



IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)

IEEE Power Engineering Society

Sponsored by the
Surge Protective Devices Committee

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(Revision of
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**Surge Protective Devices Committee
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Approved 29 December 2005
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Abstract: This standard applies to metal-oxide surge arresters (MOSAs) designed to repeatedly limit the voltage surges on 48 Hz to 62 Hz power circuits (>1000 V) by passing surge discharge current and automatically limiting the flow of system power current. This standard applies to devices for separate mounting and to devices supplied integrally with other equipment. The tests demonstrate that an arrester can survive the rigors of reasonable environmental conditions and system phenomena while protecting equipment and/or the system from damaging overvoltages caused by lightning, switching, and other undesirable surges.

Keywords: discharge current, discharge voltage, duty-cycle voltage rating, lightning protection, maximum continuous operating voltage, MCOV, metal-oxide surge arrester, MOSA, surge arrester, valve arrester

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Introduction

This introduction is not part of IEEE Std C62.11-2005, IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV).

Metal-oxide surge arresters (MOSAs) described in this standard represent the most predominant surge arrester technology applied on ac power systems above 1 kV. This standard presents minimum criteria for the testing of such surge arresters. Matters of application of this type of surge arrester are covered in IEEE Std C62.22™-1997. Testing and application of older technology silicon carbide surge arresters are covered in IEEE Std C62.1™ and ANSI Std C62.2-1987, respectively. For testing and application of surge protective devices for use in low-voltage circuits (1 kV and below), other standards in the C62 series are available.

This revision of IEEE Std C62.11 contains the following significant changes from the previous revision:

- Addition of partial discharge (PD) test requirements and elimination of internal ionization voltage test
- Addition of accelerated aging test of polymer-housed arresters with exposure to salt fog
- Addition of moisture ingress test requirements for polymer-housed arresters [combined with maximum design cantilever load (MDCL) test]
- Split of discharge-current withstand tests clause into two separate clauses: high-current short-duration withstand test and low-current long-duration withstand test
- Restructure of design test clauses and subclauses to provide consistency of format
- Revision of Table 2 to provide more helpful references to design test clauses for different classes and types of arrester
- Addition of definitions for electrical unit, mechanical unit, PD, and prospective short-circuit current
- Replacement of the terms watts loss and watt loss with power loss to provide consistency throughout the standard
- Replacement of the term creepage with leakage to provide consistency throughout the standard
- Editorial changes to correct a variety of errors of previous revision

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1. Scope

This standard applies to metal-oxide surge arresters (MOSAs) designed to repeatedly limit the voltage surges on 48 Hz to 62 Hz power circuits (>1000 V) by passing surge discharge current and automatically limiting the flow of system power current. This standard applies to devices for separate mounting and to devices supplied integrally with other equipment.

NOTE—These tests demonstrate that an arrester can survive the rigors of reasonable environmental conditions and system phenomena while protecting equipment and/or the system from damaging overvoltages caused by lightning, switching, and other undesirable surges.¹

2. Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI Std C37.42-1996, American National Standard for Switchgear-Distribution Cutouts and Fuse Links-Specifications.²

ANSI Std C62.2-1987, Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems.

ANSI Std C84.1-1995 (Reaff 2001), American National Standard Voltage Ratings for Electric Power Systems and Equipment (60 Hz).

ASTM A153/153M-04, Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.³

¹ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement this standard.

² ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org>). This particular standard is also available in the Circuit Breakers, Switchgear, Substations, Fuses Supplement Collection from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org>).

³ ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org>).

- ASTM D750-00, Standard test method for rubber deterioration in carbon-arc weathering apparatus.
- ASTM D1499-99, Standard practice for operating light and water exposure apparatus (carbon-arc type) for exposure of plastics.
- ASTM D2565-99, Standard practice for xenon arc exposure of plastics intended for outdoor applications.
- ASTM D3487-00, Specification for Mineral Insulating Oil Used in Electrical Apparatus.
- ASTM G23-96, Standard practice for operating light and water exposure apparatus (carbon-arc type) with and without water for exposure of nonmetallic materials.
- ASTM G26-96, Standard practice for operating light and water exposure apparatus (Xenon-arc type) with and without water for exposure of nonmetallic materials.
- ASTM G53-96, Standard practice for operating light and water exposure apparatus (fluorescent UV-condensation type) for exposure of nonmetallic materials.
- IEC 60815 (1986), Guide for the selection of insulators in respect to polluted conditions.⁴
- IEEE Std C37.09™-1999, IEEE Standard Test Procedure for Alternating Current High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.^{5, 6}
- IEEE Std C62.22™-1997, IEEE Guide for the Application of Metal Oxide Surge Arresters for Alternating Current Systems.
- IEEE Std 4™-1995 (Amended 2001), IEEE Standard Techniques for High-Voltage Testing.
- IEEE Std 386™-1995, IEEE Standard for Separable Insulated Connector Systems for Power Distribution Systems Above 600 V.
- IEEE Std 454-1973 (Reaff 1979; withdrawn 1988), IEEE Standard for Partial Discharges (Corona) During Dielectric Tests.
- IEEE Std 1313™-1993, IEEE Standard for Power Systems Insulation Coordination (formerly ANSI Std C92.1-1982).
- IEEE Std 1313.1™-1996, IEEE Standard for Insulation Coordination—Definitions, Principles and Rules.
- IEEE Std 1313.2™-1999, IEEE Guide for the Application of Insulation Coordination.
- NEMA LA 1-1992 (Reaff 1999), Surge Arresters.⁷
- NEMA 107-1987 (Reaff 1993), Methods of Measurement of Radio Influence Voltage (RIV) of High-Voltage Apparatus.

⁴ IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Geneve 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publication are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org>).

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3. Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition*, should be referenced for terms not defined in this clause.

3.1 arrester: *See:* **surge arrester.**

3.2 arrester, deadfront type: An arrester assembled in a shielded housing providing system insulation and conductive ground shield, intended to be installed in an enclosure for the protection of underground and pad-mounted distribution equipment and circuits.

3.3 arrester disconnecter: A means for disconnecting an arrester in anticipation of, or after, a failure in order to prevent a permanent fault on the circuit and to give indication of a failed arrester.

NOTE—Clearing of the fault current through the arrester during disconnection is generally done by the nearest source side overcurrent-protective device.

3.4 arrester, distribution, heavy duty class: An arrester normally used to protect overhead distribution systems exposed to severe lightning currents.

3.5 arrester, distribution, light duty class: An arrester normally installed on and used to protect underground distribution systems where the major portion of the lightning stroke current is discharged by an arrester located at the overhead line/cable junction.

3.6 arrester, distribution, normal duty class: An arrester normally used to protect overhead distribution systems exposed to normal lightning currents.

3.7 arrester, liquid-immersed type: An arrester designed for use immersed in an insulating liquid.

3.8 arrester, riser pole type: An arrester for pole mounting normally used to protect underground distribution cable and equipment.

3.9 arrester unit: Any section of a multi-unit arrester.

3.10 basic lightning impulse insulation level (BIL): (A) The electrical strength of insulation in terms of the crest value of a standard lightning impulse under standard atmospheric conditions. BIL may be expressed as either statistical or conventional. (B) A specific insulation level expressed as the crest value of a standard lightning impulse. *See also:* **conventional basic lightning impulse insulation level (BIL); statistical basic lightning impulse insulation level (BIL).**

3.11 basic switching impulse insulation level (BSL): (A) The electrical strength of insulation expressed in terms of the crest value of a standard switching impulse. BSL may be expressed as either statistical or conventional. (B) A specific insulation level expressed as the crest value of a standard switching impulse. *See also:* **conventional basic switching impulse insulation level (BSL); statistical basic switching impulse insulation level (BSL).**

3.12 certification tests: Tests run on a regular, periodic basis to verify that selected, key performance characteristics of a product or representative samples thereof have remained within performance specifications.

3.13 classification of arresters: Arrester classification is determined by prescribed test requirements of this standard. These classifications are station, intermediate, distribution heavy duty, distribution normal duty, distribution light duty.

3.14 classifying current: The designated current used to perform the classification tests.

3.15 conformance tests: Tests made, when required, to demonstrate selected performance characteristics of a product or representative samples thereof.

3.16 conventional basic lightning impulse insulation level (BIL): Applicable specifically to nonself-restoring insulations. The crest value of a standard lightning impulse for which the insulation does not exhibit disruptive discharge when subjected to a specific number of applications of this impulse under specified conditions. *See also:* **statistical basic lightning impulse insulation level (BIL).**

3.17 conventional basic switching impulse insulation level (BSL): Applicable specifically to nonself-restoring insulations. The crest value of a standard switching impulse for which the insulation does not exhibit disruptive discharge when subjected to a specific number of applications of this impulse under specified conditions. *See also:* **statistical basic switching impulse insulation level (BSL).**

3.18 cracking: The rupture of the weathershed material to depths greater than 0.1 mm.

3.19 crest (peak) value (of a wave, surge, or impulse): The maximum value that a wave, surge, or impulse attains.

3.20 deflector: A means for directing the flow of the gas discharge from the vent of the arrester.

3.21 design tests: Tests made on each design to establish the performance characteristics and to demonstrate compliance with the appropriate standards of the industry. Once made, they need not be repeated unless the design is changed so as to modify performance.

3.22 discharge counter: A means for recording the number of arrester discharge operations.

3.23 discharge current: The surge current that flows through an arrester.

3.24 discharge indicator: A means for indicating that the arrester has discharged.

3.25 discharge voltage: The voltage that appears across the terminals of an arrester during passage of discharge current.

3.26 discharge voltage-current characteristic: The variation of the crest values of discharge voltage with respect to discharge current.

NOTE—This characteristic is normally shown as a graph based on three or more current-surge measurements of the same wave shape but of different crest values.

3.27 discharge withstand current: The specified magnitude and wave shape of a discharge current that can be applied to an arrester a specified number of times without causing damage to it.

3.28 disruptive discharge: The sudden and large increase in current through an insulating medium, due to the complete failure of the medium under the electrostatic stress.

3.29 duty-cycle voltage rating: The designated maximum permissible voltage between its terminals at which an arrester is designed to perform its duty cycle.

3.30 electrical unit: Portion of an arrester in which each end of the unit is terminated with an electrode which is exposed to the external environment.

3.31 fault current: The current from the connected power system that flows in a short circuit.

3.32 flashover: A disruptive discharge around or over the surface of a solid or liquid insulator.

3.33 front-of-wave impulse sparkover voltage: The impulse sparkover voltage with a wave front that rises at a uniform rate and causes sparkover on the wave front.

3.34 gapless: Not possessing gaps, series, or parallel as in *gapless arrester*.

3.35 grading or control ring: A metal part, usually circular or oval in shape, mounted to modify electrostatically the voltage gradient or distribution.

3.36 ground terminal: The conducting part provided for connecting the arrester to ground.

3.37 impulse: A surge of unidirectional polarity.

3.38 impulse protective level: For a defined wave shape, the higher of the maximum sparkover value or the corresponding discharge-voltage value.

3.39 impulse protective volt-time characteristic: The discharge-voltage time response of the device to impulses of a designated wave shape and polarity, but of varying magnitudes.

3.40 impulse sparkover voltage: The highest value of voltage attained by an impulse of a designated wave shape and polarity applied across the terminals of an arrester that will cause gap sparkover prior to the flow of discharge current.

3.41 impulse sparkover volt-time characteristic: The gap sparkover response of the device to impulses of a designated wave shape and polarity, but of varying magnitudes.

NOTE—For an arrester, this characteristic is shown by a graph of crest voltage values plotted against time to sparkover.

3.42 impulse withstand voltage: The crest value of an impulse that, under specified conditions, can be applied without causing a disruptive discharge.

3.43 indoor arrester: An arrester that, because of its construction, must be protected from the weather.

3.44 ionization current: The electric current resulting from the movement of electric charges in an ionized medium, under the influence of an applied electric field.

3.45 ionization voltage: A high-frequency voltage appearing at the terminals of an arrester, generated by all sources, but particularly by ionization current within the arrester, when a power-frequency voltage is applied across the terminals.

3.46 lightning: An electric discharge that occurs in the atmosphere between clouds or between clouds and ground.

3.47 lightning surge: A transient electric disturbance in an electric circuit caused by lightning.

3.48 line terminal: The conducting part of the arrester provided for connecting the arrester to the circuit conductor.

3.49 maximum continuous operating voltage (MCOV): The maximum designated root-mean-square (rms) value of power-frequency voltage that may be applied continuously between the terminals of the arrester.

3.50 maximum design cantilever load-static (MDCL-static): The maximum cantilever load the surge arrester is designed to continuously carry.

3.51 maximum system voltage: The highest voltage at which a system is operated.

NOTE—This is generally considered to be the maximum system voltage as prescribed in ANSI Std C84.1-1995 (Reaff 2001).⁸

3.52 mechanical unit: Portion of an arrester in which the valve elements within the unit are mechanically restrained from moving in an axial direction.

3.53 metal-oxide surge arrester (MOSA): A surge arrester utilizing valve elements fabricated from nonlinear resistance metal-oxide materials.

3.54 nominal rate of rise (of an impulse wave front): The slope of the line that determines the virtual zero. It is usually expressed in volts or amperes per microsecond.

3.55 nominal system voltage: A nominal value assigned to designate a system of a given voltage class.

NOTE—See ANSI Std C84.1-1995 (Reaff 2001).

3.56 normal lightning current: Lightning currents of 65 kA or less. *See also:* **severe lightning current.**

3.57 operating duty cycle: One or more unit operations, as specified.

3.58 oscillatory surge: A surge that includes both positive and negative polarity values.

3.59 outdoor arrester: An arrester that is designed for outdoor use.

3.60 partial discharge (PD): A localized electric discharge resulting from ionization in an insulation system when the voltage stress exceeds the critical value. This discharge partially bridges the insulation between electrodes.

3.61 power-frequency sparkover voltage: The root-mean-square (rms) value of the lowest power-frequency sinusoidal voltage that will cause sparkover when applied across the terminals of an arrester.

3.62 power-frequency withstand voltage: A specified root-mean-square (rms) test voltage at a power frequency that will not cause a disruptive discharge.

3.63 production tests: *See:* **routine tests.**

3.64 prorated section: A complete, suitably housed part of an arrester, comprising all necessary components, including gaseous medium, in such a proportion as to accurately represent, for a particular test, the characteristics of a complete arrester.

3.65 prospective (available) short-circuit current (at a given point in a circuit): The maximum current that the power system can deliver through a given circuit point to any negligible impedance, short circuit applied at the given point or at any other point that will cause the highest current to flow through the given point.

NOTE 1—This value can be in terms of either symmetrical or asymmetrical, peak or root-mean-square (rms) current, as specified.

NOTE 2—In some resonant circuits, the maximum available short-circuit current may occur when the short circuit is placed at some other point than the given one where the available current is measured.

3.66 puncture: **(A)** A disruptive discharge through a solid dielectric. **(B)** A disruptive discharge through solid insulation. **(C)** Term used to denote when a disruptive discharge occurs through a solid dielectric and produces permanent loss of dielectric strength; in a liquid or gaseous dielectric, the loss may be only temporary.

⁸ Information on references can be found in Clause 2.

3.67 radio-influence voltage (RIV): A high-frequency voltage, generated by all sources of ionization current, that appears at the terminals of electric-power apparatus or on power circuits.

3.68 rating: The designation of an operating limit for a device.

3.69 reference current (I_{ref}): The peak value of the resistive component of a power-frequency current high enough to make the effects of stray capacitance of the arrester negligible. This current level shall be specified by the manufacturer.

NOTE—Depending on the arrester design, the reference current will typically be in the range of 0.05 mA to 1.0 mA per square centimeter of disk area.

3.70 reference voltage (V_{ref}): The lowest peak value independent of polarity of power-frequency voltage, divided by the square root of 2, required to produce a resistive component of current equal to the reference current of the arrester or arrester element. The reference voltage of a multi-unit arrester is the sum of the reference voltages of the series units. The voltage level shall be specified by the manufacturer.

3.71 routine tests: Tests made by the manufacturer on every device or representative samples, or on parts or materials, as required, to verify that the product meets the design specifications.

3.72 series gap: Intentional gap(s) between spaced electrodes in series with the valve elements across which all or part of the impressed arrester terminal voltage appears.

3.73 severe lightning current: Lightning currents greater than 65 kA but not greater than 100 kA. *See also: normal lightning current.*

3.74 shunt gap: Intentional gap(s) between spaced electrodes that is electrically in parallel with one or more valve elements.

3.75 sparkover: A disruptive discharge between electrodes of a measuring gap, voltage-control gap, or gap-type protective device.

3.76 statistical basic lightning impulse insulation level (BIL): Applicable specifically to self-restoring insulations. The crest value of a standard lightning impulse for which the insulation exhibits a 90% probability of withstand (or a 10% probability of failure) under specified conditions. *See also: conventional basic lightning impulse insulation level (BIL).*

NOTE—See ANSI Std C62.2-1987.

3.77 statistical basic switching impulse insulation level (BSL): Applicable specifically to self-restoring insulations. The crest value of a standard switching impulse for which the insulation exhibits a 90% probability of withstand (or a 10% probability of failure) under specified conditions. *See also: conventional basic switching impulse insulation level (BSL).*

NOTE—See ANSI Std C62.2-1987.

3.78 surge: A transient wave of current, potential, or power in an electric circuit.

3.79 surge arrester: A protective device for limiting surge voltages on equipment by diverting surge current and returning the device to its original status. It is capable of repeating these functions as specified.

NOTE—Hereafter, the term *arrester* as used in this standard shall be understood to mean *surge arrester*.

3.80 system voltage: The root-mean-square (rms) power-frequency voltage from line to line as distinguished from the voltage from line to neutral.

3.81 terminals: The conducting parts provided for connecting the arrester across the insulation to be protected.

3.82 time-to-impulse sparkover: The time between virtual zero of the voltage impulse causing sparkover and the point on the voltage wave at which sparkover occurs.

3.83 tracking: Irreversible degradation of surface material from the formation of conductive carbonized paths.

3.84 ultimate mechanical strength-static (UMS-static): The load at which any part of the surge arrester fails to perform its mechanical function.

3.85 unit operation: A discharge of a surge through an arrester while the arrester is energized.

3.86 valve arrester: An arrester that includes one or more valve elements.

3.87 valve element: A resistor that because of its nonlinear current-voltage characteristic, limits the voltage across the arrester terminals during the flow of discharge current and contributes to the limitation of follow current at normal power-frequency voltage.

3.88 vent: An intentional opening for the escape of gases to the outside.

3.89 virtual duration of wave front (of an impulse): (A) For voltage waves with wave front duration less than 30 μs , either full or chopped on the front, crest, or tail, 1.67 times the time for the voltage to increase from 30% to 90% of its crest value. (B) For voltage waves with wave front duration of 30 μs or more, the time taken by the voltage to increase from actual zero to maximum crest value. (C) For current waves, 1.25 times the time for the current to increase from 10% to 90% of crest value.

3.90 virtual zero point (of an impulse): The intersection with the time axis of a straight line drawn through points on the front of the current wave at 10% and 90% crest value, or through points on the front of the voltage wave at 30% and 90% crest value.

3.91 wave: The variation with time of current, potential, or power at any point in an electric circuit.

3.92 wave front (of a surge or impulse): That part that occurs prior to the crest value.

3.93 wave shape (of an impulse test wave): The graph of the wave as a function of time.

3.94 wave shape designation (of an impulse): (A) The wave shape of an impulse (other than rectangular) of a current or voltage is designated by a combination of two numbers. The first, an index of the wave front, is the virtual duration of the wave front in microseconds. The second, an index of the wave tail, is the time in microseconds from virtual zero to the instant at which one-half of the crest value is reached on the wave tail. Examples are 1.2/50 and 8/20 waves. (B) The wave shape of a rectangular impulse of current or voltage is designated by two numbers. The first designates the minimum value of current or voltage that is sustained for the time in microseconds designated by the second number. An example is the 75 A 1000 μs wave.

3.95 wave tail (of an impulse): That part between the crest value and the end of the impulse.

3.96 withstand voltage: The voltage that an insulation is capable of withstanding. In terms of insulation, this is expressed as either conventional or statistical withstand voltage.

NOTE—See IEEE Std 1313.1-1996.

4. Service conditions

An arrester conforming to this standard shall be capable of successful operation under the service conditions given in 4.1 and 4.2.

4.1 Usual service conditions

4.1.1 Physical conditions

- a) Ambient air temperature in the general vicinity of the arrester shall be between -40°C and $+40^{\circ}\text{C}$,⁹ except that
 - 1) Ambient air temperature in the general vicinity of deadfront arresters shall be between -40°C and $+65^{\circ}\text{C}$
 - 2) Ambient liquid temperature in the general vicinity of liquid-immersed arresters shall be between -40°C and $+95^{\circ}\text{C}$
- b) Maximum temperature of the arrester, due to external heat sources in the general vicinity of the arrester, shall not exceed 60°C , except that
 - 1) Maximum temperature of the deadfront arrester shall not exceed 85°C
 - 2) Maximum temperature of the liquid-immersed arresters shall not exceed 120°C
- c) Altitude shall not exceed 1800 m (6000 ft), except for liquid-immersed arresters.

4.1.2 System conditions

- a) Nominal power system frequency of 48 Hz to 62 Hz
- b) System line-to-ground voltage within the ratings of the arrester under all system operating conditions

4.2 Unusual service conditions

Exposure to any of the service conditions described in 4.2.1 and 4.2.2 may require special consideration in the design or application of arresters.

4.2.1 Physical conditions

- a) Ambient temperatures in the general vicinity of the arrester exceeding the values given in 4.1.1
- b) Maximum arrester temperatures exceeding the values given in 4.1.1

⁹ This operating temperature is suitable for arresters not mounted in proximity to external heat sources causing a continuous ambient temperature in the vicinity of the arrester in excess of 40°C .

- c) Altitude exceeding 1800 m (6000 ft). Arresters for service at higher altitudes shall be suitable for operation at either of the following altitude ranges:
 - 1) 1801–3600 m (6001–12 000 ft)
 - 2) 3601–5400 m (12 001–18 000 ft)
- d) Exposure to any of the following:
 - 1) Damaging fumes or vapors
 - 2) Excessive dirt, salt spray, or other current-conducting deposits
 - 3) Steam
 - 4) Explosive atmospheres, abnormal vibrations, or shocks
- e) Limitation on clearances to nearby conducting objects, particularly at altitudes exceeding 1800 m (6000 ft)
- f) Unusual transportation or storage

4.2.2 System conditions

- a) Nominal power frequency other than 48 Hz to 62 Hz
- b) System operating conditions whereby the ratings of the arrester may be temporarily exceeded. Some examples are as follows:
 - 1) Loss of neutral ground on normally grounded circuit
 - 2) Generator overspeed
 - 3) Resonance during faults upon loss of major generation
 - 4) System instability
 - 5) Persistent single line-to-ground fault on ungrounded three-phase systems
- c) Any other unusual conditions known to the user

5. Standard voltage ratings: duty-cycle voltage and maximum continuous operating voltage (MCOV)

The standard root-mean-square (rms) duty-cycle voltage ratings and the corresponding rms MCOV rating are identified in Table 1.

Table 1—Arrester ratings^a

Duty-cycle voltage (kV rms)	MCOV (kV rms)	Duty-cycle voltage (kV rms)	MCOV (kV rms)
3	2.55	144	115
6	5.1	168	131
9	7.65	172	140
10	8.4	180	144
12	10.2	192	152
15	12.7	228	180
18	15.3	240	190
21	17	258	209
24	19.5	264	212
27	22	276	220
30	24.4	288	230
36	29	294	235
39	31.5	312	245
45	36.5	396	318
48	39	420	335
54	42	444	353
60	48	468	372
72	57	492	392
90	70	540	428
96	76	564	448
108	84	576	462
120	98	588	470
132	106	612	485

^aFor ratings not shown, consult with manufacturer.

6. Performance characteristics and tests

Each class and type of arrester shall be subjected to a series of design tests as listed in Table 2.

NOTE—A blank cell in Table 2 indicates that testing is not required.

Clause 7 contains general requirements for selection of test samples and for measurement practices. Clause 8 contains the specific requirements for each design test. Design test parameters are summarized for convenient reference in Table B.1.

Requirements for conformance tests, certification tests, and routine tests are contained in Clause 9, Clause 12, and Clause 13, respectively.

Table 2—Arrester design tests

Design test	Station and intermediate class		Distribution class			
	Porcelain	Polymer	Porcelain	Polymer	Liquid-immersed	Deadfront
Arrester insulation withstand test	8.1.2.4	8.1.2.4	8.1.2.1	8.1.2.1	8.1.2.2	8.1.2.3
Power-frequency sparkover test	8.2	8.2	8.2	8.2	8.2	8.2
Discharge-voltage characteristics test	8.3	8.3	8.3	8.3	8.3	8.3
Impulse protective level voltage-time characteristic test	8.4	8.4	8.4	8.4	8.4	8.4
Accelerated aging procedure	8.5	8.5	8.5	8.5	8.5	8.5
Accelerated aging test of polymer-housed distribution arresters with exposure to light and electrical stress				8.6		
Accelerated aging test of polymer-housed arresters with exposure to salt fog		8.7		8.7		
Contamination test	8.8	8.8	8.8	8.8		
Distribution arrester seal integrity design test			8.9	8.9		
Radio-influence voltage (RIV) test	8.10	8.10	8.10	8.10		
Partial discharge (PD) test	8.11	8.11	8.11	8.11	8.11	8.11
High-current short-duration withstand test	8.12	8.12	8.12	8.12	8.12	8.12
Low-current long-duration withstand test	8.13.1	8.13.1	8.13.2	8.13.2	8.13.2	8.13.2
Duty-cycle test	8.14	8.14	8.14	8.14	8.14	8.14
Temporary overvoltage (TOV) test	8.15	8.15	8.15	8.15	8.15	8.15
Pressure-relief test for station and intermediate arresters	8.16	8.16				
Short-circuit test for porcelain-housed distribution arresters			8.17			
Short-circuit test for polymer-housed distribution arresters				8.18		
Failure mode test for liquid-immersed arresters					8.19	
Deadfront arrester failure mode test						8.20
Distribution arrester disconnector test			8.21	8.21		
Maximum design cantilever load (MDCL) and moisture ingress test for polymer-housed arresters		8.22		8.22		
Ultimate mechanical strength-static (UMS-static) test for porcelain-housed arresters	8.23		8.23			

7. Test requirements

7.1 Complete arrester test samples

- New and clean arresters shall be used for each test unless otherwise specified.
- All test samples for arrester designs incorporating a disconnector, either as an integral part or as an accessory, shall include the disconnector.

- c) The arrester shall be mounted in the position(s) in which it is designed to be used.
- d) The arrester-mounting bracket, if used, shall be connected to the ground terminal.
- e) The grading or corona ring, if used, shall be included in design tests influenced by stray capacitance effects.
- f) Deadfront arresters shall be properly assembled with actual or simulated components. All parts that are normally grounded shall be connected to the ground of the test circuit.

7.2 Prorated section

Several design tests permit the use of scaled representations of a complete arrester. These prorated sections must be constructed so that they accurately represent the electrical and thermal characteristics of the represented arrester for the test being performed. The parameters of the prorated section depend on the particular design test being performed.

7.2.1 Prorating for discharge voltage tests

Tests may be made on open-air samples consisting of valve elements only. The diameter of valve elements used in the prorated section shall be the same as the diameter of the valve elements used in the arrester being modeled. The maximum discharge voltage of the complete arrester for a given discharge current is given by Equation (1).

$$V_{dmax} = \text{discharge voltage measured on the prorated section at the given current} \times K_s \quad (1)$$

where

K_s is the prorated section scale factor, given by Equation (2).

$$K_s = V_{DA} / V_{DS} \quad (2)$$

where

V_{DA} is the maximum discharge voltage of the arrester at classifying current

V_{DS} is the discharge voltage measured on the prorated section at classifying current

7.2.2 Prorating for design tests involving demonstration of thermal recovery

Design tests that involve application of power-frequency voltage and demonstration of thermal recovery (namely, TOV, discharge current withstand, and duty cycle) must be performed on a model that properly represents the thermal characteristics of the complete arrester and its environment. The diameter of valve elements used in the prorated section shall be the same as the diameter of the valve elements used in the arrester being modeled.

The prorated section must contain all organic components that are contained in the complete arrester, and they must be in the same nominal quantity per unit length. The prorated section does not have to be a slice out of the complete arrester, and it does not have to contain the inorganic components (e.g., porcelain) used in the arrester.

The specific construction of the housed model depends on the arrester type (see 7.2.2.1 and 7.2.2.2).

The duty-cycle voltage rating (V_R) and MCOV (V_C) of the prorated section are given by Equation (3) and Equation (4).

$$V_R = \text{arrester duty-cycle voltage rating} / K_p \quad (3)$$

$$V_C = \text{Arrester MCOV} / K_p \quad (4)$$

where

K_p is the prorated section scale factor

The prorated section scale factor shall be determined on the basis of reference voltage scaling or metal-oxide volume scaling, whichever results in the most conservative modeling. In other words, K_p shall be the lower of K_V or K_M where Equation (5) and Equation (6) apply.

$$K_V = V_{RA} / V_{RS} \text{ (reference voltage scaling factor)} \quad (5)$$

$$K_M = M_A / M_S \text{ (metal-oxide volume scaling factor)} \quad (6)$$

where

V_{RA} is the minimum reference voltage of arrester (specified by the manufacturer)

V_{RS} is the voltage measured on prorated section at reference current

M_A is the minimum metal-oxide volume in the complete arrester (specified by the manufacturer)

M_S is the metal-oxide volume in the prorated section

In addition, the valve elements used for the prorated section shall have a power-frequency power loss equal to the maximum allowed by the manufacturer in the arrester being modeled. In the event that maximum power loss valve elements are not available, prorated sections may be constructed with lower power-loss valve elements provided that the voltage applied during the thermal recovery portion of the test is adjusted as shown in Equation (7).

$$\text{Recovery voltage} = V_C \times K_W \times k_C \quad (7)$$

where Equation (8) applies.

$$K_W = V_{WI} / V_{WN} \quad (8)$$

where

V_{WI} is the voltage required to increase power loss to maximum allowed level, at the temperature at which power loss is normally measured

V_{WN} is the voltage at which power loss is normally measured

k_C is the accelerated aging factor determined by the procedure in 8.5.2.2

7.2.2.1 Outdoor arresters

Test models shall be constructed as follows:

- a) Housing length shall be great enough to enclose the prorated internal element(s), but shall not be more than 50% longer than the internal element(s). Housing length in excess of 10% longer than the internal element(s) shall be insulated both internally and externally with at least 5 cm thickness of uncompressed glass wool insulation or equivalent. The total mass of the housing in the model shall not exceed 110% of the mass of the housing in the section of the arrester being modeled.

- b) Both ends of the housing shall be closed using at least 5 cm thickness of uncompressed glass wool insulation or equivalent, and the insulation shall be arranged to cover the ends of the housing. The thermal resistivity constant (R-value) of the insulation shall be five or greater.
- c) Maximum conductor size for electrical connections within the sample shall be AWG # 12.

7.2.2.2 Liquid-immersed arresters

A requirement for liquid-immersed arresters has not yet been established. The manufacturer shall describe the thermal prorating procedure used. The thermal model should take into account the thermal effects of the liquid and other major components that may be contained in the tank or vessel in which the arrester will be installed in the field.

7.2.2.3 Test to verify thermal equivalency between complete arrester and thermally prorated arrester section

If, for any test requiring demonstration of thermal recovery, a complete arrester cannot be tested, then a thermally prorated section must be verified according to the procedure in this subclause. Once the prorated section has been verified for a given arrester type and design, the verification need not be repeated for future use of prorated sections of identical construction.

This procedure evaluates the validity of a thermally prorated section by heating it and a complete arrester to the same temperature, via internal power loss, and then by monitoring and comparing the cooling rates of the two devices with voltage switched off.

7.2.2.3.1 Ambient conditions

The complete arrester of the unit containing the most valve elements per unit length of a multi-unit arrester is placed, along with the prorated section, in still air having an ambient temperature of 20 °C (+20 °C, −10 °C). The ambient temperature shall be the same ± 3 °C for the duration of each test.

7.2.2.3.2 Cooling rate monitoring methods

To determine the cooling rates of the arrester and of the prorated section, thermocouples or other types of sensors may be attached to the blocks, or power loss or resistive component of current may be monitored. If power loss or resistive component of current is used, the complete arrester and the prorated section must be made using valve elements from the same lot.

If temperature sensors are used, they may be placed at a number of points and an average temperature calculated, or the temperature at any point located 1/3 to 1/2 of the arrester length from the top may be used. (Using the single point 1/3 to 1/2 length from the top gives a conservative result.)

7.2.2.3.3 Heating the valve elements

Valve elements in the complete arrester and in the prorated section shall be heated to a temperature of 120 °C ± 10 °C, within 1 min to 120 min, by application of power-frequency voltage with an amplitude above reference voltage. The temperature attained by the valve elements in the complete arrester and in the prorated section shall be equivalent within 3 °C. When this temperature is reached, the voltage source shall be disconnected.

The heating time for the complete arrester and the prorated section shall be the same within $\pm 5\%$. (A shorter heating time is more representative of most field circumstances, but a longer heating time is conservative.)

7.2.2.3.4 Determination of cooling rate curve

Within 1 min after disconnecting the heating (voltage) source, begin monitoring the cooling rate using any of the methods in 7.2.2.3.2 at intervals not exceeding 5 min. Continue monitoring for a period of not less than 2 h.

If power loss or resistive component of current is used, MCOV shall be applied in a periodic manner for a time not exceeding 30 s to determine the measured quantity. Voltage on time should be kept as short as possible to most closely duplicate the result that would be obtained with thermocouples. In order to give a conservative result, voltage on time for the prorated section shall not exceed voltage on time for the complete arrester.

Draw a smooth curve through the temperature, power loss, or resistive component of current versus time measured points.

7.2.2.3.5 Evaluation

After the complete arrester and the prorated section cooling rate curves have been determined, the two curves shall be compared.

Thermal equivalency of the prorated section is verified provided that, for all instants during the cooling period, the monitored quantity (e.g., temperature, power loss, or resistive component of current) for the prorated section is equal to or higher than for the complete arrester. If, at any instant, the section is not equal to or higher than the complete arrester, the section is not a valid proration.

If power loss is used, time zero power shall be set equal to 1 per unit for the arrester and 1 per unit for the prorated section in order to superimpose the starting points of the two curves.

7.3 Test measurements

Measurement practices shall be in accordance with the following:

- a) The specifications for the individual tests, as given in this standard
- b) The specifications for dielectric tests, as given in IEEE Std 4-1995

7.4 Impulse test-wave tolerances

For all test waves in these standards, specifications per Table 3 shall apply unless otherwise specified.

Table 3—Impulse wave shapes

Measured quantity	1.2/50 waves	All other exponential waves
Crest value	± 3%	± 10%
Front time	± 30%	± 10%
Time to half value	± 20%	± 10%
Nominal rate of rise of wave front	—	± 10%