

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

Sponsor

**Surge Protective Devices Committee
of the
IEEE Power Engineering Society**

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Abstract: Metal-oxide surge arresters designed to repeatedly limit the voltage surges on 48–62 Hz power circuits (>1 kV) are covered in this standard. These devices operate by discharging surge current. Devices for separate mounting and those supplied integrally with other equipment are also discussed.

Keywords: classifying current, discharge current, discharge voltage, duty-cycle voltage rating, maximum continuous operating voltage (MCOV), maximum design cantilever load-static (MDCL-static), metal-oxide surge arrester (MOSA), operating duty cycle, rating, reference current (I_{ref}), reference voltage (V_{ref}), sparkover, surge arrester, ultimate mechanical strength-static (UMS-static), valve

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Introduction

[This introduction is not part of IEEE Std C62.11-1999, IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV).]

This standard presents minimum criteria for the testing of metal-oxide surge arresters that are applied to ac power systems above 1 kV (1000 V).

Metal-oxide surge arresters described in this standard are the most predominant arrester technology applied on ac power systems above 1 kV. Other valve-type arresters are covered in IEEE Std C62.1-1989. For protection of low-voltage circuits, including vulnerable or susceptible electronics, the latest standards published in the C62 series should be consulted.

This standard is written for metal-oxide surge arresters both with and without spark gaps.

The following additions are included in this revision:

- a) Expanded definitions for basic lightning impulse insulation level (BIL);
- b) New definitions for maximum design cantilever load-static (MDCL-static) and ultimate mechanical strength-static (UMS-static);
- c) Short-circuit design tests for polymer-housed distribution arresters;
- d) MDCL-static tests for polymer-housed arresters;
- e) UMS-static tests for porcelain-housed arresters;
- f) Expanded routine test requirements.

This standard was developed by three working groups within the Surge Protective Devices Committee.

Working Group No. 3.3.8 had the following membership:

S. Brewer and D. W. Lenk, Chairs

J. Bennett	B. Johnnerfelt	J. C. Osterhout
T. Bialek	J. Kester	B. Parsons
J. Case	M. V. Lat	T. Rozek
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C. C. Erven	J. Mackevich	A. Vitols
P. Freeman	A. Maguire	J. Wilson
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J. P. DuPont	D. W. Lenk	A. Vitols
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Working Group No. 3.3.11 had the following membership:

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R. Moore

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T. Rozek
B. Steinbrecher
K. B. Stump
E. Tarasiewicz
E. R. Taylor
R. Thallam
A. Vitols
J. Williams
J. Wilson
J. J. Woodworth

The following members of the balloting committee voted on this standard:

Phil P. Barker
John S. Bonnesen
H. Steve Brewer
James J. Burke
James Case
Mike G. Comber
Randall L. Dotson
Cliff, C. Erven
Francis J. Fiederlein
Harald Fien
Laurence H. Fish
Ernie Gallo
George S. Haralampu
Steven P. Hensley
Andrew Robert Hileman
David W. Hutchins
Hieu Huynh
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Bengt Johnnerfelt
Jeff J. Kester
Ed Knapp
Joseph L. Koepfinger
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IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (> 1 kV)

1. Scope

This standard applies to metal-oxide surge arresters (MOSA) designed to repeatedly limit the voltage surges on 48–62 Hz power circuits (> 1 kV) by passing surge discharge current and automatically limiting the flow of system power current. This standard applies to devices for separate mounting and to those supplied integrally with other equipment.

2. References

This standard shall be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the revision shall apply.

ANSI C37.42-1996, American National Standard for Switchgear—Distribution Cutouts and Fuse Links—Specifications.¹

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

ASTM A153/A13M-98, Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.²

ASTM D750-95, Standard Test Method for Rubber Deterioration in Carbon-Arc Weathering Apparatus.

ASTM D1499-92a, Standard Practice for Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) for Exposure of Plastics.

¹ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>). This particular standard is also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://www.standards.ieee.org/>).

²ASTM 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 D2556-93a, Standard Test Method for Apparent Viscosity of Adhesives Having Shear-Rate-Dependent Flow Properties.

ASTM D3487-88 (1993), Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus.

ASTM G23-96, Standard Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials.

ASTM G26-96, Standard Practice for Operating Light-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.

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.³

IEEE Std 386-1995, IEEE Standard for Separable Insulated Connector Systems for Power Distribution Systems Above 600 V.

IEEE Std 1313.1-1996, IEEE Standard for Insulation Coordination—Definitions, Principles, and Rules (Revision and redesignation of IEEE Std 1313-1993).

IEEE Std C37.09-1979 (Reaff 1988), IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis (ANSI/DoD).

IEEE Std C62.22-1997, IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.

NEMA LA 1-1992, Surge Arresters.⁴

NEMA 107-1987 (R1993), Methods of Measurement of Radio-Influence Voltage (RIV) of High Voltage Apparatus.

3. Definitions

The following definitions apply to metal-oxide surge arresters. They do not necessarily cover other applications.

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 over-current-protective device.

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://www.standards.ieee.org/>).

⁴NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://www.global.ihs.com/>).

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 multiunit arrester.

3.10 basic lightning impulse insulation level (BIL): **(A)** The electrical strength of insulation expressed in terms of the crest value of a standard lightning impulse under standard atmospheric conditions. BIL may be expressed as either statistical or conventional (see IEEE Std 1313.1-1996). **(B)** A specific insulation level expressed as the crest value of a standard lightning impulse (see ANSI C92.1-1982 and IEEE Std C62.22-1991).

- **BIL (conventional):** Applicable specifically to non-self-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 IEEE Std C62.2-1987).
- **BIL (statistical):** 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 IEEE Std C62.2-1987).

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 (see ANSI C92.2-1982 and IEEE Std C62.2-1987). **(B)** A specific insulation level expressed as the crest value of a standard switching impulse (see ANSI C92.1-1982 and IEEE Std C62.22-1991).

- **BSL (conventional):** Applicable specifically to non-self-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 impulses under specified conditions (see IEEE Std C62.2-1987).
- **BSL (statistical):** 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 IEEE Std C62.2-1987).

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 the 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. *Note:* See Annex B for a summary of test parameters by classification.

3.15 conformance tests: Tests made, when required, to demonstrate selected performance characteristics of a product or representative samples thereof. *Note:* See Table 4, Table 5, and Table 6 in Clause 8.

- 3.16 cracking:** Rupture of the weathershed material to depths greater than 0.1 mm.
- 3.17 crest (peak) value (of a wave, surge, or impulse):** The maximum value that a wave, surge, or impulse attains.
- 3.18 current, normal lightning:** Lightning currents of 65 kA or less.
- 3.19 current, severe lightning:** Lightning currents greater than 65 kA, but not greater than 100 kA.
- 3.20 deflector:** A means for directing the flow of 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 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 fault current:** The current from the connected power system that flows in a short circuit.
- 3.31 flashover:** A disruptive discharge around or over the surface of a solid or liquid insulator.
- 3.32 front-of-wave impulse sparkover voltage:** The impulse sparkover voltage with a wavefront that rises at a uniform rate and causes sparkover on the wavefront.
- 3.33 gapless:** Not possessing gaps, series or parallel, as in “gapless arrester.”
- 3.34 grading or control ring:** A metal part, usually circular or oval in shape, mounted to modify electrostatically the voltage gradient or distribution.
- 3.35 ground terminal:** The conducting part provided for connecting the arrester to ground.
- 3.36 impulse:** A surge of unidirectional polarity.

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

3.38 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.

3.39 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.

3.40 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.

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

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

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

3.44 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.

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

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

3.47 line terminal: The conducting part of the arrestor provided for connecting the arrester to the circuit conductor. *Note:* When a line terminal is not supplied as an integral part of the arrester, and the series gap is obtained by providing a specified air clearance between the line end of the arrester and a conductor, or arcing electrode, etc., the words “line terminal” used in the definition refer to the conducting part that is at line potential and that is used as the line electrode of the series gap.

3.48 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.

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

3.50 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 C84.1-1995.

3.51 metal-oxide surge arrester (MOSA): A surge arrester utilizing valve elements fabricated from non-linear resistance metal-oxide materials.

3.52 nominal rate of rise (of an impulse): For a wavefront, the slope of the line that determines the virtual zero. It is usually expressed in volts or amperes per microsecond.

3.53 nominal system voltage: A nominal value assigned to designate a system of a given voltage class.
Note: See ANSI C84.1-1995.

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

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

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

3.57 power-frequency sparkover voltage: The rms value of the lowest power-frequency sinusoidal voltage that will cause sparkover when applied across the terminals of an arrester.

3.58 power-frequency withstand voltage: A specified rms test voltage at power frequency that will not cause a disruptive discharge.

3.59 production tests: *See:* routine tests.

3.60 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.

3.61 puncture: **(A)** A disruptive discharge through the body of 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.

3.62 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.

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

3.64 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 I_{ref} will typically be in the range of 0.05–1.0 mA per sq cm of disk area.

3.65 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 multiunit arrester is the sum of the reference voltages of the series units. The voltage level shall be specified by the manufacturer.

3.66 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.

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

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

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

3.70 surge: A transient wave of current, potential, or power in an electric circuit. *Note:* The use of this term to describe a momentary overvoltage consisting of a mere increase of the main voltage for several cycles is deprecated.

3.71 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:* The term “arrester” as used in this standard shall be understood to mean surge arrester.

3.72 system voltage: The rms power-frequency voltage from line-to-line, as distinguished from the voltage from line-to-neutral.

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

3.74 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.

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

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

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

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

3.79 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.

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

3.81 virtual duration of wavefront (of an impulse): The virtual value for the duration of the wavefront is as follows: **(1)** For voltage waves with wavefront duration less than 30 μ s, either full or chopped on the front, crest, or tail, 1.67 times the time for the voltage to increase from 30–90% of its crest value; **(2)** For voltage waves with wavefront duration of 30 μ s or more, the time taken by the voltage to increase from actual zero to maximum crest value; **(3)** For current waves, 1.25 times the time for the current to increase from 10% to 90% of crest value.

3.82 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.

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

3.84 wavefront (of a surge or impulse): The part that occurs prior to the crest value.

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

3.86 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 wavefront, is the virtual duration of the wavefront 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 μ s wave.

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

3.88 withstand voltage: The voltage that an insulation is capable of withstanding. In terms of insulation, this is expressed as either conventional withstand voltage or statistical withstand voltage (see IEEE Std 1313.1-1996).

4. Service conditions

An arrester conforming to this standard shall be capable of successful operation under the following service conditions.

4.1 Usual service conditions

4.1.1 Physical conditions

- a) Ambient air temperature in the general vicinity of the arrester shall be between $-40\text{ }^{\circ}\text{C}$ and $+40\text{ }^{\circ}\text{C}$ ⁵, except that
 - 1) Ambient air temperature in the general vicinity of deadfront arresters shall be between $-40\text{ }^{\circ}\text{C}$ and $+65\text{ }^{\circ}\text{C}$;
 - 2) Ambient liquid temperature in the general vicinity of liquid-immersed arresters shall be between $-40\text{ }^{\circ}\text{C}$ and $+95\text{ }^{\circ}\text{C}$.
- b) Maximum temperature of the arrester, due to external heat sources in the general vicinity of the arrester, shall not exceed $60\text{ }^{\circ}\text{C}$, except that
 - 1) Maximum temperature of deadfront arresters shall not exceed $85\text{ }^{\circ}\text{C}$;
 - 2) Maximum temperature of liquid-immersed arresters shall not exceed $120\text{ }^{\circ}\text{C}$.
- 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 48–62 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.

⁵This 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 $40\text{ }^{\circ}\text{C}$.

- 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
 - 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 48–62 Hz.
- b) System operating conditions whereby the ratings of the arrester may be temporarily exceeded. Some examples are
 - 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 the 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. Clause 7 contains general requirements for selection of test specimens 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 of Annex B.

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

Table 2—Arrester design tests

Design test	Reference	Station	Inter- mediate	Heavy duty	Normal duty	Light duty
Arrester insulation withstand tests	8.1	X	X	X	X	X
Power-frequency sparkover tests	8.2	X	X	X	X	X
Discharge-voltage characteristics	8.3	X	X	X	X	X
Impulse protective level voltage-time characteristic	8.4	X	X	X	X	X
Accelerated aging procedure	8.5	X	X	X	X	X
Accelerated aging tests of external polymeric insulating systems	8.6			X	X	X
Contamination test	8.7	X	X	X	X	X
Distribution class surge arrester seal integrity design test	8.8			X	X	
IIV and RIV tests	8.9	X	X	X	X	X
Discharge-current withstand tests	8.10	X	X	X	X	X
Duty-cycle tests	8.11	X	X	X	X	X
TOV tests	8.12	X	X	X	X	X
Pressure-relief tests for station and intermediate arresters	8.13	X	X			
Short-circuit test for porcelain-housed distribution surge arresters	8.14			X	X	X
Short-circuit test for polymer-housed distribution arresters	8.15			X	X	X
Failure mode test for liquid-immersed arresters	8.16			X	X	X
Deadfront arrester failure mode	8.17			X	X	X
Distribution arrester disconnecter tests	8.18			X	X	X
MDCL-static test	8.19	X	X			

7. Test procedure

7.1 Complete arrester test specimens

- New and clean arresters shall be used for each test unless otherwise specified.
- All test specimens for arrester designs incorporating a disconnecter, either as an integral part or as an accessory, shall include the disconnecter.
- The arrester shall be mounted in the position(s) in which it is designed to be used.
- 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 arrester test 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 the 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

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

where K_s is the prorated section scale factor given by

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

and 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, temporary overvoltage (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 the 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 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 maximum continuous operating voltage (V_C) of the prorated section are given by

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

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

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. That is, K_p shall be the lower of K_v or K_M .

where

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

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

and where

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

V_{RS} is the voltage measured on the 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 watts loss equal to the maximum allowed by the manufacturer in the arrester being modeled. In the event that maximum watts-loss valve elements are not available, prorated sections may be constructed with lower watts-loss valve elements, provided that the voltage applied during the thermal recovery portion of the test is adjusted as follows:

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

where

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

and where

V_{WI} is the voltage required to increase watts loss to the maximum allowed level, at the temperature at which watts loss is usually measured;

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

k_C is the accelerated aging factor determined by the procedure in 8.5.2.

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 of uncompressed glass wool insulation or the 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 of uncompressed glass wool insulation or the 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 5 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 the complete arrester and a thermally prorated arrester section

If, for any test requiring demonstration of thermal recovery, a complete arrester cannot be tested, then a thermally prorated section shall be verified per this procedure. 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 watts loss, then monitoring and comparing the cooling rates of the two devices with the 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 multiunit arrester, and the prorated section, are placed 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 type sensors may be attached to the blocks, or watts loss or resistive component of current may be monitored. If watts loss or resistive component of current is used, the complete arrester and the prorated section shall 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 1/3–1/2 of the arrester length from the top may be used. (Using the single point 1/3–1/2 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 ± 10 °C, within 1–120 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 watts 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 which 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, watts loss, or resistive component of current vs. 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 (temperature, watts loss, or resistive component of current) for the prorated section is equal to or higher than that for the complete arrester. If, at any instant, the section is not equal to or higher than that for the complete arrester, the section is not a valid proration.

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

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 4-1995.⁶

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 wavefront	—	±10%

⁶Information on references can be found in Clause 2.