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IEEE Guide for Maintenance Methods on Energized Power Lines

IEEE Power Engineering Society

Sponsored by the
Transmission and Distribution Committee

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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

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Introduction

(This introduction is not part of IEEE Std 516-2003, 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 kilovolts phase-to-phase, 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 became 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, and again in 1995, 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. The ESMOL Subcommittee has added sections from other ESMOL-sponsored standards in this edition to expand the scope of the standard to cover more of the industry's needs.

During the original development of the guide, it was not intended that it would be used as a 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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Contents

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, in-service inspection, 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 inspection, 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.

As 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 other applications that are not covered in full detail in this guide are as follows:

— Effect of damaged insulators (including nonceramic insulators)
— Fiber optic maintenance procedures
— Influence of the capacitance of a nonconductive object or worker in the air gap
— Application of transient overvoltage (TOV) and switching surge (SI) control devices (e.g., metal oxide varistor, lightning arrestors, preinsertion resistors)
— Further review of insulated tools with metal components
— Conductive clothing testing and care
— Insulator cleaning
— Hazard assessment of workers' clothes exposed to electric arcs

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.

2. References

This guide should be used in conjunction with the following publications. When the following specifications are superseded by an approved revision, the revision shall apply.

Accredited Standards Committee C2-2000, National Electrical Safety Code® (NESC®).[1]

ANSI/SIA A92.2-2001, Vehicle Mounted Elevating and Rotating Aerial Devices.[2]

ASTM D120-95 (Reaff 2002), Specification for Rubber Insulating Gloves.[3]

[1]The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).
[2]ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).
[3]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

ASTM D1048-99, Specification for Rubber Insulating Blankets.

ASTM D1049-98, Specification for Rubber Insulating Covers.

ASTM D1050-90 (Reaff 1999), Specification for Rubber Insulating Line Hose.

ASTM D1051-95 (Reaff 2000), Specification for Rubber Insulating Sleeves.

ASTM F478-92 (Reaff 1999), Specification for In-Service Care of Insulating Line Hose and Covers.

ASTM F479-95 (Reaff 2001), Specification for In-Service Care of Insulating Blankets.

ASTM F496-01, Specification for In-Service Care of Insulating Gloves and Sleeves.

ASTM F696-02, Specifications for Leather Protectors for Rubber Insulating Gloves and Mittens.

ASTM F711-00, Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used in Live Line Tools.

ASTM F712-88 (Reaff 2000), Test Methods of Testing Electrically Insulating Plastic Guard Equipment for Protection of Workers.

ASTM F855-00, Standard Specification for Temporary Protective Grounds Used On De-Energized Electric Power Lines.

ASTM F968-98, Specification for Electrically Insulating Plastic Guard Equipment for Protection of Workers.

ASTM F1236- 96 (Reaff 2001), Guide for Visual Inspection of Electrical Protective Rubber Products.

ASTM F1701-96 (Reaff 2001), Standard Specification for Unused Polypropylene Rope with Special Electrical Properties.

CSA C225-00, Vehicle-Mounted Aerial Devices.[4]

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

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

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

IEC 60060-1 (1989), High-Voltage Testing Techniques, Part 1: General Definitions and Test Requirements.

IEC 60060-2 (1994) High-Voltage Test Techniques, Part 2: Measuring Systems.

IEC 60625-1 (1998), High-voltage Switches, Part 1: High-Voltage Switches For Rated Voltages Above 1 Kilovolts and Less Than 52 Kilovolts.[6]

[4]CSA publications are available from the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Etobicoke, Ontario, Canada M9W 1R3 (http://www.csa.ca/).

[5]CFR publications are available from the Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082, USA (http://www.access.gpo.gov/).

[6]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

IEC 60625-2 (1988, A94, A98), High-voltage Switches, Part 2: High-Voltage Switches for Rated Voltages of 52 Kilovolts and Above.

IEC 60855-01 (1985), Insulating Foam-Filled Tubes and Solid Rods for Live Working.

IEC 60895-12 (1987), Conductive Clothing for Live Working at a Nominal Voltage Up to 800 Kilovolts AC.

IEC 60903-03 (1988), Specifications for Gloves and Mitts of Insulating Material for Live Working.

IEC 60984-02 (1990), Sleeves of Insulating Material for Live Working.

IEC 61057-06 (1991), Aerial devices with Insulating Boom used for Live Working.

IEC 61111-12 (1992), Matting of Insulating Material for Electrical Purposes.

IEC 61112-12 (1992), Blankets of Insulating Material for Electrical Purposes.

IEC 61229-07 (1993), Rigid Protective Covers for Live Working on AC Installations.

IEC 61235-09 (1993), Live Working-Insulating Hollow Tubes for Electrical Purposes.

IEC 61236-08 (1993), Saddles, Pole Clamps (Stick Clamps) and Accessories for Live Working.

IEEE Std 4™-1995 (Reaff 2001), IEEE Standard Techniques for High Voltage Testing.[7, 8]

IEEE Std 62™-1995, Part 1, IEEE Guide for Field Testing Power Apparatus Insulation.

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

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.

IEEE Std 935™-1995 (Reaff 2001), IEEE Guide on Terminology for Tools and Equipment to Be Used in Live Line Working.

IEEE Std 957™-1995, IEEE Guide for Cleaning Insulators.

IEEE Std 1048™-1995, IEEE Guide for Protective Grounding of Power Lines.

IEEE Std 1067™-1996, IEEE Guide For In-Service Use, Care, Maintenance, and Testing of Conductive Clothing for use on Voltages up to 765 kilovolts AC.

IEEE Std 1070™-1995, IEEE Guide for the Design and Testing of Transmission Modular Restoration Structure Components.

IEEE Std 1307™-1996, IEEE Draft Trial-Use Guide for Fall Protection for the Utility Industry.

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

[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 (http://standards.ieee.org/).

3. Definitions and abbreviations

3.1 Definitions

For the purposes of this guide, the following terms and definitions apply. Additional terminology can be found in IEEE Std 935-1995.[9] *The Authoritative Dictionary of IEEE Standards Terms,* Seventh Edition [B9], should be referenced for terms not defined in this clause.[10]

3.1.1 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 support workers in an elevated working position.

3.1.2 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.

3.1.3 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. It usually includes the use of insulating tools.

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

3.1.5 bucket: A device designed to be attached to the boom tip of a line truck, crane, or aerial device 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**.

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

3.1.7 clearance: *See:* **work permit**.

3.1.8 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 electrical resistance of the material comprising the tool or equipment.

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

3.1.10 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.**

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

3.1.12 cover-up equipment: Equipment designed to protect persons from brush contact to 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.

[9]Information on references can be found in Clause 2.

[10]The numbers in brackets correspond to those of the bibliography in Annex A.

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

3.1.14 de-energized: Disconnected from all sources of electrical supply by open switches, jumpers, taps, or other means.

NOTE—De-energized conductors or equipment could be electrically charged or energized through various means, such as induction from energized circuits, portable generators, lightning, etc.

3.1.15 disruptive discharge: The phenomena associated with the failure of insulation, under electric stress, that includes a collapse of voltage and the passage of current: the term applies to electrical breakdown in solid, liquid, and gaseous dielectrics and combinations of these.

3.1.16 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.**

3.1.17 equipotential: An identical state of electrical potential for two or more items.

3.1.18 gloving: A method of performing live work on energized electrical conductors and equipment whereby a worker or workers, wearing specially made and tested insulating gloves, with or without sleeves, work(s) directly on the energized electrical conductor or equipment.

3.1.19 ground: (1) earth ground system: A conducting connection, whether intentional or accidental, by which an electric current or equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth.

NOTE—It is used for establishing and maintaining the potential of the earth (or of the conducting body) or approximately that potential, on conductors connected to it, and for conducting body current to and from the earth (or conducting body).

(2) transmission path: (A) Direct conducting connection to the earth or body of water that is a part thereof. **(B)** Conducting connection to a structure that serves a function similar to that of an earth ground (that is not conductively connected to earth). **(3) hydroelectric power plants:** Connection to earth or a common conducting body that serves in place of the earth.

3.1.20 grounded: Connected to earth or to some extended conducting body that serves instead of the earth. *Syn:* **earthed.**

3.1.21 helicopter work: A technique of using a helicopter for performing live work on energized wires and equipment, whereby one or more line workers work(s) directly on an energized part after being raised and bonded to the energized wire or equipment.

3.1.22 hot: *See:* **energized**.

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

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

3.1.25 insulating tool or device: (A) 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. **(B)** A tool or device that has conductive parts separated by dielectric parts.

3.1.26 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**.

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

3.1.28 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.

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

3.1.30 line-work: Various operations performed by a person on electrical facilities, including groundwork, aerial work, and associated maintenance.

3.1.31 live: *See:* **energized**.

3.1.32 live work: Work on or near 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.**

3.1.33 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 minimum approach distance (MAD) calculation, the maximum operating peak phase-to-ground voltage is equal to 1 per unit (p.u.).

3.1.34 minimum air insulation distance (MAID): The shortest distance in air between an energized electrical apparatus and/or a line worker's body at different potential. With a floating electrode in the gap, it 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.

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

3.1.36 protective grounding equipment: *See:* **temporary protective grounding equipment.**

3.1.37 portable protective air gap (PPAG): A gap placed between live parts and ground to limit the maximum overvoltage that may otherwise occur.

3.1.38 power loss: A means used to determine dielectric strength of an object by measuring the power loss through the object. *Syn:* **watts loss, Doble Test.**

3.1.39 puncture: A disruptive discharge through the body of a solid dielectric.

3.1.40 qualified: Having been trained in and having demonstrated adequate knowledge of the installation, construction, or operation of lines and equipment and the hazards involved, including identification of, and exposure to, electric supply and communication lines and equipment in, or near, the workplace. An employee, who is undergoing on-the-job training and who, in the course of such training, has demonstrated an ability to perform duties safely at his or her level of training, and who is under the direct supervision of a qualified person, is considered to be a qualified person for the performance of those duties.

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

3.1.42 sparkover: A disruptive discharge between preset electrodes in either a gaseous or a liquid dielectric.

3.1.43 sparkover voltage: A voltage level at which a sparkover probably will occur under the stated conditions.

3.1.44 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%.

3.1.45 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%.

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

3.1.47 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.

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

3.1.49 suspension of reclosing: To make inoperative automatic reclosing equipment. *Syn:* **hold off, hold order, hold out, live-line permit, non-reclose.**

3.1.50 temporary protective grounding equipment: A system of ground clamps, ferrules, cluster bar, and covered cables designed and suitable for carrying maximum anticipated fault current and grounding conductive objects. (ASTM F855-00, IEC 61230, IEEE Std 1048-1995).

3.1.51 tool or equipment current: The total current delivered to the tool or equipment.

3.1.52 withstand voltage: A voltage level at which a sparkover probably will not occur under the stated conditions.

3.1.53 work permit: The authorization to perform work on a circuit, part of lockout-tagout procedure. *Syn:* **clearance, guarantee.**

3.2 Abbreviations

a	60 Hz switching surge saturation factor[11]
ac	alternating current, 60 Hz
C_1	for voltages above 50 kilovolts, 0.01 is used to obtain distances in feet, which can be converted to meters by multiplying the distance in feet by 0.3048. See 4.2.2.3 for more details.
C_2	is composed of an additional 6% for the effect of line working tools in the air gap plus additional 4% for intangibles The additional 6% variable may range from an additional 2% to 20% depending on the structure and the electrode configuration (see IEEE Committee Report [B13]). For calculation in this guide, a value of C_2 = 1.1 or 10% is used. See 4.2.2.3 for more details.
cm	centimeter

[11]See Table 4 and Figure 4.

D	MAID in meters[12]
dc	direct current
FRP	fiberglass reinforced plastic
I_w	amperes: only the current in phase from the "Watt Loss Testing"
m	meters
mA	milliampere
MAD	minimum approach distance
MAID	minimum air insulation distance
mm	millimeter
p.u.	per unit transient overvoltage or switching surge factor
peak	transient peak
σ	sigma
RF	radio frequency
T	maximum anticipated per-unit switching surge (transient overvoltage)
V_{50}	transient or temporary overvoltage level that produces a 50% probability of sparkover in kilovolts. *Syn:* **critical sparkover voltage**
V_{P-G}	For ac work: voltage (ac) phase to ground in kilovolts
V_{P-G}	For dc work: voltage (dc) pole to ground in kilovolts
V_{P-P}	voltage pole-to-pole (rms) in kilovolts
V_m	maximum operating voltage (rms) in kilovolts, phase-to-phase
V_{mP-G}	maximum operating voltage (rms) in kilovolts, phase-to-ground
V_{PEAK}	switching surge or transient overvoltage peak voltage in kilovolts
V_R	manufacture's rating in kilovolts
V_{RPEAK}	manufacture's rating in kilovolts, peak
V	voltage in volts
Ω	ohms
W	watts
μ	50% (critical) sparkover value
μA	microampere
$\mu + 2\sigma$	sparkover voltage
$\mu - 3\sigma$	withstand voltage

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.

[12]See Annex D for tables in feet.

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.

4.2.1.1 Air as insulation

The insulating characteristics of air are defined in terms of its dielectric strength, the capability of the air to withstand electric stresses. The dielectric strength of air is expressed in the unit of kilovolts per meter or an equivalent unit. The disruptive discharge voltage in air is influenced by the following:

a) Air density (temperature, pressure, altitude) (Table 1 gives altitude correction factors to be used with altitudes above 900 m)
b) Humidity
c) Airborne impurities
d) Dimensions, separation, and shape of electrodes
e) Time-dependent characteristics of the applied voltage

Table 1—Altitude correction factor

Altitude (meters)	Correction factor
0–900	1.00
901–1200	1.02
1201–1500	1.05
1501–1800	1.08
1801–2100	1.11
2101–2400	1.14
2401–2700	1.17
2701–3000	1.20
3001–3600	1.25
3600–4200	1.30
4200–4800	1.35
4801–5400	1.39

Table 1—Altitude correction factor *(continued)*

Altitude (meters)	Correction factor
5401–6000	1.44

NOTES

1—The correction factor applies only to the MAID and not the inadvertent movement factor.

a) For the MAID tables, multiply the distance D given in Table 3, Table 5 through Table 9, Table 11, and Table 12 by the correction factor for altitude at which the work is being performed.

b) For the MAD tables, multiply the distance D given in Table 18 through Table 24 minus the inadvertent factor from Table 17 by the correction factor for altitude at which the work is being performed and then add in the inadvertent factor from Table 17 again.

2—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer (76 cm of mercury at sea level), uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

3—If the actual altitude at the work location and current barometric pressure is not known, the altitude, corrected for the local current barometric pressure, can be determined by use of an aircraft type altimeter adjusted for a zero altitude at 76 cm of mercury at sea level.

4—For values in feet, see Table D.1.

4.2.1.2 Insulating materials used in live work

Insulating materials are generally defined in terms of their dielectric strength. The desirable property of the insulating materials is their ability to prevent the flow of current through them. Dielectric strength is the maximum electric field that the material can withstand without sparkover or insulation puncture. Factors, which affect the electrical performance of insulating materials, include the following:

a) Air density (temperature, pressure, altitude)
b) Humidity
c) Dimensions, separation, and shape of electrodes
d) Time-dependent characteristics of the applied voltage
e) Contamination
f) Impurities
g) Aging

4.2.1.3 Contamination

The equipment used for gloving, cover-up materials, and insulated sections of aerial devices and tools shall be kept free from contamination. Live work can be performed on dry contaminated insulators. Work on wet contaminated insulator should be avoided. Such conditions require special and controlled work practices.

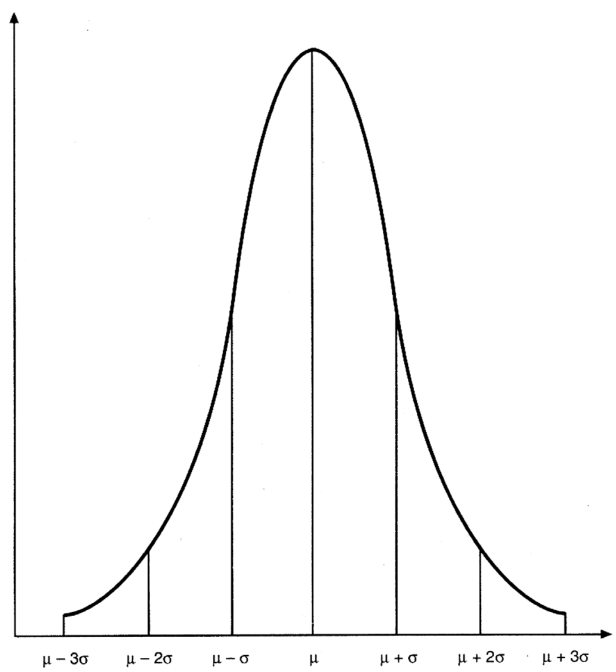
4.2.2 Minimum air insulation distance (MAID)

This guide describes the various method of determining the MAID for use in work involving live lines and equipment. For work on lines and equipment with a phase-to-phase voltage of 72 500 or less, see 4.2.2.2. The MAID distance can be obtained from Table 3. For work on 60 Hz lines and equipment with a phase-to-phase voltage above 72 500, see 4.2.2.3. The MAID distance can be obtained by calculation using Equation (1) and Equation (2) or from Table 5, Table 6, Table 7, Table 8, Table 11, and Table 12. For work on dc lines and equipment with a pole-to-ground voltage above 72 500, see 4.2.2.3. The MAID distance can be obtained from Table 9.

4.2.2.1 General

In 1962, an AIEE Transaction paper, “Safe clearance and protection against shocks during live-line work” [B3], was published. This paper summarized the results of various testing and data from established practices regarding the required minimum approach distances for safely performing live maintenance. The paper developed a formula for a minimum approach distance for line workers that was equal to the spacing of the “phase-to-tower” gap times a safety factor of 1.25, plus an inadvertent movement factor of 36 inches.

In 1968, an IEEE Committee Report on “Recommendations for safety in live-line maintenance” [B13] was published. This report summarized the results of various testing and data from 13 worldwide high-voltage laboratories that resulted in Figure 3 and established minimum approach distances for safely performing live maintenance. This distance did not include an inadvertent movement adder. This testing also provided data to develop a saturation curve to permit including this effect at voltages over 630 kV_{peak}. This plot is shown in Figure 4. With this data, the committee developed equations that relate withstand distance to system peak voltage. These equations will be discussed in detail in 4.2.2.3. The committee also suggested maximum transient overvoltage multipliers for various system voltage ranges. These values have subsequently been revised and appear in Table 2. In addition, statistical methods were introduced to illustrate the probability of withstand and a sparkover voltage. Figure 1 and Figure 2 resulted.

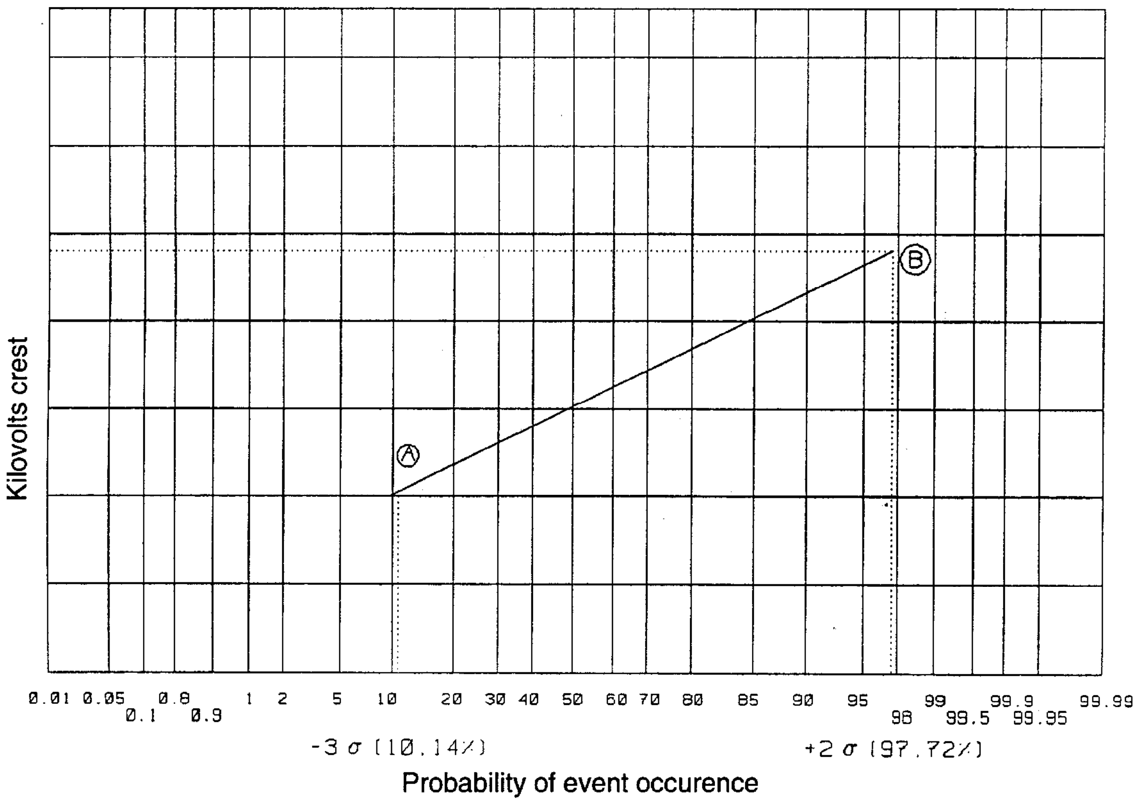


NOTE—This figure is a copy of a statistical textbook plot and is used as an example of a plot and does not show the actual test results.

Figure 1—Probability density function of an air gap

The voltage level required to sparkover a single air gap may vary as much as 30% over a series of tests. In order to statistically determine the probability of a sparkover at a certain voltage level, a plot similar to the one shown in Figure 1 is made.

Figure 1 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.



NOTE—This figure is a copy of a statistical textbook plot and is used as an example of a plot and does not show the actual test results.

Figure 2—Peak voltage in kilovolts versus probability of sparkover

From the data plotted in Figure 1, Figure 2 is developed using statistical methods. Point A is the withstand voltage (the $\mu - 3\sigma$ value), the 50% point is U_{50} (the μ value), and point B is the sparkover voltage (the $\mu + 2\sigma$ value).

In 1973, a second IEEE Committee Report on "Live-line maintenance methods" [B10] was published updating the data from the previous report and expanding information on live-line work methods. As a result of this work, a new graphic plot was published, Figure 4. They used the equation previously developed to generate a series of MAID tables, one for clear hot stick length and one for worker approach distance without any adder for inadvertent movement. The clear hot stick length later became the minimum approach distance with tools in the air gap. They also introduced the portable protective air gap (PPAG) concept.

Table 2—Per-unit maximum anticipated transient overvoltage factors (T) to be used when the value of (T) is not known

Voltage phase-to-phase	Transient overvoltage factor (p.u.)
72.5 kilovolts and below	3.0
72.501–362 kilovolts	3.5
500–550 kilovolts	3.0
700–800 kilovolts	2.5

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

2—These values of (T) were used in the calculation of Table 3, Table 5, Table 6, Table 18, Table 19, Table D.2, Table D.3, Table D.4, Table D.11, and Table D.12.

Table 3—Example of detailed calculations for air gap distance (MAID) phase to ground work 72 500 Volts or less in meters

1	2	3	4	5	6
Maximum phase-to-phase voltage in kilovolts (V_M)	**Overvoltage in p.u. (T)**	**Maximum phase-to-phase voltage on a p.u. base in kilovolts**	**Maximum peak voltage in kilovolts**	**Maximum peak voltage 3σ in kilovolts**	**Electrical withstand distance in meters**
0.30	3.0	0.52	0.73	0.87	0.001
0.75	3.0	1.30	1.84	2.17	0.002
15.0	3.0	26.0	36.7	43.2	0.038
36.0	3.0	62.4	88.2	104.0	0.160
46.0	3.0	79.7	113.0	133.0	0.228
72.5	3.0	126.0	178.0	209.0	0.383

NOTES

1—Column #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—Column #3 = $\frac{(\text{Column \#1})(\text{Column \#2})}{\sqrt{3}}$

3—Column #4 = $(\text{Column \#3})\sqrt{2}$ [Transient overvoltage]

4—Column #5 = $\frac{(\text{Column \#4})}{0.855}$ [Maximum transient overvoltage]

5—Column #6 [Minimum Air Insulation Distance (MAID)] = The basic electrical withstand (W/S) distance is determined by use of IEEE Std 4-1978, Annex 2B [B15], using linear interpolation between the two values that bracket the maximum overvoltage, plus 3σ peak, of Column 5. The feet values were converted to metric by multiplying the feet values by 0.3048 and rounding up. The centimeters/kilovolts for the 2 cm test has been used for the two lowest voltage ranges.

6—Values are based on altitudes below 900 m. See Table 1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

7—Table distances do not include any factor for inadvertent movement. See 7.2 for inadvertent movement considerations. These factors must be added to the values in Column #6 to obtain the total MAD.

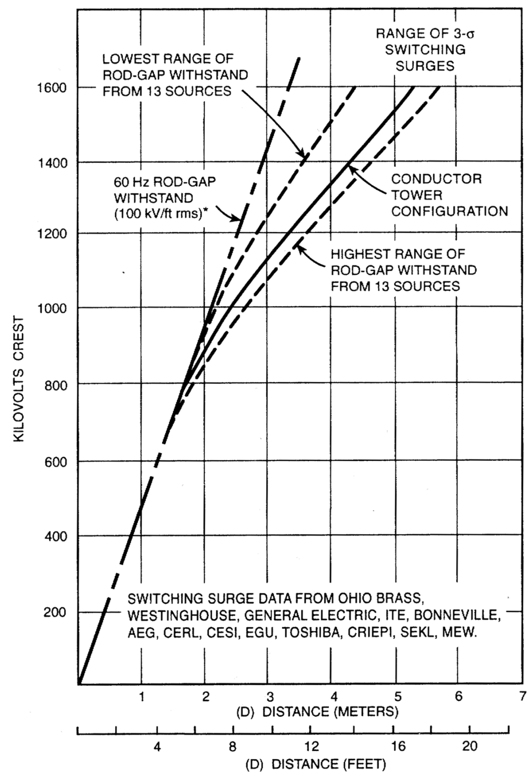
8—Higher or lower transient overvoltage factors can occur depending on the design and operation of the system.

9—For single-phase systems with a solidly grounded neutral, use voltage line-to-ground.

10—For single-phase systems without a solidly grounded neutral, use voltage phase-to-phase.

11—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

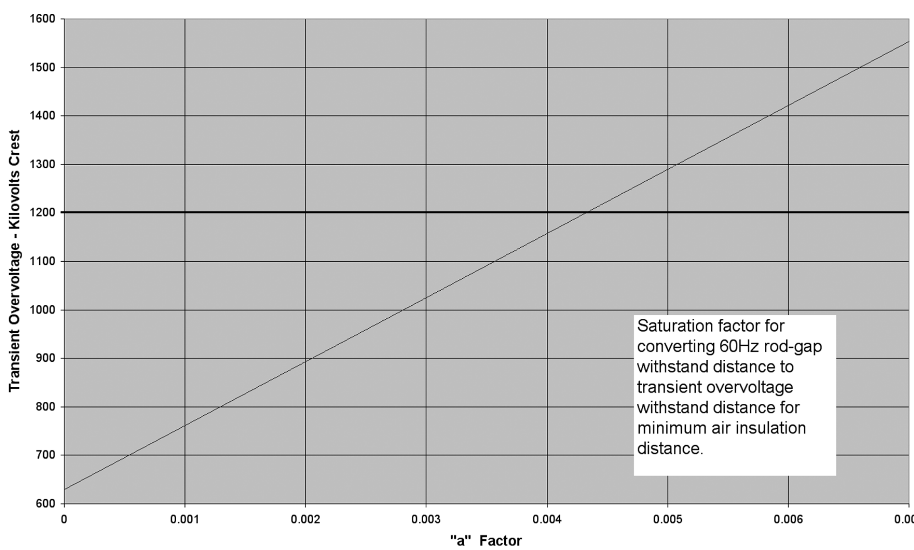
12—For values in feet, see Table D.2.



* This curve cannot be linear at high voltages due to the size and shape of the rod-gap electrodes.

NOTE—This figure is a graphical representation of an actual data plot. The accuracy of the figure may have been reduced due to printing.

Figure 3—Typical withstand voltage for switching surges



NOTE—This figure is a graphical representation of an actual data plot. The accuracy of the figure may have been reduced due to printing.

Figure 4—60 Hz Switching surge saturation factor

Table 5 through Table 9 summarize the MAID for a range of operating voltages and p.u. values. Users must determine the proper p.u. value for each line or facility in their systems. Table 2 provides recommended transient overvoltage p.u. values, when specific transient overvoltage at the work location or facilities are not available. The distances in these tables do not include any factor for inadvertent movement (ergonomic distance).

Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which have introduced into the U.S. market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

There are various methods to reduce transient overvoltage, such as blocking reclosing, use of arresters, or use of portable protective air gaps.

4.2.2.2 Calculation of minimum phase-to-ground 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 [B15].[13]

Gap spacing	V_{peak}
cm	kilovolts
2	25
3	36
4	46
5	53
6	60
8	70
10	79
12	86
14	95
16	104
18	112
20	120
25	143
30	167
35	192
40	218

NOTE—Portion of Table 2 B.1 from IEEE Std 4-1978 [B15].

Figure 5—60 Hz sparkover voltage of a 0.5 x 0.5 inch square rod gap

b) An example of the calculations is summarized in Table 3. The minimum approach distance (MAD) contain an inadvertent movement factor as listed in Table 17. The factor for inadvertent movement is discussed in 7.2.2. The phase-to-phase values are calculated using a multiplier to adjust the phase-to-ground MAID. This multiplier is discussed in 4.2.2.4.

[13]This table can be found in IEEE Std 4-1995 as Table 11.

Table 4—60 Hz saturation factors "a" used in the calculation of the tables in this guide

$V_{P–P}$ $V_{P–G}$	242 140	362 209	550 318	800 462
T	a	a	a	a
1.5	0.0	0.0	0.0004	0.0025
1.6	0.0	0.0	0.0007	0.0030
1.7	0.0	0.0	0.0010	0.0035
1.8	0.0	0.0	0.0013	0.0040
1.9	0.0	0.0	0.0016	0.0045
2.0	0.0	0.0	0.0020	0.0051
2.1	0.0	0.0	0.0023	0.0056
2.2	0.0	0.0002	0.0026	0.0061
2.3	0.0	0.0004	0.0029	0.0066
2.4	0.0	0.0006	0.0032	0.0072
2.5	0.0	0.0008	0.0036	0.0077
2.6	0.0	0.0010	0.0039	
2.7	0.0	0.0012	0.0043	
2.8	0.0	0.0015	0.0047	
2.9	0.0	0.0017	0.0050	
3.0	0.0	0.0019	0.0054	
3.1	0.0	0.0021		
3.2	0.0001	0.0023		
3.3	0.0002	0.0025		
3.4	0.0003	0.0027		

Table 4—60 Hz saturation factors "a" used in the calculation of the tables in this guide *(continued)*

V_{P-P} V_{P-G}	242 140	362 209	550 318	800 462
T	**a**	**a**	**a**	**a**
3.5	0.0005	0.0029		

NOTES

1—The values of "a" are valid for 60 Hz only and should be only used with C_1 and C_2 to calculate distances in feet. To obtain distances in meters, the distances in feet should be multiplied by 0.3048.

2—When the switching surge peak voltage (V_{PEAK}) is less than 630 kV, the values of "a" are shown as 0.0 and "a" is zero. The switching surge peak voltage is equal to the transient overvoltage and is calculated using $(V_{P-G})\sqrt{2}$ (T).

3—Column spaces left blank are not used in this guide.

4—The values of "a" were calculated from data obtained from reference material, from a plot similar to Figure 4. Due to possible errors resulting from redrawing and photographic reproduction of Figure 4, Figure 4 should not be used to obtain data from calculations.

a—For switching surge peak voltages between 630 and 1025 kV,

$$a = \frac{((V_{PEAK}) - 630)\text{rounded up to four decimal places}}{140\,000}$$

b—For switching surge peak voltages above 1025 kV,

$$a = \frac{((V_{PEAK}) - 683)\text{rounded up to four decimal places}}{124\,440}$$

4.2.2.3 Calculation of 60 Hz MAID, phase-to-ground, 72,501–800 000 Volts

4.2.2.3.1 Calculation of MAID, phase-to-ground, without tools in the air gap.

The general formula for determining the 60 Hz MAID, phase-to-ground, in meters for energized work above 72 500 volts, without tools in the air gap is shown in Equation (1)[14]:

$$D = 0.3048\ ((C_1 + a)(T)(V_{P-G})) \tag{1}$$

where

0.3048	is the conversion factor to convert from feet to meters,
D	is the phase-to-ground distance in meters,
C_1	is 0.01 (1.0% of the line-to-ground voltage in kilovolts) for 60 Hz,
a	is saturation factor for peak voltages of 630 kilovolts and above (see Table 4 and Figure 4) [$(T)(V_{P-G})$],
T	is maximum anticipated per-unit transient overvoltage (switching surge),
V_{P-G}	is the actual rms system phase-to-ground voltage in kilovolts.

[14]For D in feet, $D = ((C_1 + a)(T)(V_{P-G}))$.

4.2.2.3.2 Calculation of MAID, phase-to-ground, with tools in the air gap

The general formula for determining the 60 Hz MAID, phase-to-ground, in meters for energized work above 72 500 volts, with tools in the air gap is shown in Equation (2)[15]:

$$D = 0.3048\ (((C_1)(C_2) + a)(T)(V_{P-G})) \tag{2}$$

where

0.3048	is the conversion factor to convert from feet to meters,
D	is the phase-to-ground distance in meters,
C_1	is 0.01 (1.0% of the line-to-ground voltage in kilovolts) for 60 Hz,
C_2	is composed of an additional 6% for the effect of line working tools in the air gap plus additional 4% for intangibles. The additional 6% variable may range from an additional 2% to 20% depending on the structure and the electrode configuration (see [B13]). For calculation in this guide, a value of C_2 =1.1 is used.
a	is saturation factor for peak voltages of 630 kilovolts and above (see Table 4 and Figure 4) $[(T)(V_{P-G})]$,
T	is maximum anticipated per-unit transient overvoltage (switching surge),
V_{P-G}	is the actual rms system phase-to-ground voltage in kilovolts.

4.2.2.3.3 Note for using Equation (1) and Equation (2)

a) Equation (1) and Equation (2) and the values of C_1 and C_2 were obtained from published and peer-reviewed papers [B10], [B13] and have been used in previous editions of this guide. The equations were used to calculate the tables using the rounded-up methods to obtain the required number of decimal places.

b) If there is a discrepancy between the distance calculated by using Equation (1) and Equation (2) and the distances listed in the tables, the distance calculated by using Equation (1) and Equation (2) should have preference over the distances listed in the tables.

c) The saturation factor "*a*" is derived from the transient overvoltage sparkover data. See Table 4 and Figure 4 for typical values.

d) The saturation factor "a" is zero when V_{Peak} is less than 630 kV.

$$V_{PEAK} = \frac{(V_{P-P})(\sqrt{2})}{\sqrt{3}}$$

e) The transient overvoltage factor T, used in Equation (1) and Equation (2), should be correlated with characteristics of each individual application. Transient overvoltages are important in determining alternating current air insulation distances. The maximum transient overvoltage is 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. The maximum p.u. values shown in Table 2 shall be used if the maximum transient overvoltage is not known.

f) The polarity of the transient overvoltage applied to the electrodes influences sparkover. For the usual application of rigid insulating tools, the positive polarity results in the lowest sparkover of the electrodes. It has been shown that the withstand curve for the conductor-tower electrode

[15]For D in feet, $D = (((C_1)C_2 + a)(T)(V_{P-G}))$.

configuration lies approximately midway between withstand curves for the rod-rod and rod-plane gaps for positive polarity transient voltages in Figure 3.

g) 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.

h) The air insulation distance determined by means of the formulas should be used only at elevations below 900 m.[16] Higher elevations require applicable correction factors, as indicated in Table 1.

i) In determining dc pole air insulation distances, equivalents to ac line-to-ground peak voltages are used.

j) The minimum air insulation distance, as given in the tables, 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 7.2 for inadvertent movement distance.)

Table 5—Example of detailed calculations for MAID 60 Hz. Energized work, without tools in the air gap, when the transient overvoltage factors (T) is not known in meters

Voltage in kilovolts phase to phase	Distance in meters	
	Phase to ground	Phase to phase
72.6–121	0.75	1.09
138–145	0.90	1.31
161–169	1.05	1.52
230–242	1.57	2.28
345–362	2.88	4.18
500–550	4.48	6.90
765–800	6.24	10.22

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—Values are based on altitudes below 900 m. See Table 1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

3—Table distances do not include a factor for inadvertent movement. See 7.2 for inadvertent movement considerations. These factors must be added to the values to obtain the total MAD.

4—The clear live tool length should be equal to or exceed these values for the indicated voltage ranges.

5—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

6—Data for this table was obtained from Table 7 and Table 11.

7—For values in feet, see Table D.3.

[16]900 m = 3000 feet.

Table 6—Example of detailed calculations for MAID 60 Hz. Energized work, with tools in the air gap, when the transient overvoltage factors (T) is not known in meters

Voltage in kilovolts phase to phase	Distance in meters	
	Phase to ground	Phase to phase
72.6–121	0.83	1.20
138–145	0.99	1.43
161–169	1.15	1.67
230–242	1.72	2.50
345–362	3.10	4.50
500–550	4.77	7.34
765–800	6.59	10.80

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—Values are based on altitudes below 900 m. See Table 1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

3—Table distances do not include a factor for inadvertent movement. See 7.2 for inadvertent movement considerations. These factors must be added to the values to obtain the total MAD.

4—The clear live tool length should be equal to or exceed these values for the indicated voltage ranges.

5—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

6—Data for this table was obtained from Table 8 and Table 12.

7—For values in feet, see Table D.4.

Table 7—MAID phase to ground, 60Hz. energized work, using the transient overvoltage factor, without tools in the air gap in meters

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	m	m	m	m	m	m	m
1.5	0.33	0.39	0.45	0.65	0.96	1.52	2.65
1.6	0.35	0.41	0.48	0.69	1.03	1.66	2.93
1.7	0.37	0.44	0.51	0.73	1.09	1.82	3.24
1.8	0.39	0.476	0.54	0.77	1.15	1.97	3.55
1.9	0.41	0.49	0.57	0.82	1.22	2.14	3.89
2.0	0.43	0.52	0.60	0.86	1.28	2.33	4.26
2.1	0.45	0.54	0.63	0.90	1.34	2.51	4.62
2.2	0.47	0.57	0.66	0.94	1.44	2.69	4.99
2.3	0.50	0.59	0.69	0.99	1.53	2.88	5.38
2.4	0.52	0.62	0.72	1.03	1.63	3.07	5.82
2.5	0.54	0.65	0.75	1.07	1.73	3.30	6.24
2.6	0.56	0.67	0.78	1.11	1.83	3.50	
2.7	0.58	0.70	0.81	1.16	1.93	3.74	
2.8	0.60	0.72	0.84	1.20	2.06	3.99	
2.9	0.62	0.75	0.87	1.24	2.17	4.22	
3.0	0.65	0.77	0.90	1.29	2.28	4.48	
3.1	0.67	0.80	0.93	1.33	2.40		
3.2	0.69	0.82	0.96	1.38	2.51		
3.3	0.71	0.85	0.99	1.44	2.64		
3.4	0.73	0.87	1.02	1.50	2.76		

Table 7—MAID phase to ground, 60Hz. energized work, using the transient overvoltage factor, without tools in the air gap in meters *(continued)*

$V_{P–P}$ $V_{P–G}$	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	**m**	**m**	**m**	**m**	**m**	**m**	**m**
3.5	0.75	0.90	1.05	1.57	2.88		

NOTES

1—Distances listed are for standard atmospheric conditions. The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

2—Values are based on altitudes below 900 m. See Table 1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

3—Distances do not include any factor for inadvertent movement (see 7.2).

4—The metric values were calculated from data in Table D.5 using the conversion factor of 0.3048 m per foot and rounded up to 2 decimal places.

5—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

6—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example T = 2.51; use T = 2.6.

7—For values in feet, see Table D.5.

Table 8—MAID phase to ground, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in meters

$V_{P–P}$ $V_{P–G}$	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	**m**	**m**	**m**	**m**	**m**	**m**	**m**
1.5	0.36	0.43	0.50	0.71	1.06	1.66	2.86
1.6	0.38	0.46	0.53	0.75	1.13	1.82	3.16
1.7	0.40	0.48	0.56	0.80	1.20	1.98	3.48
1.8	0.43	0.51	0.60	0.85	1.27	2.15	3.81
1.9	0.45	0.54	0.63	0.90	1.34	2.32	4.15
2.0	0.47	0.57	0.66	0.94	1.41	2.52	4.54
2.1	0.50	0.60	0.69	0.99	1.48	2.71	4.92
2.2	0.52	0.62	0.73	1.04	1.58	2.90	5.30

Table 8—MAID phase to ground, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in meters *(continued)*

V_{P-P} V_{P-G}	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**m**	**m**	**m**	**m**	**m**	**m**	**m**
2.3	0.55	0.65	0.76	1.08	1.68	3.10	5.70
2.4	0.57	0.68	0.79	1.13	1.78	3.31	6.16
2.5	0.59	0.71	0.82	1.18	1.89	3.54	6.59
2.6	0.61	0.74	0.86	1.22	2.00	3.76	
2.7	0.64	0.76	0.89	1.27	2.11	4.00	
2.8	0.66	0.79	0.92	1.32	2.24	4.26	
2.9	0.68	0.82	0.96	1.36	2.35	4.50	
3.0	0.71	0.85	0.99	1.41	2.47	4.77	
3.1	0.73	0.88	1.02	1.46	2.59		
3.2	0.75	0.90	1.05	1.52	2.72		
3.3	0.78	0.93	1.09	1.58	2.85		
3.4	0.80	0.96	1.12	1.64	2.97		
3.5	0.83	0.99	1.15	1.72	3.10		

NOTES

1—Distances listed are for standard atmospheric conditions. The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

2—Values are based on altitudes below 900 m. See Table 1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

3—Distances do not include any factor for inadvertent movement (see 7.2).

4—The metric values were calculated from data in Table D.6 using the conversion factor of 0.3048 m per foot and rounded up to 2 decimal places.

5—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

6—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example T = 2.51; use T = 2.6.

7—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

8—For values in feet, see Table D.6.

Table 9—MAID pole-to-ground, DC energized work, using the transient overvoltage factor, in meters

$V_{P\text{–}G}$	250 kilovolts		400 kilovolts		500 kilovolts		600 kilovolts		750 kilovolts	
T	**a**	**m**	**a**	**m**	**a**	**m**	**a**	**m**	**a**	**m**
1.5 or below	0.0	0.81	0.0	1.29	0.8	1.75	1.9	2.31	3.6	3.30
1.6	0.0	0.86	0.0	1.38	1.2	1.93	2.3	2.55	4.2	3.67
1.7	0.0	0.92	0.3	1.51	1.5	2.11	2.8	2.81	4.8	4.07
1.8	0.0	0.97	0.6	1.65	1.9	2.31	3.3	3.08	5.4	4.48

NOTES

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

2—Distances listed are for standard atmospheric conditions. The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

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 7.2).

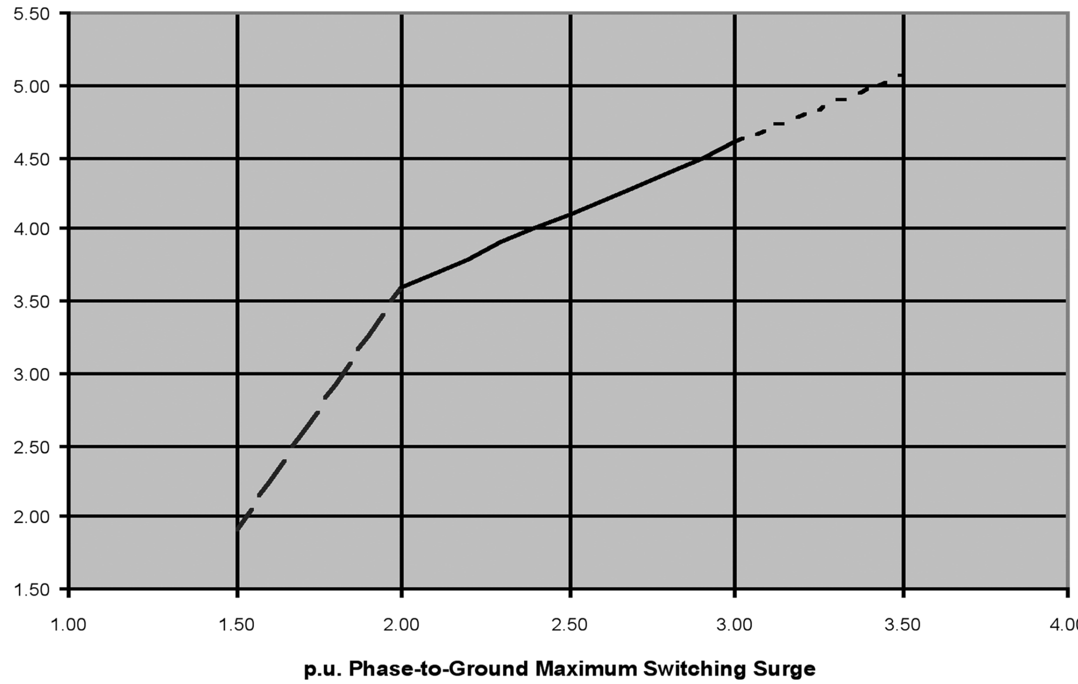
5—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example T = 1.61; use T = 1.7.

6—The metric values were calculated from data in Table D.7 using the conversion factor of 0.3048 m per foot and rounded up to 2 decimal places.

7—For values feet, see Table D.7.

4.2.2.4 Calculation of MAID phase-to-phase.

Determining the minimum air distance, phase-to-phase, 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 on the p.u. of the system phase-to-ground peak, appears in the EPRI Transmission Line Reference Book [B5] (Section 5, Figure 5.2) and CIGRE SC 33.07.02 [B2].



NOTE—From EPRI Transmission Line Reference Book (Blue Book) [B5], Section 5, Figure 5.2. This figure was redrawn from the figure in the published document. Printing size changes may have reduced the accuracy of the data. The data obtained from this figure should be used with caution.

Figure 6—Approximate relationship of phase-to-phase and phase-to-ground switching surges

Using data from EPRI Transmission Line Reference Book [B5] Section 5, Figure 5.2, Table 10 was developed.

Table 10—Factor used to convert MAID distances from phase-to-ground to phase-to-phase

$p.u._{P-G}$	$p.u._{P-P}$	$p.u._{P-P}/p.u._{P-G}$
1.50	1.91	1.28
1.60	2.25	1.41
1.70	2.59	1.53
1.80	2.93	1.63
1.90	3.26	1.73
2.00	3.60	1.80
2.10	3.70	1.77

Table 10—Factor used to convert MAID distances from phase-to-ground to phase-to-phase *(continued)*

$p.u._{P-G}$	$p.u._{P-P}$	$p.u._{P-P}/p.u._{P-G}$
2.20	3.80	1.73
2.30	3.90	1.70
2.40	4.00	1.67
2.50	4.10	1.64
2.60	4.20	1.62
2.70	4.30	1.60
2.80	4.40	1.58
2.90	4.50	1.56
3.00	4.60	1.54
3.10	4.70	1.52
3.20	4.79	1.50
3.30	4.89	1.49
3.40	4.98	1.47
3.50	5.07	1.45

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

Example:

If p.u. = 3.0 p.u. at 209.01 kilovolts

From Table 10, 3.0 $p.u._{p-g}$ = 4.6 $p.u._{p-p}$

From Table 7, 362 kilovolts at 3 p.u., electrical distance = 2.28 m

Electrical distances phase-to-phase = (2.28 m)(4.6)/(3.0) or (2.28 m)(1.54) = 3.50 m

For the air insulation phase-to-phase distances for ac-energized work, where the maximum transient overvoltage is known, see Table 11 and Table 12. For the air insulation phase-to-phase distances for ac-energized work, where the maximum transient overvoltage is not known, see Table 5 and Table 6.

Table 11—MAID phase to phase, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in meters

V_{P-P} V_{P-G}	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**m**	**m**	**m**	**m**	**m**	**m**	**m**
1.5	0.42	0.50	0.58	0.82	1.23	1.94	3.39
1.6	0.49	0.58	0.68	0.97	1.45	2.35	4.14
1.7	0.56	0.67	0.78	1.12	1.67	2.78	4.95
1.8	0.63	0.76	0.88	1.26	1.88	3.21	5.79
1.9	0.71	0.84	0.99	1.41	2.11	3.70	6.72
2.0	0.77	0.93	1.08	1.54	2.31	4.19	7.66
2.1	0.80	0.96	1.11	1.59	2.38	4.44	8.17
2.2	0.82	0.98	1.14	1.63	2.49	4.65	8.64
2.3	0.84	1.01	1.17	1.68	2.60	4.89	9.15
2.4	0.86	1.03	1.20	1.72	2.71	5.13	9.71
2.5	0.88	1.06	1.23	1.75	2.83	5.41	10.22
2.6	0.90	1.08	1.26	1.80	2.96	5.67	
2.7	0.93	1.11	1.29	1.85	3.09	5.99	
2.8	0.95	1.14	1.32	1.89	3.25	6.31	
2.9	0.97	1.16	1.35	1.94	3.38	6.58	
3.0	0.99	1.19	1.38	1.98	3.51	6.90	
3.1	1.01	1.21	1.41	2.02	3.64		
3.2	1.03	1.23	1.44	2.07	3.77		
3.3	1.06	1.26	1.47	2.14	3.92		
3.4	1.07	1.28	1.50	2.20	4.05		

Table 11—MAID phase to phase, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in meters *(continued)*

V_{P-P} V_{P-G}	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**m**	**m**	**m**	**m**	**m**	**m**	**m**
3.5	1.09	1.31	1.52	2.28	4.18		

NOTES

1—Distances listed are for standard atmospheric conditions. The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

2—Distances are based on altitudes below 900 m (see Table 1).

3—The metric values were calculated from data in Table D.8 using the conversion factor of 0.3048 m per foot and rounded up to two decimal places.

4—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

5—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

6—For values in feet, see Table D.8.

Table 12—MAID phase to phase, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in meters

V_{P-P} V_{P-G}	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**m**	**m**	**m**	**m**	**m**	**m**	**m**
1.5	0.46	0.55	0.64	0.91	1.35	2.13	3.66
1.6	0.54	0.64	0.75	1.06	1.59	2.56	4.46
1.7	0.62	0.74	0.86	1.23	1.83	3.03	5.32
1.8	0.70	0.83	0.97	1.38	2.06	3.50	6.21
1.9	0.78	0.93	1.08	1.55	2.31	4.02	7.18
2.0	0.85	1.02	1.18	1.70	2.53	4.54	8.17
2.1	0.88	1.05	1.23	1.75	2.61	4.79	8.70
2.2	0.90	1.08	1.26	1.79	2.73	5.02	9.17
2.3	0.92	1.11	1.29	1.84	2.85	5.27	9.69

Table 12—MAID phase to phase, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in meters *(continued)*

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	**m**	**m**	**m**	**m**	**m**	**m**	**m**
2.4	0.95	1.14	1.32	1.89	2.97	5.52	10.28
2.5	0.97	1.16	1.35	1.93	3.09	5.81	10.80
2.6	0.99	1.19	1.39	1.98	3.23	6.09	
2.7	1.02	1.22	1.42	2.03	3.37	6.41	
2.8	1.05	1.25	1.46	2.08	3.53	6.73	
2.9	1.07	1.28	1.49	2.13	3.67	7.02	
3.0	1.09	1.31	1.52	2.18	3.80	7.34	
3.1	1.11	1.33	1.55	2.22	3.94		
3.2	1.13	1.36	1.58	2.28	4.07		
3.3	1.16	1.39	1.62	2.36	4.24		
3.4	1.18	1.41	1.64	2.41	4.37		
3.5	1.20	1.43	1.67	2.50	4.50		

NOTES

1—Distances listed are for standard atmospheric conditions. The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

2—Distances are based on altitudes below 900 m (see Table 1).

3—The metric values were calculated from data in Table D.9 using the conversion factor of 0.3048 m per foot and rounded up to two decimal places.

4—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

5—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

6—For values in feet, see Table D.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.

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 device working on an energized conductor are all within an electric field of much different strength.

One of the most common manifestations of an electric field on a person is an electric "shock." Such a shock may be as a transient, or steady state, or both. A nonbonded worker assumes a potential other than that of adjacent objects, and the worker can receive a small perceptible transient shock and a perceptible steady-state "shock." Transient shocks occur as contact is made or broken with an object at a potential different from the worker. A short duration transfer of energy characterizes the shock. The steady-state "shock" perception level is 0.6 to 1.1 mA. The let-go level is considered in the range of 10 to 15 mA (see Kouwenhoven et al. [B20]). These values are valid for ac transmission. Both types of shocks can be mitigated by either bonding the worker to adjacent objects or 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 Bridges [B1], Elek and Simpson [B3], EPRI Project RP-38 1-1 [B4], IEEE Committee Report [B10], IEEE/PES Special Publication No. 10 [B14], IEEE WG Report [B18], Kouwenhoven and Langworthy [B19], Kouwenhoven et al. [B20], Kouwenhoven et al. [B21], Krivova et al. [B22], Singewald et al. [B24]). 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.

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 using barehand methods on energized lines 230 kilovolts and higher, full shielding may be necessary. Full shielding may not be necessary at lower voltages or when using other work methods at higher voltages. 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.

4.2.3.1.3 Forms of shielding from electric fields

a) *Conductive clothing.* Conductive clothing, including footwear, socks, gloves, and a suit, is a very effective form of shielding and is widely accepted, particularly in barehand work [IEEE Std 935-1995 and IEC 60895-12 (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 kilovolts 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 A92.2-2001.

c) *Metallic structures*.

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 13. The types of shielding employed in the comparisons in Table 13 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 the suit having to carry line or fault current.

Table 13—Worker exposure and body current

Position of worker	Type of shielding	Body current	
		at 138 kilovolts	at 345 kilovolts
On tower (see NOTE)	None	125 µA	395 µA
In bucket	A	70 µA	130 µA
In bucket	B	155 µA	300 µA
In bucket	C	320 µA	Not measured
In bucket	D	375 µA	Not Measured
In bucket	Suit	Not measured	50 µA

NOTE—Worker on tower approximately 240 cm (8 feet) from conductor at 138 kilovolts and 320 cm (10.5 feet) from the conductor at 345 kilovolts.

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 stresses are 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 that 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 or meter) of the tool or equipment. Examples are suspended or supported 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 personal 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. Surface contamination may significantly increase the leakage current when wet.

The conduction current is normally negligible. For clean, dry tools and equipment, the leakage current is small and the capacitive current predominates.

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 in series, 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 kilovolts peak, the dielectric strength of an air gap with typical electrode shapes is not constant but increases at a lesser rate as the gap length increases. As a result, the curve of withstand versus gap length exhibits saturation for withstand values vs. gap length (see Figure 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 D1048-99, ASTM D1049-98, IEC 61111-12 (1992), and IEC 61112-12 (1992).

4.2.5.2 Portable protective air gaps (PPAG)

A portable protective air gap (PPAG) can be employed to provide worker protection by establishing a controlled sparkover path that is coordinated with the sparkover 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. Figure 7 shows a typical PPAG being installed.

NOTE—If the PPAGs 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. Workers on the ground near the structure supporting the PPAG must be protected from any step and touch voltages should the PPAG operate by sparking over. See 7.4.

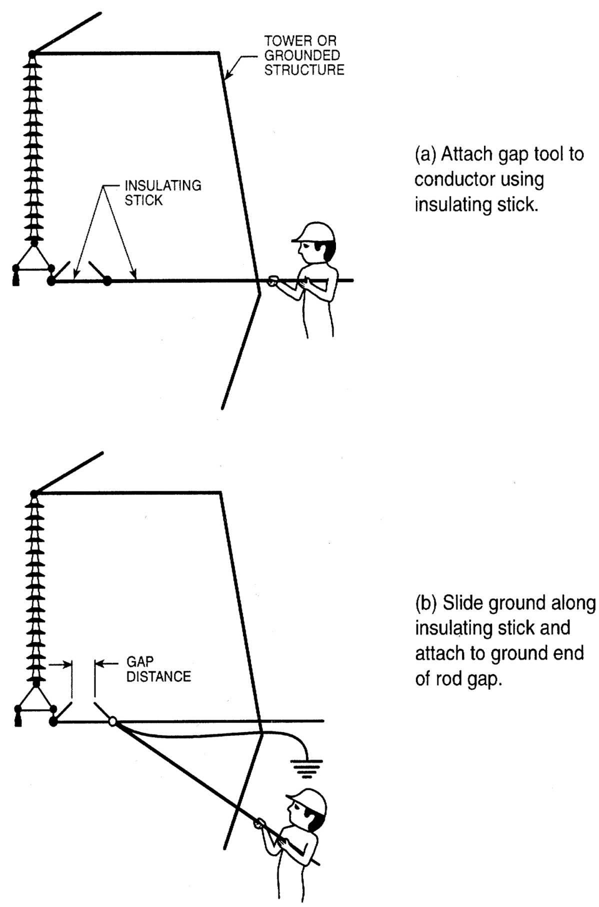


Figure 7—Installation of PPAG

When gaps are installed at the terminals (line ends), their ability to control the transient overvoltage level at the remote work area should also be considered in determining the required protection.

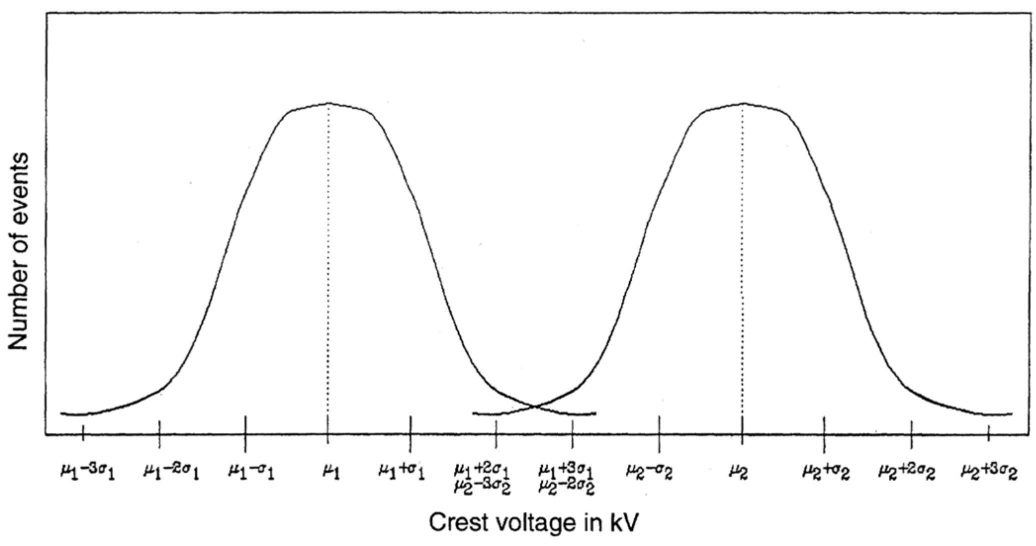
The key to the use of PPAGs is in establishing the statistical withstand and sparkover voltage of the PPAG. The withstand and sparkover characteristics of a PPAG are determined by sparkover probability data for the particular protective gap geometry, gap distance, and conductor bundle geometry.

The 50% sparkover voltage (V_{50}) and the statistical withstand and sparkover voltage of the PPAG are determined from the test data in IEEE WG Report [B17] and Hutzler [B7].

Figure 1 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 2 on probability graph paper. Point A is the withstand voltage, the 50% point is the V_{50}, and point B is the sparkover voltage.

The setting of the withstand voltage of the PPAG is dependent on 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 PPAG and, therefore, a line outage. Each user should investigate the probability of the PPAG 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.

Whatever protective gap withstand voltage is selected by the user, the PPAG must sparkover below the sparkover voltage corresponding to the minimum approach distance in the work area. In order to ensure this, the -3σ withstand voltage for the minimum air insulation distance must always be equal to or greater than the $+2\sigma$ sparkover voltage of the protective gap (see Figure 8). Another way to say this is that the V_{50} of the minimum air distance at the work site shall be 5% higher than the V_{50} of the protective gap (see Figure 9). It is recommended that, for EHV lines or lower, a conservative or safe standard deviation of 5% be used to determine the -3σ (i.e., 85% of V_{50}) and the minimum air approach distance at the work site (i.e., 110% of the V_{50}) of the gap, to establish the minimum air insulation approach distance.

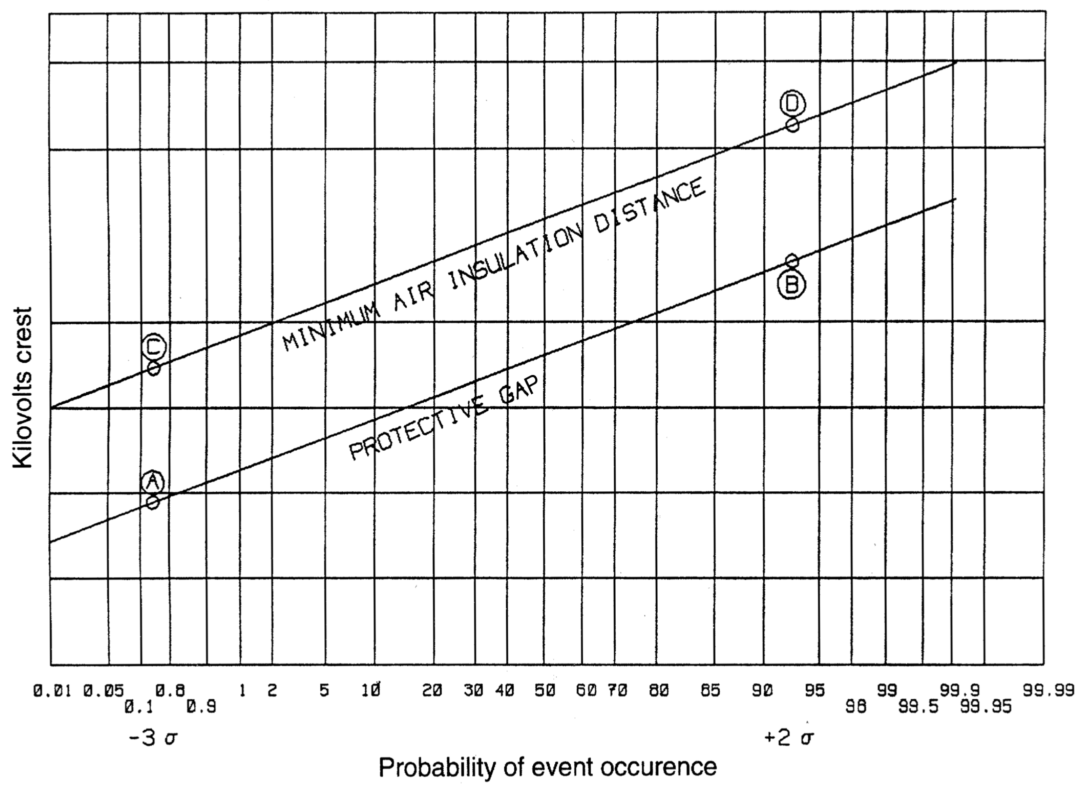


NOTE—This figure is a copy of a statistical textbook plot and is used as an example of a plot and does not show the actual test results.

Figure 8—Coordinated probability density functions of two air gaps

Figure 9 shows a plot of the PPAG with point A, the –3σ withstand voltage, and point B, the +2σ sparkover voltage and the minimum air insulation distance without the PPAG, with point C, the –3σ withstand voltage, and point D, the +2σ sparkover voltage. Note that the two curves are displaced by a factor of 1.28 (i.e., 1.1/0.85 times the protective gap peak 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 C.



NOTE—This figure is a copy of a statistical textbook plot and is used as an example of a plot and does not show the actual test results.

Figure 9—Peak voltage in kilovolts versus probability of sparkover

4.3 Electrical tests

4.3.1 Introduction

Table 14, Table 15, and Table 16 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 tests 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 withstand test should be made with 60 Hz ac. Testing with dc is at this time left to the discretion of the user.

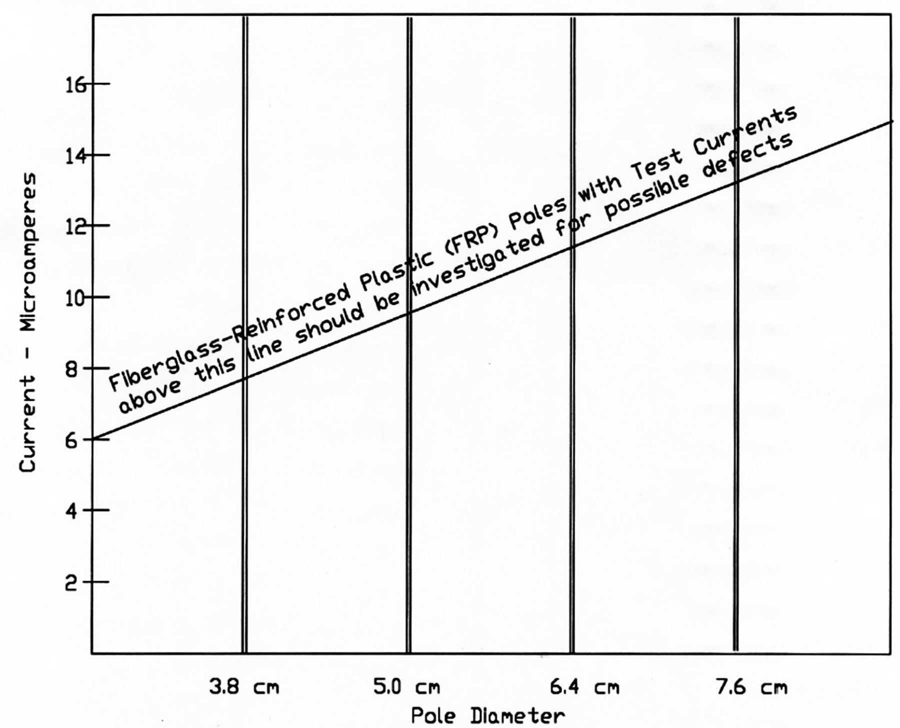
4.3.2 Tool or equipment current

The preferred criterion is the measurement of tool or equipment current because 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 6 to 15 microamperes depending on the tool diameter at an applied voltage of 100 kilovolts across 0.3 m (Figure 10).[17] Current values exceeding these values may indicate deterioration of insulating qualities. 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.



NOTE—This figure is a graphical representation of an actual data plot, and the plot should not be used to obtain data for calculation

Figure 10—Typical accept/reject values of equipment current for fiberglass-reinforced-plastic (FRP) pole of various diameters using 60 Hz, 100 kilovolts per 0.3048 m, with the voltage applied between two electrodes in contact with the surface of the pole

[17]1 foot.

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 kilovolts systems, the maximum operating voltage is 362 kilovolts 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.

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 F696-02
- ASTM F712-88
- ASTM F1236-96
- IEC 60060 (1989)
- IEC 60855-01 (1985)
- IEC 60903-03 (1988)
- IEC 60984-02 (1990)
- IEC 61057-06 (1991)
- IEC 61229-07 (1993)
- IEC 61235-09 (1993)
- IEC 61236-08 (1993)
- IEEE Std 1067-1996
- ANSI/SIA A92.2-2001

NOTE—The previously listed documents 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 61472 [B8], still under review, does not provide a value for the ratio of impulse-to-power frequency (peak) withstand voltage, but it 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.

4.4 Job site procedures

4.4.1 Field care, handling, and storage

When not in use, insulating tools should be stored where they will remain dry and clean and are not subjected to abuse. Wood insulating tools should be stored in a temperature-controlled room and adequately supported, or hung vertically to prevent warping. Insulating tools used for energized line maintenance should not be laid on the ground because of possible contamination or wetting. They should be placed on clean, dry tarpaulins, on moisture-proof blankets, in tool racks, or leaned against dry supports. 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 so constructed that the tools are held firmly in place to prevent abrasive or bumping action against any surface that would damage the glossy surface of the tools.

4.4.2 Periodic inspection and checking

Insulating tools should be visually inspected before use for indications that they may have been mechanically or electrically overstressed (see 4.5.1.1). Tools that show evidence of overstress (such as damaged, bent, worn, or cracked components) should be removed from service and evaluated for repair. Elongated or deformed rivet ends, for instance, indicate that excessive mechanical loading has occurred and has weakened or sheared the bond between the ferrules and the insulating pole.

The surface of each tool must be inspected before and after each use for contamination such as dirt, creosote, grease, or any other foreign material. If any of the above contaminants exist, the tool surface should be cleaned.

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

When tools have been exposed to excess moisture, their moisture content can be measured with a moisture meter, which is commercially available (see 4.4.5), or their general condition determined on the basis of ac power-loss measurements (see 4.5.9.3).

4.4.3 Cleaning

Before each use, insulating tools should be wiped with a clean, absorbent paper towel or a clean, absorbent cloth. This may be followed by wiping with a silicone-treated cloth.

If simple wiping does not remove the contaminant, then apply a solvent or cleaner used as recommended by the manufacturers of the insulating tool with a paper towel or clean, absorbent cloth and may be followed by wiping with a silicone-treated cloth.

CAUTION

Do not use soap detergents in liquid or powdered form to clean fiberglass tools under field conditions because of the following possible problems:

1—The above-described cleaning agents will leave a conductive residue unless rinsed with generous amount of water.

2—Abrasive cleaners will destroy the surface gloss on the stick.

All fiberglass tools that are subjected to such cleaning agents should be electrically tested under wet conditions to ensure complete removal of residue from soap-type cleaners (see 4.5.3)

4.4.4 Portable live tool tester

These portable units provide a means for conveniently field testing live-line tools without auxiliary equipment except for a power supply. It is very important to note that some portable units are designed to test the entire live-line tool cross-sectional areas for conductivity. To be certain of the tester's capability, the user should check the applicable literature or contact the equipment manufacturer.

NOTE—Reliance on electrical testing should be the prerogative of the user who is responsible for maintaining equipment calibration, application, and interpretation.

4.4.5 Use of moisture or dielectric property determination meters

Moisture meters are portable devices that can be used for job site inspection of live-line tools for indications of excessive moisture or tracking. One model employs the radio-frequency, power-loss circuit at 10 MHz.

By way of roller electrodes, this meter projects an RF field into the sample and measures the power loss as affected by moisture. The meter scale can be set arbitrarily at either of two levels of intensity.

Another dielectric meter employs a measurement of the real part of a radio-frequency field transmitted through part of the cross section of the tool. The real part of the transmitted field is related to conductive faults caused by moisture, carbon tracking, or conductive elements in the sample. The response of this meter is adjustable according to the sample diameter and wall thickness. An internal standard is used to set the instrument response to the prescribed level for each tool configuration to be measured.

When using either meter, measurements should be made at several points along the circumference of the insulated tool even for small diameter tools.

NOTE—Reliance on moisture and dielectric property determination meter readings should be the prerogative of the user who is responsible for maintaining equipment calibration, application, and interpretation.

4.5 Shop or laboratory procedures

4.5.1 Periodic inspection and testing

4.5.1.1 When to perform shop or laboratory testing

Insulating tools should be shop maintained and tested at an interval dependent on their exposure, manner of use, care they receive, individual company policy, and as field inspection dictates. Wood tools should be checked more frequently during periods of high humidity or after exposure to moisture.

The following field observations, if present, should warrant the removal of tools from service and their return to the laboratory or shop for repair and electrical testing:

a) A tingling or fuzzy sensation when the tool is in contact with energized conductor or hardware.
b) Failure to pass the electric test or the moisture-meter test (see 4.4.4 and 4.4.5).
c) Deep cuts, scratches, nicks, gouges, dents, or delamination in the stick surface.
d) A mechanically overstressed tool showing such evidence as damaged, bent, worn, or cracked components.
e) A loss or deterioration of the glossy surface.
f) A pole inadvertently cleaned with a soap cleaner (see 4.4.3).
g) Improper storage or improper exposure to weather.
h) An electrically overstressed tool showing evidence of electrical tracking, burn marks, or blisters caused from heat.

4.5.1.2 Inspection procedure

Tools should be carefully inspected or tested, or both, before returning it to service when visual inspection indicates that the tool might have been mechanically or electrically overstressed or for any of the reasons in 4.5.1.1.

NOTE—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 material, the same as the original part. Nondestructive testing (for example, Magnaflux, Zyglo, and X-Ray) should be performed on the mechanical end fittings after a tool has been subject to possible overstressing or vibrating loads for any extended period of time.

4.5.2 Cleaning, waxing, refinishing, and repair

4.5.2.1 Fiberglass-reinforced plastic (FRP) tools

Fiberglass-reinforced plastic (FRP) tools should be cleaned and waxed or refinished in accordance with the tool manufacturer's recommendations.

4.5.2.1.1 Fiberglass-reinforced plastic (FRP) tools cleaning and waxing

Waxing is not necessary after every use of the tools, but rather as needed to maintain a glossy surface that will cause any moisture or water to bead on the surface (see 4.5.5). Before the tool is rewaxed, to avoid a wax buildup, the pole should always be cleaned with a solvent or cleanser recommended by the manufacturer of the tools. Waxing not only imparts a glossy finish to the surface of the fiberglass, but also adds to the electrical integrity of the tool by providing a protective barrier against dirt, creosote and other contaminants, and moisture.

The note from 4.4.3 cautioning the use of certain cleansers or detergents applies here.

4.5.2.1.2 Fiberglass-reinforced plastic (FRP) tools repair or refinishing

In view of various available repair or refinishing processes, the decision shall be left to the user as to the adequacy of the repair process and the quality of workmanship.

FRP insulating tools should be repaired or refinished only by competent personnel. Light spots are caused by impact blows and may have a noticeable effect on the mechanical strength or electrical properties of the tool. Numerous light spots may show excessive abuse and, coupled with surface contamination, may lower the sparkover voltage or contribute to insulation degradation. If there is no roughness on the surface, there is no need for repair. Small surface ruptures can be seen with the naked eye and should be repaired by competent personnel by removing the damaged fibers and cleaning the void 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 the surface, the tools should be removed from service and refinished as recommended by the manufacturer. Such voids can accumulate moisture or, under electrical stress, become ionized leading to degradation in the organic materials. The resulting conductive deposits act as an extension of the electrode and cause further progressive degradation.

All repairs and refinishing should be followed by a high-potential dielectric leakage (see 4.5.3 to 4.5.8) or ac power-loss test (see 4.5.9).

4.5.2.2 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 conditions. Therefore, extra precautions should be taken during wet seasons of the year. Treatment in a drying cabinet is recommended if high leakage currents are encountered. In these cases, tools should be dried at 32 °C for approximately 48 hours in a 31.6% to 38% relative humidity controlled and ventilated area to provide air circulation, and subsequently subjected to a high-potential leakage or ac power loss test.[18] 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 conductive paths.

When general refinishing is required, wood tools should be thoroughly dried to 6% or 7% moisture content. After the old varnish and foreign material have been scraped off, the surface should be rendered smooth with

[18](90 °F)

flint paper and finished with two or three coats of varnish, sanding lightly between coats. Damage to the finish should be repaired according to the manufacturer's recommendations.

Repairs and refinishing should be performed by competent personnel and followed by a high-potential leakage or ac dielectric loss test. Replacement of wood tools with FRP tools is encouraged.

4.5.3 High-potential ac test method

The entire length of the tool should be divided into test segments for testing. In some cases, the test segments may overlap. One test segment must include the area adjacent to the metal fittings with one electrode making contact to the end fitting. The test contacts may be two helical springs (see 4.5.6 and Figure 11).

The test instructions are as follows:

a) Suspend or support the tool in a horizontal position, using insulating material, approximately 1.2 m above the floor.[19]
b) Orient the tool to the transformer to give the minimum leakage current at a fixed voltage (see 4.5.8). Maintain this reference location for all subsequent tests.
c) Wrap the spring electrodes around the tool. Spring contact should be maintained around the entire circumference of the tool (see 4.5.6 and 4.5.6.1).
d) Attach the test leads to the springs so that sharp edges extend inside the coiled area of the spring. The power lead of the test set shall be routed directly to the nearest electrode. Coil excess lead in the center of the lead maintaining 0.60 m ground distance.[20] Metal-conductor spark-plug wire may be used for the power lead. Use shielded cable for the ground lead. Attach the inner conductor of the shielded cable to the ground spring and to the ground-return meter of the test set. Float the shield on the spring end, and attach the shield to the ground lug on the test set.
e) For fiberglass poles only, spray the test segment with distilled water to thoroughly wet its surface. A clean spray applicator adjusted to a fine mist is suitable for this purpose. Spray water uniformly on the pole until droplets just begin to drip from the bottom surface. Apply potential to the test segment immediately after wetting.
f) NOTE—Wood poles should be dry when tested (see 4.5.2.2).
g) Increase the voltage gradually: 3000 V/s to 75 kilovolts/30 cm for fiberglass[21] and 50 kilovolts/30 cm for wood.[22] Maintain this voltage for one-minute minimum (see NOTE in 4.5.7). Read the maximum leakage current in the ground return meter.
h) If the current continues to rise after full voltage is reached, the test should be discontinued, the pole should be cleaned or refinished, and the pole should be retested. If the condition is not corrected, the pole should be removed from service.

4.5.4 Current evaluation

Current measurement provides an objective evaluation of the specimen quality.

Typical current (leakage) values on new FRP poles using guarded electrodes and tested at 100 kilovolts/30 cm may be in the range of 5 μA to 25 μA depending on the diameter of the pole and other factors.[23] See ASTM F711-00 and 4.3.2 and Figure 12. This range of values can vary from laboratory to laboratory, or from test to test within a given laboratory; therefore, historical data must be established by performing tests exactly the same way from day to day. The electrode's shapes, spacing, pole orientations, lead wires, instruments, etc. should not be varied (see 4.5.3 and 4.5.8).

[19] 4 feet.
[20] 2 feet.
[21] 75 kilovolts/foot.
[22] 50 kilovolts/foot.
[23] 100 kilovolts/foot.

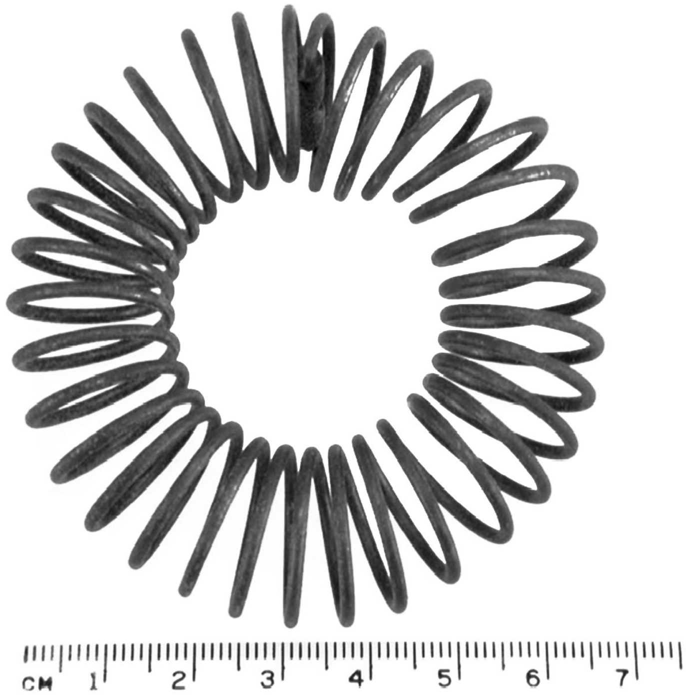


Figure 11—Helical spring electrode for in-service electrical testing of FRP tools (see 4.5.6 for the electrode specification)

If nonguarded electrodes are used, the current values will be appreciably higher by a factor of 10, 15, or more depending on the voltage.

Sample current readings should be made when the specimen has clean, uncontaminated surfaces so as to establish historical data. These data are used to establish a benchmark range for making a comparison between the in-service tool tested and the acceptance levels established for that particular diameter of pole and specific electrode configuration.

Changes in current may be cause for rejection. Significant changes in current values during a test are indications of any or all of the following conditions: contamination, moisture, specimen degradation, or 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 retested.

If the current decreases as the voltage is maintained across the test specimen, it may be indicative of absorbed moisture drying out during the test. A reading that shows an increase may be indicative of incipient degradation of the specimen.

4.5.5 Wet and dry testing

Experience has shown that live-line tools with contaminated surfaces having failed electrically under humid, moist, or wet conditions may pass 100 kilovolts/30 cm after the tools have been dried.[24]

It is the surface conditions of the tool that determines the performance under wet conditions. A glossy stick will allow water to bead on the surface, whereas a dull surface will allow the water to spread in a sheeting

[24] 100 kilovolts/foot.

action. Fairly dirty tools that retain surface gloss will show an increase in leakage current but may sustain 100 kilovolts/30 cm with an acceptable leakage level.[25] Conversely, fairly clean tools with a dull surface that has been wetted may fail at a low applied voltage. Tests on tools under wet conditions therefore verify whether the surface condition of the tool is satisfactory.

NOTE—Only fiberglass tools should be tested under wet conditions.

4.5.6 Electrode design

Guarded electrodes are required to measure the high-potential leakage current through and along the surface of the test specimen.

Manufacturers use guarded electrodes in design testing of FRP poles without end fittings. See ASTM F 711-83.

When testing FRP poles with end fittings or operating rods, special electrodes should be designed to slide over the end fittings or they should be a clamshell design.

Nonguarded electrodes are not recommended. However, if they are used, they should have a rounded edge contour to reduce the streamers that can occur before sparkover. Such streamers can cause ionic bombardment and cause electrons to rupture the chemical bonds of the stick material leading to degradation of the organic materials of the specimen being tested.

One type of contoured electrode used for in-service testing is a spring toroid that can be formed from 12.7 mm outside diameter[26] (minimum) springs wound from 1.02 mm (18 gauge) stainless steel.[27] These should be made with the inside diameter of the toroid slightly less than the pole diameters tested. Such springs are flexible enough to expand and roll over most end fittings. The 12.7 mm outside diameter of the spring gives a rounded contour to reduce the streamers (see Figure 11).[28]

Another type of electrode system, but less contoured than the one described above, is made using conductor straps or collars, which are easily wrapped around the specimen. Metal rings secured to the ends of the straps serve both to help hold the straps securely in place and as a point to attach the test electrodes (see 4.5.9.2).

The cables connecting the electrodes to the instruments should be shielded.

4.5.6.1 Electrode spacing

The spacing of electrodes is determined by the purpose of the test and the voltage chosen. For in-service testing of FRP materials, the voltage should be 75 kilovolts across 30 cm of the pole.[29] Wood poles should be tested at 50 kilovolts/30 cm spacing.[30] Close spacing of electrodes allows inspection of more minute sections for quality control and thus avoids the averaging effects of wider electrode spacing; for example, 75 kilovolts/30 cm spacing[31] or an equivalent potential difference such as 37.5 kilovolts/15 cm spacing[32] prove satisfactory. Testing may also be performed over a greater distance provided the applied voltage and distance are proportionally increased.

NOTE—For larger or smaller distances the relationship may be nonlinear.

Spacing of adjacent spring toroids should be measured between the centerlines of the springs.

[25] 100 kilovolts/foot.
[26] 0.5 inches.
[27] 0.4 inches.
[28] 0.5 inches.
[29] 1 foot.
[30] 50 kilovolts/foot.
[31] 75 kilovolts/foot.
[32] 37.5 kilovolts/foot.

4.5.6.2 Rack testing

Rack testing is the procedure of placing poles or tools on an insulated lattice structure whereby line and ground electrodes are attached alternately to the metal supports at a distance of one foot along the length of the tool.

This type of testing is intended primarily for high-volume acceptance testing of new poles in the manufacturing process (see Figure 12).

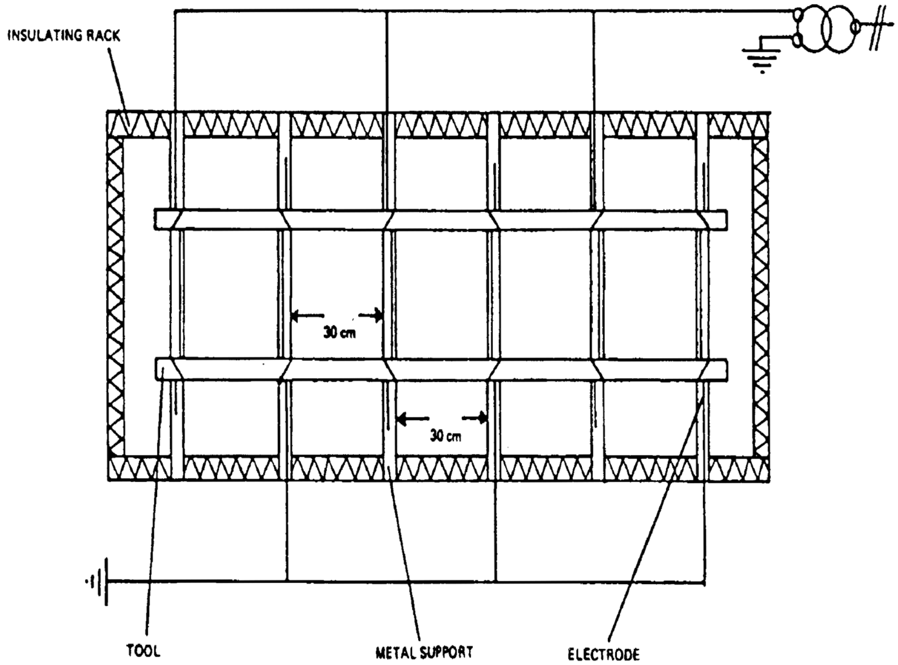


Figure 12—Typical rack for testing of FRP tools (see Appendix B of IEC 60832 for details)

The electrodes, which are impractical to shield, must be of a shape to minimize corona streamers. Typical electrodes are beaded chain, machined clamps, stranded wire, helical springs, or flat braid up to 6.35 cm wide.[33] Racks may also be used for in-service testing provided that certain disadvantages are recognized. For instance, assembled tools having metal end fittings, handles, or hooks might shorten some of the 30 cm spacing[34] on the rack, thus not allowing the voltage to be raised to the appropriate level without premature sparkover. Also it is inconvenient to monitor the current unless a meter is placed in each ground lead. Therefore, the rack is primarily used for testing new FRP poles where 100 kilovolts is impressed across each 30 cm for 5 minutes and observing any puncture, surface tracking, or heating (see CFR Title 29 1926.951 (d) and 1910.269(j)(1)(i)) [3])(OSHA).[35] Since new poles have an inherent high gloss, only dry electrical testing is required.

4.5.7 Test-voltage supply for high-potential testing

Either ac or dc may be used. Direct current testing is less sensitive to slight changes in the geometry of the test setup. Also, dc equipment is much lighter, compact, and portable enough to perform live-line tool

[33]2.5 inches.
[34]1.0 feet.
[35]1.0 feet.

testing at many different locations. It is a good practice to test equipment to be used on ac lines with ac and equipment to be used on dc lines with dc.

The required test voltage for acceptance testing by users is that which will give a voltage gradient great enough for evaluation of material but not so great as to lead to material degradation from corona or streamer discharges.

The power supply voltage parameters are dependent on factors such as electrode design and the distance over which the tests are conducted. The required test voltage capacity for in-service testing is that which will give an average voltage gradient of 75 kilovolts/30 cm of FRP specimen[36] being tested or 50 kilovolts/30 cm of wood specimen[37] being tested.

NOTE—The 75 kilovolts/30 cm [38] and 50 kilovolts/30 cm [39] are in-service tests. New poles are tested by the manufacturer at 100 kilovolts/30 cm [40] and 75 kilovolts/30 cm,[41] respectively (see CFR Title 29 1926.951 (D) 1974 (3) (OSHA). The lower recommended test voltage for wood recognizes that wood tools are more susceptible to cumulative damage by repeated overvoltage tests than FRP tools. However, this lower test voltage does not compromise tool integrity or safety under proper use.

4.5.8 Orientation of equipment and test specimen

The high voltage should be applied to the end of the test specimen nearest to the power supply. The orientation of the high-voltage bus and test specimen should be such that nearby ground planes do not introduce significant capacitive effects.

To reduce the effects of stray currents on the specimen and on the meter indication, the specimen tested, especially on ac circuits, should be parallel to the high-voltage lead or bus and the high-voltage connection (bus) should be kept as short as possible.

Other factors to be considered are as follows:

a) Leads, bushings, and instruments should be shielded to minimize stray currents to any nearby ground planes.
b) Meters or other current-indicating devices should be incorporated to give quantitative data for material evaluation.
c) The power supply should have an adjustable interrupting device (circuit breaker) to ensure against leakage currents significantly greater than the highest acceptance level for a given specimen and against damage to the power supply.
d) Interlocks and grounding features should be included for operator protection.

NOTE—For more details on test connections, see 4.5.3.

4.5.9 AC power-loss (watts-loss) test method

4.5.9.1 General

The power-loss (watts-loss) method is employed to determine the electrical condition of FRP and wood materials using the loss or dissipation of energy in the material compared to a reference based on a new or good condition value.

[36] 75 kilovolts/foot.
[37] 50 kilovolts/foot.
[38] 75 kilovolts/foot.
[39] 50 kilovolts/foot.
[40] 100 kilovolts/foot.
[41] 75 kilovolts/foot.

4.5.9.2 Test equipment

A suitable test voltage, preferably 10 kilovolts or above, but greater than 2500 Volts, shall be supplied by the test equipment. Provision for the measurement of watts-loss or the loss (leakage) component, I_w, of the total specimen current is required. If desired the average alternating voltage resistance of the specimen can be calculated as:

$$R = \frac{V_{volts}{}^2}{R}$$

$$W = \frac{V_{volts}{}^2}{R}$$

where

R is ohms (Ω),
I_w is amperes (A),
W is watts (W),
V_{volts} is volts (V).

Measurement sensitivity should be sufficient to distinguish between 10^{10} Ω and 10^{11} Ω resistance.

NOTE—Capacitance and power-factor measurements are not recommended for routine tests of specimens having a capacitance of only a few picofarads. Accurate measurement of these quantities depends on complete specimen shielded systems, which are not feasible for routine tests.

A guard shield to avoid measurement errors shall be incorporated in the test equipment, including connections to the specimen. Preferably, the test equipment should be able to make measurements using the ungrounded specimen test (UST) method with the guard shield at ground potential (see IEEE Std 62-1995, Part 1). The watts-loss test is relatively unaffected by extraneous objects in the vicinity of the specimen.

Test electrodes are applied in the selected area. Each electrode may be a conducting strap or collar wrapped tightly around the specimen or clamped to it. A metal fitting attached to the specimen is sometimes used as an electrode. A common arrangement is three electrodes with a spacing of 7.5 cm (see Figure 13).[42] The test voltage is applied to the center electrode and the measurement made between it and the two other electrodes.

NOTE—With 10 kilovolts applied across every 7.5 cm, [43] the 15 cm [44] under test will be stressed at 20 kilovolts (or the equivalent of 40 kilovolts/30 cm). [45]

For long poles and other specimens of considerable length, measurements may be made at two or more locations along the length using the three-electrode method described in Figure 13. An important test location is at both ends of the insulating tool, that is, the end normally applied to the energized line and the end held by the workman. An alternative method but less desirable is to use two electrodes separated by a considerable distance, although this usually requires a high-voltage test so as to meet the test equipment sensitivity requirements specified in this clause. When making a two-electrode measurement, use of the ungrounded specimen test (UST) method (where ground is guard) is recommended.

[42] 3 inches.
[43] 3 inches.
[44] 6 inches.
[45] 40 kilovolts/foot.

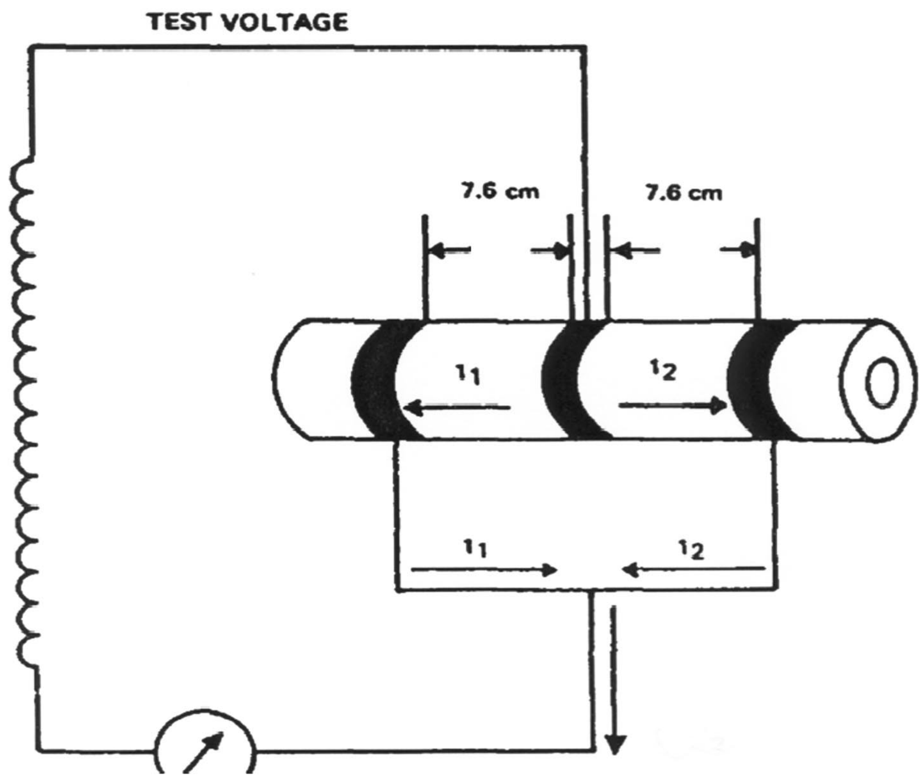


Figure 13—General circuit for power-loss (Watt-loss) testing

4.5.9.3 Power-loss (watts-loss) method criteria

The criteria for acceptance of tools checked by the power-loss (watts-loss) method should be based on power-loss (watts-loss) values formulated from historical data. Test criteria for specimens made of the same material and similar dimensions are usually determined from statistical analysis. Wood, FRP, and many composite-insulating materials, when clean and dry, have very low losses on the order of 0.01 watts at 10 kilovolts with the usual three-electrode test arrangement (ac resistance greater than 10^{10} Ω). When the loss exceeds 0.1 watts at 10 kilovolts (resistance of 10^9 Ω), this usually indicates presence of moisture in the tool, dirt, or damage. Equivalent criteria in terms of leakage current can be derived, if desired.

4.5.9.4 Orientation

The orientation of the watts-loss equipment should be in accordance with the instructions of the test-equipment manufacturer.

4.6 Acceptance-test reference

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

4.6.1 Standard test classification

Table 14 references the standards to which the tools and equipment are made. Table 15 references the acceptance test, which is used on the tools and equipment at the time of manufacture.

Upon issuance of new or revised applicable ASTM, IEC or IEEE standards, their provisions shall supersede 4.6.

Table 14—Types of tools and equipment

Device	Reference	Remarks
Aerial devices	ANSI/SIA A92.2-2001 IEC 61057-06(1991)	Latest revision. Aerial devices with insulating boom used for live working
Rope	ASTM F1701-96	Latest revision
Gloves	ASTM D120-95	Latest revision
Sleeves	ASTM D1051-95	Latest revision
Blankets	ASTM D1048-99	Latest revision
Hose	ASTM D1050	Latest revision
Hoods	ASTM D1049-98	Latest revision
Hard cover-up	ASTM F968-98	Latest revision
Hot sticks	ASTM F711-00	Latest revision
Conductive suits	IEC 60855-01(1985)	Latest revision
Conductive footwear	IEC 60855-01(1985)	Latest revision
Stringing equipment	IEEE Std 524-1993	Latest revision
Line guards	ASTM F968-98	Latest revision
Couplers	ASTM F968-98	Latest revision
Cross arm guards	ASTM F968-98	Latest revision
Polo covers	ASTM F968-98	Latest revision
Cutout covers	ASTM F968-98	Latest revision
Helicopters	CFR Title 29 1926 (551)	Used to lower workers
	CFR Title 29 1910 (183)	Used raise workers to and from structures

4.6.2 Design-test data

The persons involved in the initial specification, design, component selection and testing, and assembly of the equipment should use the same values and other design criteria.

See Table 2 for commonly used values for the anticipated maximum transient overvoltage T.

4.6.2.1 Insulating tools and other equipment

a) Maximum rated voltage test (for insulating tools and other equipment used line-to-ground)
   1) Test voltage = $2V_{P-G}$ (Twice the phase-to-ground voltage of a system on which the tools or equipment are to be used). Example: for 121 kV system, $2 \times 69.890 = 139.780$ kilovolts.
   2) Maximum permissible leakage current = 1 µA per $Volt_{P-G}$ (1 microampere of leakage current for each phase-to-ground volt of rating of the system on which the tools or equipment are to be used). Example: for 121 kV system, 69 890 microamperes or 69.890 milliamperes.
   3) Test voltage applied for 3 minutes.
b) Double rated test (for insulating tools and other equipment used line-to-ground with transient overvoltage included)
   1) Test voltage = 2(T)(V_{P-G}), when (T)(V_m)>Test Voltage, use 1.3(T)(V_{P-G}). Example: for 121 kV system with T = 3, $2 \times 3 \times 69.890 = 49.340$ kilovolts and $2 \times 121 = 242$ kilovolts, since (T)(V_m) is greater than the test voltage; therefore, use 1.3(T)(V_{P-G}) in place of 2(T)(V_{P-G}) resulting in $3 \times 1.3 \times 69.890 = 272.571$ kilovolts. If the maximum anticipated per-unit transient overvoltage is not known, refer to Table 2 for typical values.
   2) Maximum permissible current = 1 mA per $V_{P\text{-}G}$ (1 microampere of leakage current for each phase-to-ground volt of rating of the system on which the tools or equipment are to be used) Example: for 121 kV system, 69 890 microamperes or 69.890 milliamperes.
   3) Test voltage applied for 3 minutes.
c) Withstand test
   1) Test voltage = (T) (V_{P-G}) (maximum anticipated per-unit transient overvoltage times the phase-to-ground voltage of system on which the tools or equipment are to be used) Example: for 121 kV system with a T = 3, $3 \times 69.890 = 209.607$ kilovolts.
   2) Test voltage applied momentarily.
   3) Test is acceptable, if sparkover does not occur.

4.6.2.2 Conducting protective (shielding) equipment

Design Tests

a) During the 3 minute proof test, the leakage current surface should be monitored and recorded. The constant current on 25 cm^2 of surface[46] should be I = 2 mA
b) Shielding current = 1 µA/6.5 cm^2/1 Ω at an electric field[47] of 25 kilovolts per meter
c) Thermal withstand of the material = 200 °C on contact[48]

4.6.3 Acceptance test criteria

4.6.3.1 Insulating tools and other equipment

Test values and conditions are the same as in 4.6.2.1.

[46] 4 inches squared.
[47] 1 µA/1 Ω/inch squared.
[48] 400 °F.

4.6.3.2 Insulating protective equipment

V_R = manufacturer's rating kilovolts

a) 3 minute proof withstand voltage = $(1.4)(\sqrt{3})(V_R)$
b) minimum disruptive discharge voltage = $(1.6)(\sqrt{3})(V_R)$
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 = $(2.4)(\sqrt{3})(V_{Rpeak})$

Transmission voltages = $(3.0)(\sqrt{3})(V_{Rpeak})$

e) Shielding current = (1 µA/1 Ω)/6.5 cm^2 [at an average electric field of 25 kV per meter] [49]

Table 15—Acceptance test references

Tool equipment or device	Standard or other	Remarks
Cover-up equipment: Flexible material		
Glove	ASTM D120-02	Latest revision
Insulator hoods	ASTM D1049-98	Latest revision
Line hose	ASTM D1050-99	Latest revision
Sleeves	ASTM D1051-95	Latest revision
Blankets	ASTM D1078-01	Latest revision
Cover-up equipment: Rigid material		
All	ASTM F968-98	Latest revision
Inspection		
Visual-rubber pallets	ASTM F1236-96	Latest revision

4.6.4 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

[49] 1 µa/1 Ω/1 inch squared.

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.

4.6.4.1 Energized-line tools and other similar equipment

a) Test voltage = V_{P-G} (operating voltage)
b) Maximum permissible current = 1 µA per V_{P-G}
c) Time of applied voltage = 1 minute
d) Check insulation for cracks, blisters, or other visual signs of deterioration

4.6.5 Number of impulse or switching surge 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.

4.6.6 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.

4.6.7 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 FRP provided in Figure 10 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.

4.6.8 Electrical-test references

a) Low frequency: ASTM D1049-98a
b) Lightning impulse: IEEE Std 4-1995
c) Water for wetting: IEC 60625-1(1998) and IEC 60625-2(1988, A94,A98). Method of test, 17 800 Ω/cm^3 +15% [50] at 25 °C [51]
d) Standard atmospheric conditions: Temperature of 20 °C + 5 °C; relative humidity of 35% minimum[52, 53]
e) Correction to standard conditions: lightning and switching surge voltage, IEC 60060 (1989)

[50] 7000 Ω/in^3.
[51] 77 °F.
[52] 20 °C = 68 °F.
[53] 5 °C = 9 °F.

4.7 Tools and equipment

4.7.1 Acceptance tests required

Acceptance tests for various tools, devices, and equipment should be as shown in Table 15.

4.7.2 Nonconductive rope

ASTM F1701-96 is a standard for testing live-line rope. It is incumbent upon the user to assure that ropes used as live-line tools are adequate for the voltage and working conditions to which they will be applied.

4.7.3 Aerial devices and similar devices

Aerial devices and similar devices shall follow the requirements of A92.2-2001 for design, testing, and in-service care [ANSI/SIA A92.2-2001, IEC 61057-06 (1991)].

4.7.4 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 16.

Table 16—Marking and identification guide

Equipment	Information to be supplied
Gloves	ASTM D120-95 section 7
Blankets	ASTM D1048-99 section 7
Hoods	ASTM D1049-98 section 7
Hose	ASTM D1050-90 section 7
Sleeves	ASTM D1051-95 section 7
Rigid or plastic cover-up	ASTM F968-98

4.8 Bibliography documents

The following documents from the bibliography (Annex A) are cited in Clause 4:

- Bridges [B1]
- CIGRE SC 33.07.02 [B2]
- Elek and Simpson [B3]
- EPRI Project RP-38 1-1 [B4]
- EPRI Transmission Line Reference Book [B5]
- Hutzler [B7]
- IEC 61472 [B8]
- IEEE Committee Report [B10], [B13]
- IEEE/PES Special Publication [B14]
- IEEE WG Report [B17], [B18]
- Kouwenhoven and Langworthy [B19]
- Kouwenhoven et al. [B20], [B21]
- Krivova et al. [B22]
- Singewald et al. [B24]

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 D120-95, ASTM D1048-99, ASTM D1050-90, ASTM D1051-95, ASTM F968-98, and IEEE Committee Report [B13]). 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 FRP is tested by manufacturers in accordance with ASTM F711-00. See Clause 4 for testing requirements.

See Caution Note in 4.4.3 regarding cleaning.

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. The tools 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 devices

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 the resin is exposed to temperatures of 80 °C or more.[54]

The recommended maximum boom and bucket mechanical 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.

[54]176 °F.

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.

5.3.4 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 and it should not be left on the structure overnight.

Hand lines 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 also 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 light 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 hand line. Rubber insulating gloves, expect class 0, 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 Cable carts

Care shall be taken to ensure that the combined weight of the conductor cart, workers, and equipment does not allow the design electrical clearance (particularly at midspan) to be reduced below the design electrical minimum clearances.

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 1048-1995.)

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.

5.4 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 15.

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 or 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.

Jackscrews 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 devices

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.

In addition to the above equipment, which is being used with the work platform at line potential should include the following:

— Elevate device to its height (max) for 5 minutes to stabilize hydraulic system
— Place bucket (must have metal liner bonded to all metal) in contact with energized conductor and record leakage

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 takeoff 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 oil line for trucks with a reach exceeding 18 m [55]

5.4.3 Insulating cover-up equipment

Cover-up equipment should be inspected for dents, tears, cracks, punctures, burns, 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 inspected before using, for deterioration, wear, broken strands, and condition of eyes and splices. Periodic examination of the inner strands, or fibers, is also 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 1067-1996.

5.4.6 Cable carts

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

5.5 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. (See 4.5.2).

[55]50 feet.

5.5.2 Insulating aerial devices

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 A92.2-2001).

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 F479-95, and ASTM F496-01b). 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 repaired 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 sparkover voltage tests for plastic guards (ASTM F711-00).

Repairs to rubber 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. Severing the defective area from the undamaged portion of the cover-up may salvage blankets with defects too extensive to repair. Repairs and salvaging of blankets must meet the requirements of the ASTM standard [ASTM F479- 95(01)].

5.5.3.1 Testing repaired equipment

Repairs and refinishing should be done by competent personnel and followed by a dielectric or power loss (power factor) test.

5.5.4 Nonconductive rope

Damaged ropes should be removed from service. For additional information, see ASTM F1701-96.

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 1067-1996.

5.5.5.2 Insulating clothing

Repairs to insulating clothing are not generally recommended (IEEE Std 1067-1996, ASTM F496-01b).

5.5.6 Cable carts

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

5.6 Bibliography documents

The IEEE Committee Report [B13] from the bibliography is cited in this clause.

6. Work methods

6.1 Introduction

This clause covers work methods and equipment usage 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 Categorized of energized-line maintenance

6.2.1 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. Workers perform their work with insulated tools and equipment.

6.2.2 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.

6.2.3 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.

6.2.4 Other related work procedures

IEEE Std. 1048-1995 provides guidelines for safe protective grounding methods for persons engaged in de-energized and grounded 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 (MAD)

Refer to 7.2.2 for the derivation of this parameter.

6.3.1 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 7.2.2. 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 electrically 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.

6.3.2 Transient overvoltage control, at and above 72.5 kilovolts

For voltages at and above 72.5 kilovolts, 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, 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:

a) The operation of a circuit breaker or other switching device shall be modified, including blocking reclusion, if required.
b) The overvoltage itself is forcibly held to an acceptable level by the installation of arresters or transient protective gaps, or similar devices.
c) 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) Protective glasses or other appropriate face protection should be worn to protect the eyes and if required the face. Ultraviolet (UVA and UVB) protective glasses should be worn during daylight to protect the eyes from damage that may result from long-term exposure to the sun and when there is any possibility of an arc.
e) The maximum operating 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 7.2.2, 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 transient 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 hand line 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 pull 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 equipment is available and rated for the voltages involved, 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) Line workers doing energized line-work should have satisfactorily completed a formal training course of instruction. Records of training or work experience should be maintained.[56]
b) Whenever workers are exposed to electric fields, shielding should be provided as required and noted in 4.2.3.1.3.

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[56]Required by OSHA guidelines, Title 29, Part 1910.269.

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 should be 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 crewmember should be allowed to work during periods, either transient 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 air gaps (PPAGs) are used, they should be installed preferably on a structure adjacent to the work location.

6.5.2 Requirements when at ground potential

a) When working from structures at voltages above 230 kilovolts 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 kilovolts 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 clauses 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 with special precautions (see Singewald, et al [B24]).

6.5.5.1 General

Rubber and synthetic gloves and sleeves are available for use on voltages through 36 kilovolts (class 4). See also 1.4.

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 workday.

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 except class 0 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 and a thorough rinse to remove all traces of the 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 Additional requirements[57]

6.5.5.5.1 When working with voltages from 600 up to 7500 Volts[58]

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

6.5.5.5.2 When working with voltages from 7501 up to 17 000 Volts[59]

Additional insulation, such as insulated platforms, ladders, or aerial devices, 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 cannot or will not violate the approach distance phase-to-phase, or phase-to-ground for the voltage involved.

[57]The 2002 Edition of the NESC® contains changes to Rule 441 that address working energized distribution circuits. Questions regarding working from an insulated aerial lift or platform versus working from a wooden pole, and phase-to-ground versus phase-to phase rating of insulating gloves brought forth these changes. Two basic rules were developed: (1) When working 15 kV and above, supplemental insulation will be used. (2) When phase-to-ground rating of rubber insulating equipment is used, supplemental insulation will also be used.

[58]Before using this information, check the codes and regulations in effect in the area where the work is being preformed.

[59]Before using this information, check the codes and regulations in effect in the area where the work is being preformed.

6.5.5.5.3 When working with voltages from 17 001 up to 26 500 Volts[60]

The same practices usually apply to this level as at the 7500 to 17 000 volt 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 devices are often preferred at this level.

6.5.5.5.4 When working with voltages from 26 501 up to 36 000 Volts[61]

a) Insulated aerial devices or insulating pole platform equipment is universally accepted as necessary for gloving at this voltage level. The use of this equipment may be required by local codes and regulations. Sleeves are used when there is no positive assurance (e.g., adequate use of cover-up) that the arms cannot or will not violate the approach distance for the voltage involved. 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. Special precautions should be taken to avoid contact of the tools with unprotected parts of the worker’s body. The MAD must be maintained to the unprotected parts of the worker’s body.
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 insulation 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 boson’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 boson’s chair, basket or bucket, or tree trimmer’s saddle, to position the worker.

[60]Before using this information, check the codes and regulations in effect in the area where the work is being preformed.
[61]Before using this information, check the codes and regulations in effect in the area where the work is being preformed.

6.6.6 Insulating platform board

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

6.7 Noninsulating equipment used in energized 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 14, Part 133.

6.7.3 Restoration structures

There are three categories of dedicated equivalent type structures used for restoration structures:

— Type I: Structures that are lightweight, modular structures designed specifically for fast line restoration
— Type II: Wood pole structures
— Type III: Steel pole and lattice structure type, including those designed for permanent installation only

Restoration structures are generally used under emergency conditions, and they are frequently obtained from other utilities in a mutual assistance arrangement, or secured from a manufacturer. It is therefore advantageous that strength of the structure be determined with a minimum of detailed analysis. Most companies have design application tables for Type II and Type III structures.

For Type I structures, IEEE Std 1070-1995 was developed. The purpose of this guide is to provide a generic specification that can be used by electric utilities for acquiring transmission modular restoration structure components. This particular design would then be compatible with the modular restoration structures presently in use within the industry and would allow the highly successful plan of transmission mutual aid to be greatly enhanced. In addition to the forgoing guide, application guidance for such systems should be available.

Restoration structures can be used for either emergency, transient, or permanent installations. During emergency installation of restoration structures, the following may be considered due to their relatively short exposure time.

a) Minimum approach distances, including climbing spaces, may be reduced considering the voltage involved and the absence of live-line maintenance from these structures. Minimum approach distance reductions involving the public require barriers and/or markers to restrict access.
b) Structural loading criteria should be selected appropriately and should be designed to withstand expected loads, including that imposed by line workers and construction equipment. Designing for the requirements of a permanent installation may severely penalize the restoration structures and unnecessarily increase restoration time.
c) Less than optimal electrical and mechanical designs (i.e., overhead ground wire shield angle and conductor clamping) may be acceptable due to limited exposure.

During installation of restoration structures used as transient structures, the installation shall meet the requirements for permanent installations, except structural loading criteria should be selected appropriately and should be designed to withstand expected loads, including that imposed by the line workers and construction equipment.

During installation of restoration structures used as permanent structures, the installation shall meet the requirements for permanent installations.

6.8 Insulating devices used in energized line-work

6.8.1 Insulating tools

Insulating tools made of either wood or, preferably, FRP 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 tool or an insulator. 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 Table 4 through Table 8. In general, 2.4 m should be added to the minimum clear insulation length of the ladder to account for the area usually occupied by the worker.[62]
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 7.2.
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 Table 3, and Tables 5 through Table 9, plus an appropriate distance added for inadvertent movement (see 7.2).
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 7.2.
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 9, plus an appropriate distance added for inadvertent movement (see 7.2).

[62]8 feet.

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 A92.2-2001.
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 worn 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 C225-00, IEC 61057-06 (1991), or IEC 61472 [B8].
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 Std 1307-1996.
j) When good dielectric characteristics in the buckets are required, a removable insulating liner that can be used and tested is recommended by the manufacture.

6.9.2.2 General precautions

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 minutes.
e) Workers in the vicinity of a support platform, in contact with or near energized lines, should avoid making contact with the support platform.

6.9.2.3 General requirements for aerial devices performing barehand work

6.9.2.3.1 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.

6.9.2.3.2 Lower controls

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

6.9.2.4 Functional testing of atmospheric check valves in aerial devices being used for live work

Aerial buckets with hydraulic lines at the bucket position should be equipped with check valves on hydraulic lines at the bucket position to admit air into the lines in the event of a line leak, which would normally cause a partial vacuum to form in the hydraulic line. If a partial vacuum was allowed to form along the entire length of the insulated boom section when the bucket is in contact with a conductor, a sparkover could occur because the dielectric strength of partial vacuum is lower than that of the hydraulic fluid.

Check valves should be tested using manufacture's recommended procedures and intervals.

6.9.3 Structure-mounted ladder for barehand work

6.9.3.1 General precautions

a) The structure (e.g., hook) end of the ladder should be firmly secured to an anchorage point on the structure capable of supporting at least twice the potential impact load of a worker's fall, or 22.2 kN. [63]
b) The ladder should not be secured to a defective component or to a component that will be taken apart or moved.
c) Before the worker mounts the ladder, the leader of the crew should first assure that all rigging has been checked. When transferring to and from the ladder, continuous attachment should be required. Refer to IEEE Std 1307-1996, 6.2.1.6.2.1.
d) The process of mounting or dismounting a ladder should be given special consideration. If the ladder is not tagged in a manner that does allow swinging and rotation, then attachment is required at all times. The fall protection system shall be used in a manner that does not permit the worker sliding down the ladder in the event of a slip off a ladder rung.[64]

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 leakage 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 air insulation distance (MAID)

The minimum air insulation distance specified in Table 5 through Table 9, plus an additional distance for inadvertent movement (ergonomic), should be maintained between the worker and any grounded part. (See also 6.3 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.
b) Personnel should stay clear of the ladder and base while the ladder is being moved into position.

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[63] 5000 ft-lb/sec^2.
[64] See IEEE Std 1307-1996 for more details.

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 (MAD)

A distance of 2.4 m should be added to the MAID indicated in Table 5 through Table 9 to allow for the length of ladder occupied by the person.[65]

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 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 (MAD)

Noninsulating portions of the equipment should not be closer to energized devices than the distances indicated in Table 5 through Table 9. 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.

[65]8 feet.

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 (MAD)

a) The minimum insulation distance between the worker and any grounded part shall not be less than that specified in 7.2.
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 7.2.
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 19 or Table 20.
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 8, plus an appropriate distance added for inadvertent movement (see 7.2).

6.9.7 Conductor cart used in barehand 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 the worker. 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 should be mounted on the conductor near the worker.

6.9.7.2 General requirements

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

6.9.7.3 Minimum working distance

Care should be exercised during installation of the cart on the conductor so that the minimum distances indicated in Table 5 through Table 9 are not violated.

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 Table 5 through Table 9.

6.9.8 Helicopter performed barehand 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 Std 1307-1996
l) The platform or sling load method may be used to position worker on the line or structure

6.10 Bibliography documents

The following document from the bibliography (Annex A) is cited in this clause:

— IEC 61472 [B8]

7. Work in the proximity of energized lines and devices

7.1 Introduction

This clause suggests ways to provide protection for workers during energized line maintenance or while working in the vicinity of other energized lines. In addition, this clause determines the minimum approach distance for grounded bodies, workers, or equipment operating or positioning in the vicinity of energized lines and/or energized components while performing work in the proximity of energized circuits or devices. This includes mobile work equipment, such as aerial devices used as work platforms, radial boom derricks, aerial ladders, and live-line insulator washing equipment. Step-and-touch voltages are also considered in this clause.

7.2 Approach distances

7.2.1 Minimum air insulation distances

The distances in Table 3, Table 5 through Table 9, Table 11, and Table 12 should be only used to establish MAID, and these distances do not consider inadvertent movement (accidental or unplanned movements).

7.2.2 Minimum approach distances

The MAD is equal to the MAID plus a factor for inadvertent movement. Minimum suggested inadvertent movement factors for different voltage ranges are tabulated in Table 17. MADs are developed by adding the minimum inadvertent movement to the distances in Table 3, Table 5 through Table 9, Table 11, and Table 12. For MAD values, see Table 18 through Table 24.

Table 17—Minimum suggested inadvertent movement factors

Voltage range in kilovolts 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 0.30 m	Concern of hazard from self-sustaining arc
0.751–72.5	Add 0.61 m	Based on ergometric considerations of worker and equipment movement
72.6–800	Add 0.30 m	Based on ergometric considerations of worker and equipment movement

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.

3—For distances in feet see Table D.10.

7.2.3 Minimum approach distances for helicopter work methods

Due to the complexities introduced by the helicopter and worker configuration, it is essential that the MAD is calculated for each situation in accordance with its geometry. A methodology for MAD calculations for helicopter work methods is provided in IEEE Committee Report PE-046PRD [B12].

7.2.4 Reduced approach distances (above 72 500 V)

When transient overvoltage control, as outlined in 6.3 is used to reduce the MAID and MAD distances, the precautions in 7.3.1 should be considered.

Table 18—Example of detailed calculations for MAD 60 Hz. Energized work, without tools in the air gap, when the transient overvoltage factors (T) is not known

Voltage in kilovolts phase to phase	Distance in meters	
	Phase to ground	Phase to phase
72.6–121	1.05	1.39
138–145	1.20	1.61
161–169	1.35	1.82
230–242	1.87	2.58
345–362	3.18	4.48

Table 18—Example of detailed calculations for MAD 60 Hz. Energized work, without tools in the air gap, when the transient overvoltage factors (T) is not known *(continued)*

Voltage in kilovolts phase to phase	Distance in meters	
	Phase to ground	Phase to phase
500–550	4.78	7.20
765–800	6.54	10.52

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—Values are based on altitudes below 900 m. See Table 1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

3—Table distances include a factor for inadvertent movement. See 7.2 for inadvertent movement considerations.

4—The clear live tool length should be equal to or exceed these values for the indicated voltage ranges.

5—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

6—Data for this table was obtained from Table 20 and Table 22.

7—For values in feet, see Table D.11.

Table 19—Example of detailed calculations for MAD 60 Hz. Energized work, with tools in the air gap, when the transient overvoltage factors (T) is not known

Voltage in kilovolts phase to phase	Distance in meters	
	Phase to ground	Phase to phase
72.6–121	1.13	1.50
138–145	1.29	1.73
161–169	1.45	1.97
230–242	2.02	2.80

Table 19—Example of detailed calculations for MAD 60 Hz. Energized work, with tools in the air gap, when the transient overvoltage factors (T) is not known *(continued)*

Voltage in kilovolts phase to phase	Distance in meters	
	Phase to ground	Phase to phase
345–362	3.40	4.80
500–550	5.07	7.64
765–800	6.89	11.10

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—Values are based on altitudes below 900 m. See Table 1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

3—Table distances include a factor for inadvertent movement. See 7.2 for inadvertent movement considerations.

4—The clear live tool length should be equal to or exceed these values for the indicated voltage ranges.

5—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometer per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

6—Data for this table was obtained from Table 21 and Table 23.

7—For values in feet, see Table D.12.

Table 20—MAD phase-to-ground, 60 Hz. energized work, using the transient overvoltage factor, without tools in the air gap in meters

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	m	m	m	m	m	m	m
1.5	0.63	0.69	0.75	0.95	1.26	1.82	2.95
1.6	0.65	0.71	0.78	0.99	1.33	1.96	3.23
1.7	0.67	0.74	0.81	1.03	1.39	2.12	3.54
1.8	0.69	0.77	0.84	1.07	1.45	2.27	3.85
1.9	0.71	0.79	0.87	1.12	1.52	2.44	4.19
2.0	0.73	0.82	0.90	1.16	1.58	2.63	4.56
2.1	0.75	0.84	0.93	1.20	1.64	2.81	4.92
2.2	0.77	0.87	0.96	1.24	1.74	2.99	5.29
2.3	0.80	0.89	0.99	1.29	1.83	3.18	5.68
2.4	0.82	0.92	1.02	1.33	1.93	3.37	6.12
2.5	0.84	0.95	1.05	1.37	2.03	3.60	6.54
2.6	0.86	0.97	1.08	1.41	2.13	3.80	
2.7	0.88	1.00	1.11	1.46	2.23	4.04	
2.8	0.90	1.02	1.14	1.50	2.36	4.29	
2.9	0.92	1.05	1.17	1.54	2.47	4.52	
3.0	0.95	1.07	1.20	1.59	2.58	4.78	
3.1	0.97	1.10	1.23	1.63	2.70		
3.2	0.99	1.12	1.26	1.68	2.81		
3.3	1.01	1.15	1.29	1.74	2.94		

Table 20—MAD phase-to-ground, 60 Hz. energized work, using the transient overvoltage factor, without tools in the air gap in meters ***(continued)***

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	m	m	m	m	m	m	m
3.4	1.03	1.17	1.32	1.80	3.06		
3.5	1.05	1.20	1.35	1.87	3.18		

NOTES

1—The distance specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known. It the maximum anticipated per-unit transient overvoltage is not known or is not limited by external means (for example, by installation of a transient control device), the highest per-unit transient overvoltage listed in the table should be used.

2—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

3—The metric values were calculated from data in Table D.7 using the conversion factor of 0.3048 m per foot and rounded up to 2 decimal places.

4—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

5—For values in feet, see Table D.13.

6—Distance are valid only for altitudes below 900 meters. Above 900 meters they must be corrected for altitude. See Table 1.

Table 21—MAD phase-to-ground, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in meters

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	m	m	m	m	m	m	m
1.5	0.66	0.73	0.80	1.01	1.36	1.96	3.16
1.6	0.68	0.76	0.83	1.05	1.43	2.12	3.46
1.7	0.70	0.78	0.86	1.10	1.50	2.28	3.78
1.8	0.73	0.81	0.90	1.15	1.57	2.45	4.11

Table 21—MAD phase-to-ground, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in meters *(continued)*

V_{P-P} V_{P-G}	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**m**	**m**	**m**	**m**	**m**	**m**	**m**
1.9	0.75	0.84	0.93	1.20	1.64	2.62	4.45
2.0	0.77	0.87	0.96	1.24	1.71	2.82	4.84
2.1	0.80	0.90	0.99	1.29	1.78	3.01	5.22
2.2	0.82	0.92	1.03	1.34	1.88	3.20	5.60
2.3	0.84	0.95	1.06	1.38	1.98	3.40	6.00
2.4	0.87	0.98	1.09	1.43	2.08	3.61	6.46
2.5	0.89	1.01	1.12	1.48	2.19	3.84	6.89
2.6	0.91	1.04	1.16	1.52	2.30	4.06	
2.7	0.94	1.06	1.19	1.57	2.41	4.30	
2.8	0.96	1.09	1.22	1.62	2.54	4.56	
2.9	0.98	1.12	1.26	1.66	2.65	4.80	
3.0	1.01	1.15	1.29	1.71	2.77	5.07	
3.1	1.03	1.18	1.32	1.76	2.89		
3.2	1.05	1.20	1.35	1.82	3.02		
3.3	1.08	1.23	1.39	1.88	3.15		

Table 21—MAD phase-to-ground, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in meters *(continued)*

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	m	m	m	m	m	m	m
3.4	1.10	1.26	1.42	1.94	3.27		
3.5	1.13	1.29	1.45	2.02	3.40		

NOTES

1—The distance specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known. It the maximum anticipated per-unit transient overvoltage is not known or is not limited by external means (for example, by installation of a transient control device), the highest per-unit transient overvoltage listed in the table should be used.

2—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

3—Table was calculated from Table 8 with 0.30 m added for the inadvertent movement and rounded up.

4—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

5—For values in feet, see Table D.14.

Table 22—MAD phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in meters

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	m	m	m	m	m	m	m
1.5	0.72	0.80	0.88	1.12	1.53	2.24	3.69
1.6	0.79	0.88	0.98	1.27	1.75	2.65	4.44
1.7	0.86	0.97	1.08	1.42	1.97	3.08	5.25
1.8	0.93	1.06	1.18	1.56	2.18	3.51	6.09
1.9	1.01	1.15	1.29	1.71	2.41	4.00	7.02
2.0	1.07	1.23	1.38	1.84	2.61	4.49	7.96
2.1	1.10	1.26	1.41	1.89	2.68	4.74	8.47
2.2	1.12	1.28	1.44	1.93	2.79	4.95	8.94

Table 22—MAD phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in meters *(continued)*

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	m	m	m	m	m	m	m
2.3	1.14	1.31	1.47	1.98	2.90	5.19	9.45
2.4	1.16	1.33	1.50	2.02	3.01	5.43	10.01
2.5	1.18	1.36	1.53	2.05	3.13	5.71	10.52
2.6	1.20	1.38	1.56	2.10	3.26	5.97	
2.7	1.23	1.41	1.59	2.15	3.39	6.29	
2.8	1.25	1.44	1.62	2.19	3.55	6.61	
2.9	1.27	1.46	1.65	2.24	3.68	6.88	
3.0	1.29	1.49	1.68	2.28	3.81	7.20	
3.1	1.31	1.51	1.71	2.32	3.94		
3.2	1.33	1.53	1.74	2.37	4.07		
3.3	1.36	1.56	1.77	2.44	4.22		
3.4	1.37	1.58	1.80	2.50	4.35		
3.5	1.39	1.61	1.82	2.58	4.48		

NOTES

1—The distance specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known. It the maximum anticipated per-unit transient overvoltage is not known or is not limited by external means (for example, by installation of a transient control device), the highest per-unit transient overvoltage listed in the table should be used.

2—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

3—Table was calculated from Table 11 with 0.30 m added for the inadvertent movement and rounded up.

4—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

5—For values in feet, see Table D.15.

6—Distance are valid only for altitudes below 900 meters. Above 900 meters they must be corrected for altitude. See Table 1.

Table 23—MAD phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in meters

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	m	m	m	m	m	m	m
1.5	0.76	0.85	0.94	1.21	1.65	2.43	3.96
1.6	0.84	0.94	1.05	1.36	1.89	2.86	4.76
1.7	0.92	1.04	1.16	1.53	2.13	3.33	5.62
1.8	1.00	1.13	1.27	1.68	2.36	3.80	6.51
1.9	1.08	1.23	1.38	1.85	2.61	4.32	7.48
2.0	1.15	1.32	1.48	2.00	2.83	4.84	8.47
2.1	1.18	1.35	1.53	2.05	2.91	5.09	9.00
2.2	1.20	1.38	1.56	2.09	3.03	5.32	9.47
2.3	1.22	1.41	1.59	2.14	3.15	5.57	9.99
2.4	1.25	1.44	1.62	2.19	3.27	5.82	10.58
2.5	1.27	1.46	1.65	2.23	3.39	6.11	11.10
2.6	1.29	1.49	1.69	2.28	3.53	6.39	
2.7	1.32	1.52	1.72	2.33	3.67	6.71	
2.8	1.35	1.55	1.76	2.38	3.83	7.03	
2.9	1.37	1.58	1.79	2.43	3.97	7.32	
3.0	1.39	1.61	1.82	2.48	4.10	7.64	
3.1	1.41	1.63	1.85	2.52	4.24		
3.2	1.43	1.66	1.88	2.58	4.37		
3.3	1.46	1.69	1.92	2.66	4.54		

Table 23—MAD phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in meters *(continued)*

$V_{P–P}$ $V_{P–G}$	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	m	m	m	m	m	m	m
3.4	1.48	1.71	1.94	2.71	4.67		
3.5	1.50	1.73	1.97	2.80	4.80		

NOTES

1—The distance specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known. It the maximum anticipated per-unit transient overvoltage is not known or is not limited by external means (for example, by installation of a transient control device), the highest per-unit transient overvoltage listed in the table should be used.

2—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

3—Table was calculated from Table 12 with 0.30 m added for the inadvertent movement and rounded up.

4—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

5—For values in feet, see Table D.16.

6—Distance are valid only for altitudes below 900 meters. Above 900 meters they must be corrected for altitude. See Table 1.

Table 24—MAD dc-energized work, using the transient overvoltage factor, conductor-to-worker, clear live-line tool and barehand distance in meters

Maximum anticipated per-unit transient overvoltage	Maximum pole-to-pole voltage (kilovolts)				
	250	400	500	600	750
1.50 or lower	1.12	1.60	2.06	2.62	3.61
1.31–1.60	1.17	1.69	2.24	2.86	3.98
1.61–1.70	1.23	1.82	2.41	3.12	4.37

Table 24—MAD dc-energized work, using the transient overvoltage factor, conductor-to-worker, clear live-line tool and barehand distance in meters *(continued)*

Maximum anticipated per-unit transient overvoltage	Maximum pole-to-pole voltage (kilovolts)				
	250	400	500	600	750
1.71–1.80	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.

3—This table was calculated from the values in Table D.17 with a conversion factor of 0.3048 and rounded up.

4—For distances in feet, see Table D.17.

5—Distance are valid only for altitudes below 900 meters. Above 900 meters they must be corrected for altitude. See Table 1.

7.3 Precautions when performing live work

7.3.1 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, the metal component at the end of an energized line tool, or any equipment with voltage induced from an alternative source.

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, although 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) Consideration of the amount of insulation provided at the work site should include an analysis of the minimum number of healthy insulators [B11]. If the work method provides for the shunting of insulators at the hot or cold ends of the string, the analysis should not include the damaged or shunted insulators.

f) 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 MAD. When installing this equipment, the employee shall maintain the MAD.

7.3.2 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.

7.4 Step and touch voltages

7.4.1 Introduction

When induced current flows or a ground fault occurs on a transmission or distribution tower or metal structure, the voltage rise, with respect to ground, may present a hazard through excessive step or touch voltages. The degree of the hazard depends on the magnitude of the fault current available at the work location, the earth (ground) resistance, and the duration of the exposure. Although the probability of a line-to-ground fault during the work period has not increased in recent years, the magnitude of available 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.

7.4.2 Voltage-gradient distribution

a) The dissipation of the voltage or voltage drop from the ground electrode is called the ground voltage gradient or, simply, the voltage gradient. The voltage drop depends on the ground resistivity. Figure 14 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 resistivety
b) Step and touch voltage is illustrated in Figure 15. 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.

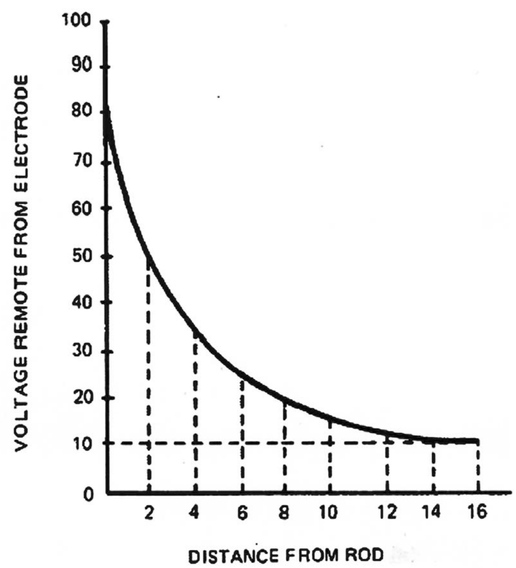

Figure 14—Typical voltage-gradient distribution curve

7.4.3 Protection of the worker from ground voltage gradients

The use of a metal mat connected to the electrode will protect a worker standing on it from any step or touch voltage. However, if the worker is standing with one foot on the conducting mat and one foot on the ground, the worker will be exposed to a step voltage, which is at least equivalent to the touch voltage, as illustrated in Figure 15.

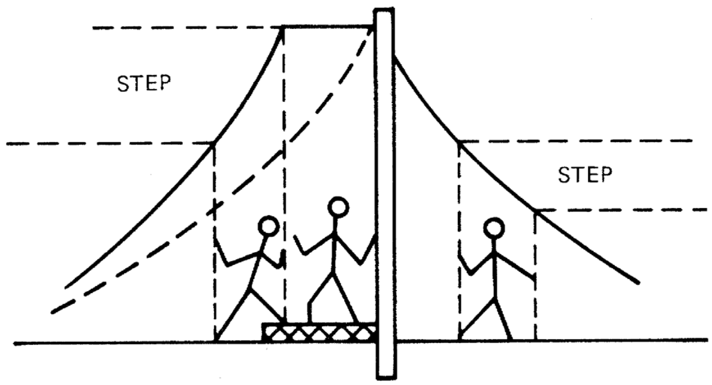

Figure 15—Protection of the workers from step and touch voltages

7.5 Vehicles in the vicinity of energized lines and devices

7.5.1 Methods

Three basic methods are used, separately or in combination, to provide personal protection for the public and workers standing near vehicles working near energized facilities [B6], [B23].

a) Grounding Equipotential Zones: All equipment is electrically interconnected by bonding cables and grounded to a system neutral, system ground, and/or grids that provide negligible potential difference across the zone.
b) Insulation: Workers are insulated by gloves, footwear, insulated booms, insulated mats, insulated platforms, etc., suitable for the voltage resulting from maximum fault currents and the voltage available at the work site.
c) Isolation: Isolation may be provided by physical restraints such as barricades or barriers. No one should be inside the isolating perimeter unless protected by one of the above methods. Isolation, if properly used, provides a positive means of protecting the public. With respect to the step voltage hazard, the isolation distance may vary from a few meters to 9 m or more depending on the available fault current and voltage.[66]

NOTE—It has been shown in tests that the use of transient ground connections to earth can produce hazardous step and touch voltages around equipment connected to these connections. Other protection must be used if the equipment is electrically connected to ground.

If the isolation method is combined with the use of ground rods, the location of the isolation perimeter shall consider the location of the ground rods. The voltage gradient in the ground radiating from the ground rod may be large when accidental contact is made and the ground connection should also be isolated. Barricading these points should be considered.

The protection system chosen shall be adequate for the hazard that exists.

[66]30 feet.

7.5.2 General precautions

Aerial equipped vehicles (e.g., aerial platforms, digger derricks, booms) that could make contact with an energized facility, or could become energized during the work process, should be grounded with transient protective grounding equipment capable of carrying the maximum anticipated fault current magnitude for the time required to "clear" the "fault." Isolation or insulation methods are usually employed to keep both workers and the public away from possible exposure to step and touch hazards.

It is also recommended that the vehicle chassis be connected to the common transient or permanent electrode when possible, or that the vehicle be isolated from contact.

Workers on the ground should be aware of the step potential hazards near the vehicle chassis as well as the structure and ground electrode and should not contact a vehicle while the boom or aerial device is in motion. To minimize the hazard, all work vehicles and equipment on the ground should be bonded together.

Subclause 1.4.1 of IEEE 524a-1998 indicates a different method of bonding depending on the type of aerial device in use.

7.5.3 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 approach distance for conductive booms shall exist among 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 minimum approach distance for conductive booms.
b) When it is necessary to operate the controls at ground or vehicle level, the operators shall protect themselves by standing on one of the following:
    1) The operator's metallic platform installed for this specific purpose
    2) The deck of the vehicle
    3) A portable conducting mat electrically attached to the vehicle
    4) An insulated platform rated for the voltage involved

7.6 Insulator cleaning

Cleaning contaminated insulators on energized lines can be done by using various methods (see IEEE WG Report [B16]). See also IEEE Std 957-1995.

7.7 Bibliography documents

The following documents from the bibliography (Annex A) are cited in this clause:

— "Factors in Sizing Protective Grounds" [B6]
— IEEE Committee Report [B11]
— IEEE Committee Report PE-046PRD [B12]
— IEEE WG Report [B16]
— "Methods for Protecting Workers and the Public Adjacent to Electric Utility Vehicle" [B23]

Annex A

(informative)

Bibliography

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Annex B

(informative)

Derivation of live-line minimum air insulation distance (MAID) using Equation (2)

Use Equation (2): $D = 0.3048\ (((C_1)C_2 + a)(T)(V_{P-G}))$

Example:

A 500 kilovolts line has the following parameters:

V is 550 kilovolts phase-to-phase (assuming maximum load)
T is 2.0 p.u. with autoreclosing disabled

Determine "a" from the Table 4

$a = 0.002$

then

$D = 0.3048(((0.01)(1.1) + 0.002)(2.0)(318)) = 2.52$ m

Add 0.30 m for inadvertent movement (NESC®).

Then

D is 2.52 + 0.30 = 2.82 m

is the live-line work minimum approach distance.

NOTE—In calculation of the tables in this document, the calculations were rounded up. Therefore this distance does not exactly match the distance from the tables.

Annex C

(informative)

Distance calculations

In order to make these calculations, the portable protective air gap (PPAG) to be used must be laboratory tested to determine its flashover characteristics. Do not use data from Figure 1, Figure 2, Figure 3, Figure 8, and/or Figure 9 in this guide for these calculations.

C.1 Determining a minimum approach distance that can be employed by use of a portable protective air gap in feet

The steps are as follows:

a) Select the appropriate (statistical) withstand voltage of the PPAG based on system requirements and the acceptable probability of gap sparkover.
b) From previous test data, select a gap distance that provides a (statistical) withstand voltage (85% of gap V_{50}) equal to or greater than the one selected in Step a).
c) Use the gap's (statistical sparkover) +2σ sparkover voltage (110% of gap V_{50}) to determine the minimum air insulation distance from a plot similar to Figure 9 in this guide, which has been plotted from the test results of the PPAG to be used. Do not use Figure 9 in this guide.
d) To determine the minimum approach distance, add 1 foot for inadvertent movement. See 7.2 for inadvertent movement discussion. If the PPAG test data do not include a test for the specific structure and work method, additional distance should be provided.

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

— 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 PPAG is installed on the line. Therefore, the minimum statistical withstand peak voltage of the PPAG is

$$\frac{(550\text{ kilovolts})(1.414)(1.25)}{1.732} = 562\,V_{PEAK}$$

— Do not use Figure 9. 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 V_{50} equal to or greater than

$$\frac{(562\text{ kilovolts})}{0.85} = 661\,V_{PEAK}$$

— For example, if tests on a particular protective gap with a 4.0 foot gap spacing had a V_{50} equal to 665 V_{PEAK}, select this gap spacing.
— The protective gap's (statistical sparkover) +2σ voltage is (665 kilovolts)(1.10) = 732 V_{PEAK}.
— From Figure 2, Figure 3, and using Equation (1), 734 V_{PEAK} corresponds to a 5.6 foot minimum air insulation distance

$$D = \frac{(0.01 + 0.0007)(732)}{1.414} = 5.6 \text{ feet}$$

— The minimum approach distance is 5.6 feet + (1.0 foot for inadvertent movement) = 6.5 feet.
— If there is a live-line tool in the gap, use Equation (2):

$$D = \frac{(0.01(1.1) + 0.0007)(732)}{1.414} = 6.1 \text{ feet}$$

and the minimum approach distance is 6.1 feet + (1.0 foot for inadvertent movement) = 7.1 feet.

C.2 Determining the portable protective air gap (PPAG) distance necessary to allow use of a new minimum approach distance in feet

The steps are as follows:

a) Find the value of the minimum approach distance that is required by the task.
b) Subtract 1 foot from the value determined in Step a) to determine the minimum air insulation distance and its corresponding statistical withstand voltage from Figure 3 (see 7.2 for inadvertent movement discussion).
c) From previous test data, select a protective gap distance that provides a (statistical) +2σ sparkover voltage (110% of gap V_{50}) equal to or less than the (statistical) +3σ withstand voltage determined in Step b)].
d) Determine the statistical withstand voltage (85% of the V_{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 kilovolts line subject to 2.4 p.u. transient overvoltage and operating at a 550 kilovolts maximum operating voltage. Determine an acceptable portable protective air gap (PPAG) distance to allow use of a 9.0 feet minimum approach distance.

— Only 9.0 feet is available to climb by a conductor rather than the 11 feet, 3 inches required.
— The minimum air insulation distance is 9.0 feet – (1.0 foot for inadvertent movement) = 8.0 feet. From Figure 3, the corresponding (statistical) –3σ withstand voltage for 8.0 feet is 930 V_{PEAK}.
— Do not use Figure 3; 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) +2σ sparkover voltage (110% of gap V_{50}) equal to or less than 930 V_{PEAK}. Therefore, the gap V_{50} must be equal to or less than

$$V_{50} < (930 \text{ kilovolts}) \div (1.10) = 845\ V_{PEAK}$$

— For example, if tests on a particular protective gap with a 5.8 feet gap spacing had a U_{50} equal to 820 V_{PEAK}, select this gap spacing.
— The (statistical) –3σ withstand voltage of the protective gap is (820 kilovolts) x (0.85) = 697 V_{PEAK}. The maximum operating peak voltage is

$$(550 \text{ kilovolts} \div \sqrt{3}) \text{ x } \sqrt{2} = 449\ V_{PEAK}$$

— Therefore, the maximum per unit transient overvoltage that could be allowed while the protective gap is installed is

697 kilovolts ÷ 449 kilovolts = 1.55 or 155%.

— If the risk of this occurrence is acceptable, then the PPAG tool and new minimum approach distance can be used.

Annex D

(informative)

Tables in feet

Table D.1—Altitude correction factor

Feet	Correction factor
0–3000	1.00
3001–4000	1.02
4001–5000	1.05
5001–6000	1.08
6001–7000	1.11
7001–8000	1.14
8001–9000	1.17
9001–10 000	1.20
10 001–12 000	1.25
12 000–14000	1.30
14 000–16 000	1.35
16 001–18 000	1.39
18 001–20 000	1.44

NOTES

1—The correction factor applies only to the MAID and not to the inadvertent movement factor:

a—For the MAID Tables, multiply the distance D given in Table D.2 through Table D.9 by the correction factor for altitude at which the work is being preformed.

b—For the MAD Tables, multiply the distance D given in Table D.11 through Table D.17, minus the inadvertent factor from Table D.10 by the correction factor for altitude at which the work is being performed, and then add in the inadvertent factor from Table D.10 again.

2—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 15 mph, unsaturated air, normal barometer (30 inches of mercury at sea level), uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

3—If the actual altitude at the work location and current barometric pressure is not known, the altitude, corrected for the local current barometric pressure, can be determined by use of an aircraft type altimeter adjusted for a zero altitude at 30 inches of mercury at sea level.

4—For metric values, see Table 1.

Table D.2—Example of detailed calculations for air gap distance (MAID) phase-to-ground work 72 500 Volts or less in feet

1	2	3	4	5	6
Maximum phase-to-phase voltage in kilovolts (V_M)	**Overvoltage in p.u. (T)**	**Maximum phase-to-phase voltage on a p.u. base in kilovolts**	**Maximum peak voltage in kilovolts**	**Maximum peak voltage 3σ in kilovolts**	**Electrical withstand distance in feet**
0.30	3.0	0.52	0.73	0.87	0.003
0.75	3.0	1.30	1.84	2.17	0.006
15.0	3.0	26.0	36.7	43.2	0.123
36.0	3.0	62.4	88.2	104.0	0.524
46.0	3.0	79.7	113.0	133.0	0.746
72.5	3.0	126.0	178.0	209.0	1.256

NOTES

1—Column #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—Column #3 = (Column #1)(Column #2)/ $\sqrt{3}$.

3—Column #4 = (Column #3) $\sqrt{2}$.

4—Column #5 = (Column #4)/0.8555.

5—Column #6 = The basic electrical withstand (W/S) distance is determined by use of IEEE Std 4-1978, Annex 2B [B15], using linear interpolation between the two values that bracket the maximum overvoltage, plus 3σ peak, of Column #5. The centimeters/kilovolts for the 2-cm test has been used for the two lowest voltage ranges.

6—Values are based on altitudes below 3000 feet. See Table D.1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

7—Table distances do not include any factor for inadvertent movement. See 7.2 for inadvertent movement considerations. These factors must be added to the values in Column #6 to obtain the total MAD.

8—Higher or lower transient overvoltage factors can occur depending on the design and operation of the system.

9—For single-phase systems with a solidly grounded neutral, use voltage line-to-ground.

10—For single-phase systems without a solidly grounded neutral, use voltage phase-to-phase.

11—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 24 kilometers per hour, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

12—For metric values, see Table 3.

Table D.3—Example of detailed calculations for MAID 60 Hz. Energized work, without tools in the air gap, when the transient overvoltage factors (T) is not known in feet

Voltage in kilovolts phase to phase	Distance in feet	
	Phase to ground	Phase to phase
72.6–121	2.45	3.56
138–145	2.94	4.27
161–169	3.42	4.96
230–242	5.14	7.46
345–362	9.44	13.69
500–550	14.68	22.61
765–800	20.44	33.53

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—Values are based on altitudes below 3000 feet. See Table D.1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

3—Table distances include a factor for inadvertent movement. See 7.2 for inadvertent movement considerations. These factors must be added to the values to obtain the total MAD.

4—The clear live tool length should be equal to or exceed these values for the indicated voltage ranges.

5—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 15 mph, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

6—Data for this table was obtained from Table D.5 and Table D.8.

7—For metric values, see Table 5.

Table D.4—Example of detailed calculations for MAID 60 Hz. Energized work, with tools in the air gap, when the transient overvoltage factors (T) is not known in feet

Voltage in kilovolts phase to phase	Distance in feet	
	Phase to ground	Phase to phase
72.6–121	2.70	3.92
138–145	3.23	4.69
161–169	3.76	5.46
230–242	5.63	8.17
345–362	10.17	14.75
500–550	15.63	24.08
765–800	21.60	35.43

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—Values are based on altitudes below 3000 feet. See Table D.1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

3—Table distances include a factor for inadvertent movement. See 7.2 for inadvertent movement considerations. These factors must be added to the values to obtain the total MAD.

4—The clear live tool length should be equal to or exceed these values for the indicated voltage ranges.

5—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 15 mph, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

6—Data for this table was obtained from Table D.6 and Table D.9.

7—For metric values, see Table 6.

Table D.5—MAID phase to ground, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in feet

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	feet	feet	feet	feet	feet	feet	feet
1.5	1.05	1.26	1.47	2.10	3.14	4.96	8.67
1.6	1.12	1.34	1.57	2.24	3.35	5.44	9.61
1.7	1.19	1.43	1.66	2.38	3.56	5.94	10.61
1.8	1.26	1.51	1.76	2.52	3.77	6.46	11.64
1.9	1.33	1.60	1.86	2.66	3.98	7.00	12.73
2.0	1.40	1.68	1.96	2.80	4.19	7.63	13.95
2.1	1.47	1.76	2.05	2.94	4.39	8.21	15.14
2.2	1.54	1.85	2.15	3.08	4.70	8.81	16.37
2.3	1.61	1.93	2.25	3.22	5.00	9.43	17.64
2.4	1.68	2.01	2.35	3.36	5.32	10.07	19.07
2.5	1.75	2.10	2.44	3.50	5.65	10.80	20.44
2.6	1.82	2.18	2.54	3.64	5.98	11.48	
2.7	1.89	2.27	2.64	3.78	6.33	12.27	
2.8	1.96	2.35	2.74	3.92	6.74	13.08	
2.9	2.03	2.43	2.83	4.06	7.10	13.82	
3.0	2.10	2.52	2.93	4.20	7.47	14.68	
3.1	2.17	2.60	3.03	4.34	7.85		
3.2	2.24	2.68	3.03	4.52	8.23		
3.3	2.31	2.77	3.23	4.71	8.63		

Table D.5—MAID phase to ground, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in feet *(continued)*

$V_{P–P}$ $V_{P–G}$	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**
3.4	2.38	2.85	3.32	4.90	9.03		
3.5	2.45	2.94	3.42	5.14	9.44		

NOTES

1—Distances listed are for standard atmospheric conditions. The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 15 mph, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

2—Values are based on altitudes below 3000 feet (see Table D.1).

3—Distances do not include any factor for inadvertent movement (see 7.2).

4—Tables were calculated using the formulas from 4.2.2.3 and rounded up.

5—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which have introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

6—When the value of T being used in this table, has a significant decimal figure beyond the value listed in the Table D.9, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

7—For metric values, see Table 7.

Table D.6—MAID phase to ground, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in feet

$V_{P–P}$ $V_{P–G}$	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**
1.5	1.16	1.39	1.62	2.31	3.45	5.44	9.36
1.6	1.23	1.48	1.72	2.46	3.68	5.95	10.35
1.7	1.31	1.57	1.83	2.62	3.91	6.48	11.39
1.8	1.39	1.66	1.94	2.77	4.14	7.04	12.48
1.9	1.47	1.75	2.04	2.93	4.37	7.61	13.61
2.0	1.54	1.85	2.15	3.08	4.60	8.26	14.88
2.1	1.62	1.94	2.26	3.23	4.83	8.87	16.11

Table D.6—MAID phase to ground, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in feet *(continued)*

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**
2.2	1.70	2.03	2.37	3.39	5.16	9.51	17.38
2.3	1.77	2.12	2.47	3.54	5.49	10.16	18.70
2.4	1.85	2.22	2.58	3.69	5.82	10.83	20.18
2.5	1.93	2.31	2.69	3.85	6.17	11.60	21.60
2.6	2.00	2.40	2.80	4.00	6.53	12.31	
2.7	2.08	2.49	2.90	4.16	6.89	13.12	
2.8	2.16	2.58	3.01	4.31	7.32	13.96	
2.9	2.23	2.68	3.12	4.46	7.70	14.74	
3.0	2.31	2.77	3.23	4.62	8.09	15.63	
3.1	2.39	2.86	3.33	4.77	8.49		
3.2	2.46	2.95	3.44	4.97	8.90		
3.3	2.54	3.04	3.55	5.17	9.32		
3.4	2.62	3.14	3.65	5.37	9.74		
3.5	2.70	3.23	3.76	5.63	10.17		

NOTES

1—Distances listed are for standard atmospheric conditions. The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 15 mph, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

2—Values are based on altitudes below 3000 feet (see Table D.1).

3—Distances do not include any factor for inadvertent movement (see 7.2).

4—Tables were calculated using the formulas from 4.2.2.3 and rounded up.

5—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which have introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

6—When the value of T being used in this table, has a significant decimal figure beyond the value listed in the Table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

7—For metric values, see Table 8.

Table D.7—MAID pole-to-ground, dc energized work, using the transient overvoltage factor, in feet

V_{P-G}	250 kilovolts		400 kilovolts		500 kilovolts		600 kilovolts		750 kilovolts	
T	**a**	**feet**	**a**	**feet**	**a**	**feet**	**a**	**feet**	**a**	**feet**
1.5 or below	0.0	2.66	0.0	4.24	0.8	5.73	1.9	7.57	3.6	10.52
1.6	0.0	2.83	0.0	4.53	1.2	6.34	2.3	8.38	4.2	12.05
1.7	0.0	3.01	0.3	4.95	1.5	6.91	2.8	9.23	4.8	13.34
1.8	0.0	3.19	0.6	5.40	1.9	7.57	3.3	10.11	5.4	14.70

NOTES

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

2—Distances listed are for standard atmospheric conditions. The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 15 mph, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

3—Distances are based on altitudes below 3000 feet (see Table D.1). It is not necessary to correct for other atmospheric conditions.

4—Distances do not include any factor for inadvertent movement (see 7.2).

5—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 1.61; use T = 1.7.

6—For metric values, see Table 9.

Table D.8—MAID phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in feet

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**
1.5	1.35	1.62	1.89	2.69	4.02	6.35	11.10
1.6	1.58	1.89	2.22	3.16	4.73	7.68	13.56
1.7	1.83	2.19	2.54	3.65	5.45	9.09	16.24
1.8	2.06	2.47	2.87	4.11	6.15	10.53	18.98
1.9	2.31	2.77	3.22	4.61	6.89	12.11	22.03
2.0	2.52	3.03	3.53	5.04	7.55	13.74	25.11
2.1	2.61	3.12	3.63	5.21	7.78	14.54	26.80

Table D.8—MAID phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in feet *(continued)*

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	feet	feet	feet	feet	feet	feet	feet
2.2	2.67	3.21	3.72	5.33	8.14	15.25	28.33
2.3	2.74	3.29	3.83	5.48	8.50	16.04	29.99
2.4	2.81	3.36	3.93	5.62	8.89	16.82	31.85
2.5	2.87	3.45	4.01	5.74	9.27	17.72	33.53
2.6	2.95	3.54	4.12	5.90	9.69	18.60	
2.7	3.03	3.64	4.23	6.05	10.13	19.64	
2.8	3.10	3.72	4.33	6.20	10.65	20.67	
2.9	3.17	3.80	4.42	6.34	11.08	21.56	
3.0	3.24	3.89	4.52	6.47	11.51	22.61	
3.1	3.30	3.96	4.61	6.60	11.94		
3.2	3.36	4.02	4.70	6.78	12.35		
3.3	3.45	4.13	4.82	7.02	12.86		
3.4	3.50	4.19	4.89	7.21	13.28		
3.5	3.56	4.27	4.96	7.46	13.69		

NOTES

1—Distances listed are for standard atmospheric conditions. The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 15 mph, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

2—Distances are based on altitudes below 3000 feet (see Table D.1).

3—The table was calculated from data in Table 10 and Table D.5 and rounded up.

4—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

5—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

6—For metric values, see Table 11.

Table D.9—MAID phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in feet

V_{P-P} V_{P-G}	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**
1.5	1.49	1.78	2.08	2.96	4.42	6.97	11.99
1.6	1.74	2.09	2.43	3.47	5.19	8.39	14.60
1.7	2.01	2.41	2.80	4.01	5.99	9.92	17.43
1.8	2.27	2.71	3.17	4.52	6.75	11.48	20.35
1.9	2.55	3.03	3.53	5.07	7.57	13.17	23.56
2.0	2.78	3.33	3.87	5.55	8.28	14.87	26.79
2.1	2.87	3.44	4.01	5.72	8.55	15.70	28.52
2.2	2.95	3.52	4.11	5.87	8.93	16.46	30.07
2.3	3.01	3.61	4.20	6.02	9.34	17.28	31.79
2.4	3.09	3.71	4.31	6.17	9.72	18.09	33.71
2.5	3.17	3.79	4.42	6.32	10.12	19.03	35.43
2.6	3.24	3.89	4.54	6.48	10.58	19.95	
2.7	3.33	3.99	4.64	6.66	11.03	21.00	
2.8	3.42	4.08	4.76	6.81	11.57	22.06	
2.9	3.48	4.19	4.87	6.96	12.02	23.00	
3.0	3.56	4.27	4.98	7.12	12.46	24.08	
3.1	3.64	4.35	5.07	7.26	12.91		
3.2	3.69	4.43	5.16	7.46	13.35		
3.3	3.79	4.53	5.29	7.71	13.89		

Table D.9—MAID phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in feet *(continued)*

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**
3.4	3.86	4.62	5.37	7.90	14.32		
3.5	3.92	4.69	5.46	8.17	14.75		

NOTES

1—Distances listed are for standard atmospheric conditions. The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 15 mph, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

2—Distances are based on altitudes below 3000 feet (see Table D.1).

3—The table was calculated from data in Table 10 and Table D.6 and rounded up.

4—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

5—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

6—For metric values, see Table 12.

Table D.10—Minimum suggested inadvertent movement factors

Voltage range in kilovolts phase-to-phase	Inadvertent movement factor	Comments
0.000–0.050	Not Specified	—
0.051–0.300	Avoid contact	Similar to 120 V house-hold voltage
0.301–0.750	Add 1 foot	Concern of hazard from self-sustaining arc
0.751–72.5	Add 2 feet	Based on ergometric considerations of worker and equipment movement
72.6–800	Add 1 foot	Based on ergometric considerations of worker and equipment movement

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.

3—For metric distances, see Table 17.

Table D.11—Example of detailed calculations for MAD 60 Hz. energized work, without tools in the air gap, when the transient overvoltage factors (T) is not known, in feet

Voltage in kilovolts phase to phase	Distance in feet	
	Phase to ground	Phase to phase
72.6–121	3.45	4.56
138–145	3.94	5.27
161–169	4.42	5.96
230–242	6.14	8.46
345–362	10.44	14.69
500–550	15.68	23.61

Table D.11—Example of detailed calculations for MAD 60 Hz. energized work, without tools in the air gap, when the transient overvoltage factors (T) is not known, in feet *(continued)*

Voltage in kilovolts phase to phase	Distance in feet	
	Phase to ground	Phase to phase
765–800	21.44	34.53

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—Values are based on altitudes below 3000 feet. See Table D.1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

3—Table distances include a factor for inadvertent movement. See 7.2 for inadvertent movement considerations. These factors must be added to the values to obtain the total MAD.

4—The clear live tool length should be equal or exceed these values for the indicated voltage ranges.

5—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 15 mph, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

6—Data for this table was obtained from Table D.13 and Table D.15.

7—For metric values, see Table 18.

Table D.12—Example of detailed calculations for MAD 60 Hz energized work, with tools in the air gap, when the transient overvoltage factors (T) is not known, in feet

Voltage in kilovolts phase to phase	Distance in feet	
	Phase to ground	Phase to phase
72.6–121	3.70	4.92
138–145	4.23	5.69
161–169	4.76	6.46
230–242	6.63	9.17
345–362	11.17	15.75
500–550	16.63	25.08

Table D.12—Example of detailed calculations for MAD 60 Hz energized work, with tools in the air gap, when the transient overvoltage factors (T) is not known, in feet *(continued)*

Voltage in kilovolts phase to phase	Distance in feet	
	Phase to ground	Phase to phase
765–800	22.60	36.43

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—Values are based on altitudes below 3000 feet. See Table D.1 for correction factors for higher altitudes. It is not necessary to correct for atmospheric conditions.

3—Table distances include a factor for inadvertent movement. See 7.2 for inadvertent movement considerations. These factors must be added to the values to obtain the total MAD.

4—The clear live tool length should be equal or exceed these values for the indicated voltage ranges.

5—The data used to formulate this table was obtained from test data taken with standard atmospheric conditions. Standard atmospheric conditions are defined as temperatures above freezing, wind less than 15 mph, unsaturated air, normal barometer, uncontaminated air, and clean and dry insulators. If standard atmospheric conditions do not exist, extra care must be taken.

6—Data for this table was obtained from Table D.14 and Table D.16.

7—For metric values, see Table 19.

Table D.13—MAD phase-to-ground, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in feet

V_{P-P} V_{P-G}	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**
1.5	2.05	2.26	2.47	3.10	4.14	5.96	9.67
1.6	2.12	2.34	2.57	3.24	4.35	6.44	10.61
1.7	2.19	2.43	2.66	3.38	4.56	6.94	11.61
1.8	2.26	2.51	2.76	3.52	4.77	7.46	12.64
1.9	2.33	2.60	2.86	3.66	4.98	8.00	13.73
2.0	2.40	2.68	2.96	3.80	5.19	8.63	14.95
2.1	2.47	2.76	3.05	3.94	5.39	9.21	16.14
2.2	2.54	2.85	3.15	4.08	5.70	9.81	17.37

Table D.13—MAD phase-to-ground, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in feet *(continued)*

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	feet	feet	feet	feet	feet	feet	feet
2.3	2.61	2.93	3.25	4.22	6.00	10.43	18.64
2.4	2.68	3.01	3.35	4.36	6.32	11.07	20.07
2.5	2.75	3.10	3.44	4.50	6.65	11.80	21.44
2.6	2.82	3.18	3.54	4.64	6.98	12.48	
2.7	2.89	3.27	3.64	4.78	7.33	13.27	
2.8	2.96	3.35	3.74	4.92	7.74	14.08	
2.9	3.03	3.43	3.83	5.06	8.10	14.82	
3.0	3.10	3.52	3.93	5.20	8.47	15.68	
3.1	3.17	3.60	4.03	5.34	8.85		
3.2	3.24	3.68	4.13	5.52	9.23		
3.3	3.31	3.77	4.23	5.71	9.63		
3.4	3.38	3.85	4.32	5.90	10.03		
3.5	3.45	3.94	4.42	6.14	10.44		

NOTES

1—The distance specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known. It the maximum anticipated per-unit transient overvoltage is not known or is not limited by external means (for example, by installation of a transient control device), the highest per-unit transient overvoltage listed in the table should be used.

2—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

3—Table was calculated from Table D.5 with 1 foot added for the inadvertent movement and rounded up.

4—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

5—For metric values, see Table 20.

Table D.14—MAD phase-to-ground, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in feet

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	feet	feet	feet	feet	feet	feet	feet
1.5	2.16	2.39	2.62	3.31	4.45	6.44	10.36
1.6	2.23	2.48	2.72	3.46	4.68	6.95	11.35
1.7	2.31	2.57	2.83	3.62	4.91	7.48	12.39
1.8	2.39	2.66	2.94	3.77	5.14	8.04	13.48
1.9	2.47	2.75	3.04	3.93	5.37	8.61	14.61
2.0	2.54	2.85	3.15	4.08	5.60	9.26	15.88
2.1	2.62	2.94	3.26	4.23	5.83	9.87	17.11
2.2	2.70	3.03	3.37	4.39	6.16	10.51	18.38
2.3	2.77	3.12	3.47	4.54	6.49	11.16	19.70
2.4	2.85	3.22	3.58	4.69	6.82	11.83	21.18
2.5	2.93	3.31	3.69	4.85	7.17	12.60	22.60
2.6	3.00	3.40	3.80	5.00	7.53	13.31	
2.7	3.08	3.49	3.90	5.16	7.89	14.12	
2.8	3.16	3.58	4.01	5.31	8.32	14.96	
2.9	3.23	3.68	4.12	5.46	8.70	15.74	
3.0	3.31	3.77	4.23	5.62	9.09	16.63	
3.1	3.39	3.86	4.33	5.77	9.49		
3.2	3.46	3.95	4.44	5.97	9.90		

Table D.14—MAD phase-to-ground, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in feet *(continued)*

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	feet	feet	feet	feet	feet	feet	feet
3.3	3.54	4.04	4.55	6.17	10.32		
3.4	3.62	4.14	4.65	6.37	10.74		
3.5	3.70	4.23	4.76	6.63	11.17		

NOTES

1—The distance specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known. It the maximum anticipated per-unit transient overvoltage is not known or is not limited by external means (for example, by installation of a transient control device), the highest per-unit transient overvoltage listed in the table should be used.

2—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

3—Table was calculated from Table D.6 with 1 foot added for the inadvertent movement and rounded up.

4—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

5—For metric values, see Table 21.

Table D.15—MAD phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in feet

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	feet	feet	feet	feet	feet	feet	feet
1.5	2.35	2.62	2.89	3.69	5.02	7.35	12.10
1.6	2.58	2.89	3.22	4.16	5.73	8.68	14.56
1.7	2.83	3.19	3.54	4.65	6.45	10.09	17.24
1.8	3.06	3.47	3.87	5.11	7.15	11.53	19.98
1.9	3.31	3.77	4.22	5.61	7.89	13.11	23.03
2.0	3.52	4.03	4.53	6.04	8.55	14.74	26.11
2.1	3.61	4.12	4.63	6.21	8.78	15.54	27.80
2.2	3.67	4.21	4.72	6.33	9.14	16.25	29.33

Table D.15—MAD phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, without tools in the air gap in feet *(continued)*

V_{P-P} V_{P-G}	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**
2.3	3.74	4.29	4.83	6.48	9.50	17.04	30.99
2.4	3.81	4.36	4.93	6.62	9.89	17.82	32.85
2.5	3.87	4.45	5.01	6.74	10.27	18.72	34.53
2.6	3.95	4.54	5.12	6.90	10.69	19.60	
2.7	4.03	4.64	5.23	7.05	11.13	20.64	
2.8	4.10	4.72	5.33	7.20	11.65	21.57	
2.9	4.17	4.80	5.42	7.34	12.08	22.56	
3.0	4.24	4.89	5.52	7.47	12.51	23.61	
3.1	4.30	4.96	5.61	7.60	12.94		
3.2	4.36	5.02	5.70	7.78	13.35		
3.3	4.45	5.13	5.82	8.02	13.86		
3.4	4.50	5.19	5.89	8.21	14.28		
3.5	4.54	5.27	5.96	8.46	14.69		

NOTES

1—The distance specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known. It the maximum anticipated per-unit transient overvoltage is not known or is not limited by external means (for example, by installation of a transient control device), the highest per-unit transient overvoltage listed in the table should be used.

2—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

3—Table was calculated from Table D.8 with 1 foot added for the inadvertent movement and rounded up.

4—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

5—For metric values, see Table 22.

Table D.16—MAD phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in feet

V_{P-P} V_{P-G}	121 69.9	145 83.7	169 97.6	242 140	362 209	550 318	800 462
T	feet	feet	feet	feet	feet	feet	feet
1.5	2.49	2.78	3.08	3.96	5.42	7.97	12.99
1.6	2.74	3.09	3.43	4.47	6.19	9.39	15.60
1.7	3.01	3.41	3.80	5.01	6.99	10.92	18.43
1.8	3.27	3.72	4.17	5.52	7.75	12.48	21.35
1.9	3.55	4.03	4.53	6.07	8.57	14.17	24.55
2.0	3.78	4.33	4.87	6.55	9.28	15.87	27.79
2.1	3.87	4.44	5.01	6.72	9.55	16.70	29.52
2.2	3.95	4.52	5.11	6.87	9.93	17.46	31.07
2.3	4.01	4.61	5.20	7.02	10.34	18.28	32.79
2.4	4.09	4.71	5.31	7.17	10.72	19.09	34.71
2.5	4.17	4.79	5.42	7.32	11.12	20.03	36.43
2.6	4.24	4.89	5.54	7.48	11.58	20.95	
2.7	4.33	4.99	5.64	7.66	12.03	22.00	
2.8	4.42	5.08	5.76	7.81	12.57	23.06	
2.9	4.48	5.19	5.87	7.96	13.02	24.00	
3.0	4.56	5.27	5.98	8.12	13.46	25.08	
3.1	4.64	5.35	6.07	8.26	13.91		
3.2	4.69	5.43	6.16	8.46	14.35		
3.3	4.79	5.53	6.29	8.71	14.89		

Table D.16—MAD phase-to-phase, 60 Hz energized work, using the transient overvoltage factor, with tools in the air gap in feet *(continued)*

V_{P-P} V_{P-G}	**121** **69.9**	**145** **83.7**	**169** **97.6**	**242** **140**	**362** **209**	**550** **318**	**800** **462**
T	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**	**feet**
3.4	4.86	5.62	6.37	8.90	15.32		
3.5	4.92	5.69	6.46	9.17	15.75		

NOTES

1—The distance specified in this table may be applied only when the maximum anticipated per-unit transient overvoltage is known. It the maximum anticipated per-unit transient overvoltage is not known or is not limited by external means (for example, by installation of a transient control device), the highest per-unit transient overvoltage listed in the table should be used.

2—Historical maximum p.u. transient overvoltage values (shown above the heavy line) for 121 to 362 kilovolts was 3 p.u., for 550 kilovolts was 2.4 p.u., and for 800 kilovolts was 2 p.u. The values listed below the heavy line are transient overvoltage p.u. values caused by the use of single break interrupters devices, which were introduced into the US market in the early 1990s. If these single break interrupting devices are not in use on your system, the historical values may still apply.

3—Table was calculated from Table D.9 with 1 foot added for the inadvertent movement and rounded up.

4—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 2.51; use T = 2.6.

5—For metric values, see Table 23.

Table D.17—MAD dc-energized work, using the transient overvoltage factor, conductor-to-worker, clear live-line tool and barehand distance in feet

Maximum anticipated per-unit transient overvoltage	Maximum pole-to-pole voltage (kilovolts)				
	250	**400**	**500**	**600**	**750**
1.50 or lower	3.68	5.25	6.76	8.60	11.85
1.31–1.60	3.84	5.55	7.35	9.39	13.06
1.61–1.70	4.04	5.98	7.91	10.24	14.34
1.71–1.80	4.20	6.40	8.60	11.13	15.72

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 per-unit maximum anticipated transient overvoltage factor (T) is not known, a T factor of 1.8 shall be used.

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

4—Distances are based on altitudes below 3000 feet (see Table D.1). It is not necessary to correct for other atmospheric conditions.

5—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example: T = 1.61; use T = 1.7.

6—For metric distances, see Table 24.