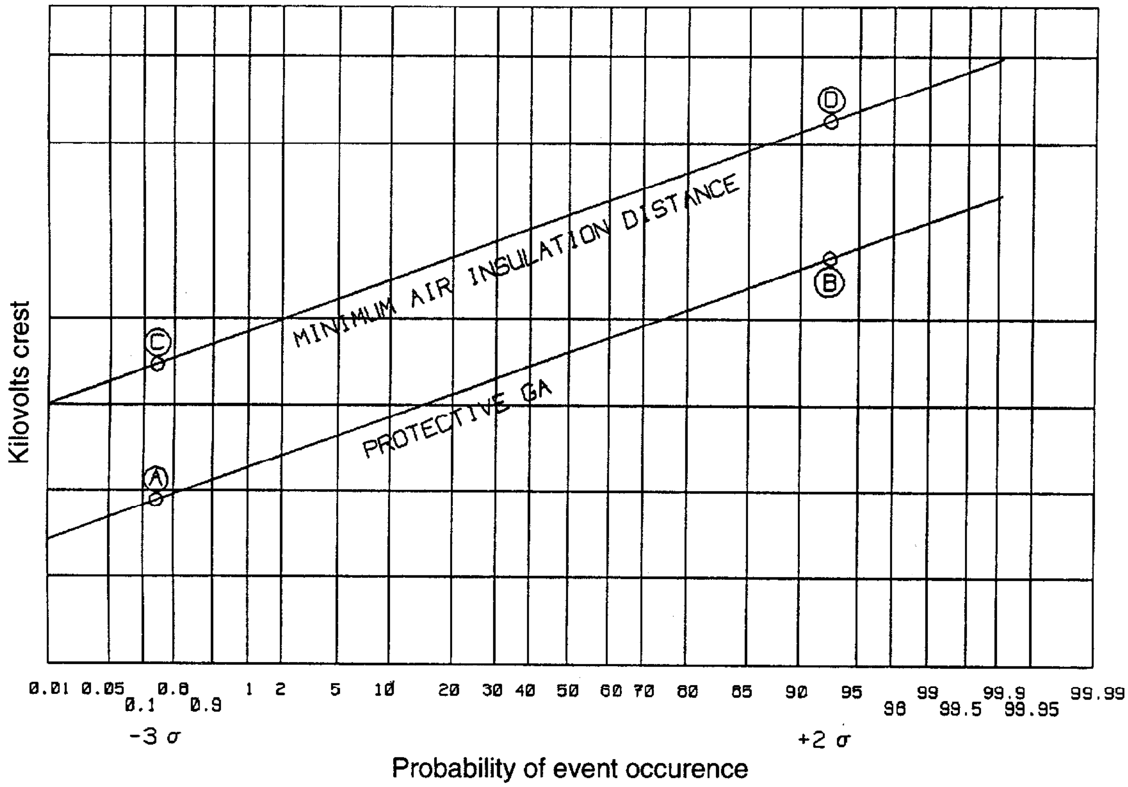


**Figure 7 — Probability of event occurrence**

Changes in measured tool or equipment current values may be indications of any or all of the following factors:

a) Contamination
b) Moisture
c) Specimen degradation
d) Instability of the test setup

If the test setup is not at fault, the tool should be cleaned, dried, refinished as recommended by the manufacturer, and electrically retested. If it is not possible to retest the tool, then the tool should not be used.

### 4.3.3 Maximum operating voltage

The maximum power frequency operating voltage ($V_M$) is the voltage to which the tools and equipment could be subjected during routine employment in work operations. For example, for 345 kV systems, the maximum operating voltage is 362 kV or $V_M$. In cases where the bus voltage is unregulated, the user should recognize the possible voltage transformation ratio, and also that the maximum voltage that can appear under normal situations from the source line can then be reflected through the transformer.

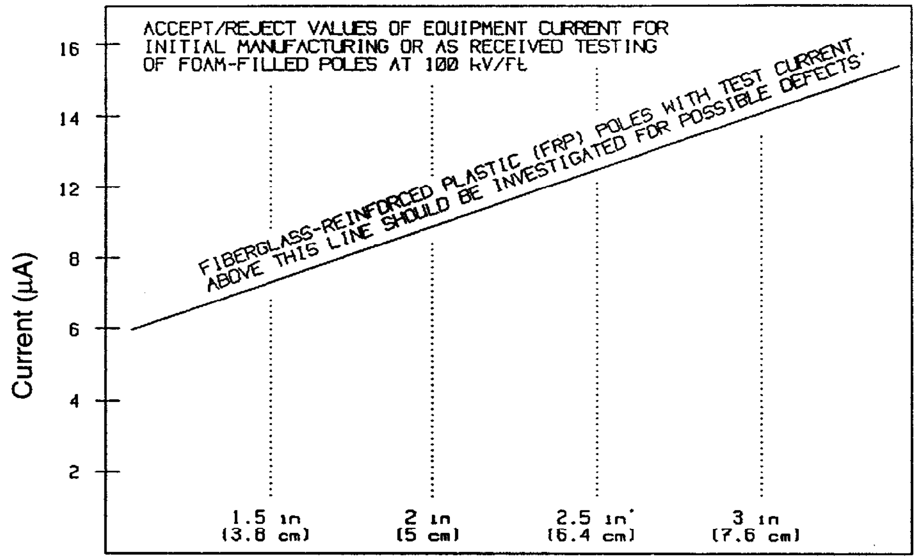


**Figure 8 — Typical values of equipment current for fiberglass-reinforced-plastic (FRP) pole of various diameters**

**Table 12—Marking and identification guide**

| Equipment | Information to be supplied |
|---|---|
| Gloves | ASTM D120-87, section 7 |
| Blankets | ASTM D1048-93, clause 7 |
| Hoods | ASTM D1049-93, clause 7 |
| Hose | ASTM D1050-90, clause 7 |
| Sleeves | ASTM D 1051-87, clause 7 |
| Rigid or plastic cover-up | ASTM F968-93 |

### 4.3.4 Evaluation of tools and equipment

#### 4.3.4.1 General

Tools and equipment shall be evaluated using the applicable standard(s), as follows:

ASTM F696-91, ASTM F712-88, ASTM F1236-89, IEC 60-1 (1989), IEC 60-3 (1976), IEC 60-4 (1977), IEC 855 (1985), IEC 903 (1988), IEC 984 (1990), IEC 1057 (1991), IEC 1229 (1993), IEC 1235 (1993), IEC 1236 (1993), IEEE Std 978-1984, IEEE Std 1067-1990.

NOTE —The previously listed documents do not refer to impulse tests, and do not discuss equivalence of withstand voltages for the tools and equipment under ac and impulse voltage stresses. Ongoing research has indicated that, for equipment such as blankets and line hoses, the ratio of withstand voltage (peak) under impulse conditions to the withstand voltage (peak) with ac energization, is not equal to 1.0. IEC Document 78 [B7], still under review, does not provide a value for the ratio of impulse (peak)-to-power frequency (peak) withstand voltage, but supports the use of the ratio of 1.3 for testing of flexible insulating equipment. For rigid insulating covers, the ratio appears to be affected by the geometrical details of test electrodes used in testing. Work is continuing to obtain precise values of the ratios.

For aerial lift device standard test classifications, see ANSI/SIA A92.2-1990 and IEC 1057 (1991).

### 4.3.5 Acceptance-test reference

#### 4.3.5.1 Standard test classification

Tables 10 and 11 are based on the life history aspect of tools, material, and equipment.

NOTES

1—Upon issuance of applicable ASTM or IEEE standards, their provisions shall supersede 4.3.5, 4.3.6, 4.3.7, and 4.3.8.

2—To simplify further references in this clause, the term “equipment” will be used to cover tools, material, and equipment.

#### 4.3.5.2 Design-test data

The values and other criteria recommended should be used by the persons involved in the initial specification, design, component selection and testing, and assembly of the equipment.

Commonly used values for the anticipated maximum transient overvoltage $T_m$ are as follows:

<362 kV - $T_m$ = 3.0 p.u. or less

362–550 kV - $T_m$ = 2.4 p.u. or less

551–800 kV - $T_m$ = 2.0 p.u. or less

NOTE —These values may be reduced by factors within the system.

##### 4.3.5.2.1 Insulating tools and other equipment

a) Maximum rated voltage test
   1) Test voltage = 2 $V_{\text{L-G RMS}}$
   2) Maximum permissible leakage current = 1 µA/$kV_{\text{L-G}}$
   3) Test voltage applied for 3 min

b) Double rated test
   1) Test voltage = 2 $V_{\text{L-G}}$ where $T_m V_m < 2 V_m$, substitute 1.3 $V_m$ for 2 $V_m$
   2) Maximum permissible current = 1 µA/$kV_{\text{L-G}}$
   3) Test voltage applied for 3 min

c) Withstand test
   1) Test voltage = $T_m \cdot V_{\text{mL-G}}$ NOTE—$T_m$ is maximum *TOV.*
   2) Test voltage applied momentarily

##### 4.3.5.2.2 Conducting protective (shielding) equipment

a) During the 3 min proof test, the leakage current surface should be monitored and recorded. The constant current on 25 $cm^2$ (4 $in^2$) of surface should be $I$ = 2 mA

b) Shielding current = (1 μA/1Ω)/in$^2$ [(1 μA/1 Ω)/6.5 cm$^2$] at an electric field of 25 kV/m
c) Thermal withstand of the material = 200 °C (400 °F) on contact

#### 4.3.5.3 Test criteria

For impulse and transient overvoltage tests, the magnitude of voltage used is given as crest value.

**Table 13—Minimum suggested inadvertent movement factors**

| Voltage range in kV phase-to-phase | Inadvertent movement factor | Comments |
|---|---|---|
| 0.000–0.050 | Not specified | — |
| 0.051–0.300 | Avoid contact | Similar to 120 V household voltage |
| 0.301–0.750 | Add .30 m (1 ft) | Concern of hazard from self-sustaining arc |
| 0.751–72.5 | Add .61 m (2 ft) | Based on ergometric considerations of worker and equipment movement |
| 72.6–800 | Add .30 m (1 ft) | Based on ergometric considerations of worker and equipment movement |

Adding 30 m (1 ft) will result in a value greater than that resulting from replacing the term (0.01 + *a*) in equation (lb) with (0.011 + *a*) as was done in IEEE Std 516-1987 to determine the minimum tool insulation distance.

Commonly used values for the anticipated maximum transient overvoltage $T_m$ are as follows:

<362 kV - $T_m$ = 3.0 p.u. or less

362–550 kV - $T_m$ = 2.4 p.u. or less

551–800 kV - $T_m$ = 2.0 p.u. or less

NOTE —These factors may be reduced by factors within the system.

##### 4.3.5.3.1 Insulating tools and other equipment

Test values and conditions are the same as in 4.3.5.2.1

##### 4.3.5.3.2 Insulating protective equipment

$V_R$= manufacturer's rating kV

a) 3 min proof withstand voltage = 1.4 ÷ $\sqrt{3}$ $V_R$rms
b) Minimum disruptive discharge voltage = 1.6 ÷ $\sqrt{3}$ · $V_R$rms
c) Impulse withstand voltage (1.2 ÷ 50 μs) Distribution voltages = 2.8 ÷ $\sqrt{3}$ · $V_{Rpeak}$ Transmission voltages = 3.0 ÷ $\sqrt{3}$ · $V_{Rpeak}$

d) Transient impulse withstand voltage (250/2500 µs) Distribution voltages = $2.4 \div \sqrt{3} \cdot V_{\text{Rpeak}}$ Transmission voltages = $3.0 \div \sqrt{3} \cdot V_{\text{Rpeak}}$
e) Shielding current = (1 µA/1 Ω) ÷ $\text{in}^2$ [(1 µA ÷ 1 Ω) ÷ 6.5 $\text{cm}^2$] at an electric field of 25 kV/m

#### 4.3.5.4 Periodic-test criteria

Periodic tests may be made to determine the condition of the equipment. The most important activity in this area is to visually inspect all tools and equipment before each use. A visual check by qualified personnel is the best practice, because abuse or misuse since the date of the electrical test can radically change the electrical performance of the tool or equipment. Intervals between electrical tests may be established based on criteria such as elapsed time, voltage level, number of times used, condition of use or company user policy, or a combination of these. Even when equipment passes a periodic electrical test, the user should still visually inspect or otherwise check the equipment before use. For example, even though a rubber glove is given a periodic electrical test, there is no assurance that the glove has not been damaged in transportation from the test site to the work site, so a visual inspection should always be made before use to check for mechanical damage.

##### 4.3.5.4.1 Energized-line tools and other similar equipment

a) Test voltage = $V_{\text{L-G}}$ (operating voltage)
b) Maximum permissible current = 1 µA/$\text{kV}_{\text{L-G}}$
c) Time of applied voltage = 1 min
d) Check insulation for cracks, blisters, or other visual signs of deterioration

### 4.3.6 Acceptance-test reference

#### 4.3.6.1 Number of tests

If no disruptive discharge occurs during any five consecutive impulses, the specimen should be considered as having met the test. If more than one of the applied impulse waves causes a disruptive discharge, the test specimen should be considered as having failed the test. If only one of the five applied impulses causes a disruptive discharge, 10 additional impulses should be applied. If no disruptive discharge occurs on any of the 10 additional impulses, the specimen should be considered as having met the test, otherwise the specimen has failed.

### Table 14—Minimum approach distance, ac energized work

| Voltage in kV phase-to-phase | Distance to employee | | | |
|---|---|---|---|---|
| | Phase-to-ground | | Phase-to-phase | |
| | (ft, in) | (m) | (ft, in) | (m) |
| 0.05–0.30 | Avoid contact | | Avoid contact | |
| 0.31–0.75 | 1, 0 | 0.31 | 1, 0 | 0.31 |
| 0.76–15.0 | 2, 1 | 0.65 | 2, 2 | 0.67 |
| 15.1–36.0 | 2, 7 | 0.77 | 2, 10 | 0.86 |
| 36.1–46.0 | 2, 9 | 0.84 | 3, 2 | 0.96 |
| 46.1–72.5 | 3, 3 | 0.95 | 3, 11 | 1.20 |
| 72.6–121 | 3, 2 | 1.00 | 4, 3 | 1.29 |
| 138–145 | 3, 7 | 1.09 | 4, 11 | 1.50 |
| 161–169 | 4, 0 | 1.22 | 5, 8 | 1.71 |
| 230–242 | 5, 3 | 1.59 | 7, 6 | 2.27 |
| 345–362 | 8, 6 | 2.59 | 12, 6 | 3.80 |
| 500–550 | 11, 3 | 3.42 | 18, 1 | 5.50 |
| 765–800 | 14, 11 | 4.53 | 26, 0 | 7.91 |

NOTES

1—These distances take into consideration the highest transient overvoltage an employee will be exposed to on any system with air as the insulating medium and the maximum voltages shown.

2—The clear live-line tool length should equal or exceed these values for the indicated voltage ranges.

#### 4.3.6.2 Differences in tool or equipment current

When the tool or equipment-current values for two adjacent sections differ by more than 20% of the smaller value, the tool should be rejected even if it meets other criteria.

#### 4.3.6.3 Histograms

Histograms of initial tool or equipment-current values for acceptance of tools or equipment can be established from production or manufacturing limits. The basic purpose of these histograms is to indicate a trend and to establish reference points for each tool being tested. In the absence of historical information or another equivalent basis, the tool or equipment-current values for fiberglass-reinforced plastic “frp” provided in figure 8 are applicable.

Plotting of histograms on graph paper gives a good graphic review of the testing of the tool or equipment and shows trends in the performance of the material under test.

#### 4.3.6.4 Electrical-test references

a) Low frequency: ASTM D149-93a
b) Lightning impulse: IEEE Std 4-1978
c) Water for wetting: IEC 265-1 (1983) and IEC 265-2 (1988). Method of test, 7000 Ω/in$^3$ (17 800 Ω/cm$^3$) + 15% at 25 °C (77 °F)
d) Standard atmospheric conditions: Temperature of 22 °C (77 °F) + 5 °C (9 °F); relative humidity of 35% minimum
e) Correction to standard conditions: lightning and switching impulse voltage, IEC 60-1 (1989).
f) IEC 60-3 (1976)
g) IEC 60-4 (1977)

#### 4.3.6.5 Tools and equipment

See table 10 for types of tools and equipment.

#### 4.3.6.6 Acceptance tests required

Acceptance tests for various tools, devices, and equipment should be as shown in table 11.

### 4.3.7 Nonconductive rope

ASTM is currently developing a standard for testing live-line rope. Pending completion of this standard, it is incumbent upon the user to assure that ropes used as live-line tools are adequate for the voltage gradient and working conditions to which they will be applied.

### 4.3.8 Aerial lift and similar devices

Aerial lift and similar devices shall follow the requirements of A92.2-1990 for design, testing, and in-service care (ANSI/SIA A92.2-1990, IEC 1057 [1991]).

### 4.3.9 Marking and identification—general

All equipment should be marked with the manufacturer's name or logo, and date of manufacture, (month and year). All markings and identification should be permanent—that is, weather-resistant, not susceptible to sunlight, fading, etc. They should be tested, as required, to ensure that they will remain legible for the intended service life of the device. See table 12.

## 4.4 Bibliography documents

The following documents from the bibliography (clause 8) are cited in clause 4:

[B4], [B1], [B2], [B3], [B5], [B6], [B8], [B9], [B10], [B12], [B13], [B14], [B15], [B16], [B17], [B18].

**Table 15—Minimum approach distance, ac energized work with transient overvoltage factor**

| Maximum anticipated per-unit transient overvoltage | Distance-to-worker, phase-to-ground air, clear live-line tool and bare hand distance (ft, in) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Maximum phase-to-phase voltage (kV) | | | | | | |
| | 121 | 145 | 169 | 242 | 362 | 550 | 800 |
| 1.5 | — | — | — | — | — | 6, 0 | 9, 8 |
| 1.6 | — | — | — | — | — | 6, 6 | 10, 8 |
| 1.7 | — | — | — | — | — | 7, 0 | 11, 8 |
| 1.8 | — | — | — | — | — | 7, 7 | 12, 8 |
| 1.9 | — | — | — | — | — | 8, 1 | 13, 9 |
| 2.0 | 2, 5 | 2, 9 | 3, 0 | 3, 10 | 5, 3 | 8, 9 | 14, 11 |
| 2.1 | 2, 6 | 2, 10 | 3, 2 | 4, 0 | 5, 5 | 9, 4 | — |
| 2.2 | 2, 7 | 2, 11 | 3, 3 | 4, 1 | 5, 9 | 9, 11 | — |
| 2.3 | 2, 8 | 3, 0 | 3, 4 | 4, 3 | 6, 1 | 9, 4 | — |
| 2.4 | 2, 9 | 3, 1 | 3, 5 | 4, 5 | 6, 4 | 9, 11 | — |
| 2.5 | 2, 9 | 3, 2 | 3, 6 | 4, 6 | 6, 8 | — | — |
| 2.6 | 2, 10 | 3, 3 | 3, 8 | 4, 8 | 7, 1 | — | — |
| 2.7 | 2, 11 | 3, 4 | 3, 9 | 4, 10 | 7, 5 | — | — |
| 2.8 | 3, 0 | 3, 5 | 3, 10 | 4, 11 | 7, 9 | — | — |
| 2.9 | 3, 1 | 3, 6 | 3, 11 | 5, 1 | 8, 2 | — | — |
| 3.0 | 3, 2 | 3, 7 | 4, 0 | 5, 3 | 8, 6 | — | — |

The distances specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known and supplied by the utility. If the system is not designed and operated to limit transient overvoltages to the selected values, transients shall be limited to the selected value by external means (for example, by the installation of a transient control device).

# 5. In-service checking and care

## 5.1 Introduction

Tools and devices used in energized-line maintenance are usually tested by the manufacturer for certification (see ANSI/SIA 92.2-1990, ASTM D120-87, ASTM D1048-93, ASTM D1050-90, ASTM D1051-87, ASTM F968-93, and [B9]). Very often the user conducts electrical certification (acceptance) testing of equipment and tools to verify the manufacturer's tests. After the equipment is put into service, periodic testing and in-service checking ensures that the capability of the equipment remains adequate.

The material for tools constructed of fiberglass reinforced plastic (frp) is tested by manufacturers in accordance with ASTM F711-93.

Additional information may also be obtained from IEEE Std 978-1984.

## 5.2 Scope

This clause covers field care in use, handling and storage, periodic inspection and checking, and maintenance and repair of tools and devices.

## 5.3 Field care, handling, and storage

### 5.3.1 Insulating tools

When not in use, insulating tools should be stored where they will remain dry and clean and not be subjected to abuse. Wood insulating tools should be adequately supported, or hung vertically to prevent warping, and stored in a temperature and humidity controlled room. Insulating tools used for energized-line maintenance should be placed on clean, dry tarpaulins, moisture-proof blankets, on tool racks, or leaned against dry supports--they should not be laid on the ground because of possible contamination or wetting. When transporting insulating tools, ventilated containers should be provided to prevent damage to the surfaces of the individual tools, or the tools should be mounted on racks in trucks or trailers. These racks should be well padded and constructed so that the tools are held firmly in place.

### 5.3.2 Insulated aerial equipment

When parking aerial devices in buildings or maintenance garages where heat sources are present, care should be taken to avoid damage to the insulating portion of the arm from excessive heat. Fiberglass portions can be damaged if their resins are exposed to temperatures of 80 °C (176 °F) or more.

The recommended maximum boom and bucket loads should not be exceeded.

When moving an aerial device, the boom should be in the rest position, the buckets in the normal storage place, and the boom tie downs secured, unless the device is specifically designed to be moved with the boom elevated.

When the unit is being moved, the boom hydraulic system should be disengaged, the auxiliary engine, if used, should be shut down, and in the case of hydraulically leveled buckets, the free-swing valve should be open.

**Table 16—Minimum approach distance, ac energized work with transient overvoltage factor**

| Maximum anticipated per-unit transient overvoltage | Distance-to-worker, phase-to-ground air, clear live-line tool and bare hand distance (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Maximum phase-to-phase voltage (kV) | | | | | | |
| | 121 | 145 | 169 | 242 | 362 | 550 | 800 |
| 1.5 | — | — | — | — | — | 1.82 | 2.95 |
| 1.6 | — | — | — | — | — | 1.97 | 3.23 |
| 1.7 | — | — | — | — | — | 2.13 | 3.54 |
| 1.8 | — | — | — | — | — | 2.29 | 3.86 |
| 1.9 | — | — | — | — | — | 2.47 | 4.19 |
| 2.0 | 0.74 | 0.83 | 0.92 | 1.16 | 1.59 | 2.65 | 4.53 |
| 2.1 | 0.76 | 0.85 | 0.95 | 1.20 | 1.65 | 2.83 | — |
| 2.2 | 0.78 | 0.88 | 0.98 | 1.25 | 1.74 | 3.01 | — |
| 2.3 | 0.80 | 0.91 | 1.01 | 1.29 | 1.84 | 3.20 | — |
| 2.4 | 0.82 | 0.93 | 1.04 | 1.33 | 1.94 | 3.42 | — |
| 2.5 | 0.84 | 0.96 | 1.07 | 1.38 | 2.04 | — | — |
| 2.6 | 0.86 | 0.98 | 1.10 | 1.42 | 2.14 | — | — |
| 2.7 | 0.88 | 1.01 | 1.13 | 1.45 | 2.25 | — | — |
| 2.8 | 0.91 | 1.03 | 1.16 | 1.50 | 2.36 | — | — |
| 2.9 | 0.93 | 1.06 | 1.19 | 1.54 | 2.47 | — | — |
| 3.0 | 0.95 | 1.09 | 1.22 | 1.59 | 2.59 | — | — |

The distances specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known and supplied by the utility. If the system is not designed and operated to limit transient overvoltages to the selected values, transients shall be limited to the selected value by external means (for example, by the installation of a transient control device).

### 5.3.3 Insulating cover-up equipment

Cover-up equipment should be stored in a clean, dry condition. Tars and oils left in contact for long periods can cause softening of plastics and rubber which, in turn, can reduce the dielectric strength of the materials. The equipment preferably should be stored in canvas bags or draped with a plastic cloth to prevent dust and other contaminants from building-up on the surfaces. Equipment should not be stored close to heating pipes or in places where they might be exposed to the sunlight for prolonged periods of time.

Protective cover-up equipment should be transported in canvas bags or other protective containers. Materials that might crack or distort cover up equipment should not be placed or piled on top of these containers.

**Table 17—Minimum approach distance, ac energized work with transient overvoltage factor**

| Maximum anticipated per-unit transient overvoltage | Phase-to-phase air, clear live-line tool and bare hand distance (ft, in) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Maximum phase-to-phase voltage (kV) | | | | | | |
| | 121 | 145 | 169 | 242 | 362 | 550 | 800 |
| 1.5 | — | — | — | — | — | 7,4 | 12, 1 |
| 1.6 | — | — | — | — | — | 8, 9 | 14, 6 |
| 1.7 | — | — | — | — | — | 10, 2 | 17, 2 |
| 1.8 | — | — | — | — | — | 11, 47 | 19, 11 |
| 1.9 | — | — | — | — | — | 13, 21 | 22, 11 |
| 2.0 | 3, 7 | 4, 1 | 4, 8 | 6, 1 | 8, 7 | 14, 10 | 26, 0 |
| 2.1 | 3, 7 | 4, 2 | 4, 9 | 6, 3 | 8, 10 | 15, 7 | — |
| 2.2 | 3,8 | 4,3 | 4, 10 | 6, 4 | 9, 2 | 16, 4 | — |
| 2.3 | 3, 9 | 4, 4 | 4, 11 | 6, 6 | 9, 6 | 17, 2 | — |
| 2.4 | 3, 10 | 4, 5 | 5, 0 | 6, 7 | 9, 11 | 18, 1 | — |
| 2.5 | 3, 11 | 4, 6 | 5, 2 | 6, 9 | 10, 4 | — | — |
| 2.6 | 4, 0 | 4, 7 | 5, 3 | 6, 11 | 10,9 | — | — |
| 2.7 | 4, 1 | 4, 8 | 5, 4 | 7, 0 | 11, 2 | — | — |
| 2.8 | 4, 1 | 4, 9 | 5, 5 | 7, 2 | 11, 7 | — | — |
| 2.9 | 4, 2 | 4, 10 | 5, 6 | 7, 4 | 12, 1 | — | — |
| 3.0 | 4, 3 | 4, 11 | 5, 8 | 7, 6 | 12, 6 | — | — |

The distances specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known and supplied by the utility. If the system is not designed and operated to limit transient overvoltages to the selected values, transients shall be limited to the selected value by external means (for example, by the installation of a transient control device).

### 5.3.4 Nonconductive rope

#### 5.3.4.1 General

Rope used in energized line work should be kept clean and dry. It should be stored in clean, dry containers when not in use. The use of a moisture absorbing agent such as desiccant is suggested. The rope should not be permitted to contact the ground; this can be accomplished by paying the rope in and out of the container, or by having a tarpaulin or other type of ground cloth on which to put the rope. Rope used in energized line work should not be used for any other purpose.

Handlines and slings should be stored by tying them in hanks or coils and suspending them from a rack where the air can circulate freely between them. Rope should never be used wet when a voltage is applied across it. Not only can a current pass through the rope, but this current can cause localized internal heating resulting in an almost total loss of mechanical strength which is not easily detected by visual inspection. Inspection can be accomplished by unwrapping the strands to see if there are any fused filaments or threads, which indicate high stress (either electrical or mechanical).

#### 5.3.4.2 Natural fibers

Natural-fiber rope should be stored so as to remain clean, cool, and dry as deterioration is accelerated by hot, humid conditions. Care should also be taken so that the rope does not come into contact with acids, caustics, or their vapors.

Natural-fiber rope used for conductor-pulling lines, when wet, should not be wound on a drum or reel and allowed to remain there for long periods of time. A minimum safety factor of 5 should be applied to the mechanical strength of natural fiber ropes.

#### 5.3.4.3 Synthetic fibers

Synthetic rope should not be stored under tension because it has a tendency to become permanently elongated. This will reduce its breaking strength. It should also be stored in a dark place as exposure to sunlight or ultraviolet tends to lessen the mechanical strength and cause deterioration. A safety factor between 5 and 9 should be applied to synthetic ropes, depending on the material and type of construction. The manufacturer should be consulted for the exact value.

### 5.3.5 Clothing

#### 5.3.5.1 Conductive clothing

Conductive clothing, including footwear, should be stored separately in a location that is dry and dust-free to prevent contamination by grease, oil, dirt, or water. It should not be exposed to direct sunlight for long periods of time.

Other objects should not be stacked on the suits of clothing because of possible damage to the fine interwoven material that forms the conductive portion of the suit and result in hot spots.

Extreme care should be taken when storing the suits of clothing to ensure that they are clean and that no sharp or rough objects, which could rip or tear the materials, are stored with the suits.

Conductive suits and related equipment should be transported in separate containers to prevent damage.

#### 5.3.5.2 Insulating clothing

Insulating clothing, such as rubber gloves, rubber sleeves, and overshoes, should be stored in clean, dry locations. Care should be taken to prevent damage from rough objects. In addition, insulating equipment, such as gloves, should not be dropped or allowed to ride down a handline. Rubber insulating gloves should never be used without placing protector gloves over them. A small puncture in the rubber could render any insulating apparel useless. In general, the same care should be given to insulating clothing as is given to conductive clothing.

### 5.3.6 Conductor carts

Care shall be taken to ensure that the combined weight of the conductor cart, workers, and equipment does not allow the electrical clearance at midspan to be reduced below the electrical minimums.

### 5.3.7 Grounding and bonding devices

The effectiveness of these devices depends on the integrity of the electrical-contact surfaces, the cable stranding, and the clamping mechanism. Care should be taken to prevent damage to the cable and the clamping mechanism. These devices should be stored separately to avoid kinking the cable. Contact surfaces and threads should always be kept clean. Heavily oxidized or tarnished contact surfaces can present excessive contact resistance. Poor contact surfaces can compromise safety in the event of a line fault. (See personal electrical protective equipment in IEEE Std 1048-1990.)

**Table 18—Minimum approach distance, ac energized work with transient overvoltage factor**

| Maximum anticipated per-unit transient overvoltage | Phase-to-phase air, clear live-line tool and bare hand distance (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Maximum phase-to-phase voltage (kV) | | | | | | |
| | 121 | 145 | 169 | 242 | 362 | 550 | 800 |
| 1.5 | — | — | — | — | — | 2.24 | 3.67 |
| 1.6 | — | — | — | — | — | 2.65 | 4.42 |
| 1.7 | — | — | — | — | — | 3.09 | 5.23 |
| 1.8 | — | — | — | — | — | 3.53 | 6.07 |
| 1.9 | — | — | — | — | — | 4.01 | 6.97 |
| 2.0 | 1.08 | 1.24 | 1.41 | 1.85 | 2.61 | 4.52 | 7.91 |
| 2.1 | 1.10 | 1.27 | 0.44 | 1.89 | 2.68 | 2.83 | — |
| 2.2 | 1.12 | 1.29 | 0.47 | 1.93 | 2.78 | 3.01 | — |
| 2.3 | 1.14 | 1.32 | 1.50 | 1.97 | 2.90 | 3.20 | — |
| 2.4 | 1.16 | 1.35 | 1.53 | 2.01 | 3.02 | 3.42 | — |
| 2.5 | 1.18 | 1.37 | 1.56 | 2.06 | 3.14 | — | — |
| 2.6 | 1.20 | 1.40 | 1.59 | 2.10 | 3.27 | — | — |
| 2.7 | 1.23 | 1.43 | 1.62 | 2.13 | 3.40 | — | — |
| 2.8 | 1.25 | 1.45 | 1.65 | 2.19 | 3.53 | — | — |
| 2.9 | 1.27 | 1.48 | 1.68 | 2.22 | 3.67 | — | — |
| 3.0 | 1.29 | 1.50 | 1.71 | 2.27 | 3.80 | — | — |

The distances specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known and supplied by the utility. If the system is not designed and operated to limit transient overvoltages to the selected values, transients shall be limited to the selected value by external means (for example, by the installation of a transient control device).

## 5.4 Periodic inspection and checking

Procedures for periodic electrical testing of tools and devices used in energized-line maintenance are given in clause 4. The acceptance in-service check values for these devices are provided in the ASTM standards listed in table 11.

### 5.4.1 Insulating tools

Insulating tools should be inspected visually by qualified personnel for indications that show they could have been mechanically overstressed. Tools that show evidence of being overstressed (such as, damaged, bent, worn, or cracked components) should be removed from service and evaluated for repair. Feathered, elongated, or deformed rivet ends indicate that excessive mechanical loading has occurred and has weakened or sheared the bond between the ferrules and the insulating pole.

Hardware, bolts, and pins should be replaced only with high-strength, tempered-steel material, or the same as the original part for Grade 5. Nondestructive testing should be performed on the mechanical end-fittings and saddle clamps after a tool has been subjected to possible overstressing or vibrating loads for any extended periods of time (Magnaflux, Zyglo, and X ray may be used for checking ferrous and nonferrous parts).

When the insulating member of a tool shows signs of accumulated contamination, tracking, surface blisters, excessive abrasion, nicks, or deep scratches, the tool should be removed from service, cleaned or refinished as recommended by the manufacturer, and electrically retested. Moisture will reduce the insulating properties of these tools.

When tools have been exposed to excess moisture, their moisture content can be measured with a commercially available moisture meter in accordance with the manufacturer's recommendations.

Jack screws should be examined for excessive looseness (indicative of worn threads) and freedom from binding. Worn elements should be replaced. Bolt and nut threads should be free of burrs, roughness, or other damage that can seriously erode mating threads, and all threads should be lubricated only with “dry” lubricants.

### 5.4.2 Insulating aerial equipment

#### 5.4.2.1 Inspection before live work

Before equipment is used for live work it should undergo a comprehensive daily inspection. Items to be checked or inspected daily, or both, should include, but not be limited to

a) Emergency power system, including battery
b) Hoses and controls (hoses should not be cut or damaged and controls should move freely)
c) Insulating section of boom, which must be wiped down and visually inspected
d) The engine should be started and the device operated through its normal operating cycle with no one in the bucket. Any unusual noise, malfunctions, oil leaks, erratic movement, or other occurrence that is not normal should be noted.

#### 5.4.2.2 Periodic inspection

Comprehensive periodic inspections should be made and records kept on file. Items to be checked, serviced, and repaired should include, but are not limited to

a) Vehicle and aerial device for lubrication as specified by the manufacturer
b) Vehicle power take-off for mounting, controls, linkage, and leaks
c) Hydraulic pump for mounting, hose connection, leaks, and noise level
d) Filters for cleanliness or replacement
e) Hydraulic lines for leaks and general condition
f) Mast and turret for cracks and excessive motion in the bearings

g) Rotation motor and gear box for oil level, leaks, and drive mechanism
h) Manifold block or rotary connections for leaks
i) Bucket controls for free movement and self-centering
j) Oil reservoir for oil level
k) Outriggers for mounting, welds, and proper functioning of holding valves
l) Pivot points for lubrication, proper hose routing, wear, and hose condition
m) Bucket-leveling system to ensure that the bucket levels properly
n) Boom-lift cables for wear, broken strands, and proper adjustment
o) Booms for cracks, alignment, and general condition of the insulating sections
p) Boom cylinders for leaks and properly functioning holding valves
q) Bucket and bucket liners for bruises, cuts, and cracks
r) Emergency systems for proper operation
s) D ring attachment for security
t) Throttle control for proper cycling and system settings
u) Vacuum prevention system, or other devices to preclude the drawing of a vacuum in any out/fluid line for track with a reach exceeding 18 m (50 ft)

### 5.4.3 Insulating cover-up equipment

Cover-up equipment should be inspected for dents, tears, cracks, punctures, bums, tracking, distortion, soft spots, loose or broken appendages, contamination, and dampness. Cover-up equipment that is damaged, as distinguished from being soiled or damp, should not be used but set aside for electrical tests and possible repairs.

Equipment that is damp should be wiped thoroughly with a clean cloth both inside and outside before use. Where wiping internally by hand is impossible because of space, a clean cloth should be thrust through to swab internal surfaces. Covers that are soiled with dust or mud should be wiped with a moist rag and dried.

### 5.4.4 Nonconductive rope

Ropes used for energized line-work should be frequently inspected for deterioration, wear, broken strands, and condition of eyes and splices. Periodic examination of the inner strands, or fibers, is strongly recommended.

### 5.4.5 Conductive clothing

All conductive clothing should be inspected visually before and after use to check for rips, brown or burnt marks, punctures, or any damage that can prevent complete shielding. A defect in the conductive clothing or its bonding apparatus should be a reason for removing it from service, instituting immediate repairs, if possible, and testing.

Particular care should be given to removing any dirt or gravel that may be embedded in conductive shoes.

For additional information on the use, care, maintenance, and testing of conductive clothing, see IEEE Std 1067-1990.

### 5.4.6 Conductor carts

Conductor carts should be checked prior to use to make certain the wheels, drive mechanisms, safety slings, and bonding traveler wheel are in good condition.

### 5.4.7 Grounding and bonding devices

These devices should be inspected for strand breakage (especially around the areas where the ferrule is crimped to the cable), tightness of the cable terminal to the clamp body, and condition of the threads for smooth operation and clean surfaces.

## 5.5 Maintenance and repair of tools and equipment

### 5.5.1 Insulating tools

Repair to insulating tool fittings by welding or reshaping should not be done because damage by impact or overstressing may have weakened the member elsewhere. Welding may also damage heat treatment of the part. Tools damaged as a result of any mechanical stress (e.g., falls, overloads) shall therefore be removed from service.

#### 5.5.1.1 Fiberglass-reinforced plastic (frp) tools

Insulating tools of fiberglass-reinforced plastic should be wiped with a clean cloth or paper towel before use and as soon as they become noticeably contaminated. Cleaning with a strong nonconductive detergent solution followed by thorough rinsing or a cleaning recommended by the manufacturer is usually sufficient. However, if this does not remove all foreign matter, tools may be washed with a suitable solvent. After cleaning, the tools should be wiped with a finish restorer recommended by the manufacturer.

FRP insulating tools should be repaired only by competent personnel. Light spots are caused by impact blows and may or may not have a noticeable effect on the strength or electrical properties of the tools. If there is no surface roughness, there is no need for repair. Small surface ruptures can be seen with the naked eye. Repairs (by competent personnel only) should be made by removing the damaged fibers, cleaning the void, and following the manufacturer's recommended procedure for repair.

If there is any indication that the outer layer of material has separated, leaving a void beneath (this void can accumulate moisture or, under electrical stress, become ionized), the tools should be removed from service and refinished as recommended by the manufacturer. Numerous light spots may show excessive abuse and, coupled with surface contamination, may reduce the flashover voltage or contribute to insulation degradation.

After any repairs, the tools shall be tested electrically to ensure that the damage, or repair, has not affected its properties.

#### 5.5.1.2 Wood tools

Although the surface of the tool may appear to be perfectly dry and the finish in excellent condition, the wood may have absorbed excessive moisture from the air if the tool has been exposed to high humidity. Therefore, extra precautions should be taken during wet seasons of the year. Treatment in a drying cabinet is recommended if excessive leakage current is noted during electrical tests. In these cases, tools should be dried at 32 °C (90 °F) for approximately 48 h and subsequently subjected to a dielectric or watts loss (power-factor) test (see IEEE Std 978-1984). Prompt touching-up is recommended where the finish is worn or damaged to prevent dirt or moisture from entering and becoming absorbed by the wood fibers where it might form dangerous conducting paths.

**Table 19—Minimum approach distance, dc energized work with transient overvoltage factor**

| Maximum anticipated per-unit transient overvoltage | Conductor-to-worker air, clear live-line tool and bare hand distance (ft, in) | | | | |
|---|---|---|---|---|---|
| | Maximum phase-to-phase voltage (kV) | | | | |
| | 250 | 400 | 500 | 600 | 750 |
| 1.5 or lower | 3, 8 | 5, 3 | 6, 9 | 8, 7 | 8, 7 |
| 1.6 | 3, 10 | 5, 7 | 7, 4 | 9, 5 | 8, 10 |
| 1.7 | 4, 1 | 6, 0 | 7, 11 | 10, 3 | 14, 4 |
| 1.8 | 4, 3 | 6, 5 | 8, 7 | 11, 2 | 15, 9 |

NOTES
distances specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known and supplied by the utility. If the system is not designed and operated to limit transient overvoltages to the selected values, transients shall be limited to the selected value by external means (for example, by the installation of a transient control device).
If the transient overvoltage factor is not known, a factor of 1.8 shall be used.

When general refinishing is required, wood tools should be thoroughly dried to 6% or 7% moisture content. After the old varnish or other type of coating and foreign material have been removed, the surface should be rendered smooth with flint paper and finished with two or three coats (with a light sanding between coats) of an appropriate moisture resisting material.

Damage to the finish should be repaired according to the manufacturer's recommendations.

Repairs and refinish should be done by competent personnel and followed by a dielectric or watts loss (power-factor) test (see IEEE Std 978-1984). Before repair or refinishing is undertaken, replacement with modem fiberglass tools should be considered.

### 5.5.2 Insulating aerial equipment

All repair work should be performed by or under the supervision of competent workers. A detailed record should be kept of all maintenance and repairs performed on the aerial device. Replacement parts should be as specified by the manufacturer or as approved by the user.

After major repair work has been performed on the insulating portion of the aerial device, a certification or periodic test should be made before the device is returned to service.

A thorough inspection of the device should be made if the recommended maximum load of the bucket or boom has been exceeded (see ANSI/SIA A92.2-1990).

### 5.5.3 Insulating cover-up equipment (e.g., plastic, fiberglass)

Repairs to cover-up equipment having cracks, tears, or holes are not recommended (ASTM F478-92, ASTM F479-93, and ASTM F496-93b). The only parts that might be repaired are appendages, damaged or loose, that have no effect on the dielectric strength of the equipment.

For instance, a loose rope loop might be recemented using the manufacturer's recommended repair kit or the scissors bar, or its mounting hardware might be replaced or reattached to the bottom lip of the line guard. Repairs to this equipment should be made according to the manufacturer's recommendation. ASTM provides proof test withstand voltage and flashover voltage tests for plastic guards (ASTM F711-93).

*Rubber insulating covers:* Repairs to insulating line hose and covers are not recommended. Hose may be used in shorter lengths if the defective portion is cut off (ASTM F478-92). Repairs to rubber blankets are permissible. Blankets with defects too extensive to repair may be salvaged by severing the defective area from the undamaged portion of the cover-up. Repairs and salvaging of blankets must meet the requirements of the ASTM standard (ASTM F479-93).

#### 5.5.3.1 Testing repaired equipment

Repairs and refinishing should be done by competent personnel and followed by a dielectric or watts loss (power factor) test (see IEEE Std 978-1984).

#### 5.5.4 Nonconductive rope

Damaged ropes should be removed from service.

#### 5.5.5 Clothing

##### 5.5.5.1 Conductive clothing

Body residues and other impurities will cause deterioration of conductive clothing. Clothing should be washed with a mild detergent and thoroughly rinsed in clean water.

For additional information on the use, care, maintenance, and testing of conductive clothing, see IEEE Std 1067-1990.

##### 5.5.5.2 Insulating clothing

Repairs to insulating clothing are not generally recommended (IEEE Std 935-1989, ASTM F496-93b).

#### 5.5.6 Conductor carts

Damaged or fatigued members should be replaced and bonding circuits periodically checked for continuity.

### 5.6 Bibliography documents

Document [B9] from the bibliography (clause 8) is cited in clause 5.

## 6. Work methods

### 6.1 Introduction

This clause covers work methods based on accepted minimum approach distances and techniques used by qualified electrical workers when working on energized lines. It should in no way be considered as a training outline or be used by untrained personnel as instructions for doing work on or in the vicinity of energized lines or equipment.

### 6.2 Scope

This section covers detailed methods and proper use of equipment for the various conditions under which live-line maintenance can be performed.

**Table 20—Minimum approach distance, dc energized work with transient overvoltage factor**

| Maximum anticipated per-unit transient over-voltage | Conductor-to-worker air, clear live-line tool and bare hand distance (m) | | | | |
|---|---|---|---|---|---|
| | Maximum phase-to-phase voltage (kV) | | | | |
| | 250 | 400 | 500 | 600 | 750 |
| 1.5 or lower | 1.12 | 1.60 | 2.06 | 2.62 | 3.61 |
| 1.6 | 1.17 | 1.69 | 2.24 | 2.86 | 3.98 |
| 1.7 | 1.23 | 1.82 | 2.41 | 3.12 | 4.37 |
| 1.8 | 1.28 | 1.95 | 2.62 | 3.39 | 4.79 |

NOTES

1— The distances specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known and supplied by the utility. If the system is not designed and operated to limit transient overvoltages to the selected values, transients shall be limited to the selected value by external means (for example, by the installation of a transient control device).

2— If the transient overvoltage factor is not known, a factor of 1.8 shall be used.

### 6.2.1 Categories of energized-line maintenance

#### 6.2.1.1 Workers at ground potential

The workers are located on the structure supporting the conductor or on other work platforms and remain essentially at ground potential using insulated tools and equipment.

#### 6.2.1.2 Workers at intermediate potential

The workers are isolated from grounded objects by insulating means, such as an aerial device or an insulated ladder or platform. Workers perform their work with insulated tools and equipment.

#### 6.2.1.3 Workers at line potential

Workers are bonded to the energized device on which work is to be performed and are insulated from grounded objects and other energized devices that are at a different potential. This is commonly known as the barehand technique.

#### 6.2.1.4 Other related work procedures

IEEE Std 1048-1990 provides guidelines for safe protective grounding methods for persons engaged in de-energized overhead transmission and distribution line maintenance.

IEEE Std 524-1992 and IEEE Std 524a-1993 provide general recommendations for the selection of methods, equipment, and tools that have been found practical for the stringing of overhead transmission line conductors and overhead ground wires. The purpose of these guides is to present sufficient details of present day methods, materials, and equipment and to outline the basic considerations necessary for maintaining safe and adequate control of conductors during stringing operations.

## 6.3 Minimum approach distance

a) Refer to 7.3.2 for the derivation of this parameter.
b) *Intermediate Potentials:* When a person is at an intermediate potential, whether to perform work isolated from energized parts or when approaching such parts, the distance between the worker and ground, plus the distance between the worker and the energized device, should never be less than the distance determined in 7.3.2. The strength of an air gap changes as a function of the gap length when a conductive object is placed in the air gap, and varies with the position of the object in relation to the air gap. The precise information is under consideration. New experimental results obtained in the USA and Europe on large objects floating between phases indicate the sum of the air distances on either side of the electrically floating objects has a lower dielectric strength than the same air distance between two energized electrodes. At this time the preliminary information does not warrant any change in the data as used in this guide.

*Transient overvoltage control, 72.5 kV and above:* For voltages above 72.5 kV, the approach distance may be reduced if the maximum anticipated per-unit transient overvoltage is known for the work site. The minimum air insulation distances derived from the appropriate tables in 4.2.2.3, as developed based on the applicable transient overvoltage control system and, adding the required inadvertent movement distance, may be used. When a reduced approach distance is used for a specific per-unit transient overvoltage, the maximum per-unit transient overvoltage shall be controlled at the work site by one of the following methods:

1) The operation of a circuit breaker or other switching device shall be modified, including blocking reclosing, if required.
2) The overvoltage itself is forcibly held to an acceptable level by the installation of arresters or temporary protective gaps, or similar devices.
3) The operation of the system shall be changed to restrict the effect of switching operations.

### NOTES

1—When preinsertion resistors are employed, they shall be operational.

2—Engineering analysis is required when transient overvoltage techniques are employed.

## 6.4 Precautions when working energized lines

### 6.4.1 General precautions

a) Energized-line maintenance should not be started when lightning is visible or thunder is audible at the work location. Lightning-ground radar detection equipment can be used to aid in making decisions.
b) Decisions regarding blocking reclosing during energized line maintenance work should be consistent with other safety considerations, system conditions (integrity, coupling, etc.), or the method of overvoltage control. On distribution lines, the nature of the work being performed usually determines the action to be taken.
c) All equipment should be inspected for defects before use.
d) Ultraviolet (UV) protective glasses or other appropriate face protection should be worn if there is any possibility of an arc.
e) The nominal voltage of the circuit should be known before starting work to ensure that proper minimum approach distances are maintained.
f) Care should be taken to maintain proper minimum approach distances, as determined by 7.3.2, when using conductive material, including noninsulating ropes or slings, in the vicinity of energized devices.
g) When required, insulated measuring tools should be used for verifying the insulating distance.
h) Insulated tools should be inspected for condition and indication of damage before and after each job.
i) When an energized conductor is being moved, checks should be made to avoid sparkover to trees or other objects located in the adjacent spans.
j) Persons not involved in the work operation should be kept clear of the work site.

### 6.4.2 Precautions when working at ground potential

a) It is important to determine correct locations relative to mechanical loadings that may be added or changes in electrical distances on structures for the placement of temporary rigging loads.
b) Care should be exercised to ensure that tools properly engage conductors or hardware, or both, before transferring a mechanical load to the tool.
c) Tools should not be mechanically overloaded.
d) Care should be exercised when handling metallic objects while working near the end of the insulator string as they can become electrically charged, which can result in unexpected shocks.

### 6.4.3 Precautions when working at intermediate potential

a) When passing conductive objects to the worker at intermediate potential, a handline or tool, insulated for the voltage involved, should be used so as not to decrease the insulating value to ground or to other objects at a different potential. The possible effect of the conductive part should also be taken into account.
b) To avoid shocks, the worker should first bond to any conductive object being passed to him.
c) When returning to a metal structure from an insulating ladder or similar support platform, the worker should drain the charge off his or her body by first contacting the structure with a small metal tool or object held tightly in his or her hand.

### 6.4.4 Precautions when working at line potential

a) The worker should be insulated from ground or objects at a potential other than that of the device he or she is working on.
b) The worker should be adequately shielded from the electric field.
c) Bonding should be such that the worker is at the potential of the device on which he or she is working.
d) If possible, all objects passed to the worker should be brought to the line worker's potential before the line worker touches them.
e) When working with bundled conductors, the worker should bear in mind that a heavy fault current will slam the subconductors together with violent force.
f) When working in close proximity to other conductors or objects, the worker should cover them with protective cover-up equipment, if such rated for the voltages involved is available, or move them to avoid inadvertent contact with other potentials or ground by the worker or the equipment being used.

## 6.5 Requirements when working energized lines

### 6.5.1 General requirements

a) Personnel doing energized line-work should have satisfactorily completed a formal training course of instruction and practice for each applicable category of insulating device to be used. Records should be maintained that include training and work experience in the categories of work the worker is expected to perform. In addition, personnel performing live work should be examined periodically to determine the adequacy of the worker's knowledge of rules and procedures, his or her ability to estimate distances visually while in elevated working positions, and his or her ability to safely use the barehand technique, including the control and positioning of supporting insulating devices.
b) Whenever workers are exposed to electric fields, shielding should be provided as required and noted in 4.2.3.1.3.
c) A well-developed set of formal, written work rules should be provided for safe implementation of energized-line maintenance. All personnel should be familiar with these rules.
d) Procedures should be continuously examined and updated to take advantage of new equipment, and lessons learned during use of present procedures and work methods.
e) Frequent, well developed on-the-job or tailgate discussions of the aspect of each energized line-work program or job by the working personnel are necessary. Communication by all participants should constantly be

encouraged, both during the discussions and during the progress of the work program. Every effort should be made to provide logical, understandable answers or reasons for all questions, and all proposals should be readily received and discussed, with immediate action initiated on any approved changes. A high degree of intra-crew discussion and participation demonstrates a highly trained, well adjusted, energized-line crew.

f) The leader of the crew should be present for every job and should personally direct all energized line-work. An awareness of the capabilities and the physical and mental condition of each member of the crew is necessary. No crew member should be allowed to work during periods, either temporary or sustained, when one is suspected to be in a physical or mental state that could contribute to an unsafe operation of the crew or equipment. The leader of the crew should be responsible for seeing that detailed plans are worked out in advance and for determining the location of all grounded and energized parts in the vicinity of the proposed work. Minimum approach distances for personnel and their supporting insulating devices (considering movements during the work) should be determined in advance and strictly observed.
g) When portable protective gaps are used, they should be installed preferably on a structure adjacent to the work location.

### 6.5.2 Requirements when working at ground potential

a) When working from structures at voltages above 230 kV phase-to-phase, workers should be protected by the conductive clothing or shielding, if required, to avoid electric shocks.
b) The condition of conductors, tie wires, and insulators should be carefully checked for signs of burns or other weaknesses. When such defects are found, extra special care should be taken while doing the work. Workers at ground level should stay clear of the area underneath the work area to the extent possible.

### 6.5.3 Requirements when workers are at intermediate potential

The mechanical and electrical integrity of any insulated device used to support the worker should be ensured.

### 6.5.4 Requirements when workers are at line potential

a) For work on circuits energized above 230 kV phase-to-phase, the worker should wear conductive clothing.
b) Workers should be bonded to the energized device on which they are to work.

### 6.5.5 Requirements for gloving

References to voltages in the following paragraphs are phase-to-phase on multiphase circuits. When exposure is limited to phase-to-ground voltage only, gloves rated for that voltage can be used.

#### 6.5.5.1 General

Rubber and synthetic gloves and sleeves are available for use on voltages through 36 kV (class 4).

#### 6.5.5.2 General requirements

a) Rubber gloves (with or without sleeves) should be worn before entering a hazardous area and removed only after leaving the hazardous area.
b) Energized or neutral conductors, ground wires, messengers, guy wires, etc. in the proximity should be covered with approved protective equipment. This equipment should be installed and removed from below, when practicable, and in such a manner and sequence as to provide maximum protection. Protective covering should be applied to the nearest and lowest conductor first and removed in reverse order.
c) Special care should be exercised when working in proximity to fuses, lightning arrestors, etc. Procedures may require that fuses be bypassed for the duration of the work.
d) Protective equipment is normally removed at the end of the work day.

#### 6.5.5.3 Field inspection

Rubber gloves and sleeves should be inspected at least daily while in use for cracks, bruises, and other damage or defects. Gloves should be given an air test at the beginning of the work period and at any time their condition is suspect.

#### 6.5.5.4 Field care and storage

a) Rubber gloves should never be stored or worn inside out, nor worn without glove protectors. Gloves should be stored in their natural shape. Sleeves and blankets should not be folded or creased, but should be stored flat or in an approved roll-up.
b) All rubber protective equipment should be protected from mechanical damage and exposure to harmful chemicals, heat, ozone, oil, grease, etc. Harsh chemicals, oil, grease, etc. should be removed as soon as practicable by wiping or by using a mild detergent. The gloves or sleeves should be checked for any damage. If there is any indication of damage, they should be returned to an approved testing facility for an electrical proof test. Thorough rinsing is important to prevent damage.

#### 6.5.5.5 Working 600–7500 V

With the use of proper protective equipment (line hoses, blankets, etc.), this voltage level may be worked directly off of wood poles.

#### 6.5.5.6 Working above 7 500–17 000 V

Some additional insulation, such as insulated platforms, ladders, or aerial lifts, is usually employed. Installation of line hose, blankets, and other protective equipment can be performed from the structure without additional insulation because contact with the energized conductor is not necessary. Sleeves are used when there is no positive assurance (e.g., adequate use of cover up) that the arms can or will violate the approach distance phase-to-phase, or phase-to-ground for the voltage involved.

#### 6.5.5.7 Working above 17 000–26 500 V

The same practices usually apply to this level as at the "above 7 500–17 000 V" level, except that line hose, blankets, etc. may be installed with live-line tools or with the benefit of additional insulation, such as insulated platforms and lifts. Aerial lifts are often preferred at this level.

#### 6.5.5.8 Working above 26 500–36 000 V

a) Insulated aerial devices or insulating pole platform equipment is universally accepted as necessary for gloving at this voltage level. Sleeves are optional. Insulated basket liners are often used.
b) Work in damp or foggy weather is restricted—often limited by the boom leakage current or the atmospheric humidity.
c) Frequently, a combination of gloves and live-line tools is used because of construction, approach distances, congestion, etc.
d) Lower voltage class gloves should not be permitted at the job site or should be collected and stored at a specific location before work at this voltage is started.

## 6.6 Insulating equipment used in energized line-work

### 6.6.1 Insulating aerial devices

Vehicle mounted devices are used to position the worker near energized lines or equipment and provide electrical isolation between the energized equipment and the ground potential at the vehicle location (e.g., aerial ladders, articulating boom platforms, extendable boom platforms, vertical towers, and telescoping boom platforms). The device should be rated and certified by the manufacturer.

### 6.6.2 Insulating ladder

A single- or multiple-section ladder is used for personnel support during energized line-work. This ladder may be structure mounted, base-supported, or cable-supported by a crane or similar device.

### 6.6.3 Insulating platform

An aerial device used to elevate a platform in a vertical axis by means of insulating arms operating in a scissors action

### 6.6.4 Insulating tower boom

An insulating tower boom is used, in conjunction with support platforms such as a bosun's chair, basket or bucket, or tree trimmer's saddle, to position the worker.

### 6.6.5 Insulating cargo boom

An insulating cargo boom is used, in conjunction with support platforms such as a bosun's chair, basket or bucket, or tree trimmer's saddle, to position the worker.

### 6.6.6 Insulating platform board

A fiberglass board, when attached to the pole or structure, provides a nonconductive horizontal surface on which the workers stands. It electrically isolates the worker from the pole to which it is attached.

## 6.7 Noninsulating equipment used in energized line-work

### 6.7.1 Conductor cart

A cart suspended from the conductor can be used as a work platform for operations, such as removing insulator strings or inspecting dampers, spacers, or the conductor itself.

### 6.7.2 Helicopter

Helicopters can be used to lower and raise the workers and tools to and from structures carrying lines and to place line workers in a position for contacting and performing work. Refer to CFR Publication 14CFR, Part 133.

### 6.7.3 Restoration structures

Refer to IEEE Std 1070-1988.

## 6.8 Insulating devices used in energized line-work

### 6.8.1 Insulating tools

Insulating tools made of either wood or, preferably, fiberglass-reinforced plastic are used for work on energized devices while the worker is at ground potential or at an intermediate potential.

### 6.8.2 Nonconductive rope

Nonconductive rope is used in rigging support platforms for positioning personnel, controlling conductors, and raising or lowering tools and equipment whenever work is being done on, or in, the vicinity of energized lines or devices. It can be used alone or in series with an insulating pole. Insulating chain can be used in place of nonconductive rope when high humidity levels are likely to be encountered.

### 6.8.3 Protective cover-up

Protective cover-up equipment is used to insulate energized lines and devices from the worker. When the worker is at the conductor potential, the cover-up equipment may be used to insulate the worker from ground potential.

## 6.9 Methods for positioning personnel

### 6.9.1 Minimum approach distances

a) The minimum clear approach ladder insulation distance from the worker to the ground shall not be less than the distances specified in tables 2 and 3. In general, 2.4 m (8 ft) should be added to the minimum clear insulation length of the ladder to account for the area usually occupied by the worker.
b) The minimum approach distance between any grounded part of the insulating aerial device and any energized device shall not be less than that specified in 7.3.
c) When bonding to any energized device, the minimum approach distance from the worker and all energized parts shall not be less than that specified in tables 1 and 2, plus an appropriate distance added for inadvertent movement (see 7.3).
d) When bonding to an energized phase, the minimum approach distance to another energized phase of the same circuit shall not be less than the distance required by 7.3.
e) When bonding to an energized pole of a dc line, the minimum approach distance to the other pole shall not be less than that specified in table 5 , plus an appropriate distance added for inadvertent movement (see 7.3).

### 6.9.2 Aerial devices

#### 6.9.2.1 Vehicle-mounted elevating and rotating aerial devices

a) All aerial devices shall meet the criteria for design, testing, installation, maintenance, use, training, and operation as specified in ANSI/SIA A92.2-1990.
b) Before the boom of an aerial device is elevated, the outriggers on the truck should be extended, and if required, the aerial device adequately grounded.
c) The boom should be operated through its full range to ensure all functions are operating correctly.
d) The floor of the aerial device buckets or platform should be kept clean of dirt or material. This is especially important when conductive liners or metal platforms require good contact for conductive footwear when worm by workers.
e) When working aloft, workers should stand on the bottom of the bucket or platform.
f) Workers on the ground should minimize contact with the aerial device chassis while the lift is near or in contact with energized devices.
g) The aerial device, including buckets or platform and upper insulating boom, should not be overstressed by attempting to lift or support weights in excess of the manufacturer's rating. To protect the fiberglass parts, none of the parts of the bucket, platform, or upper arm should be used as a support point for prying or lifting.
h) The fiberglass of buckets should not be considered to have any insulating value unless designed, maintained, and operated in accord with the appropriate standard: CSA C225-M88, IEC 1057 (1991), or [B7].
i) When it is necessary to move to or from an insulated aerial device or ladder to a structure or conductor, workers shall be attached in accordance with IEEE P1307/D7A.

### 6.9.3 Structure-mounted ladder for barehand work

a) Before the platform is elevated, the outriggers on the unit should be extended and adjusted to stabilize and level the unit.
b) The body of the unit should be properly grounded when required. Grounding through the outriggers is not sufficient.
c) Before moving the insulating platform into the work position, all controls both at ground level and on the support platform should be checked.
d) For scissors-type platforms with hydraulic lines to the controls at the support platform level, all arms supporting the platform should be raised to their maximum height and left in the raised position for 5 min.
e) Workers in the vicinity of a support platform, in contact with or near energized lines, should avoid making contact with the support platform.
f) Bond cables should use break-away clamps or have a break-away section that allows for separation from the energized conductor in an emergency situation.

#### 6.9.3.1 General precautions

a) The structure (e.g. hook) end of the ladder should be firmly secured to the structure.
b) The ladder should not be secured to a defective component or to a device that will be taken apart or moved.
c) Before the worker mounts the ladder, the leader of the crew should first assure himself or herself that all rigging has been checked.
d) The process of mounting or dismounting a ladder should be given special consideration. If a safety strap or lanyard is used when climbing, it should be not used when mounting or dismounting.

#### 6.9.3.2 General requirements

a) Before a worker mounts the ladder, it should be tested electrically by making contact with the line to be worked on to check the current.
b) The ladder should be moved to a safe position prior to allowing the worker to mount or dismount.
c) Controlling the movement of the ladder should be done with insulating tools, or nonconductive rope or chain, or both.

#### 6.9.3.3 Minimum clearance distance

The minimum insulation distance specified in tables 2  and 3 , plus an additional distance for inadvertent movement, should be maintained between the worker and any grounded part. (See also the change in 6.3 , item b) for cautions regarding the worker acting as a floating electrode in an air gap.)

### 6.9.4 Base-supported ladder for live-line work

#### 6.9.4.1 General precautions

a) The equipment being used as a fixed base support should provide a sturdy, safe prop for the length of ladder and weight to be supported. NOTE—See the ANSI A10 series of standards for ladder placement, care, and use relative to mechanical situations.
b) Personnel should stay clear of the ladder and base while the ladder is being moved into position.

#### 6.9.4.2 General requirements

a) The equipment being used as a fixed base support for the ladder should be grounded.
b) Insulating devices, when needed to assure either the minimum approach distance or insulating tool length requirements, should be used to move the ladder to the energized device.
c) The ladder should be checked electrically each time the base is relocated when barehand work is being performed.

#### 6.9.4.3 Minimum approach distance

A distance of 2.4 m (8 ft) should be added to the minimum installation distance indicated in table 2 to allow for the length of ladder occupied by the person.

### 6.9.5 Cable-supported ladder for live line-work

#### 6.9.5.1 General precautions

a) The lifting device should be of adequate capacity to handle the ladder load without any risk of an operating deficiency.
b) The ladder should be adequately supported and secured to ensure safe operation at all expected angles and positions.
c) The equipment should be closely inspected by the supervisor and operator following setup, and any noted or suspected deficiencies should be corrected.
d) Insulating devices (e.g., link sticks or nonconductive rope) should be used between the cable and the ladder whenever possible to facilitate the dielectric current testing or to improve the insulating quality of the setup, if needed.

#### 6.9.5.2 General requirements

a) The equipment being used as the lift device should have both power raise and power lowering facilities. Brake-type lowering should not be used.
b) When workers are on the ladder, all movements of the lifting device should be directed or controlled from aloft.
c) One person capable of operating all controls should be near the lifting device when workers are on the ladder to allow rapid response to movement needs, and to warn other persons not to walk under the work area and to keep them clear from the lifting device when the ladder is elevated.
d) Link sticks or ladders should be solidly attached to the lifting cable. Open-load hooks should not be used.

#### 6.9.5.3 Minimum approach distance

Noninsulating portions of the equipment should not be closer to energized devices than the distances indicated in tables 2 and 7 . Depending on the work location, additional distances may be specified by the person in charge to ensure that minimum distances are not violated.

### 6.9.6 Insulating cargo boom for live-line work

#### 6.9.6.1 General precautions

a) The cargo boom should be erected at an appropriate location on the structure to facilitate moving the worker or equipment to the desired location.
b) The specific support platform to be used should be properly attached to the cargo boom and all component parts should have an adequate factor of safety for the load to be carried.

#### 6.9.6.2 Minimum approach distance

a) The minimum insulation distance between the worker and any grounded part shall not be less than that specified in 7.3 .
b) When bonding on to any energized device, the minimum approach distance from the worker and all energized parts shall not be less than that specified in 7.3 .
c) When bonding on to an energized phase, the minimum distance to another energized phase of the same circuit shall not be less than the distance required by 6.3, modified by 4.2.2.4 and table 17 .

d) For dc, when bonding to an energized dc pole conductor, the minimum distance to the other pole conductor shall not be less than the 2 times the pole-to-ground distance, derived from table 5 , plus an appropriate distance added for inadvertent movement (see 7.3 ).

### 6.9.7 Conductor cart used in bare hand work

#### 6.9.7.1 General precautions

a) A worker using a conductor cart should not make contact with the cart during its installation on the conductor until it is at the same potential as he or she is. This can be done either by allowing the cart to be pulled against the conductor to which the worker is bonded or by the worker reaching out and hooking it with his bonding wand.
b) A nonconductive tag (e.g., rope, rope with link stick) should be tied to the cart to control its motion during hoisting and at other times as required.
c) After the trolley wheels are on the conductor, safeties should be installed across the wheel attachment to prevent the cart from dropping if a wheel should jump off the conductor.
d) When transferring from an insulating ladder to a cart attached to the conductor, the worker should make sure that the safety strap, which is fastened to the ladder, and the conductive clothing bond are of sufficient length to permit transfer from the ladder to the cart.
e) When the cart is being mounted on bundled conductors, the rigid side of the cart support should be mounted on the conductor away from the worker on the insulating ladder, and the hinged side of the cart support then mounted on the conductor near the worker.

#### 6.9.7.2 General requirements

a) Appropriate bonding and shielding should be observed.
b) For carts propelled by internal-combustion engines, care should be exercised in handling fuel. An appropriate sized fire extinguisher (generally in excess of 30 lbs) should be in the cart at a readily accessible position, and as far away from the engine and fuel as is possible.

#### 6.9.7.3 Minimum working distance

a) Care should be exercised during installation of the cart on the conductor so that the minimum distances indicated in tables 2 and 7 are not violated.
b) The weight of the cart and the worker should be such that when installed on the conductor they do not alter the sag of the conductor to the extent that they violate the distances indicated in tables 4 and 5 .

### 6.9.8 Helicopter performed bare-hand procedures

#### 6.9.8.1 General requirements

When performing barehand live-line techniques with a helicopter:

a) The pilot and the worker shall be checked out on the particular job to be done
b) All applicable minimum working distances shall be discussed
c) Constant communications between pilot and worker should be provided
d) The pilot and worker should be dressed in equivalent conductive clothing
e) The pilot, in consultation with the worker, shall be responsible for all decisions regarding safe flying conditions
f) A regulatory approved work platform should be provided for the worker
g) Pull-away bonding clamps should be used
h) The worker shall be fastened to the helicopter or work platform, or both, by an approved safety harness and lanyard
i) A conductive wand shall be used to bring the platform and the helicopter to line potential.

j) The helicopter shall not be permanently tethered to the line or structure during personnel transfer.
k) When transferring to or from the helicopter mounted platform, the line worker shall be attached in accordance with IEEE P1307/D7A.
l) The platform or sling load method may be used to position worker on the line or structure.

#### 6.9.9 General requirements for aerial devices performing barehand work

##### 6.9.9.1 Bonds

a) Bonding leads should use pull-away clamps or have a pull-away section that allows for separation in an emergency situation.
b) Bond leads must remain firmly attached to the energized device throughout the work operation.

##### 6.9.9.2 Lower controls

a) One person qualified to operate the lower controls shall be nearby whenever the aerial device is aloft.

# 7. Work in the proximity of energized lines and devices

## 7.1 Introduction

This clause concerns itself with suggesting ways to provide protection for workers during energized-line maintenance or while working in the vicinity of other energized lines.

## 7.2 Scope

This clause determines the minimum approach distance for grounded bodies or equipment operating and moving in the vicinity of energized lines or energized components, or both, in station yards while performing work on energized circuits or devices.

This includes mobile work equipment, such as aerial lifts used as work platforms, radial boom derricks, aerial ladders, and live-line insulator washing equipment. Step-and-touch voltages are also considered.

## 7.3 Approach distances

### 7.3.1 Minimum air insulation distances

The distances in tables 2 , 6 , 7 , and 8 should be only used to establish minimum air insulation distance and they do not allow for accidental or unplanned movements (inadvertent movement).

### 7.3.2 Minimum approach distances

The minimum approach distance is equal to the minimum air insulation distance plus a factor for inadvertent movement. Minimum suggested inadvertent movement factors for different voltage ranges are tabulated in table 13 .

Minimum approach distances are developed by adding the minimum inadvertent movement to the distances in tables 2 , 6 , 7 , 8 , and 14 – 17 .

### 7.3.3 Reduced approach distances (above 72 500 V)

a) When work is to be performed at the grounded end of an insulator assembly, the approach distance employed may be equal to the length of the insulator assembly. For cap and pin insulators, two insulators at the grounded end may be temporarily shorted out as part of the work procedure as long as the minimum approach distance is maintained. For barehand energized work, the above principle may be followed at the energized end. At an open switch, work may be performed at the grounded end as long as the minimum approach distance is not reduced.
b) Conductor support tools, such as link sticks, strain carriers, and insulator cradles, may be used provided that the tool insulation distance is at least as long as the insulator string or the applicable minimum approach distance. When installing this equipment, the employee shall maintain the minimum approach distance.

## 7.4 Precautions when performing live work

### 7.4.1 Precautions

a) The following factors are among those that should be considered when establishing the minimum approach distance for a particular work operation:
   1) The potential hazard of the work, including electrical, mechanical, or physical hazards
   2) The skills and knowledge of the worker doing the work
   3) The possible use of protective cover-up equipment
   4) The fact that the live equipment may be the energized conductor or device itself, any hardware attached to it, any conducting tool or material touching it, or the metal component at the end of an energized-line tool
b) Extreme care shall be taken to ensure the safety of all workers.
c) Voltage and current induced into objects in the vicinity of energized components may influence the risk of "inadvertent movement" by the worker and should be considered in developing work practices and procedures.
d) When conducting shoes or boots are worn while working in the vicinity of energized equipment, to eliminate the annoying, though harmless, discharging of the body capacitive charge to the grounded structure, extreme care should be taken by the worker not to make contact with a source of low voltage potential.
e) Whenever field strengths are sufficient to require it, conducting clothing should be worn by workers at ground level and on any grounded extra-high voltage (EHV) structure (switchyard or transformer station).

### 7.4.2 General requirements

Whenever field strengths are sufficient to require it, conductive clothing should be worn by workers at ground level and on any grounded extra-high voltage (EHV) structure.

## 7.5 Step and touch voltages

### 7.5.1 Introduction

When a ground fault occurs on a transmission line, the potential rise of the transmission-line tower with respect to ground may present a hazard through excessive touch or step voltages. The degree of the hazard depends upon the magnitude of the fault current, the earth (ground) resistance, and the duration of the exposure. While the probability of a line-to-ground fault during the work period has not increased in recent years, the magnitude of fault current has in many cases increased appreciably with the result that the hazard from step and touch voltage should no longer be considered as negligible.

### 7.5.2 Voltage-gradient distribution

a) The dissipation of the voltage or voltage drop from the ground electrode is called the ground potential gradient, or simply, the voltage gradient. The voltage drop depends on the ground resistivity. Figure 9 depicts a typical voltage-gradient distribution curve and shows that the voltage decreases rapidly with the distance from the electrode and that most of the voltage drop is concentrated near the electrode. The graph assumes soil of uniform resistivity.

b) Step and touch voltage is illustrated in figure 10. In the event of a fault to ground, transferred voltages can occur on any metal component connected to station grounds, transmission and distribution, including station fences, cable sheaths, pipes, and rails.

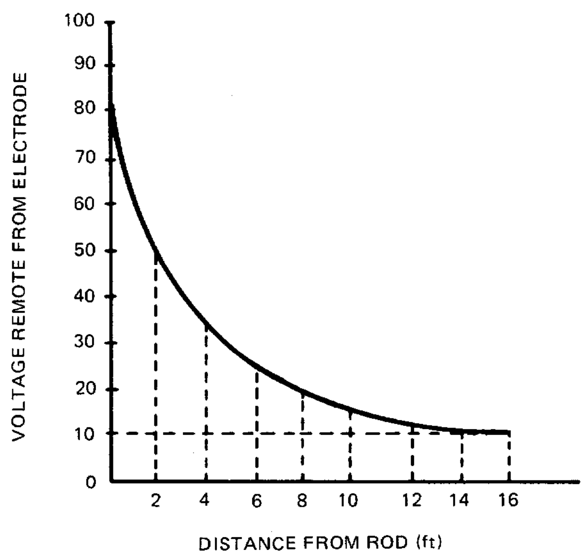


**Figure 9 — Typical voltage-gradient distribution curve**

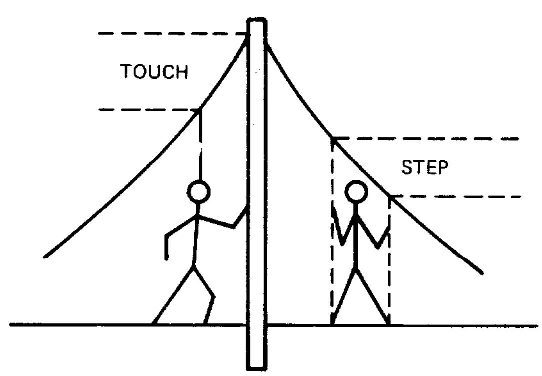


**Figure 10 — Step and touch potentials**

### 7.5.3 Protection of the worker from ground potential gradients

a) The use of a metal mat connected to the electrode will protect a worker standing on it from any step or touch potential. However, if the worker is standing with one foot on the conducting mat and one foot on the ground, he or she will be exposed to a step potential, which is at least equivalent to the touch potential, as illustrated in figure 11 .

## 7.6 Vehicles in the vicinity of energized lines and devices

### 7.6.1 General precautions

a) Vehicles equipped with any type of aerial equipment (e.g., aerial platforms, digger derricks, booms) working in the vicinity of energized conductors or apparatus should be grounded or isolated.

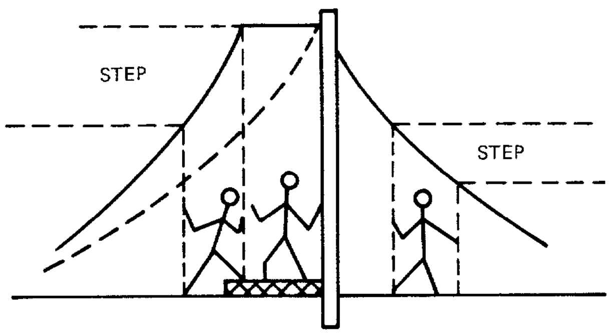


**Figure 11 — Protection of the workers from ground-potential gradients**

b) Persons standing on the ground should not be in contact with a vehicle while the boom or aerial device is being moved, or in motion, and has any possibility of contacting energized conductors or apparatus.

### 7.6.2 General requirements

a) If it becomes necessary to make contact with attachments or load during minor controlled adjustments of the boom or winch so as to contact, disconnect, or align the attachment or load, care should be taken to make sure that safe methods for controlling loads are employed. In addition,
   1) Appropriate minimum air insulation distance shall exist between the boom, attachments and load, and the energized conductors or devices.
   2) The minor controlled adjustments of the boom or winch shall not encroach on the appropriate minimum air insulation distance and the boom. Attachments and load shall avoid energized conductors or devices.

b) When it is necessary to operate the controls at ground or vehicle level, the operator shall protect himself or herself by standing on one of the following:

a) The operators metallic platform installed for this specific purpose
b) The deck of the vehicle
c) A portable conducting mat electrically attached to the vehicle
d) An insulated platform rated for the voltage involved

### 7.6.3 Insulator cleaning

Cleaning contaminated insulators on energized lines can be done by using various methods (see [B11]). See also IEEE Std 957-1995.

## 7.7 Bibliography documents

Document [B11] from the bibliography (clause 8 ) is cited in clause 7.

## 8. Bibliography

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# Annex A

# (normative)

## Derivation of live-line minimum air insulation distance using equation (1) and figure 1

a) Use equation (1b) : $D = (0.01 + a)(T)(kV_{L\text{-}G})$
b) Derive equations from the figure 1 graph to determine "a” (x-axis) for a given $V_{CREST}$ (y-axis), using equations

$$m = (Y_2 - Y_1)/(X_2 - X_1) \quad (2)$$

$$y = mx + b \quad (3)$$

$$b = y - mx, \text{ and} \quad (3a)$$

$$x = (y - b)/m \quad (3b)$$

Since the two straight-line segment equations break at or near y = 1025 kV and x = 0.00275, the equations for x (“a”) become:

1) For $V_{CREST}$ greater than 1025 kV and selecting the points from the figure 1 graph
$Y_2$ = 1305 kV, $Y_1$ = 1025 kV, $X_2$ = 0.005, and $X_1$ = 0.00275:
(equation 2) $m$ = (1305 - 1025)/(0.005 -.0.00275) = 124 444 and
(equation 3a) $b$ = 1305 - (124 444)(0.005) = 683, then
for any given $V_{CREST}$, (equation 3b) a = ($V_{CREST}$ - 683)/12 444, and
2) For $V_{CREST}$ less than 1025 kV and selecting the points from the figure 1 graph
$Y_2$ = 1025 kV, $Y_1$ = 780 kV, $X_2$ = 0.00275, and $X_1$ = 0.001:
(equation 2) $m$ = (1025 - 780)/(0.00275 - 0.001) = 140000 and
(equation 3a) $b$ = 1025 - (140 000)(0.00275) = 640,
then for any given $V_{CREST}$, (equation 3b) $a$ = ($V_{CREST}$ - 640)/140 000

c) Example: A 500 kV line has the following parameters:
1) $V_{NOM\text{-}LL}$ = 550 kV (assuming maximum load) and $T$ = 2.0 p.u. with auto-reclosing disabled where $kV_{L\text{-}G}$ = $550/\sqrt{3}$ = 318, $V_{CREST}$ = 318 ($\sqrt{3}$) 2.0 = 899, $a$ = (899 - 640)/140 000 = 0.00185, then $D$ = (0.01 + 0.00185)(2.0)(318) = 7.54 ft Add 1 ft for inadvertent movement (NESC) then, $D$ is 7.54 + 1 = 8.54 ft = 8 ft, 7 in live-line work minimum approach distance
2) $V_{NOM\text{-}LL}$ = 615 kV (assuming $n$-2 contingency) and $T$ = 2.0 p.u. with auto-reclosing disabled where $kV_{L\text{-}G}$ = $615/\sqrt{3}$ = 355, $V_{CREST}$ = 355 ($\sqrt{2}$) 2.0 = 1004, $a$ = (1004 - 640)/140000 = 0.0026, then $D$ = (0.01 + 0.0026)(2.0)(355) = 8.95 ft Add 1 ft for inadvertent movement (NESC) then, $D$ = 8.95 + 1 = 9.95 ft = 10 ft, 0 in live-line work minimum approach distance

# Annex B

# (informative)

# Distance calculations

## B.1 Determining a minimum approach distance that can be employed by use of a protective gap

The steps are as follows:

1) Select the appropriate (statistical) withstand voltage of the protective gap based on system requirements and the acceptable probability of gap sparkover.
2) From previous test data, select a gap distance that provides a (statistical) withstand voltage (85% of gap $U_{50}$) equal to or greater than the one selected in step 1).
3) Use the gap's (statistical sparkover) +2 σ sparkover voltage (110% of gap $U_{50}$) to determine the minimum air insulation distance from figure 2.
4) To determine the minimum approach distance, add 1 ft for inadvertent movement. See 7.3 for inadvertent movement discussion.

Example calculation: Assume a 500 kV line subject to 2.4 p.u. transient overvoltage, and operating at a 550 kV maximum operating voltage. Determine the minimum approach distance that can be employed by using an acceptable protective gap.

a) The user is willing to accept the risk of limiting the maximum per unit transient overvoltage to 125% of the maximum operating voltage during the time that the protective gap is installed on the line. Therefore, the minimum statistical withstand crest voltage of the protective gap is $(550 \text{ kV} \div \sqrt{3}) \times \sqrt{2} \times 1.25 = 562$ $\text{kV}_{CREST}$
b) Do not use figure 2. Use test data obtained from the particular protective gap tool geometry, bundle geometry, and varying gap distances to select a gap distance that has a $U_{50}$ equal to or greater than (562 kV) ÷ (0.85) = 661 $\text{kV}_{CREST}$ For example, if tests on a particular protective gap with a 4.0 ft gap spacing had a $U_{50}$ equal to 665 $\text{kV}_{CREST}$, select this gap spacing.
c) The protective gap's (statistical sparkover) +2 σ voltage is: (665 kV) x (1.10) = 732 $\text{kV}_{CREST}$ From figure 2 [or figure 1, and equation (1b)], 734 $\text{kV}_{CREST}$ corresponds to a 5.5 ft minimum air insulation distance. $D = (0.01 + 0.0006) \times 732 \div \sqrt{2} = 5.5$ ft
d) The minimum approach distance is 5.5 ft. + (1.0 ft. - for inadvertent movement) = 6.5 ft

## B.2 Determining the protective gap distance necessary to allow use of a new minimum approach distance

The steps are as follows:

1) Find the value of the minimum approach distance that is required by the task.
2) Subtract 1 ft from the value determined in step 1) to determine the minimum air insulation distance and its corresponding statistical withstand voltage from figure 2 (see 6.3 for inadvertent movement discussion).
3) From previous test data, select a protective gap distance that provides a (statistical) +2 σ sparkover voltage (110% of gap $U_{50}$) equal to or less than the (statistical) +3 σ withstand voltage determined in step 2).
4) Determine the statistical withstand voltage (85% of the $U_{50}$) for the protective gap to assess the acceptability of the risk of sparkover during the time the protective gap is installed.

Example calculation: Assume a 500 kV line subject to 2.4 p.u. transient overvoltage and operating at a 550 kV maximum operating voltage. Determine an acceptable protective gap distance to allow use of a 9.0 ft minimum approach distance.

a) Only 9.0 ft is available to climb by a conductor rather than the 11 ft, 3 in required.
b) The minimum air insulation distance is 9.0 ft - (1.0 ft for inadvertent movement) = 8.0 ft. From figure 2, the corresponding (statistical) -3 σ withstand voltage for 8.0 ft is 930 $kV_{CREST}$.
c) Do not use figure 2, use test data obtained from the particular protective gap tool geometry, bundle geometry, and varying gap distances to select a gap distance that has a (statistical) +2 σ sparkover voltage (110% of gap $U_{50}$) equal to or less than 930 $kV_{CREST}$. Therefore, the gap $U_{50}$ must be equal to or less than $U_{50}$ < (930 kV) ÷ (1.10) = 845 $kV_{CREST}$. For example, if tests on a particular protective gap with a 5.8 ft gap spacing had a $U_{50}$ equal to 820 $kV_{CREST}$, select this gap spacing.
d) The (statistical) -3 σ withstand voltage of the protective gap is: (820 kV) x (0.85) = 697 $kV_{CREST}$. The maximum operating crest voltage is (550 kV ÷: $\sqrt{3}$ ) x $\sqrt{2}$ = 449 $kV_{CREST.}$ Therefore, the maximum per unit transient overvoltage that could be allowed while the protective gap is installed is 697 kV ÷ 449 kV = 1.55 or 155%. If the risk of this occurrence is acceptable, then the protective gap tool and new minimum approach distance can be used.