



IEEE Guide for Maintenance Methods on Energized Power Lines

IEEE Power & Energy Society

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Transmission and Distribution Committee

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IEEE Guide for Maintenance Methods on Energized Power Lines

Sponsor

Transmission and Distribution Committee
of the
IEEE Power & Energy Society

Approved 13 May 2009

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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 516-2009, IEEE Guide for Maintenance Methods on Energized Power Lines.

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

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

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

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 guide. Since the original publication of the guide, the ESMOL Subcommittee has been working on 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 guides in this edition to expand the scope of the guide to cover more of the industry's needs.

In the guide editions up to 1995, most of table data were obtained from plots. In the 2003 guide, the tables were calculated using the formulas in the guide in a step calculation method.

In this edition of the guide, the tables were calculated using the formulas in the guide. Additional text has been added on the determination of maximum anticipated per-unit transient overvoltage (TOV) T and use of the minimum air insulation distance (MAID) and minimum approach distance (MAD).

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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1. Overview

1.1 Scope

This guide provides the 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 for persons working in 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 with maximum safety.
- 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~~ an appropriate work area, taking into consideration safety and the physical effects of the work area on personnel.

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

1.3 Application

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

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

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

The approach used in this guide is to

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

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

CAUTION

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 shall take precedence.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used; therefore, each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

~~electric arcs 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 care~~
- ~~— Insulator cleaning~~
- ~~— Hazard assessment of workers' clothes exposed~~

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

ANSI/SIA A92.2, American National Standard for Vehicle-Mounted Elevating and Rotating Aerial Devices.¹

[ASTM D 120, Standard Specification for Rubber Insulating Gloves](#).²

~~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.~~

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ASTM D 1048, Standard Specification for Rubber Insulating Blankets.

ASTM D 1049, Standard Specification for Rubber Insulating Covers.

[ASTM D 1050, Standard](#) Specification for Rubber Insulating Line Hose.

~~ASTM D1050-90 (Reaff 1999), D1051-95 (Reaff 2000),~~

ASTM [D 1051, Standard](#) Specification for Rubber Insulating Sleeves.

ASTM [F 478, Standard](#) Specification for In-service Care of Insulating Line Hose and Covers.

ASTM ~~-95 (Reaff 2001)~~, F 479, [Standard](#) Specification for In-service Care of Insulating Blankets.

ASTM F 496, [Standard](#) Specification for In-service Care of Insulating Gloves and Sleeves.

[ASTM F 696, Standard Specification](#) for Leather Protectors for Rubber Insulating Gloves and Mittens.

ASTM F 711, Standard Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used in Live Line Tools.

ASTM ~~-88 (Reaff 2000), Test Methods of Testing~~ F 712, Electrically Insulating Plastic Guard Equipment for Protection of Workers.

ASTM F 855, Standard Specification for Temporary Protective Grounds [to be](#) Used on De-Energized Electric Power Lines ~~F968-98, Specification for Electrically Insulating Plastic Guard~~ [and](#) Equipment.

ASTM F 968, Standard Specification for [Electrically Insulating Plastic Guard Equipment for](#) Protection of Workers.

ASTM ~~96 (Reaff 2001)~~, F 1236, [Standard](#) Guide for Visual Inspection of Electrical Protective Rubber Products.

ASTM ~~96 (Reaff 2001)~~, F 1701, Standard Specification for Unused Polypropylene Rope with Special Electrical Properties.

[ASTM F 2522-05, Standard Test Method for Determining the Protective Performance of a Shield Attached on Live Line Tools or on Racking Rods for Electric Arc Hazards.](#)

CSA C225-~~00~~, Vehicle-Mounted Aerial Devices.³

[IEC 60060-1, High-Voltage Test Techniques—Part 1: General Definitions and Test Requirements.](#)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)~~[60060-3](#), High- Voltage ~~Switches, Part 1: High- Test Techniques—Part 3: Measuring Devices.~~

~~Switches For Rated Voltages Above 1 Kilovolts~~

[IEC 60060-4, High-Voltage Test Techniques—Part 4: Application Guide for Measuring Devices.](#)

[IEC 60625-1, Programmable Measuring Instruments—Interface System \(byte serial, bit parallel\)—Part 1: Functional, Electrical and Mechanical Specification, System Applications and ~~Less Than 52 Kilovolts.~~](#)⁶
[Requirements for the Designer and User.](#)

IEC 60625-2, Programmable Measuring Instruments—Interface System (byte serial, bit parallel)—Part 2: Codes, Formats, Protocols and Common Commands.

³ CSA publications are available from the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Etobicoke, Ontario, Canada M9W 1R3 (<http://www.csa.ca/>).

⁴ IEC publications are available from the Sales Department of the International Electrotechnical Commission, ~~Case Postale 131~~, 3, rue de Varembe, ~~Case Postale 131~~, 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.

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/>).~~

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

IEC 60895-~~12 (1987)~~, [Live Working—Conductive Clothing for ~~Live Working~~ use](#) at Nominal Voltage up to 800 kV AC [and 600 kV DC](#).

IEC 60903-~~03 (1988)~~, Specifications for Glovers 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)~~ 61230, Live Working—Portable Equipment for Earthing or Earthing and Short-Circuiting.

IEC 61235, 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 1TM~~, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus Insulation—Part 1: Oil Filled Power Transformers, Regulators, and Reactors.^{5,6}

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

IEEE Std 935TM, IEEE Guide on Terminology for Tools and Equipment to be Used in Live Line ~~524TM-1993~~, Working.

IEEE Std 957TM, IEEE Guide for Cleaning Insulators.

~~IEEE Guide to Grounding During the Installation of Overhead Transmission Line Conductors: Supplement to IEEE Guide to the Installation of Overhead Transmission Conductors~~

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

IEEE Std 1067TM-~~1996~~, ~~TM~~, IEEE Guide for In-Service Use, Care, Maintenance, and Testing of Conductive Clothing for Use on Voltages up to 765 kV ac and ± 750 kV dc.

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

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

IEEE Std 1313.2TM, IEEE Guide for the Application of Insulation Coordination.

IEEE Std C62.92.1TM-2000 (Reaff 2005), IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems—Part I: Introduction.

ISO 2307, Fiber Ropes—Determination of Certain Physical and Mechanical Properties.⁷

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3. Definitions, acronyms, and abbreviations

3.1 Definitions

This subclause provides definitions for terms used in this guide ~~For the purposes of, the following terms and definitions apply.~~ Additional terminology can be found in IEEE Std 935-1995.^{9, 8} For terminologies not listed below or in IEEE Std 935, consult The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition [B9], should be referenced for terms not defined in this clause.¹⁰ [B22].⁹

3.1.1 aerial work: Work performed on equipment used for the transmission and distribution of electricity and performed in an elevated position on various structures, conductors, associated equipment from the structure, an insulating device, or a helicopter for barehand work.

3.1.2 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, ~~noneconductive~~ insulating rope, insulating aerial device, helicopter, or the energized wires or equipment ~~being worked on. It usually~~ which they are working. Most barehand work includes the use of insulating tools.

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

3.1.4 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. For some applications, the device is a platform with a railing generally constructed of conductive material. *Syn:* **basket; platform.**

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

3.1.6 clear live tool insulation distance: The distance measured longitudinally along the insulating part of the tool between the points where the tool contacts the live parts and parts at ground potential.

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 conducting body: A conductive object or ~~made of natural synthetic material that is either~~ mass such as a structure.

3.1.10 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 and of radio frequency (RF) fields of public communication system (PCS) antennas.

3.1.11 conductor: A wire or combination of wires not insulated from one another, suitable for carrying an electrical current. ~~However, it may be~~ Conductors can 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.~~

⁸ ~~Information on references can be found in Clause 2.~~

⁹ ~~The numbers in brackets correspond to the numbers of the bibliography in Annex A.~~

3.1.12 cover-up equipment: Equipment designed to protect persons from brush or inadvertent contact to energized parts in a specific worksite. Many different types are available to cover conductors, insulators, dead-end assemblies, structures, and apparatus. Cover-up material might be either flexible or rigid. *Syn:* blanket; cover-up; eel; hard cover; hose; snake.

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 critical flashover (CFO) voltage: Fifty percent probability of sparkover voltage.

3.1.14 current-carrying part: A conducting part intended to be connected in an electric circuit to a source of voltage. Noncurrent-carrying parts are parts not intended to be connected in such a manner.

3.1.15 de-energized: Disconnected from all intentional sources of electrical supply by open switches, jumpers, taps, or other means. De-energized conductors or equipment could be electrically charged or energized through various means, e.g., induction from energized circuits, portable generators, lightning.

3.1.16 disruptive discharge: The phenomenon 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.

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

3.1.18 equipotential: A nearly identical state of electrical potential for two or more items.

3.1.19 flashover: A disruptive discharge through air around and over a surface of solid or liquid insulation, between parts at different potential or accidental polarity, produced by application of voltage wherein the breakdown path becomes sufficiently ionized to maintain an electric ~~current-arc.~~ **ground:** ~~(1) earth-ground system: A conducting connection, whether intentional~~

3.1.20 floating object: An object that may or ~~equipment is~~ may not be conductive in the air gap at unknown potential.

3.1.21 floating potential: An electric charge impressed upon conductive objects suspended in the air gap that are not electrically connected to the earth, energized conductor or to some conducting body of relatively large extent that serves in place of the earthground.

NOTE—~~It is used for establishing 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)~~

3.1.22 gloving: A method of performing live work on energized electrical conductors and maintaining the potential of the earth (equipment where one or more workers, wearing specially made and tested insulating gloves, with or without sleeves, work directly on the energized electrical conductor or equipment.

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

3.1.24 ground potential: Potential equal to or near that of ground, normally zero volts.

3.1.25 helicopter work: A technique of using a helicopter for performing live work on energized wires and equipment, where one or more line workers work directly on an energized part after being raised and bonded to the energized wire or equipment. *See also:* **aerial work**; **barehand work**.

3.1.26 hot: *See:* **energized**.

3.1.27 insulated tool or device: A tool or device that has conductive parts and is either coated or covered with a dielectric material to provide electrical insulation.

3.1.28 insulated personal equipment: Personal equipment made of natural or synthetic material that is designed primarily to provide electric insulation from an energized part or conductor.

3.1.29 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 include conductor cover, stick, and insulating tape. (B) A tool or device that has conductive parts separated by dielectric parts. *Syn:* **hot stick**.

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

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

3.1.32 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.

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

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

3.1.35 live: *See:* **energized**.

3.1.36 live parts: Items at the normal line operating voltage or some potential above ground potential.

3.1.37 live work: Work on or near energized or potentially energized lines (i.e., grounding, insulating tool work, gloving, barehand work). *Syn:* **live-line work**; **hot stick work**.

3.1.38 maximum power frequency operating voltage (V_M): The maximum system operating root-mean-square (rms) line-to-line (or line-to-ground for single phase or pole-to-ground for dc) voltage, which is also equal to the 1 per-unit (p.u.) base.

NOTE—For purposes of this guide, the maximum operating voltage is 5% higher than the rated (nominal) system voltage: $1.05 \times \text{rated (nominal) system voltage}$.¹⁰

3.1.39 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. This distance, with a floating electrode in the gap, is equal to or greater than the sum of the individual minimum approach distances (MADs). This is the electrical component and does not include any factor for inadvertent movement. *Syn:* **electrical distance**.

NOTE—For the definition of electrical distance, see IEC 61472 [B21].

3.1.40 minimum tool insulation distance (MTID): The minimum length of insulation distance required, measured using the shortest distance between the conducting part at the live end and the closest point at ground potential. This term applies to tools that are not subject to inadvertent movement.

3.1.41 minimum approach distance (MAD): The minimum air insulation distance (MAID) plus a factor for inadvertent movement.

¹⁰ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the guide.

3.1.42 minimum approach distance for tools (MAD for Tools): The minimum length of insulation distance required, measured using the shortest distance between the conducting part at the live end and the closest point at ground potential. This term applies to tools that are subject to inadvertent movement.

3.1.43 minimum helicopter approach distance (MHAD): The shortest distance in air between an energized conductor and the closest point of helicopter.

3.1.44 overvoltage: Voltage that exceeds the maximum operating line-to-ground voltage. This voltage may be the result of a transient or switching surge. *Syn:* **transient overvoltage (TOV).**

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

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

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

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

3.1.49 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.

3.1.50 rigging: An assembly of material used to manipulate or support various tools and equipment in energized, de-energized and not grounded, and grounded line work.

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

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

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

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

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

3.1.56 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.

3.1.57 structure: Material assembled to support conductors or associated apparatus, or both, used for

transmission and distribution of electricity (e.g., service pole, tower).

3.1.58 suspension of reclosing: To make inoperative automatic reclosing equipment. *Syn:* **auto-reclosing off; block reclosing; hold off; hold order; hold out; live line permit; non-reclose.**

3.1.59 switching surge: An overvoltage resulting from the operation of a circuit-interrupting device. *Syn:* **switching impulse.**

~~(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.~~

3.1.60 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.

NOTE—See ASTM F 855, IEC 61230, IEEE Std 1048.

3.1.61 tool or equipment leakage current: The total leakage current delivered to the tool or equipment. The tool or equipment provides only one path for the current, and this current is equal to the leakage current. *See also:* **leakage current.**

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

3.1.63 work permit: The authorization to perform work, such as work on a circuit. It is often part of a lockout-tagout procedure. *Syn:* **clearance, guarantee.**

3.2 Acronyms and abbreviations

a switching surge air saturation factor
A altitude correction factor
 C_1 60 Hz rod gap withstand (100 kVrms/ft)
 C_2 the tool factor
CFO critical flashover
 D_{CM} distance in centimeters
 D_{FT} distance in feet
 D_M distance in meters
 E_{MAX} maximum transient overvoltage (TOV_{MAX}) FRP
fiberglass-reinforced plastic
 I_W only the current in the phase from watt loss testing, in amperes
K gap factor
M inadvertent movement factor MAD
minimum approach distance MAID minimum
air insulation distance
MHAD minimum helicopter approach distance MTID
minimum tool insulation distance PPAG portable
protective air gap
p.u. per unit

Peak transient peak (crest) RF

radio frequency

rms root mean square

T maximum anticipated per-unit transient overvoltage (TOV) TOV rms

transient overvoltage

TOV_{Peak} peak transient overvoltage

TTOCD temporary transient overvoltage control devices

V_{50} transient or temporary overvoltage level that produces a 50% probability of sparkover, in kilovolts

V_{L-G} ac voltage line-to-ground (rms), in kilovolts

V or V_{L-L} ac voltage line-to-line (rms), in kilovolts

V_M maximum power frequency operating voltage (rms), in kilovolts, line-to-line

$V_{M P-G}$ maximum power frequency operating voltage (rms), in kilovolts, pole-to-ground

V_{NEG} peak voltage of the negative side of a sine wave

V_{P-G} dc voltage pole-to-ground, in kilovolts

V_{P-P} dc voltage pole-to-pole, in kilovolts

V_{POS} peak voltage of the positive side of a sine wave

V_{Peak} switching surge or transient overvoltage peak or crest voltage, in kilovolts

V_R manufacturer's rating, in kilovolts

$V_{R Peak}$ manufacturer's rating, in kilovolts, peak

V_W withstand voltage, peak

α (Greek small letter alpha) line-to-line insulation strength, which is the proportion of negative switching impulse voltage in the total line-to-line impulse voltage

σ (Greek small letter sigma) probability

μ (Greek small letter mu) 50% critical sparkover value

$\mu+2\sigma$ sparkover voltage

$\mu-3\sigma$ withstand voltage

4. Technical considerations

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 work method safety. For live work, minimum air insulation distance (MAID), minimum tool insulation distance (MTID), minimum approach distance (MAD), minimum approach distance for tools (MAD for Tools), and minimum helicopter approach distance (MHAD) have been developed in this clause for operating voltages up to 800 kV. These distances are used when working near the following:

– [Overhead conductors supported by suspension and tension insulators](#)

– [Overhead conductors supported by post insulators](#)

– [Overhead tubular bus supported by post insulators](#)

– [Equipment entrance bushing and cable potheads](#)

– [Live equipment such as “live tank” circuit breakers, high-speed circuit switching devices, isolating switches, wave traps, series capacitors and reactors](#)

- Insulated phase conductors not covered with a continuous conducting shield or sheath at ground potential and supported from a conductor at ground potential¹¹

¹¹ Since the condition of the conductor insulation is not known, conductors should be considered as live at their operating voltage.

The major hazard in live work on high-voltage lines and equipment is a sparkover of air gap insulation to ground at the worksite. This results in the rapid release of a large amount of energy, which may cause injury to the workers and/or damage equipment.

In an operating electrical power supply system, the phase conductors are insulated from each other and ground using the support insulators and air. When live work is performed on high-voltage systems, the primary insulation is air. However, in systems below 72.5 kV, rubber gloves and sleeves, insulating cover-up, and insulating barriers can provide additional protection for the worker. Insulating cover-up is designed only for inadvertent contact, i.e., brush contact.

~~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 Insulating properties

Personal safety and operational security during energized-line work depend on the insulating properties of the air gap and the insulating materials that are placed in the air gap for the live work.

4.2.1 Sparkover of air gap

A sparkover of the air gap insulation at the worksite can be caused by any of the following:

- a) A reduction of the air gap distance caused by the introduction of conductive objects
- b) Transient overvoltages (TOVs)
- c) Tool insulation breakdown

4.2.2 Preventing sparkover of air gap insulation at worksite

For live work, MAID, MTID, MAD, MAD for Tools, and MHAD have been developed, based on the maximum operating voltage of the system and the maximum anticipated per-unit TOV (T) of the line, to provide guidance to the workers on the required air gap insulation.

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.~~

4.3 Air as insulation

The insulating characteristics of air are defined in terms of its dielectric strength and its capability to withstand electric stresses. The dielectric strength of air is expressed in the unit of kilovolts/meter or an equivalent unit. The dielectric strength of the air gap should be greater than the electric stress to which it is exposed. The dielectric strength of air is influenced by the following:

- a) Temperature
- b) Barometric pressure
- c) Altitude (height of the worksite above sea level)
- d) Relative humidity
- e) Airborne impurities in the air gap
- f) Dimensions, shape of electrodes, and configuration of the spacing g)
- Time-dependent characteristics of the applied voltage

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~~

4.3.1 Insulating materials and tools used in live work

Insulating materials are generally defined in terms of their dielectric strength. The dielectric strength of the insulating material or tool should be greater than the electrical stress to which it is exposed. When two or more insulating materials are used in series within the air gap, the dielectric strength of each should be greater than the electrical stress to which each is exposed. See 4.10.4.1.

The primary factors that affect the electrical performance of insulating materials are the following:

- a) Temperature
- b) Barometric pressure
- c) Altitude (height of the worksite above sea level)
- d) Relative humidity
- e) Airborne impurities
- f) Dimensions, shape of electrodes, and the configuration of the spacing g)
- Time-dependent characteristics of the applied voltage
- h) Surface contamination i)
- Impurities
- j) Aging

4.3.2 Insulating tools used in live work in air gap insulation

When insulating devices (e.g., live work tools, insulating aerial lift devices, insulating ladders, rope) are used in the air gap, they are generally defined in terms of their dielectric strength. The dielectric strength or rating of this equipment should be greater than the operating voltage to which it is being applied. When two or more insulating devices are used in series within the air gap, the rating of each should be greater than the voltage to which it is being applied.

The desirable property of the insulating devices is their ability to reduce the flow of current through them to a very low value. Dielectric strength is defined as the potential gradient at which electric failure or breakdown occurs.

Factors that affect the electrical performance of insulating materials include the following:

- a) Temperature
- b) Barometric pressure
- c) Altitude (height of the worksite above sea level)
- d) Relative humidity
- e) Airborne impurities
- f) Dimensions, shape of electrodes, and configuration of the spacing g)

Time-dependent characteristics of the applied voltage

- h) Surface contamination i)

Impurities

- j) Aging

4.4 Factors that affect the air insulation

4.4.1 Atmospheric conditions

The laboratory test data used to develop the formulas and tables in the guide were obtained under atmospheric conditions that are defined as temperatures above freezing, wind speed under 24 km/h (15 mph), unsaturated air, normal barometric pressure [76 cm (29.92 in) of mercury] at sea level, and uncontaminated air, with clean and dry insulators.

4.4.2 Contamination

The equipment used for gloving, cover-up materials, and insulating 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.

4.4.3 Adverse weather conditions

Live work should not be performed when the following adverse conditions exist:

- a) Lightning activity in the worksite area b)
- Relative humidity at or near 100%
- c) Relative humidity at or above 85% for high-voltage dc work above 72.5 kV

d) Rain or snow

4.5 Air gap distances

This subclause describes the two methods for determining the MAID, MTID, MAD, MAD for Tools, and MHAD for use in work involving energized lines and equipment.

a) Calculation of distances using the formulas in 4.6 and 4.7 is recommended.

b) Distance tables calculated from the formulas in 4.6 and 4.7 have been provided in Annex D. The distance tables for line-to-line voltages above 72.5 kV are applicable for live work only when the worksite altitude is below 900 m (3000 ft) above sea level. To use the table distances when the worksite altitude is above 900 m (3000 ft) above sea level, an altitude correction should be applied. See 4.7.6.

The MAID, MTID, and MAD should not be confused with other electrical distances, such as insulator creepage distance and National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2-2007) [B1] conductor spacing, etc.

This guide does not address live work on lines and equipment with an ac and dc line-to-line or line-to-ground or pole-to-ground voltage below 50 V.

This guide recommends that contact be avoided for live work on lines with an ac and dc line-to-line or line-to-ground or pole-to-ground voltage between 51 and 300 V.

CAUTION

Additional precautions may be required when working on lines and conductors used on distribution network, transportation system catenary, and long low-capacity rural distribution circuits due to fault clearing. In some of these cases, the primary current source may not be automatically opened or interrupted if the fault is beyond the reach of the protection.

Additional precautions may also be required on dc and low-frequency circuits since a considerably larger switch gap is required to break the arc when opening a circuit.

This guide recommends the following rounding-up of the distance and switching surge air saturation factor calculation:

<u>Item</u>	<u>Number of decimal places</u>
<u>Distance in meters, D_M</u>	2
<u>Distance in feet, D_{FT}</u>	2
<u>Distance in centimeters, D_{CM}</u>	2
<u>Switching surge air saturation factor, “a”</u>	7

To round up, add 1 to the last decimal place to be retained if the next decimal place is not zero.

Example: 2.2224 rounded up to 3 decimal places is 2.223

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 de 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.

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.

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_{MP})	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 = $\frac{(\text{Column \#1})(\text{Column \#2})}{3}$ 3—Column #4 = (Column #3) 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.					

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

- 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	#	#	#	#
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 $(V_{P-G}) \geq (T)$. 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, $a = \frac{((V_{PEAK}) - 683) \text{ rounded up to four decimal places}}{140,000}$				

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:

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

4.5.1 Minimum air insulation distance (MAID)

The MAID for line-to-ground work is the minimum air gap distance required to prevent a sparkover at the worksite between the energized parts and a conducting object at ground potential during live work. This distance is normally measured in meters or feet along a straight line between the conductor and nearest item at ground potential. The nearest item at ground potential may be the worker or part of the supporting structure.

The MAID for line-to-line work is the minimum air gap distance required to prevent a sparkover at the worksite between the energized parts of two different phase conductors during live work. This distance is normally measured in meters or feet along a straight line between the conductors.

4.5.1.1 Determining MAID for line-to-ground and line-to-line work for ac and dc line-to-line voltages from 300 V and below 72.5 kV

The MAID is the required undisturbed air insulation distance required to prevent a sparkover at the worksite during a system event that results in the maximum anticipated TOV.

The formulas for MAIDs for line-to-line voltages below 72.5 kV are based on the 60 Hz rod gap test data from IEEE Std 4™-1995 [B28]. See 4.6.1, 4.7.1.1, 4.7.1.2, 4.7.4.1, and 4.7.5 for further details.

For dc lines, see also 4.7.4.4.

4.5.1.2 Determining MAID for line-to-ground work for ac line-to-line voltages above 72.5 kV

The MAID is the required undisturbed air insulation distance required to prevent a sparkover at the worksite during a system event that results in the maximum anticipated TOV.

The formulas for MAID line-to-ground distances for line-to-line voltages above 72.5 kV are based on the rod gap test data from “Recommendations for safety” [B25]. See 4.6.2.1 and 4.7.1.3 for further details.

4.5.1.3 Determining MAID for line-to-line work for ac line-to-line voltages above 72.5 kV

The MAID is the required undisturbed air insulation distance required to prevent a sparkover at the worksite during a system event that results in the maximum anticipated TOV.

The formulas for MAID line-to-line distance for line-to-line voltages above 72.5 kV are based on test data (for the live-to-line gap) published the 1993 paper by Vaisman et al. [B41]. The paper presents and compares such published test data from five laboratories found in the literature. These test data are fitted with a modified Gallet equation used to determine line-to-line MAID (see Gallet et al. [B16] and [B17]). See 4.6.2.2 and 4.7.1.4 for further details.

4.5.1.4 Reducing MAID

When using cover-up material, rubber gloves and sleeves, or insulating barriers that are properly rated and tested for the operating voltage on which the work is being done, the distance from the worker to the task location may be reduced. However, the air distance to exposed energized parts should be maintained in the area where these are applied or used.

An exception to this is when the worker is using the rubber gloving method. In this case, the distance to the exposed energized conductor may be reduced by eliminating or reducing the inadvertent movement factor distance when the worker's movement is restricted. When using the rubber gloving method, secondary supporting insulation, such as insulating footwear, an insulating platform, or an insulating aerial device, is utilized. Insulating cover-up is designed only for inadvertent contact. It may be necessary to use insulating aerial devices or insulating platforms to limit the leakage current below the worker's threshold of feeling (see Kolcio [B31]). Insulating aerial devices act as the principal insulation should the rubber gloves fail or should the worker accidentally contact the conductor.

Insulated conductors supported by a conductive material at ground potential and insulated conductors supported by insulating material from conductive material at ground potential should be considered as live at their line-to-ground voltage since the condition of conductor insulation is not known.

Insulated conductors with a continuous concentric metal shield that is maintained at ground potential should be considered as being at ground potential.

4.5.2 Minimum tool insulation distance (MTID)

The MTID is the required undisturbed air insulation distance that is needed to prevent a tool flashover at the worksite during a system event that results in the maximum anticipated TOV.

4.5.2.1 MTID for ac and dc line-to-line voltages at and below 72.5 kV

The MTID for ac and dc line-to-line voltages at and below 72.5 kV has not been determined. Industry practices normally use an MTID that is the same as or greater than the MAID. See 4.5.1.1.

4.5.2.2 MTID for ac and dc line-to-ground work with line-to-line voltages above 72.5 kV

When any foreign object, such as tools or other devices used to perform work on the line, is placed in the air gap, the MTID is used.

This guidance includes floating objects, insulating maintenance tools, and aerial devices that are tested and rated for the line-to-ground or line-to-line voltage applied across them. This distance is normally measured in meters or feet along a straight line between the conductor and nearest item at ground potential. Small conducting items [e.g., tool splices (used to join tool sections together), clamps, cradle brackets] placed on or within the insulating medium do not affect this distance.

4.5.2.3 MTID for ac and dc line-to-line work with line-to-line voltages above 72.5 kV

The definition of MTID applies only to line-to-ground application. It is rare that a worker would be at the potential of one phase while working on another phase. If a nonconductive object, such as an insulated tool, is placed in the air gap joining two phases, an engineering study should be performed. Addition testing is required to develop a line-to-line MTID. If a line-to-line MTID is required, the same factor as used in the line-to-ground distance may be used. Industry practices normally use an MTID that is the same as or greater than the MAID.

4.5.2.4 Determining MTID for ac and dc line-to-ground work with line-to-line voltages above 72.5 kV

The MTIDs are calculated using a similar formula as the MAIDs with the addition of the C_2 factor. See 4.6.2.1 and 4.7.2 for further details.

4.5.2.5 Determining MTID for ac and dc line-to-line work with line-to-line voltages above 72.5 kV

Line-to-line live working methods are normally based on when the worker is only at the potential of the phase on which live work is being conducted. In other words, the worker is not at the potential of one phase while working on the other phase. For this reason, the application of insulated tools between phases is very limited. If a nonconductive object, such as insulated tool, is placed in the air gap between two phases, the application of C_2 factor (which is used in line-to-ground MTID) is questionable because there are no test data to support this. Until such test data are available, the line-to-line MTID is not provided in this guide. However, page 520 of the EPRI *Red Book* [B9] states “tests performed with a nonceramic insulator string between two conductors at midspan of the test line have shown that the flashover pattern, also, is not appreciably altered by the presence of the string and its associated hardware.” Additional tests are planned in the near future.

4.5.3 Minimum approach distance (MAD)

To provide additional protection for workers during energized-line maintenance or while working in the vicinity of other energized lines, MAD has been developed. This distance allows for any inadvertent movement that may occur during live work.

4.5.3.1 Determining MAD for ac and dc line-to-line voltages at and above 300 V

The MAD is determined from the MAID, plus a factor for inadvertent movement (M). The M factor is not adjusted for altitude. See 4.6.1 and 4.6.2 for further details. See also 4.5.1.1.

4.5.3.2 Reducing MAD

The use of barriers that physically limit the worker’s inadvertent movement can reduce the MADs between the worker and the energized or grounded parts. They can be used on any voltage lines or equipment provided proper MAID is observed. Barriers are not relied on for electrical insulation, but act only as physical barriers.

4.5.4 Minimum approach distance for tools (MAD for Tools)

To provide additional protection for workers during energized-line maintenance or while working in the vicinity of other energized lines when any foreign object, such as tools or other devices used to perform work on the line, is placed in the air gap, the MAD for Tools is used. See 4.6.1 and 4.6.2 for further details.

4.5.4.1 MAD for Tools for ac and dc line-to-line voltages at and below 72.5 kV

The MTID for ac and dc line-to-line voltages at and below 72.5 kV has not been determined. Industry practices normally use an MTID that is the same as or greater than the MAID. See 4.5.1.1.

4.5.4.2 Determining line-to-ground MAD for Tools for ac and dc line-to-line voltages above 72.5 kV

The MAD for Tools is determined from the MTID, plus a factor for inadvertent movement (M). The M factor is not adjusted for altitude.

4.5.4.3 Determining line-to-line MAD for Tools for ac and dc line-to-line voltages above 72.5 kV

Addition testing is required to develop a MAD for Tools for line-to-line voltages above 72.5 kV. If a line-to-line MAD for Tools is required, the same factor as used in the line-to-ground distance may be used. Industry practices normally use a MAD for Tools that is the same as or greater than the MAD.

4.5.5 Minimum helicopter approach distance (MHAD)

To provide additional protection for workers during energized-line maintenance from helicopters, the MHAD has been developed. This distance covers possible corona on the helicopter, rotor wash, and movement due to wind.

4.5.5.1 Determining MHAD for ac line-to-line voltages above 72.5 kV

The MHAD is derived from the MAD, plus an industry suggested value of 10% MAD. Data for this subclause was obtained from “Helicopter-Based Live Work” [B10]. See 4.6.1 and 4.6.2 for further details.

4.6 Distance equations

When a distance equation is used, the distances that result are in the same units as the reference data source. In the United States, most of the line workers use the “English” or feet measurement in their work, and in other countries, the metric measurements are used.

For this reason, formulas and tables have been developed in both measurement systems. Table 1 lists the distance conversion factors used in this guide.

Table 1—Distance conversion factors

<u>To convert to</u>	<u>From</u>		
	<u>Centimeters</u>	<u>Feet</u>	<u>Meters</u>
	<u>Multiply by</u>		
<u>Feet</u>	<u>0.0328</u>	<u>1.0</u>	<u>3.281</u>
<u>Meters</u>	<u>0.01</u>	<u>0.3048</u>	<u>1.0</u>

The distances obtained from the equations in 4.6 should be rounded up.

4.6.1 Work on ac and dc line conductors and equipment for line-to-ground and line-to-line voltages from 50 V to 72.5 kV

These distances apply to conductors and equipment supported by insulators where air is the primary insulating medium. They do not apply to insulated cables where it has been determined that insulation is good.

The following terms are used in the formulas in this subclause:

D_M is distance, in meters

D_{FT} is distance, in feet

TOV_{Peak} is the maximum anticipated peak transient overvoltage (see 4.6.1.4) for a given voltage, in kilovolts (see 4.7.1)

T is the maximum anticipated per-unit TOV on the line (see 4.7.4)

V_{L-G} is the line-to-ground rms voltage, in kilovolts (see 4.7.5)

V_{L-L} is the line-to-line rms voltage, in kilovolts (see 4.7.5) M is the inadvertent movement factor (see 4.7.7)

The equations in 4.6.1.2 through 4.6.1.6 were developed from the 60 Hz sparkover distance for rod-to-rod configuration for a given voltage in kilovolts. See 4.7.1.

4.6.1.1 Work on ac and dc line conductors and equipment for line-to-ground and line-to-line voltages from 50 V to below 300 V

When the line-to-ground and line-to-line voltage is between 50 and 300 V, this guide recommends that contact be avoided.

4.6.1.2 Work on ac and dc line conductors and equipment for line-to-ground and line-to-line voltages from 300 V to below 750 V

When the line-to-ground and line-to-line voltage is between 300 and 750 V, sufficient test data are not available to calculate the MAID, which is less than 2 cm or 0.07 ft. This guide recommends the following:

a) MAID, line-to-ground and line-to-line

1) $D_M = 0.02$

2) $D_{FT} = 0.07$

b) MAD, line-to-ground and line-to-line

1) $D_M = 0.32$

2) $D_{FT} = 1.07$

4.6.1.3 Work on ac and dc line conductors and equipment for line-to-ground and line-to-line voltages above 750 V and below 5.0 kV

When the line-to-ground and line-to-line voltage is between 750 V and 5.0 kV, sufficient test data are not available to calculate the MAID, which is less than 2 cm or 0.07 ft. This guide recommends the following:

a) MAID, line-to-ground and line-to-line

1) $D_M = 0.02$

2) $D_{FT} = 0.07$

b) MAD, line-to-ground and line-to-line

1) $D_M = 0.63$

2) $D_{FT} = 2.07$

4.6.1.4 Work on ac and dc line conductors and equipment for line-to-line voltages from

5.0 kV to 72.5 kV

To find which equation to use when the line-to-line voltage is between 5.0 and 72.5 kV, first determine the peak transient overvoltage, TOV_{Peak} .

a) For line-to-ground work

$$TOV_{L-G Peak} = \sqrt{2} (T) (V_{L-G}) \quad (1)$$

b) For line-to-line work

$$TOV_{L-L Peak} = \sqrt{2} (T) (V_{L-L}) \quad (2)$$

If the TOV_{Peak} is less than 27.00 kV, use 4.6.1.5.

If the TOV_{Peak} is equal to or greater than 27.0084.88 kV, use 4.6.1.6. For dc line conductors, see 4.7.4.4, 4.7.5.5, and 4.7.5.6.

4.6.1.5 TOV_{Peak} less than 27.00 kV

When the TOV_{Peak} is less than 27.00 kV, sufficient test data are not available to calculate the MAID, which is less than 2 cm or 0.06 ft. This guide recommends the following:

a) MAID, line-to-ground and line-to-line

1) $D_M = 0.02$

2) $D_{FT} = 0.07$

b) MAD, line-to-ground and line-to-line

1) $D_M = 0.63$

2) $D_{FT} = 2.07$

4.6.1.6 TOV_{Peak} equal to or greater than 27.00 kV

When the TOV_{Peak} is equal to or greater than 27.00 kV, this guide recommends the following:

a) MAID, line-to-ground

$$D_M = \frac{\left(\frac{(TOV_{L-G Peak} - 36.7)}{5.6} + 2.75 \right)}{100} \quad (3)$$

$$D_{FT} = 3.28 \left(\frac{\left(\frac{(TOV_{L-G Peak} - 36.7)}{5.6} + 2.75 \right)}{100} \right) \quad (4)$$

b) MAD, line-to-ground

$$D_M = \left(\frac{\left(\frac{(TOV_{L-GPeak} - 36.7)}{5.6} + 2.75 \right)}{100} \right) + M \quad (5)$$

$$D_{PT} = \left(3.28 \left(\frac{\left(\frac{(TOV_{L-GPeak} - 36.7)}{5.6} + 2.75 \right)}{100} \right) \right) + M \quad (6)$$

c) MAID, line-to-line

$$D_M = \frac{\left(\frac{(TOV_{L-LPeak} - 63.6)}{5.15} + 5.65 \right)}{100} \quad (7)$$

$$D_{PT} = 3.28 \left(\frac{\left(\frac{(TOV_{L-LPeak} - 63.6)}{5.15} + 5.65 \right)}{100} \right) \quad (8)$$

d) MAD, line-to-line

$$D_M = \left(\frac{\left(\frac{(TOV_{L-LPeak} - 63.6)}{5.15} + 5.65 \right)}{100} \right) + M \quad (9)$$

$$D_{PT} = \left(3.28 \left(\frac{\left(\frac{(TOV_{L-LPeak} - 63.6)}{5.15} + 5.65 \right)}{100} \right) \right) + M \quad (10)$$

4.6.2 Work on ac and dc line conductors and equipment for line-to-line voltages above 72.5 kV

4.6.2.1 Line-to-ground work

The line-to-ground distance formulas for line-to-line voltages above 72.5 kV used in this guide are developed from basic formulas for live tool withstand from Figure 2 (used in previous editions of the guide). See 4.7.1.3 for further details.

$$D = (0.011 + a)(S)kV_{L-G} \quad (11)$$

where

D is distance, in feet

a is saturation factor

S is per-unit switching surge

From Equation (11), the following equations have been developed:

$$D_{MAID} = (C_1 + a)(V_{L-G})(T)(A) \quad (12)$$

$$D_{MTID} = (((C_1)(C_2)) + a)(V_{L-G})(T)(A) \quad (13)$$

$$D_{MAD} = ((C_1 + a)(V_{L-G})(T)(A)) + M \quad (14)$$

$$D_{MAD\text{forTools}} = (((((C_1)(C_2)) + a)(V_{L-G})(T)(A))) + M \quad (15)$$

$$D_{MHAD} = (((C_1 + a)(V_{L-G})(T)(A)) + M)(H) \quad (16)$$

Where

D is the distance (MAID, MTID, MAD, MAD for Tools, MHAD), in feet, since C_1 is in feet/kilovolts

C_1 is 0.01 ft/kVrms (60 Hz rod gap withstand) (100 kVrms/ft)

a is the adjustment ratio to compensate for air saturation expressed as a ratio of distance to kilovolts

C_2 is the MAIDs, which are increased based on an additional 6% for the effect of the insulating tools in the air gap plus additional 4% for intangibles. The 6% factor may range from an additional 2% to 20% depending upon the structure and electrode configuration and the surface condition of the tool. Used for MTID calculations with the line-to-line voltage above 72.5 kV (see 4.7.2)

V is the nominal voltage across the air gap, which may be V_{L-G} or V_{L-L}

V_{L-G} is the line-to-ground rms voltage, in kilovolts (see 4.7.5)

V_{L-L} is the line-to-line rms voltage, in kilovolts (see 4.7.5)

T is the maximum anticipated per-unit TOV, which can occur across the air gap (see 4.7.4) A is the altitude correction factor (see 4.7.6)

H is the helicopter factor for calculations in this guide (H is 110% of MAD) (see 4.7.8) M is the inadvertent movement factor (see 4.7.7)

CAUTION

If the $TOV [(V_{L-G}) \times (T)]$ is greater than 449 kV rms, determine the air saturation ratio, a , first to use in these equations (see 4.7.3.2).

a) **MAID for line-to-ground work**

$$D_M = 0.3048 [(C_1 + a)(V_{L-G})(T)(A)] \quad (17)$$

$$D_{FT} = (C_1 + a)(V_{L-G})(T)(A) \quad (18)$$

b) **MTID for line-to-ground work**

$$D_M = 0.3048 [(((C_1)(C_2)) + a)(V_{L-G})(T)(A)] \quad (19)$$

$$D_{FT} = (((C_1)(C_2)) + a)(V_{L-G})(T)(A) \quad (20)$$

c) **MAD for line-to-ground work**

$$D_M = 0.3048 [((C_1 + a)(V_{L-G})(T)(A)) + M] \quad (21)$$

$$D_{FT} = ((C_1 + a)(V_{L-G})(T)(A)) + M \quad (22)$$

d) **MAD for Tools for line-to-ground work**

$$D_M = 0.3048 [(((C_1)(C_2)) + a)(V_{L-G})(T)(A)) + M] \quad (23)$$

$$D_{FT} = (((C_1)(C_2)) + a)(V_{L-G})(T)(A) + M \quad (24)$$

e) **MHAD for line-to-ground work**

$$D_M = 0.3048 [(((C_1 + a)(V_{L-G})(T)(A)) + M)[H]] \quad (25)$$

$$D_{FT} = [((C_1 + a)(V_{L-G})(T)(A)) + M][H]$$

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.~~

$$(V_{P-P})(2)$$

$$V_{PEAK} = \frac{\quad}{3}$$

- 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 de-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