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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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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

¹The 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/>).

²ANSI 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/>).

³ASTM 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

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

⁵CFR 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/>).

⁶IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, 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 4TM-1995 (Reaff 2001), IEEE Standard Techniques for High Voltage Testing.^{7, 8}

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

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

IEEE Std 524aTM-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 935TM-1995 (Reaff 2001), IEEE Guide on Terminology for Tools and Equipment to Be Used in Live Line Working.

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

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

IEEE Std 1067TM-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 1070TM-1995, IEEE Guide for the Design and Testing of Transmission Modular Restoration Structure Components.

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

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⁸IEEE 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.

⁹Information on references can be found in Clause 2.

¹⁰The 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

¹¹See 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. <i>Syn: critical sparkover voltage</i>
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.

¹²See 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.

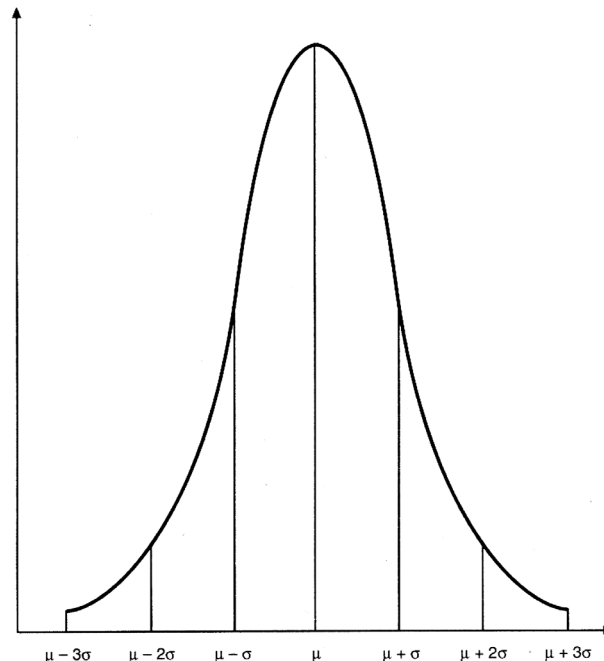
4.2.2 Minimum air insulation distance (MAID)

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.

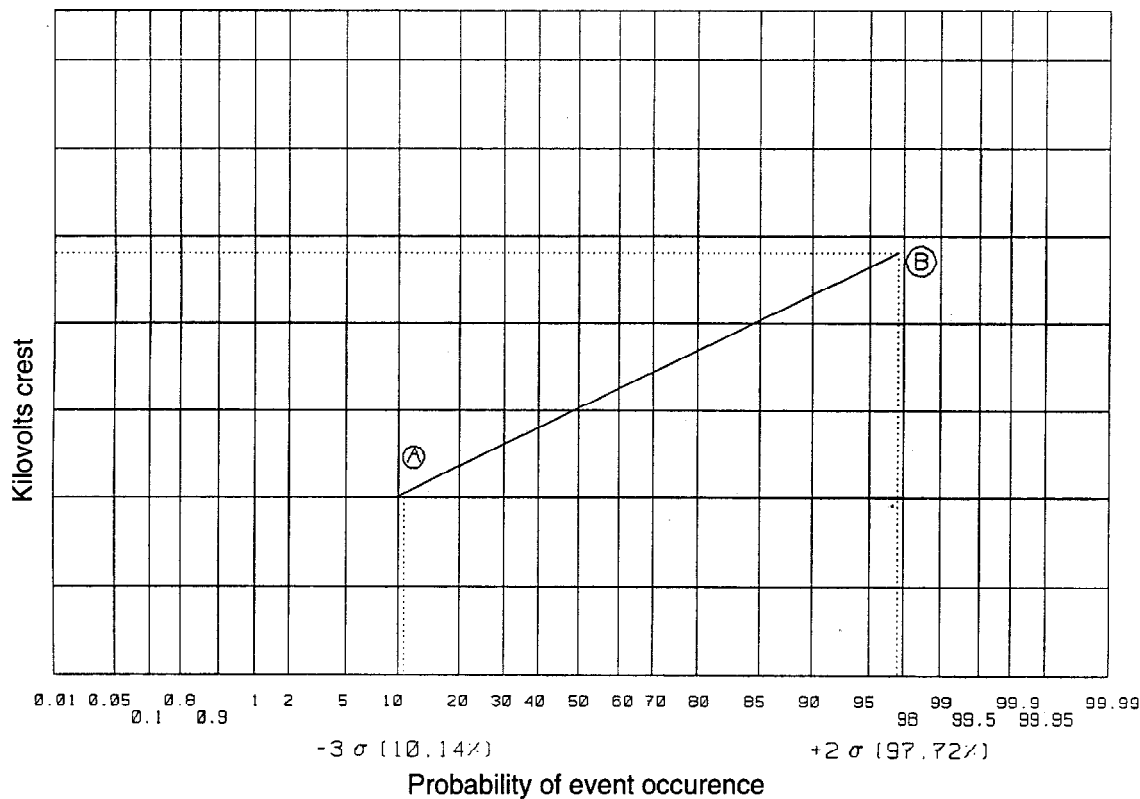


NOTE—This figure is a copy of a statistical textbook plot and is used as an example of a plot and does not show the actual test results.

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.

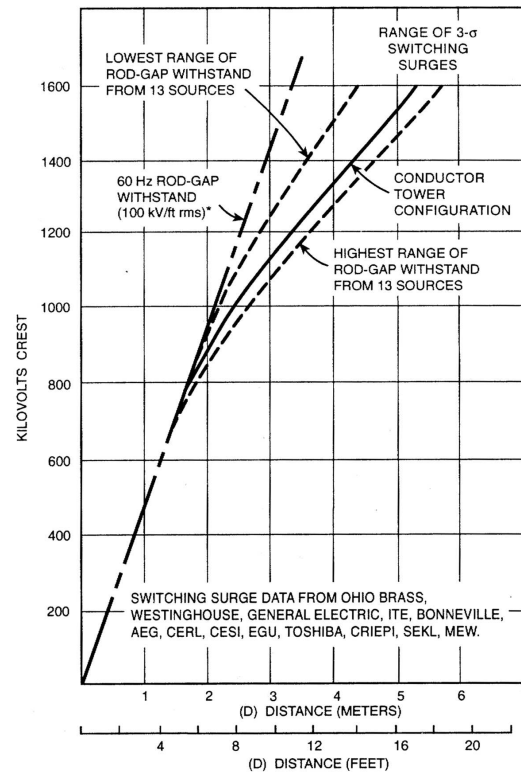
8—Higher or lower transient overvoltage factors can occur depending on the design and operation of the system.

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.

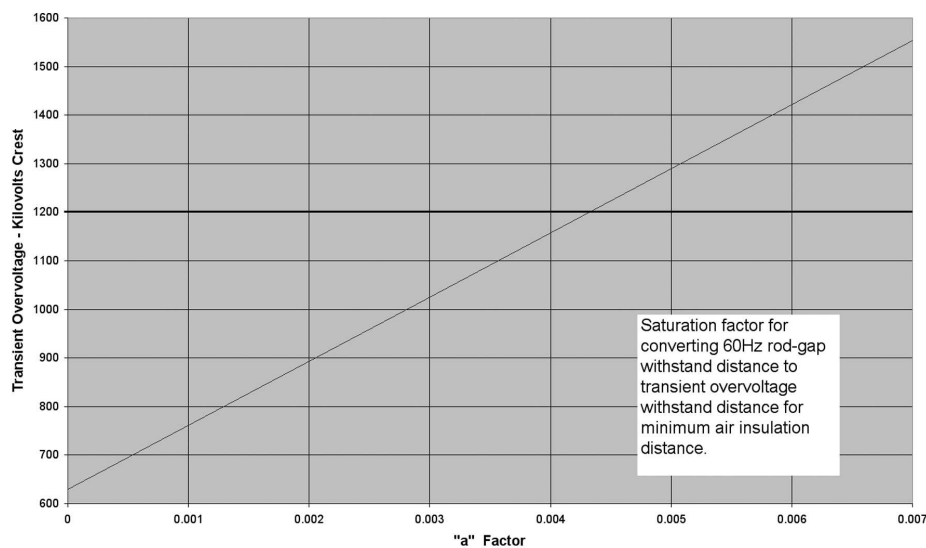
12—For values in feet, see Table D.2.



* 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.

¹³This 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:

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

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.

¹⁴For 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:

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

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

¹⁵For 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.		

¹⁶900 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-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).

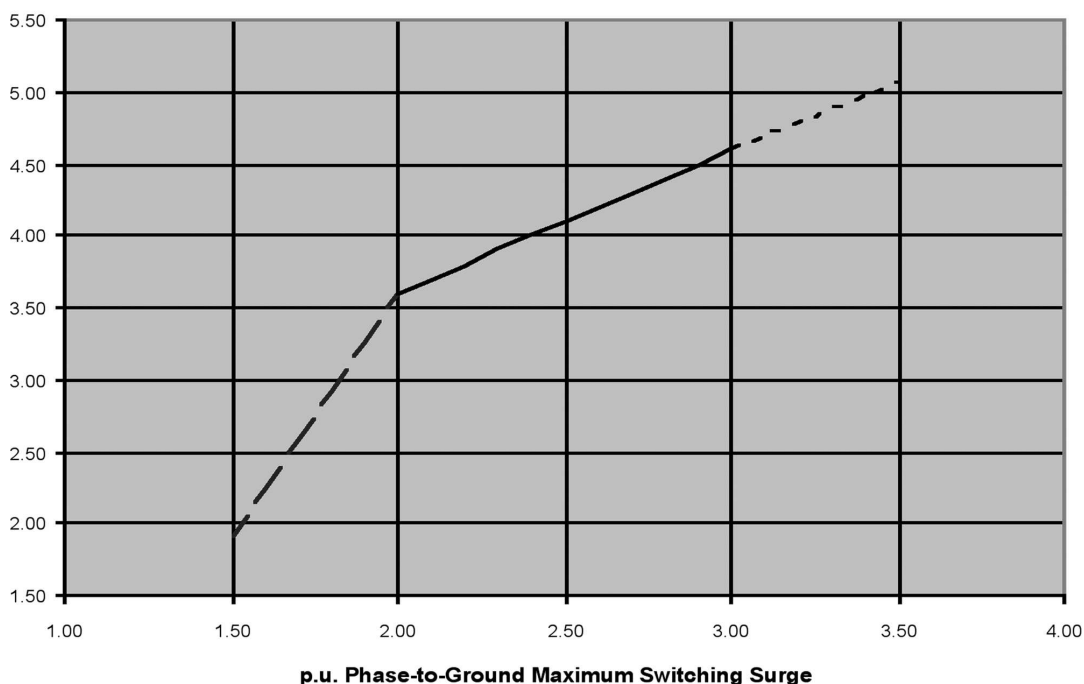
5—When the value of T being used in this table has a significant decimal figure beyond the value listed in the table, the next higher value of T should be used. Example T = 1.61; use T = 1.7.

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 = $(2.28 \text{ m})(4.6)/(3.0)$ or $(2.28 \text{ m})(1.54) = 3.50 \text{ m}$

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