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(Revision of
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IEEE Guide for Maintenance Methods on Energized Power Lines

IEEE Standards Board

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Sponsor

Engineering in Safety, Maintenance, and Operation of Lines (ESMOL) Subcommittee of the Transmission and Distribution Committee

of the

IEEE Power Engineering Society

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

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

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Introduction

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

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

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

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

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

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

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IEEE Guide for Maintenance Methods on Energized Power Lines

1. Overview

1.1 Scope

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

1.2 Purpose

The purpose of this guide is to

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

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

1.3 Application

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

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

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

The approach used in this guide is to

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

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

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

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

1.4 Other requirements

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

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

2. References

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

ANSI C2-1993, National Electrical Safety Code.²

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

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

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

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

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

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

ASTM D1048-93, Specification for Rubber Insulating Blankets.

ASTM D1049-93, Specification for Rubber Insulating Covers.

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

ASTM D1051-87, Specification for Rubber Insulating Sleeves.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4. CSA publications are available from the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd., Rexdale, Ontario, Canada M9W 1R3.

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

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

- IEC 855 (1985), Insulating foam-filled tubes and solid rods for live working.
- IEC 895 (1987), Conductive clothing for live working at a nominal voltage up to 800 kV a.c.
- IEC 903 (1988), Specifications for gloves and mitts of insulating material for live working.
- IEC 984 (1990), Sleeves of insulating material for live working.
- IEC 1057 (1991), Aerial devices with insulating boom used for live working.
- IEC 1111 (1992), Matting of insulating material for electrical purposes.
- IEC 1112 (1992), Blankets of insulating material for electrical purposes.
- IEC 1229 (1993), Rigid protective covers for live working on a.c. installations.
- IEC 1235 (1993), Live working—Insulating hollow tubes for electrical purposes.
- IEC 1236 (1993), Saddles, pole clamps (stick clamps) and accessories for live working.
- IEEE Std 4-1978 (W1994), IEEE Standard Techniques for High Voltage Testing (ANSI). (Refer only to the 1978 edition of this standard.)⁷
- IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).⁸
- IEEE Std 524-1992, IEEE Guide to the Installation of Overhead Transmission Line Conductors (ANSI).
- IEEE Std 524a-1993, IEEE Guide to Grounding During the Installation of Overhead Transmission Line Conductors: Supplement to IEEE Guide to the Installation of Overhead Transmission Line Conductors (ANSI).
- IEEE Std 935-1989, IEEE Guide on Terminology for Tools and Equipment to Be Used in Live Line Working (ANSI).
- IEEE Std 957-1995, IEEE Guide for Cleaning Insulators.⁹
- IEEE Std 978-1984, (Reaff 1990) IEEE Guide for In-Service Maintenance and Electrical Testing of Live-Line Tools (ANSI).
- IEEE Std 1048-1990, IEEE Guide for Protective Grounding of Power Lines (ANSI).
- IEEE Std 1067-1990, IEEE Guide For In-Service Use, Care, Maintenance, and Testing of Conductive Clothing for use on Voltages up to 765 kV AC (ANSI).
- IEEE Std 1070-1988, IEEE Guide for the Design and Testing of Transmission Modular Restoration Structure Components (ANSI).
- IEEE P1307/D7A, March 6, 1995, IEEE Draft Trial-Use Guide for Fall Protection for the Utility Industry.¹⁰

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

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

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

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

3. Definitions

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

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

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

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

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

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

3.6 bypass. *See:* jumper.

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

3.8 clearance. *See:* work permit.

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

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

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

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

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

3.14 cover-up equipment. Equipment designed to protect persons from energized parts in a specific work area. Many

different types are available to cover conductors, insulators, dead-end assemblies, structures, and apparatus. Cover-up material may be either flexible or rigid.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

tensioning guys. *Syn:* chain hoist; chain tugger; coffin hoist; ratchet hoist.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

NOTE—IEC uses 90%.

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

NOTE—IEC uses 2%.

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

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

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

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

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

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

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

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

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

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

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

4. Technical considerations and testing

4.1 Introduction

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

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

Table 1—Altitude correction factor

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

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

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

4.2 Basic concepts

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

4.2.1 Insulating properties

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

Table 2—Minimum air insulation distance, ac energized work

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

NOTES

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

2—Table distances do not include any factor for inadvertent movement. See 7.3 for inadvertent movement considerations.

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

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

4.2.1.1 Insulating materials

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

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

4.2.1.2 Air as insulation

The insulating characteristics of air are defined in terms of the capability of the air to withstand an electric field. The dielectric strength of air is expressed in the unit of kV per meter or an equivalent unit. The disruptive voltage is influ-

enced by the air density, humidity, temperature, pressure, dimensions and separation of the electrodes or separation of the metal terminals, shape of the electrodes, and the time dependent characteristics of the applied voltage.

4.2.1.3 Contamination—equipment

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

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

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

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

4.2.2 Minimum air insulation distance

4.2.2.1 General

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

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

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

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

Table 4—Example of detailed calculations for air gap

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

NOTES

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

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

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

4—Col. #5 = (col. #4) $\div 0.85$

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

4.2.2.3 Calculation of air insulation distances, above 72 500–800 000 V**4.2.2.3.1 General**

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

$$D = (C_1 C_2 + a) T k V_{LG} \quad (1)$$

where

D is insulation distance, ft

C_1 is 0.01, or 1% of line-to-ground

C_2 is 1.1, composed of 1.06 for energized-line tool-to-air withstand distance ratio plus intangibles (see [B9])

a is saturation factor for crest $\sqrt{2}T$ kV_{LG} kV_{LG} voltages of 630 kV and above (see figure 1)

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

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

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

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

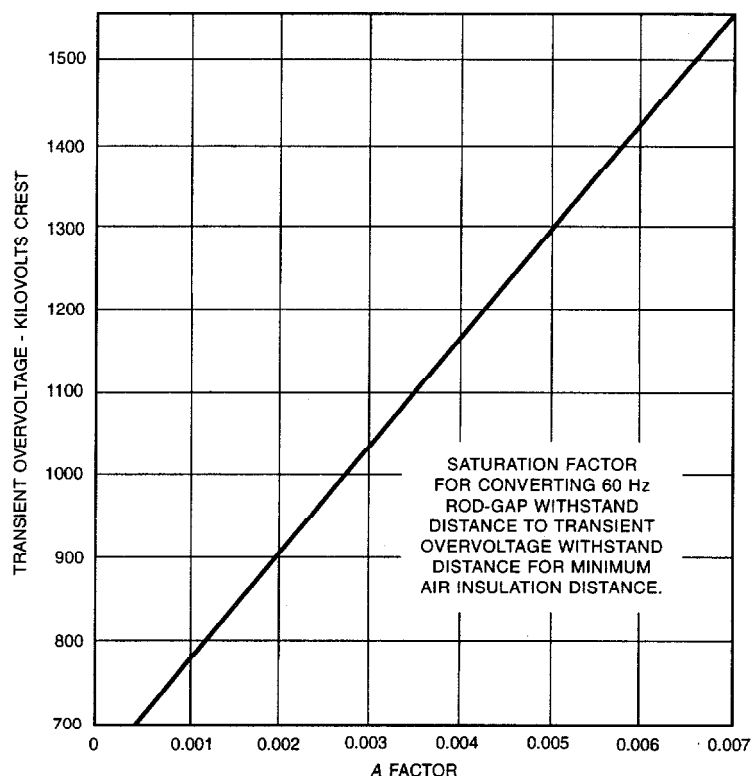


Figure 1 — 60 Hz switching-surge saturation factor

4.2.2.3.2 Calculations

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

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

where

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

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

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

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

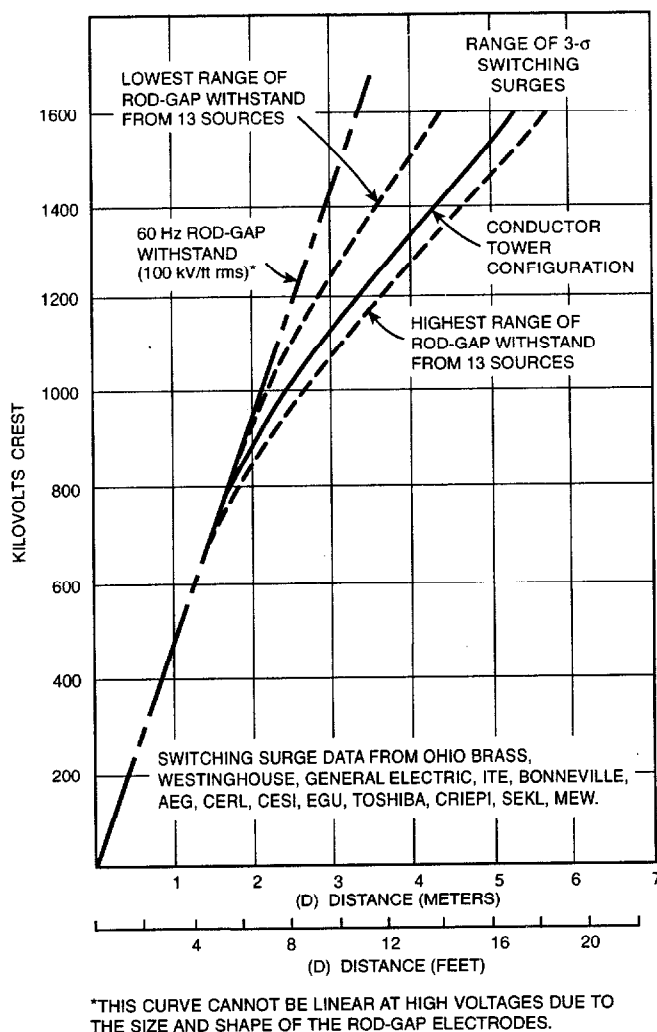


Figure 2 — Typical withstand voltage for switching surges

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

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

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

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

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