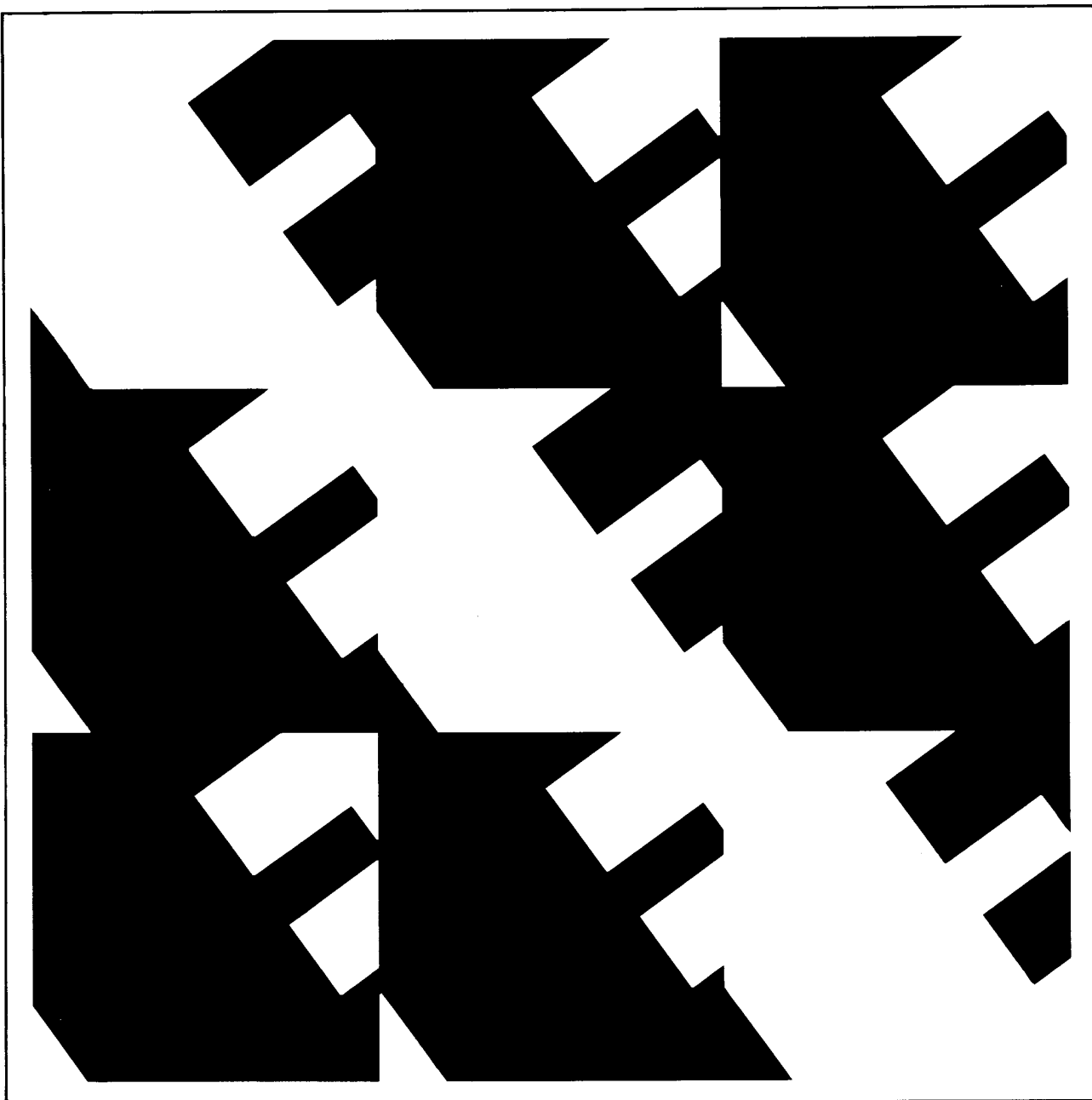


IEEE Guide for Maintenance Methods on Energized Power-Lines

ANSI/IEEE Std 516-1987



Published by The Institute of Electrical and Electronics Engineers, Inc 345 East 47th Street, New York, NY 10017, USA

November 25, 1988

SH12096

An American National Standard

IEEE Guide for Maintenance Methods on Energized Power-Lines

1. General

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 decades of 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; 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

- (1) 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.
- (2) Direct attention to appropriate standards and other documents for the acquisition of knowledge on the care and use of required tools and equipment.
- (3) 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.

This guide is not establishing a standard for maintenance of energized power-lines in the electric utility industry as such.

1.3 Application. This guide is broad enough yet 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 experiences. Advancement in technology or changes in system design will probably justify modifying the minimum requirements recommended in this guide.

The approach used within this guide is as follows:

- (1) To present definitions required for clarity.
- (2) To indicate the engineering and other technical considerations essential to the safe performance of energized-line maintenance.
- (3) To provide guidance for the necessary test equipment and procedures associated with manufacturer and user's acceptance, testing, and care of equipment.
- (4) To detail various work methods for working on or near energized lines and associated devices.

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

1.5 References. This guide shall be used in conjunction with the following publications:

- [1] ANSI A92.2-1979, American National Standard Vehicle Mounted Elevating and Rotating Devices.¹
- [2] ANSI C2-1987, American National Standard National Electrical Safety Code.
- [3] ANSI C29.1-1982, American National Standard Precision Power Transmission Chains, Attachments, and Sprockets.
- [4] ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.
- [5] ANSI/IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms.
- [6] ANSI/IEEE Std 524-1980, IEEE Guide to the Installation of Overhead Transmission Line Conductors.
- [7] ANSI/IEEE Std 978-1984, IEEE Guide for In-Service Maintenance and Electrical Testing of Live-Line Tools.
- [8] ASTM D120-87, Standard Specification for Rubber Insulating Gloves.²
- [9] ASTM D149-87, Standard Test Methods for Dielectric Breakdown Voltage and Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies.
- [10] ASTM D1048-88a, Standard Specification for Rubber Insulating Blankets.
- [11] ASTM D1049-88, Standard Specification for Rubber Insulating Gloves.
- [12] ASTM D1050-85, Standard Specification for Rubber Insulating Line Hose.
- [13] ASTM D1051-87, Standard Specification for Rubber Insulating Sleeves.
- [14] ASTM D1078-86, Standard Test Method for Distillation Range of Volatile Organic Liquids.
- [15] ASTM F 96-77(1982), Specification for Electronic Grade Alloys of Copper and Nickel in Wrought Forms.
- [16] ASTM F 478-87, Specification In-Service Care of Insulating Line Hose and Covers.
- [17] ASTM F 479-88, Specification for In-Service Care of Insulating Blankets.
- [18] ASTM F 496-85, Specification for In-Service Care of Insulating Gloves and Sleeves.
- [19] ASTM F 711-83, Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used in Live-Line Tools.
- [20] ASTM F 855-83, Temporary Grounding Systems to be Used on De-Energized Electrical Power Lines and Equipment.
- [21] ASTM F 968-85, Electrically Insulating Plastic Guard Equipment for Protection of Workers.
- [22] CFR, Section 29 1926.955(e)(11) Federal OSHA Code.
- [23] CFR, Section 29. 1926/551 and 1910. 183, OSHA.³
- [24] CSA C225-76, Vehicle-Mounted Aerial Devices.⁴
- [25] Data Sheet 12304-598-1980.⁵
- [26] EPRI Transmission-Line Reference Book (EL2500, 2nd ed).⁶
- [27] IEC 265-1968, High-Voltage Switches.⁷
- [28] IEEE Std 62-1978, IEEE Guide for Field Testing Power Apparatus Insulation.⁸
- [29] IEEE Std 957-1987, Guide for Cleaning Insulators.
- [30] Application Guide for Insulator Contamination. See Application Guide for Insulators in Contaminated Environment. IEEE Paper F77-639-8.
- [31] ASANOVA, T. P. and Rakov, A. I. The State of Health of Persons Working In Electric Field of Outdoor 400 kV and 500 kV Switchyards. Hygiene of Labor and Professional Diseases, no 5 1966, USSR.

¹ANSI publications are available from the Sales Department, American National Standard Institute, 1430 Broadway, New York, NY 10018.

²ASTM publications are available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

³CFR publications are available from Superintendent of Documents, US Government Printing Office, Washington, DC 20402.

⁴In the United States, CSA Standards are available from the Sales Department of American National Standards Institute, 1430 Broadway, New York, NY 10018. In Canada they are available at the Canadian Standards Association (Standards Sales), 178 Rexdale Blvd, Rexdale, Ontario, Canada M9W 1R3.

⁵This publication is available from the National Safety Council, 444 North Michigan Ave, Chicago, IL 60611.

⁶This publication is available from the Research Report Center, PO Box 50490, Palo Alto, CA 94303.

⁷IEC publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

⁸IEEE publications are available from IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854-1331.

[32] BRIDGES, J. E. Biological Effects of 60 Hz Electric Fields. IIT Research Institute Final Report E8151, EPRI Project RP-381-1, Nov 1975.

[33] BRIDGES, J. E. Environmental Considerations Concerning the Biological Effects of Power-Frequency (50 Hz or 60 Hz) Electric Fields. IEEE Paper F77 256-1.

[34] ELEK and SIMPSON. Safe Clearance and Protection Against Shocks During Live-Line Work. AIEE Paper, Feb 1962, pp 61-1019.

[35] IEEE COMMITTEE REPORT 31-TP67-96. Recommendations for Safety in Live-Line Maintenance.

[36] KOUWENHOVEN, W. B., et al. Body Current in Live-Line Working. IEEE Paper 31-TP65-673.

[37] KOUWENHOVEN, W. B. et al. Medical Evaluation of Man Working in AC Electric Fields. IEEE Paper 31-TP66-395.

[38] KOUWENHOVEN, W. B., and LANGWORTHY, O. R. Effects of Electric Shock. *AIEE Transactions* vol 49, Jan 1930, pp 381-394.

[39] KRIVOVA, T. I., et al. Standardization of the Intensity of an Electrical Field of Commercial Frequency by the Threshold of Stimulation with Painful Initiation of Electrical Discharges. USSR.

[40] Live-Line Maintenance Methods. Task Group for Live-Line Maintenance Methods. IEEE Paper T-73 157-5.

[41] SINGEWALD, M. R., et al. Medical Follow-Up Study of High-Voltage Lineman Working in AC Electric Fields. IEEE Paper T73 154-2.

[42] Study in the USSR of Medical Effects of Electric Fields on an Electric Power System. Translated from Russian by KNICKERBOCKER, G. G. IEEE/PES Special Pub, no 10.

2. Definitions

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

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.

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

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

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

bypass. *See:* *jumper*.

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.

clearance. *See:* *work permit*.

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.

conductive clothing. Clothing made of natural or synthetic material either conductive or interwoven with conductive thread to provide from electrostatic effects of high-voltage energized electrical conductors and equipment.

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. *Synonyms:* *cable, wire*.

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

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 is commonly used to tension guys and in some cases, 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. *Synonyms: buffalo, Chicago grip, come-along, Crescent four bolt, grip, Klein, pocketbook, seven bolt, six bolt, slip-grip, suitcase, Kellem grip.*

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.

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.

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.

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: de-energized.*

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

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).

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.

dynamometer. A device designed to measure loads or tension on conductors. Various models of these devices are used to tension guys or sag conductors. *Synonyms: clock, load cell.*

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

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

extra-high voltage (ehv). A term applied to voltage levels that are higher than 240 000 V.

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 as rigid as the boom swivels, affording greater maneuverability.

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.

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

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

hoist. An apparatus for moving a load by the application of pulling force and 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. *Synonyms: chain hoist, chain tugger, coffin hoist.*

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

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

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

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

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 a dielectric.

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

isolated.

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

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. *Synonym:* *bypass.*

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.

lineman. A person qualified to perform various line-work operations including aerial and ground work.

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

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

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. *Synonyms:* *ground set, ground stick* (ANSI/IEEE Std 100-1988 [5]⁹).

minimum approach distance. The shortest permissible distance between energized electrical apparatus and any part of a worker's body and tools or material being handled.

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

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 line-work with an insulating tool in the air gap.

NESC. National Electrical Safety Code, ANSI C2-1987 [2].

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

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

rope block. A device designed with one or more sheaves, a wood or steel 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. *Synonym:* *block and tackle.*

snatch block. A device normally designed with a single sheave, a wood or metal shell, and a hook. One side of the shell usually opens 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. *Synonyms:* *skookum, Washington, Western.*

⁹The numbers in brackets correspond to those of the references in 1.5.

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

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

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

structure. Material assembled to support conductors or associated apparatus, or both, used for transmission and distribution of electricity. *Examples:* *service pole, tower.*

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

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

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

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

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

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

3. Technical Considerations and Testing

3.1 Introduction. The performance of energized-line-maintenance 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 energized-line maintenance 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 is not practical because of the variations in test conditions. A major part of this section is devoted to dielectric-current measurements (phase sum of capacitive and resistive current) for certification and acceptance. Some aspects of watt-loss testing are also included.

3.2 Basic Concepts. A major part of this section is devoted to tool and equipment current measurements for certification and acceptance purposes.

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

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

- (1) Electrical insulation is the property of material to prevent the flow of current through it.
- (2) Dielectric strength is the maximum potential gradient that the material can withstand without rupture.
- (3) Factors affecting insulating materials include temperature, altitude, moisture, contamination, impurities, and aging.

3.2.1.2 Air As Insulation. The insulating characteristics of air are defined as its capability to withstand an electric field. The dielectric strength of air is represented by gradients of potential. The disruptive gradient is influenced by the air density, humidity, temperature, pressure, dimensions and separation of the electrodes or separation of the metal terminals, shape of the electrodes, and the characteristics of the applied voltage.

3.2.1.3 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.

3.2.2 Clearance Formulas

3.2.2.1 General

- (1) The formulas are derived empirically. In Fig 1 a saturation factor is derived from rod-gap switching-surge flashover data.

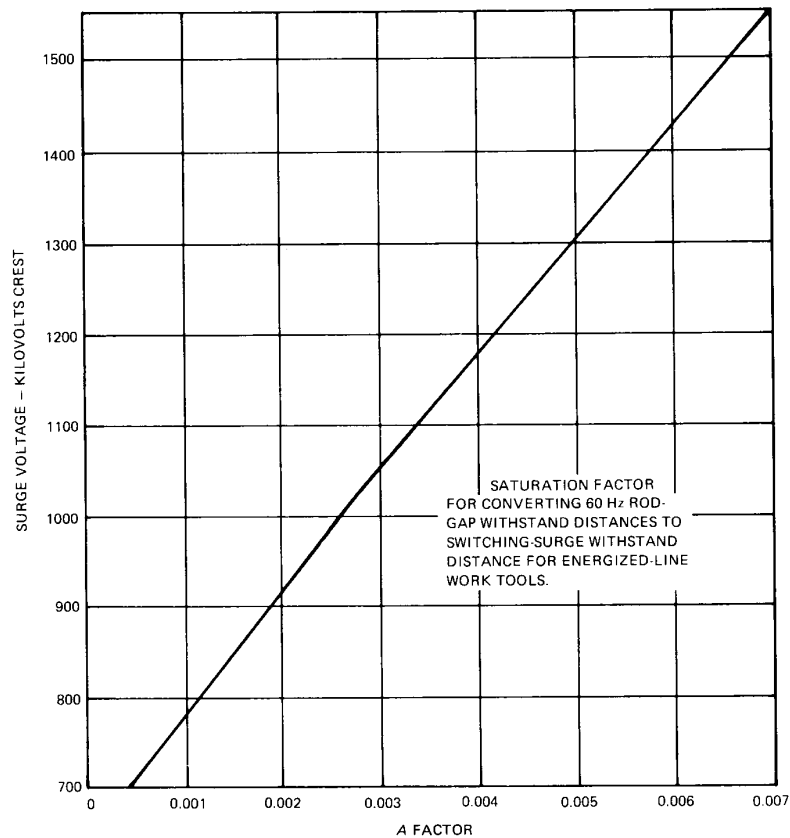


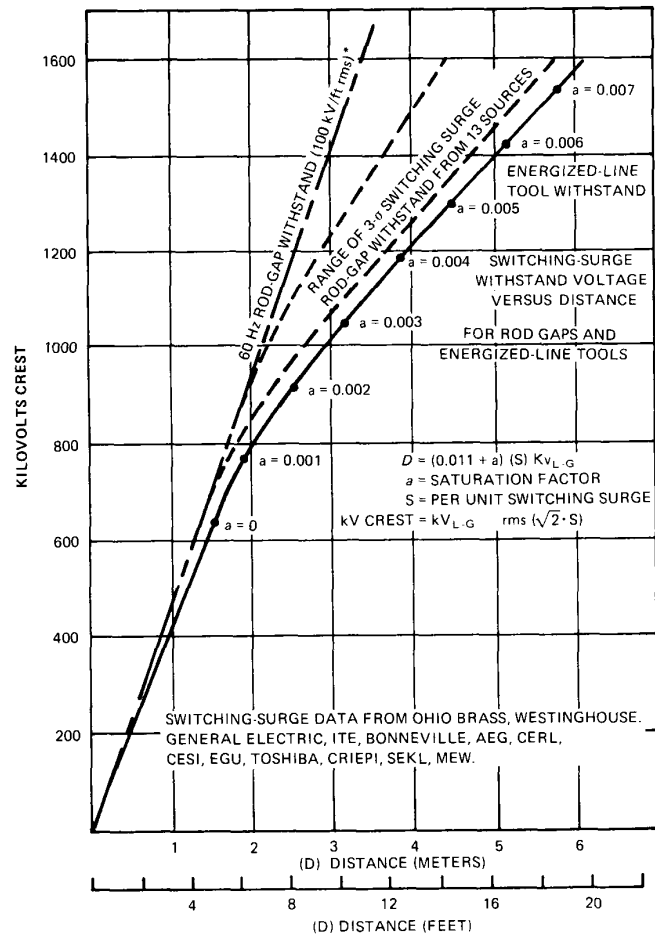
Fig 1
60 Hz Switching-Surge Saturation Factor

- The switching-surge factor S as given in Fig 2 should be correlated with characteristics of each individual power system.
- (2) Switching surges are important in determining alternating-current clearances. The maximum switching surge represents the maximum rise in voltage during a disturbance on an operating line or system. Maximum switching surge values should be used when calculating distances.
 - (3) The configuration of electrodes influences flashover as a function of the polarity of the switching surge.

In usual applications for solid insulating tools, the dry, negative-polarity, switching-surge flashover voltage is substantially above power frequency and positive-polarity values. It has been shown that the flashover curve for the conductor-tower configuration lies approximately midway between the rod-rod and rod-plane gaps as in Fig 2.

These data substantiate the clearance formula for air gaps and insulating tools, and as the derivation of clearances from modified rod-gap data.

- (4) Distances determined by means of the formulas should not be applied without reference to the other relevant factors contained in this section.
- (5) The distance determined by the formulas should be applied only at elevations below 3000 ft (914 m). Higher elevations require applicable correction factors as indicated in Table 1.
- (6) The minimum tool-insulation distance and the minimum approach distances given in Tables 2, 3, 4, and 5 are calculated distances. In practice, however, distances are rounded off up to the next highest 6 in (15 cm). When system voltages are higher than nominal, actual voltage values should always be used.



*THIS CURVE CANNOT BE LINEAR AT HIGH VOLTAGES DUE TO THE SIZE AND SHAPE OF THE ROD-GAP ELECTRODES.

Fig 2
Typical — Withstand Voltage
for Switching Surges

- (7) In determining dc clearance, values equivalent to ac peak voltages related to dc system voltage-to-ground should be used.
- (8) The minimum tool-insulation distance as given in the tables should be maintained between an energized part and a person at ground potential performing a work operation on energized lines or devices. In bare-hand work, the minimum tool-insulation distances should be maintained between a person energized at phase potential and ground.

3.2.2.2 Minimum Tool-Insulation Distance.

In practice, it is generally accepted that insulating material (clean and dry) has a dielectric-strength characteristic equal to or greater than that of air, based on rod-gap withstand values.

The following formula is recommended for deriving a minimum, safe insulation distance for clean and dry, solid or filled insulating tools intended for energized-line maintenance on ac transmission systems [35].

$$D = (C_1 C_2 + a) S kV_{LG} \quad (\text{Eq 1})$$

where

 D = insulation distance, ft C_1 = 0.01, or one percent of line-to-ground C_2 = 1.1, composed of 1.06 for energized-line tool-to-air withstand distance ratio plus intangibles [35] a = saturation factor for crest ($\sqrt{2} S \text{ kV}_{LG}$) voltages of 630 kV and above (see Fig 1) S = maximum anticipated per-unit switching surge kV_{LG} = rms system phase-to-ground kilovolts—actualThe general formula for insulating tools at all voltages becomes $D = (0.011 + a) S \text{ kV}_{LG}^{10}$ ¹⁰Use crest voltage $345 \cdot \frac{\sqrt{2}}{\sqrt{3}}$ · overvoltage.**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
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, 3, 4, and 5 by the indicated correction factor.**Table 2**
Minimum Tool-Insulation Distance AC Energized Line-Work On Insulation
(a) Distance Measured (cm)

kV (rms)																			
LL	115	121	138	145	161	169	230	242	345	362	500	552	700	800					
LG	67	70	80	85	95	100	133	140	200	210	290	320	405	462					
S	D	D	D	D	D	D	D	D	a	D	a	D	a	D	a	D	a	D	a
1.5											0	146	0.3	165	1.6	233	2.5	285	
1.6											0.2	158	0.6	181	2.0	257	3.0	315	
1.7											0.4	171	1.0	199	2.4	282	3.5	347	
1.8											0.7	186	1.3	216	2.9	309	4.0	380	
1.9											1.0	201	1.6	233	3.3	335	4.5	415	
2.0	45	47	54	56	64	67	89	94	0	134	0	141	1.3	218	2.0	254	3.8	365	5.0
2.1	47	49	56	59	67	70	94	98	0	141	0	148	1.6	234	2.3	272	4.2	394	5.6
2.2	51	52	59	62	70	74	98	103	0	148	0.1	156	1.9	251	2.6	292			
2.3	52	54	62	65	73	77	102	108	0.1	156	0.3	166	2.2	268	2.9	312			
2.4	54	56	64	68	77	80	107	113	0.3	165	0.6	178	2.5	287	3.3	335			
2.5	56	59	67	70	80	84	112	117	0.5	175	0.8	189	2.8	305	3.6	356			
2.6	59	61	70	73	83	87	116	123	0.7	185	1.0	200							
2.7	61	63	73	76	86	91	120	127	0.9	196	1.2	211							
2.8	63	66	75	79	89	94	125	131	1.1	207	1.4	222							
2.9	65	68	78	82	92	97	129	136	1.3	217	1.6	234							
3.0	67	70	80	84	96	101	134	141	1.5	228	1.8	246							

LL Phase to phase

LG Phase to ground

 S Maximum anticipated per-unit switching surge D Distance measured (cm) a Given in thousandths (saturation factor)

NOTES: (1) Distances listed are for standard atmospheric conditions.

(2) Distances are based on altitudes below 1000 m.

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

Table 2
Minimum Tool-Insulation Distance AC Energized Line-Work On Insulation
(b) Distance Measured (ft)

kV (rms)																				
LL	115	121	138	145	161	169	230	242	345		362		500		552		700		800	
LG	67	70	80	85	95	100	133	140	200		210		290		320		405		462	
<i>S</i>	<i>D</i>	<i>D</i>	<i>D</i>	<i>D</i>	<i>D</i>	<i>D</i>	<i>D</i>	<i>D</i>	<i>a</i>	<i>D</i>	<i>a</i>	<i>D</i>	<i>a</i>	<i>D</i>	<i>a</i>	<i>D</i>	<i>a</i>	<i>D</i>	<i>a</i>	<i>D</i>
1.5													0	4.79	0.3	5.42	1.6	7.65	2.5	9.35
1.6													0.2	5.20	0.6	5.94	2.0	8.42	3.0	10.34
1.7													0.4	5.62	1.0	6.53	2.4	9.22	3.5	11.39
1.8													0.7	6.11	1.3	7.08	2.9	10.11	4.0	12.47
1.9													1.0	6.61	1.6	7.66	3.3	11.00	4.5	13.61
2.0	1.47	1.54	1.76	1.85	2.09	2.20	2.93	3.08	0	4.40	0	4.62	1.3	7.14	2.0	8.32	3.8	11.99	5.0	14.78
2.1	1.55	1.62	1.85	1.94	2.19	2.31	3.07	3.23	0	4.62	0	4.85	1.6	7.67	2.3	8.94	4.2	12.93	5.6	16.11
2.2	1.62	1.69	1.94	2.03	2.30	2.42	3.22	3.39	0	4.84	0.1	5.12	1.9	8.23	2.6	9.57				
2.3	1.70	1.77	2.02	2.13	2.40	2.53	3.36	3.54	0.1	5.11	0.3	5.46	2.2	8.80	2.9	10.23				
2.4	1.77	1.85	2.11	2.22	2.51	2.64	3.51	3.70	0.3	5.42	0.6	5.85	2.5	9.40	3.3	10.98				
2.5	1.84	1.93	2.20	2.31	2.61	2.75	3.66	3.85	0.5	5.75	0.8	6.20	2.8	10.01	3.6	11.68				
2.6	1.92	2.00	2.29	2.40	2.72	2.86	3.80	4.00	0.7	6.08	1.0	6.55								
2.7	1.99	2.08	2.38	2.49	2.82	2.97	3.95	4.16	0.9	6.43	1.2	6.92								
2.8	2.06	2.16	2.46	2.59	2.93	3.08	4.10	4.31	1.1	6.78	1.4	7.29								
2.9	2.14	2.23	2.55	2.68	3.03	3.19	4.24	4.47	1.3	7.13	1.6	7.67								
3.0	2.21	2.31	2.64	2.77	3.14	3.30	4.39	4.62	1.5	7.50	1.8	8.06								

LL Phase to phase
 LG Phase to ground
S Maximum anticipated per-unit switching surge
D Distance measured (ft)
a Given in thousandths (saturation factor)

NOTES: (1) Distances listed are for standard atmospheric conditions.
 (2) Distances are based on altitudes below 1000 m.
 (3) Distances do not include any factor for inadvertant movement.

Table 3
Minimum Tool-Insulation Distance DC Energized Line-Work
DC Pole-to-Ground Voltage

LG	250 kV			400 kV			500 kV			600 kV			750 kV		
	<i>S</i>	<i>D</i>	<i>a</i>	<i>D</i>	<i>D</i>	<i>a</i>	<i>D</i>	<i>D</i>	<i>a</i>	<i>D</i>	<i>D</i>	<i>a</i>	<i>D</i>	<i>D</i>	
		(ft)	(cm)	(ft)	(cm)		(ft)	(cm)		(ft)	(cm)		(ft)	(cm)	
1.2		2.33	71	0	3.73	114	0	4.67	142	0.6	5.91	180	1.9	8.21	250
1.3		2.53	77	0	4.05	123	0	5.06	154	1.0	6.62	202	2.5	9.30	283
1.4		2.48	83	0	4.36	133	0.5	5.20	173	1.5	6.83	236	3.0	9.65	317
1.5		2.91	89	0	4.66	142	0.8	6.26	192	1.9	8.22	251	3.6	11.60	354
1.6		3.11	95	0	4.98	152	1.2	6.90	210	2.3	9.02	275	4.2	12.90	393
1.7		3.31	101	0.3	5.43	166	1.5	7.52	229	2.8	9.95	303	4.8	14.20	433
1.8		3.51	107	0.6	5.90	180	1.9	8.22	251	3.3	10.90	332	5.4	15.60	475
1.9		3.70	113	0.9	6.40	195	2.3	8.93	272	3.7	11.80	360	6.0	17.10	521
2.0		3.89	119	1.2	6.91	211	2.6	9.61	293	4.2	12.90	393	6.6	18.71	537
2.1		4.08	124	1.5	7.42	226	3.0	10.40	317	4.7	14.00	427			
2.2		4.28	130	1.8	7.96	243	3.4	11.20	341	5.2	15.10	460			

LG DC pole-to-ground voltage
S Maximum anticipated per-unit switching surge (transient overvoltage)
D Distance measured (ft and cm)
a Given in thousandths (saturation factor)

NOTES: (1) Consideration should be given to increasing some of the minimum insulation distances above, so as to reduce the stress due to the steady-state voltage a maximum steady-state stress of 60 kV/ft is suggested as an allowance for average working conditions.
 (2) If the minimum insulation distances are used, the maximum relative humidity should be restricted to 85%.
 (3) Distances listed are for standard atmospheric conditions.
 (4) Distances are based on altitudes below 1000 m.
 (5) Distances do not include any factor for inadvertant movement.