

IEEE Trial-Use Guide for Maintenance Methods on Energized Power-Lines

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Draft American National Standard

**IEEE Trial-Use Guide for Maintenance Methods on
Energized Power-Lines**

Sponsor

Transmission and Distribution Committee of the
IEEE Power Engineering Society

Draft American National Standard

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Foreword

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

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

In the 1950's when the transmission-line voltages 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 lines increased rapidly.

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

This guide has been in development and review for over 10 years and is now being released on a trial basis. The guide was originally intended to cover only subtransmission and transmission lines with voltages above 40 kV. It has since been revised to cover all voltages above 5 kV and to conform with the existing national codes. Work has also been done to coordinate this information with the International Electrotechnical Commission (IEC) on an international basis.

At the time this guide was approved the membership of the Task Group of the Engineering in Safety, Maintenance, and Operation of Lines Subcommittee was as follows:

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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. To 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.

To direct attention to appropriate standards and other documents for the acquisition of knowledge on the care and use of required tools and equipment.

To 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 pre-

sented specifically in the form of a guide to be used by those utilities that are seeking guidance in establishing methods and procedures for maintenance of energized power-lines.

This guide is not intended as 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 will be 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 operating utilities with many years of successful experiences. Advancement in technology or changes in system design will probably justify reduction of 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's 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. If any conflict exists between this guide and the rules of the owner of the line, the owner's rules should take precedence.

1.5 References

- [1] ANSI A92.2-1979, American National Standard Vehicle Mounted Elevating and Rotating Devices.¹
- [2] ANSI C2-1984, American National Standard National Electrical Safety Code.
- [3] ANSI C29.1-1975, American National Standard Precision Power Transmission Chains, Attachments, and Sprockets.
- [4] ANSI/ASTM D149-81, Standard Test Methods for Dielectric Breakdown Voltage and Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies.
- [5] ANSI/ASTM D1049-83, Standard Specification for Rubber Insulating Gloves.
- [6] ANSI/ASTM D1050-80, Standard Specification for Rubber Insulating Line Hose.
- [7] ANSI/ASTM D1051-81, Standard Specification for Rubber Insulating Sleeves.
- [8] ANSI/ASTM D1078-83, Standard Test Method for Distillation Range of Volatile Organic Liquids.
- [9] ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.
- [10] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.
- [11] ANSI/IEEE Std 524-1980, IEEE Guide to the Installation of Overhead Transmission Line Conductors.
- [12] ASTM D120-84, Standard Specification for Rubber Insulating Gloves.²
- [13] ASTM D1048-81, Standard Specification for Rubber Insulating Blankets.
- [14] CFR, Section 29. 1926/551 and 1910. 183, OSHA.³
- [15] CSA C225-76, Vehicle-Mounted Aerial Devices.⁴
- [16] Data Sheet 12304- 598-1980.⁵
- [17] EPRI Transmission-Line Reference Book (EL2500, 2nd ed).⁶
- [18] IEC 265-1968, High-Voltage Switches.⁷
- [19] IEEE Std 62-1978, IEEE Guide for Field Testing Power Apparatus Insulation.⁸
- [20] Application Guide for Insulator Contamination. See Application Guide for Insulators in Contaminated Environment. IEEE Paper F77-639-8.
- [21] 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.
- [22] BRIDGES, J. E. Biological Effects of 60 Hz Electric Fields. *IIT Research Institute Final Report* E8151, EPRI Project RP-381-1, Nov 1975.

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

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

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

⁴ In 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.

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

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

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

⁸ IEEE publications are available from the Institute of Electrical and Electronics Engineers Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

- [23] BRIDGES, J. E. Environmental Considerations Concerning the Biological Effects of Power-Frequency (50 Hz or 60 Hz) Electric Fields. *IEEE Paper F77 256-1*.
- [24] ELEK and SIMPSON. Safe Clearance and Protection Against Shocks During Live-Line Work. *AIEE Paper*, Feb 1962, pp 61–1019.
- [25] IEEE COMMITTEE REPORT 31-TP67-96. Recommendations for Safety in Live-Line Maintenance.
- [26] KOUWENHOVEN, W. B., et al. Body Current in Live-Line Working. *IEEE Paper 31-TP65-673*.
- [27] KOUWENHOVEN, W. B., et al. Medical Evaluation of Man Working in AC Electric Fields. *IEEE Paper 31-TP66-395*.
- [28] KOUWENHOVEN, W. B. and LANG-WORTHY, O. R. Effects of Electric Shock. *AIEE Transactions vol 49*, Jan 1930, pp 381–394.
- [29] 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.
- [30] Live-Line Maintenance Methods. Task Group for Live-Line Maintenance Methods. *IEEE Paper T-73 157-5*.
- [31] SINGEWALD, M. R., et al. Medical Follow-Up Study of High-Voltage Lineman Working in AC Electric Fields. *IEEE Paper T73 154-2*.
- [32] 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

accessory. A removable device attached to a major or primary operating tool allowing diversified operations. *Example:* universal tool.

alive. *See:* energized.

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.

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.

clearance. *See:* work permit.

conductor. A wire or combination of wires not insulated from one another, suitable for carrying an electric 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 which folds to completely surround and envelope 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.

conductor lifting hook. A device resembling an open boxing glove designed to permit the lifting of conductors from a position above the conductors. Normally used during clipping-in operations. Suspension clamps are sometimes used for this purpose. *Synonyms: boxing glove, conductor hook, lifting lip.*

cover-up equipment. Equipment designed to protect people 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 means 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 if 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.*

ehv. extra-high voltage.

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 more items.

extra-high voltage. *See ehv.*

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 and the boom swivels, affording greater maneuverability.

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

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 which has conductive parts and is either coated or covered with a dielectric material.

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 which has conductive parts separated by a dielectric.

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.

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.*

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

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.*

NESC. National Electrical Safety Code, ANSI C2-1984.

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.*

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

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.

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. *Synonym: hold out, live-line permit, hold order.*

uhv. Ultra-high voltage. *See: hv.*

universal stick. An accessory designed to attach to a universal stick allowing one insulated stick to be used to perform many different operations by the attachment of the specific tool required.

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 ap-

plicable 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

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 insulation and dielectric strength.

(1) Electrical insulation is the property of material to oppose 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 factors are derived from rod-gap switching-surge flashover data. 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 914 m (3000 ft). Higher elevations require applicable correction factors as indicated in Table 1.

(6) The minimum tool distance and the minimum approach distance given in Tables 2, 3, 4, and 5 are calculated distances. In practice, however, distances are rounded off up to the next highest 15 cm (6 in). When system voltages are higher than nominal, actual voltage values should always be used.

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 in Centimeters

	Kilovolts (rms)											
	115		121		138		145		161		230	
LL	67	72	72	72	80	85	85	85	95	100	133	140
LG	67	72	72	72	80	85	85	85	95	100	133	140
S	D		D		D		D		D		D	
	D		D		D		D		D		D	
1.1	25		26		30		31		35		49	
	27		28		32		34		38		54	
1.2	29		30		35		38		41		58	
	31		33		37		39		45		62	
1.3	34		35		40		42		48		67	
	36		37		43		45		51		71	
1.4	38		40		46		48		54		76	
	41		42		48		51		57		80	
1.5	43		45		51		54		61		83	
	45		47		54		56		64		89	
1.6	47		49		56		59		67		94	
	51		52		59		62		70		98	
1.7	52		54		62		65		73		102	
	54		56		64		68		77		107	
1.8	56		59		67		70		80		112	
	59		61		70		73		83		116	
1.9	61		63		73		76		86		120	
	63		66		75		79		89		125	
2.0	65		68		78		82		92		129	
	67		70		80		84		96		134	
2.1	67		70		80		84		96		134	
	67		70		80		84		96		134	

LL Phase to phase. S Maximum anticipated per-unit switching surge.

LG Phase to ground. D Distance measured in centimeters. A Gives a 10^{-3} (saturation factor).

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

		Kilovolts (rms)																	
		345				360				500				562		700		800	
		200				210				290				320		405		462	
		A	D	A	D	A	D	A	D	A	D	A	D	A	D	A	D		
LL	115	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D		
LG	67	0.81	0.85	0.97	1.02	1.15	1.21	1.60	1.69	0	2.42	0	2.54	0	3.51	0	3.87	0	
	121	0.86	0.92	1.05	1.11	1.25	1.32	1.76	1.83	0	2.64	0	2.77	0	3.83	0	4.22	0	
	72	0.96	1.00	1.14	1.20	1.36	1.43	1.90	2.00	0	2.86	0	3.00	0	4.15	0	4.59	0	
	80	1.03	1.08	1.23	1.29	1.46	1.54	2.04	2.16	0	3.09	0	3.23	0	4.47	0	4.93	0	
	85	1.11	1.16	1.32	1.39	1.57	1.65	2.19	2.31	0	3.30	0	3.47	0	4.79	0.3	5.42	1.6	
	138	1.18	1.23	1.41	1.48	1.62	1.76	2.34	2.46	0	3.52	0	3.70	0.2	5.20	0.6	5.94	2.0	
	145	1.25	1.31	1.50	1.57	1.78	1.87	2.47	2.62	0	3.74	0	3.93	0.4	5.62	1.0	6.53	2.4	
	161	1.33	1.39	1.58	1.66	1.88	1.98	2.63	2.77	0	3.96	0	4.15	0.7	6.13	1.3	7.08	2.9	
	169	1.40	1.46	1.67	1.76	1.99	2.09	2.78	2.93	0	4.18	0	4.39	1.0	6.61	1.6	7.66	3.3	
	230	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	
	242	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	
	345	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		
	360	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		
	500	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		
	562	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		
	700	1.92	2.00	2.29	2.40	2.72	2.86	3.80	4.00	0.7	6.08	1.0	6.55						
	800	1.99	2.08	2.38	2.49	2.82	2.97	3.95	4.16	0.9	6.43	1.2	6.92						
	462	2.06	2.16	2.46	2.59	2.93	3.08	4.10	4.31	1.1	6.78	1.4	7.29						
	405	2.14	2.23	2.55	2.68	3.03	3.19	4.24	4.47	1.3	7.13	1.6	7.67						
	320	2.21	2.31	2.64	2.77	3.14	3.30	4.37	4.62	1.5	7.50	1.8	8.06						

LL Phase to phase. S Maximum anticipated per-unit switching surge.

LG Phase to ground. D Distance measured in feet. A Gives a 10^{-3} (saturation factor).