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

Sponsor

Surge Protective Devices Committee
of the
IEEE Power Engineering Society

Approved 22 March 1999

IEEE-SA Standards Board

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 (Iref), reference voltage (Vref), 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.

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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.

[1]ANSI 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/).

[2]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 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 disconnector: 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.

[3]IEEE 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/).
[4]NEMA 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 (Iref): 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 Iref will typically be in the range of 0.05–1.0 mA per sq cm of disk area.

3.65 reference voltage (Vref): 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 µs, 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 µs 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 μs 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 °C and +40 °C[5], except that
   1) Ambient air temperature in the general vicinity of deadfront arresters shall be between –40 °C and +65 °C;
   2) Ambient liquid temperature in the general vicinity of liquid-immersed arresters shall be between –40 °C and +95 °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 deadfront arresters shall not exceed 85 °C;
   2) Maximum temperature of 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 48–62 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.

[5]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
    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.

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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

[a]For 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 disconnector tests	8.18			X	X	X
MDCL-static test	8.19	X	X			

7. Test procedure

7.1 Complete arrester test specimens

a) New and clean arresters shall be used for each test unless otherwise specified.

b) All test specimens 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 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

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

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

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:

$$\text{Recovery voltage} = V_C \times K_W \times k_C \tag{7}$$

where

$$K_W = V_{WI}/V_{WN} \tag{8}$$

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 ±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%

[6]Information on references can be found in Clause 2.

7.5 Power-frequency test voltages

The power-frequency test voltages shall have a crest value equal to $\sqrt{2}$ times the specified rms voltage and shall have an approximately sinusoidal shape.

8. Design tests

8.1 Arrester insulation withstand tests

Test procedures shall comply with Clause 7. The assembled insulating members of the arrester or single unit shall withstand impulse and power-frequency voltage tests between line and ground terminals. The internal parts shall be removed or rendered inoperative to permit these tests.

Any external series-gap electrodes shall be removed where the gap shunts an insulating member.

8.1.1 Distribution arresters

Insulation withstand test values for arresters used in open air shall be in accordance with Table 4. Additionally, all distribution arresters shall have a 60 Hz, 10 s wet withstand from ground terminal to grounded bracket of $1.5 \times$ MCOV. Polymeric brackets shall be grounded at the bracket mounting attachment point (see Terminal 3 in Figure 1).

Insulation withstand test values for liquid-immersed arresters shall be in accordance with Table 4 and shall be measured in mineral insulating oil, meeting ASTM D3487-88 (1993), at room temperature.

Insulation withstand test values for deadfront arresters shall be in accordance with Table 5. The corona voltage-level test, ac withstand test, direct-current withstand voltage test, and impulse withstand voltage test shall comply with IEEE Std 386-1995.

8.1.2 Intermediate and station arresters less than 54 kV duty-cycle voltage rating

Insulation withstand test values shall be in accordance with Table 4.

8.1.3 Intermediate and station arresters equal to and above 54 kV duty-cycle voltage rating

a) The 1.2/50 impulse withstand test voltage shall be the higher of the maximum 1.2/50 impulse sparkover voltage multiplied by the factor 1.42, or the maximum discharge voltage for a 20 000 A discharge current multiplied by the factor 1.42. The impulse factor includes an allowance for a 20% protective margin and an 18% correction for 1800 m (6000 ft) altitude.

b) The 10 s wet power-frequency withstand test voltage in rms volts shall be the higher of the maximum switching impulse sparkover multiplied by the factor 0.82, or the maximum switching impulse discharge voltage multiplied by the factor 0.82. The switching surge factor includes an allowance for a 15% protective margin, an 18% correction for 1800 m (6000 ft) altitude, a 0.85 multiplier relating wet switching-surge withstand to wet crest 60 Hz withstand, and a $1/\sqrt{2}$ multiplier to convert from crest to rms.

Table 4—Insulation withstand test voltage

rms duty-cycle voltage rating of arrester (kV)[a]	Station and intermediate arresters			Distribution arresters		
	Impulse test 1.2/50 full wave (kV) crest[b] (BIL)	60 Hz rms test voltage (kV)		Impulse test 1.2/50 full wave (kV) crest[b] (BIL)	60 Hz rms test voltage (kV)	
		1 min dry test	10 s wet test[c]		1 min dry test	10 s wet test[c]
1	—	—	—	30	10	6
3	60	21	20	45	15	13
6	75	27	24	60	21	20
9	95	35	30	75	27	24
10	110	50	45	75	27	24
12	110	50	45	85	31	27
15	110	50	45	95	35	36
18	150	70	60	125	42	36
21	150	70	60	125	42	36
24	150	70	60	125	42	36
27	200	95	80	150	70	60
30	200	95	80	150	70	60
36	200	95	80	—	—	—
39	250	120	100	—	—	—
48	250	120	100	—	—	—

[a]For arresters rated at values other than those listed in the first column, the insulation tests shall be those specified for the next higher rating.
[b]The values given apply for either positive or negative waves.
[c]For outdoor arresters only.

Table 5—Insulation withstand test voltages for deadfront arresters

System class rating (kV)	Impulse test 1.2/50 full wave[a] (kV) crest (BIL)	60 Hz test voltage (kV) 1 min	Corona 60 Hz test voltage (kV) rms extinction level	dc test voltage (kV) 15 min
15	95	34	11	53
25	125	40	19	78
35	150	50	26	103

[a]The values given apply for either positive or negative waves.

8.2 Power-frequency sparkover test

Test procedures shall comply with Clause 7. This test is applicable only to arrester designs that undergo a sparkover mode in response to a grading current less than 1.0 A. Power-frequency sparkover shall be measured on a representative number of voltage ratings of each significant variation in the design of the arrester. Ratings within ±20% of the tested rating (or ± 3 kV, whichever is larger) need not be tested. Indoor types shall be tested dry, and outdoor types shall be tested dry and wet.

8.3 Discharge-voltage characteristics

Test procedures shall comply with Clause 7. Obtain discharge-voltage characteristics on each arrester design for one voltage rating or prorated section. The prorated sample shall include the effects of internal lead (spacer) lengths and current-carrying elements. A sufficient number of tests shall be made to obtain a representative value of voltage for each value of current and time to crest specified using the polarity that gives the higher voltage.

8.3.1 Discharge-voltage current characteristics

Measure peak voltage using currents of 1500 A, 3000 A, 5000 A, 10 000 A, and 20 000 A crest with an 8/20 wave shape. For arrester ratings having classifying currents listed in Table 6, which are not included in the above listing, measure discharge voltage at the classifying current in addition to the listed values (for example, 15 000 A for 550 kV system arresters). The manufacturers' published information shall state for each arrester rating the maximum discharge voltage for each discharge current listed.

Table 6—Lightning impulse classifying current

Classification of arrester	Impulse value crest (kA)
Station (800 kV)[a]	20
Station (550 kV)[a]	15
Station (below 550 kV)[a]	10
Intermediate	5
Distribution, heavy duty	10
Distribution, normal duty	5
Distribution, light duty	5

[a]Maximum system voltage.

8.3.1.1 Arresters with shunt gaps

For arresters with shunt gaps

a) Apply 8/20 current waves and determine the maximum current at which shunt gap sparkover is not obtained.
b) With the shunt gap(s) disconnected, measure the discharge voltage at the maximum current determined in item (a).
c) The discharge voltage of the arrester or prorated section at a discharge current shall be the higher of the voltage measured in item (b) or the voltage measured in 8.3.1 at that discharge current.

8.3.2 Discharge-voltage-time characteristics

Obtain discharge-voltage-time characteristics for the front-of-wave and switching impulse protective levels.

8.3.2.1 Lightning impulse classifying current

Obtain the discharge-voltage-time characteristic at the lightning impulse classifying current value (see Table 6) with time-to-crest times of approximately 1 μs, 2 μs, and 8 μs.

Construct a smooth curve through the test points of crest voltage (actual) and corresponding time to crest of the voltage wave plotted on linear voltage/log time paper. The front-of-wave protective level of the test arrester is the voltage determined by the line's value at 0.5 μs or the front-of-wave sparkover, whichever is higher.

For arresters with shunt gaps

a) Apply 1/2 (1 by 2 μs) current waves, and determine the maximum current at which shunt gap sparkover is not obtained.
b) With the shunt gap(s) disconnected, measure the discharge voltage at the maximum current determined in item (a).
c) The discharge voltage of the arrester or prorated section at a discharge current shall be the higher of the voltage measured in item (b) or the voltage measured in 8.3.2.1 at that discharge current.

8.3.2.2 Switching surge classifying current

Obtain the discharge-voltage-time characteristic at the switching surge classifying current shown in Table 7 with a time to actual crest of 45–60 μs.

For arresters with shunt gaps

a) Apply switching surge current waves with a time to actual crest of 45–60 μs, and determine the maximum current at which shunt gap sparkover is not obtained.
b) With the shunt gap or gaps disconnected, measure the discharge voltage at the maximum current determined in item (a).
c) The discharge voltage of the arrester or prorated section at a discharge current shall be the higher of the voltage measured in item (b) or the voltage measured in 8.3.2.2 at that discharge current.

Table 7—Switching surge classifying current

System voltage maximum (kV)	Station class (A)	Intermediate class (A)
3–150	500	500
151–325	1000	—
326–900	2000	—

8.4 Impulse protective level voltage-time characteristic

Refer to 8.4.1 through 8.4.4 to determine whether the protective level provided by a gapped arrester for a specified wave shape is a function of the arrester's maximum sparkover value or its corresponding arrester discharge voltage for the specified wave shape.

Test procedures and test wave tolerances shall comply with Clause 7, unless otherwise specified. This test is applicable only to arrester designs that undergo a sparkover mode. Tests shall be made on arresters of each significant variation in design. Ratings within ±20% of the tested rating (or ±3 kV, whichever is larger) need not be tested.

8.4.1 General test procedure for determining arrester protective level

The general test procedure shall be as follows:

a) Apply prospective impulse voltage waves, measure the resulting peak arrester voltages, and compare these voltages with the appropriate discharge-voltage level.

b) Where the maximum arrester voltage resulting from application of these prospective voltage impulses is less than the arrester discharge-voltage level, then the protective level for that wave shape is the arrester discharge-voltage level. Sparkover tests are not required for the wave shape of overvoltage being simulated.

c) Otherwise, sparkover tests shall be made and the protective level for that wave shape is the maximum sparkover value. Impulse protective levels shall be established for front-of-wave (see 8.4.2), 1.2/50 impulse (see 8.4.3), and switching surge (see 8.4.4) wave shapes.

8.4.2 Front-of-wave impulse protective level

This test determines whether the arrester sparkover for a front-of-wave lightning impulse can exceed its 0.5 µs discharge voltage at the classifying current listed in Table 6.

8.4.2.1 Front-of-wave impulse sparkover determination test

This test is performed using both positive and negative polarity impulses. The prospective magnitude of the test wave shall be a minimum of 1.2 times the arrester's discharge voltage at a classifying current (see Table 6), resulting in a voltage wave cresting in 0.5 µs. At least five discharges will be measured for each polarity. The nominal rate of rise of the test wavefront is specified in Table 8.

Table 8—Fast front impulse rate of rise

rms duty-cycle voltage rating of arrester (kV)	Nominal rate of rise
Less than 3	10 kV/µs
3–240	100 kV/µs for each 12 kV of arrester duty-cycle rating
Above 240	2000 kV/µs

The maximum arrester voltage recorded during five positive and five negative polarity impulses shall be compared to the classifying current discharge voltage cresting in 0.5 µs. If the classifying current discharge voltage exceeds the voltage values measured during the impulse test described above, then the classifying current discharge voltage is the front-of-wave impulse protective level and no further testing is required on this wave shape. If the voltage measured during the impulse test exceeds the 0.5 µs classifying current discharge voltage, proceed to 8.4.2.2 to determine the front-of-wave impulse protective level.

8.4.2.2 Front-of-wave impulse sparkover tests

This test shall be made using both positive and negative polarity impulses. The prospective crest value of the test wave shall be high enough that the sparkover of the arrester occurs before 90% of the crest value of the test wave is reached. At least five sparkovers shall be recorded for each polarity, and the highest crest value so recorded shall be reported as the maximum front-of-wave sparkover value of the test arrester. The nominal rate of rise of the test wavefront shall be the same as described in 8.4.2.1.

8.4.3 The 1.2/50 impulse protective level test

This test series determines whether the arrester sparkover voltage for a standard 1.2/50 lightning impulse can exceed the discharge voltage obtained from an 8/20 discharge current, as given in Table 6.

8.4.3.1 The 1.2/50 impulse sparkover determination test

This test is performed using at least five positive and five negative waves. A minimum prospective magnitude of 1.2 times the arrester's discharge voltage at a classifying current (per Table 6) shall be used. The maximum arrester voltage recorded during the five positive and five negative polarity standard lightning impulses shall be compared to the discharge voltage obtained with the currents in Table 6. If the classifying current discharge voltage exceeds the voltage values measured during the impulse test described earlier, the classifying current discharge voltage is the 1.2/50 impulse protective level, and no further testing is required on this wave shape. If the voltage measured during the impulse test exceeds the classifying current discharge voltage, proceed to 8.4.3.2 to determine the 1.2/50 impulse protective level.

8.4.3.2 The 1.2/50 impulse sparkover test

The purpose of this test is to determine the highest standard lightning impulse voltage greater than 3 μs duration that the arrester will allow without sparkover.

For each polarity, the test procedure shall be as follows:

a) Determine the base generator charge voltage, V_G, according to the method described in the following note and record crest voltage and time-to-sparkover (where sparkover occurs) for each of the 20 impulses used for establishing V_G.

   NOTE—The procedure for establishing V_G is as follows. Start by applying an impulse having a prospective crest voltage somewhat lower than the expected sparkover voltage of the arrester, raising the generator charge voltage in approximately 5% steps for subsequent impulses until sparkover occurs. Then apply a series of 20 impulses, decreasing the prospective crest voltage by about 5% after every sparkover and increasing the prospective crest voltage by about 5% after every withstand. V_G is the average generator charge voltage used during the series of 20 impulses.

b) Apply five impulses using a generator charge voltage not more than 1.05 V_G; then record crest voltage and time-to-sparkover. If sparkover does not occur within 3.0 μs after the virtual zero point on each of the five impulses, raise the generator charge voltage in additional increments not greater than 0.05 V_G until a level is reached that results in sparkover within 3.0 μs after the virtual zero point on each of the five applications. The higher prospective crest voltage of either polarity required to obtain five sparkovers on five successive applications of test impulses, with constant generator charge voltage, shall be reported as the 1.2/50 sparkover of the arrester.

8.4.4 Slow-front (switching surge) impulse protective level test

This test series determines whether the arrester sparkover for a slow-front impulse voltage can exceed the switching surge discharge voltage at the classifying current in Table 7.

8.4.4.1 Slow-front (switching surge) sparkover determination test

The magnitude and wave shape of the switching surge discharge-voltage wave for each wave shape shall be a minimum of 1.2 times the arrester discharge voltage corresponding to the switching surge classifying current specified in Table 7. The test consists of at least five positive and five negative wave applications for each of the following times from zero to crest on the prospective voltage wave (in µs):

a) 30–60;
b) 50–300;
c) 1000–2000.

The times to half-crest on the tail should be appreciably longer than twice the time to crest. The exact value is not of critical importance.

The maximum arrester voltage recorded during the five positive and five negative polarity impulses for each switching surge wave shape shall be compared to the corresponding discharge voltage. If the switching surge classifying current discharge voltage (see 8.3.2.2) exceeds the voltage values measured during each of the specified switching surge wave shape impulse tests described earlier, then the switching surge classifying current discharge voltage is the slow-front (switching surge) impulse protective level, and no further switching surge testing is required. If the voltage measured during any of the switching surge impulse tests exceeds the switching surge classifying current discharge voltage, proceed to 8.4.4.2 and perform sparkover tests on only the wave shape(s) that demonstrated high switching surge impulse test voltages.

8.4.4.2 Slow-front (switching surge) impulse sparkover voltage-time characteristics

Sparkover tests shall be made using the following test waves (but not necessarily in the order given) having times from zero to crest (in µs) of:

a) 30–60;
b) 150–300;
c) 1000–2000.

The times to half-crest values on the tail should be appreciably longer than twice the time to crest, but the exact value is not of critical importance.

For each polarity, the wave shape shall be checked with the arrester in the test circuit at a test voltage that does not cause arrester sparkover in at least one of five trials.

For each wave shape and polarity, the test procedure shall be as follows:

a) Determine the base generator charge voltage, V_G, according to the method described in 8.4.3.2, recording crest voltage and time-to-sparkover (where sparkover occurs) for each of the 20 impulses used for establishing V_G.
b) Apply 10 impulses using a generator charge voltage of 1.2 times V_G and record crest voltage and time-to-sparkover.
c) Apply 10 impulses using a generator charge voltage of 1.4 times V_G and record crest voltage and time-to-sparkover.

The highest crest value of voltage with a time duration greater than 30 µs recorded during these tests shall be considered the maximum switching surge sparkover voltage of the test arrester.

8.5 Accelerated aging procedure

This is not a test and has no evaluation procedure. This is an aging procedure from which elevated voltage ratios k_C and k_R are obtained (see 8.5.2). These ratios are used in the duty-cycle and discharge-current withstand tests to simulate the performance of arresters as if they had been in service for an extended period equivalent to the test period given in 8.5.1.

This aging procedure shall be applied to three typical sample valve elements of the design being tested. If several valve element size variations are being evaluated at the same time, this procedure shall be applied to three typical samples each of the largest and the smallest diameter and three each of the thickest and the thinnest valve elements for which design tests are being run. The relevant MCOV for this procedure is the maximum voltage that the valve element(s) must support in the arrester due to unequal voltage distribution.

If the arrester fill medium is air, this procedure may be run in an open air oven without further containment. If the arrester fill medium is not air, the valve elements shall be sealed in a container of the arrester fill medium at room temperature and normal filling pressure, and that container shall then be put in the oven.

8.5.1 Determination of power ratios

Heat samples to 115 ± 2 °C and energize at MCOV for 1000 h, except

(a) Liquid-immersed arrester samples shall be heated in mineral insulating oil, meeting ASTM D3487-88 (1993), and energized at MCOV for a period of 7000 h.

(b) Deadfront arrester samples shall be heated and energized at MCOV for a period of 2000 h.

At 115 ± 2 °C, measure sample power dissipation (watts loss) at MCOV and at duty-cycle voltage 2–5 h after the start of the test and at the end of the test period while still energized. The test period may be extended up to 100 h for the purpose of test convenience only. The total time required to raise from MCOV to rated duty-cycle voltage, take power readings, and lower voltage to MCOV shall not exceed 5 min.

For each valve element, determine the ratio of the power dissipation (watts loss) at the end of the test period to the initial power dissipation after 2–5 h at MCOV and at duty-cycle voltage. Then, for each valve element, divide the end-of-period reading by the 2–5 h reading. The maximum power ratio determined from the three valve elements shall be used to determine the elevated MCOV and duty-cycle voltage rating factors.

8.5.2 Determination of elevated voltage factors k_C and k_R

If the maximum power ratio of the valve element is equal to or less than 1.0, the appropriate k_C or k_R voltage factor is 1.0.

If the maximum ratio of the power dissipation is larger than 1.0, proceed as follows:

a) At room temperature, take three new sample valve elements of the design and size used in 8.5 and measure watts loss at MCOV and at duty-cycle voltage.
b) Multiply the (new sample) watts loss by the appropriate ratios determined in 8.5.1.
c) For each sample, determine the voltage required to obtain the increased watts loss thus determined and then calculate k_C and k_R as follows:
    1) k_C is the maximum voltage for increased (MCOV) watts loss/MCOV;
    2) k_R is the maximum voltage for increased (duty-cycle voltage) watts loss/duty-cycle voltage.

If more than one valve element size is used in the same arrester design, then the relevant k_C and k_R are the largest values obtained from the sampled valve element sizes. Wherever watts loss is stated in 8.5, resistive component of current may be substituted. If the manufacturer can demonstrate that the manufacturer's valve element enveloping medium and voltage aging effects can be separated, then the manufacturer may run them as two separate tests (test period h at 115 °C).

8.6 Accelerated aging tests of external polymeric insulating systems for distribution class arresters

These tests demonstrate the minimum performance level of the external polymer insulating system when exposed to accelerated light and electrical stress pollution tests. Established tests for polymer distribution insulators were modified, as required, for application to polymer distribution arresters. Correlation to service conditions over the expected life of the product has not yet been established.

8.6.1 Accelerated aging tests by exposure to light

8.6.1.1 Specimens

The specimens shall include both arrester housings and hanger/bracket parts, or as specified by the test method used.

8.6.1.2 Test method

The test method shall be the latest revision of one of the following documents:

a) Carbon-arc methods
   1) ASTM G23-96;
   2) ASTM D1499-92a;
   3) ASTM D750-95.
b) Xenon-arc methods
   1) ASTM G26-96;
   2) ASTM D2556-93a.
c) Fluorescent UV method
   1) ASTM G53-96.

All methods used must include water. The test duration must be for a minimum of 1000 h, and a minimum of three specimens must be tested.

8.6.1.3 Test evaluation

Cracking of any specimen's surface to depths greater than 0.1 mm shall constitute failure.

8.6.2 Accelerated aging tests by exposure to electrical stress

8.6.2.1 Specimens

The specimens shall consist of full-size arresters representing the design under test. The specimens shall include hanger and disconnector, when applicable.

8.6.2.2 Test procedure

Measure the specimen discharge voltage at the classifying current and wave shape before and after the 1000 h aging test, as described in 8.6.2.3.

8.6.2.3 Aging test

The fundamental test is a cyclic type, which must include periods of wetting, drip, and surface drying, accompanied by application of a continuous or intermittent voltage. The intent of the test is to subject the specimen to periodic dry band arcing that takes place during the ac voltage application period. The wetting may be either spray or dipping; in either case, however, the entire length of the specimen must be uniformly wetted. The procedure has three test segments

a) Arrester and hanger/bracket aging;
b) Arrester evaluation;
c) Hanger bracket aging.

Test segments (a) and (c) may be tested in either order. A minimum of three specimens must be tested.

8.6.2.3.1 Test voltage

The arrester aging part of the test shall be performed at the highest MCOV stress for arresters of the same specimen type and design. The stress shall be based on the arrester creep distance. The hanger/bracket test portion shall be performed at the highest line-to-ground voltage at which the hanger/bracket will be subjected. The arrester terminals shall be connected in accordance with Figure 1 and Table 9.

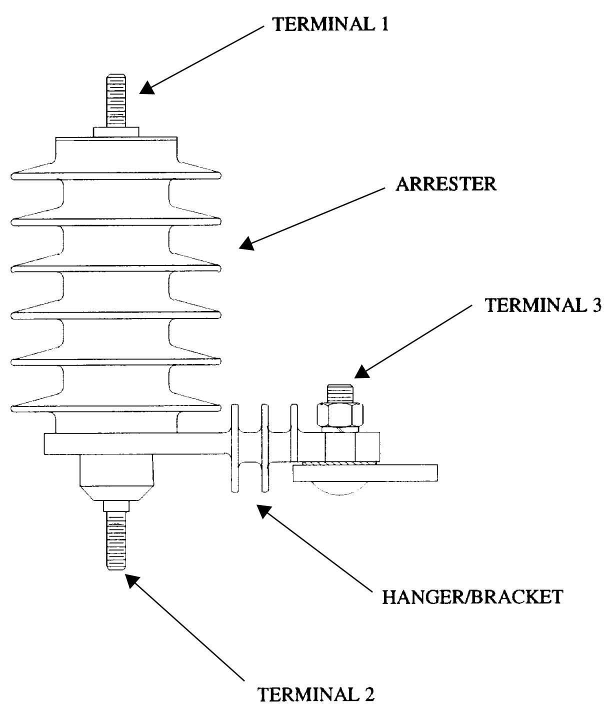

Figure 1—Typical polymeric-housed arresters

Table 9—Accelerated aging test of polymeric housing by electrical stress

Test objective	Specimen	Applied voltage at terminals			Test duration
		Terminal 1	Terminal 2	Terminal 3	
Arrester/hanger	Arrester and hanger[a]	Maximum design stress	Ground	Ground	1000 h at voltage
Arrester evaluation	Arrester and hanger[a]	8/20 current impulse	Ground	Ground	Impulse
Hanger aging	Hanger and effectively shorted arrester	Maximum system voltage applied to hanger[b]	Maximum system voltage applied to hanger[b]	Ground	20 h at voltage

[a]Where an insulating hanger is part of the design.
[b]Only when an arrester is effectively shorted.

8.6.2.3.2 Cycle time

The full cycle time shall be not less than 1 min and not more than 10 min.

8.6.2.3.3 Time at voltage

The time spent energized during each cycle shall be not less than 1 min and not more than 2 min, and shall count toward total test duration. The specimen shall not be completely dry at the beginning of the energized cycle.

8.6.2.3.4 Test duration

The parameter of importance is the time spent energized at the specified test voltage. All specimens must spend the total accumulated time at voltage (as specified in Table 9) for test duration for each segment of the aging test.

8.6.2.3.5 Wetting agent

The resistivity of the wetting agent must be 400–500 Ω–cm.

8.6.2.3.6 Power source

The short-circuit current available at the specimen terminals shall be at least 10 mA rms. The voltage tolerance at the specimen terminals must be maintained at ±5%.

8.6.2.4 Test evaluation

The specimens will be considered to pass if

a) No external flashovers, punctures, or internal breakdowns have occurred during the test;
b) No surface tracking is evidenced by physical examination;
c) The arrester discharge voltage at its classifying current has not changed by more than 10%.

8.7 Contamination test

This test demonstrates the ability of the arrester to withstand electrical stresses on the arrester housing caused by contamination, through examination of thermal stability and insulation withstand. The test shall be made on complete arresters. Only the highest voltage rating of each type and design shall be tested. Conformance of the highest voltage-rated arrester to this standard shall be considered to demonstrate conformance of lower voltage ratings of the same arrester type and design.

8.7.1 Power-frequency test voltage source

The power-frequency test voltage source and the method of measurement shall be in accordance with IEEE Std 4-1995. The regulation of the source shall be such as to maintain the specified voltage on the arrester, except for infrequent, nonconsecutive, half-cycle voltage dips of no more than 5% during leakage current pulses.

8.7.2 Test preparation

8.7.2.1 Test specimen preparation and mounting

Thermal stability of an arrester shall be demonstrated through measurement of one or more of the following:

a) Arrester temperature;
b) Resistive component of leakage current;
c) Watts loss.

If stability is to be demonstrated by temperature measurement, then a temperature sensing device (such as a thermocouple) shall be installed in each arrester section immediately adjacent to a valve element.

The arrester shall be tested completely assembled. If a multiunit arrester contains gaps that are not uniformly distributed throughout the arrester, then the units shall be restacked so that the majority of the gaps are located within the top half of the stack.

8.7.2.2 Contaminant preparation

The contaminant shall be stored in a container so that it can be thoroughly agitated just prior to application. The contaminant shall consist of a slurry of

a) Water;
b) Bentonite (5 g/L of water);
c) An undiluted, nonionic detergent consisting of nonyl-phenyl-polyethylene-glycol-ether or other comparable long-chain, nonionic esters (1 g/L water);
d) Sodium chloride.

The volume resistivity of the slurry shall range between 400 Ω–cm and 500 Ω–cm and may be adjusted by the addition of sodium chloride. Volume resistivity shall be measured at a temperature of 25 ± 5 °C with a low-voltage conductivity bridge.

8.7.3 Test procedure

The test shall be conducted as follows:

a) The arrester housing shall be clean and dry and at the ambient temperature. Washing with a detergent may be necessary to remove oil films, but the detergent should be thoroughly rinsed off with water.

b) The arrester shall be energized for a minimum of 1 h at MCOV. Measurements of resistive component of current, watts loss, or temperature shall be made at the end of the energization period.

c) With the arrester de-energized, the contaminant shall be applied to all insulating surfaces of the lower half of the arrester, including the undersides of all skirts. The coating shall be applied heavily enough to form drops of the slurry on the skirts of the housing. (Too much contaminant cannot be applied; the excess merely runs off.)
Maximum voltage-off time for contaminant application is 10 min. The contaminant coating may be applied by dipping, spraying, or flow-coating. Small arresters may be conveniently coated with a paint spray gun. Large arresters may require special racks for mounting the spray or flow-coat nozzles.

d) Within 3 min of contaminant application, the arrester shall be energized at its MCOV. Measurements of resistive leakage current, watts loss, or temperature shall be made at the end of the 15 min energization. Arrester temperature, if measured, shall be obtained immediately following de-energization. Maximum voltage-off time for contaminant application, including any temperature measurements, is 13 min.

e) Repeat steps (c) and (d), and at the end of the second cycle, energize the arrester at its MCOV. For 30 min intervals, demonstrate thermal stability as indicated by a decrease in the monitored values toward the initial values obtained in step (b).
If temperature is being measured, it is permissible to de-energize the arrester for a maximum off-time of 3 min.

8.7.4 Test evaluation

The arrester shall have passed this test if all of the following occur:

a) The arrester demonstrates thermal stability;
b) No unit or arrester flashes over;
c) There is no physical damage to the internal parts as evidenced by inspection.

8.8 Distribution class surge arrester seal integrity test

This test shall be performed on fully assembled units. Three representative samples of each seal design shall be subjected to the test described in 8.8.2. This test does not apply to deadfront or liquid-immersed arresters.

8.8.1 Test preparation

Prior to performing the test described in 8.8.2, measure (with the arrester energized at duty-cycle voltage rating) each sample's radio-influence voltage (RIV), watts loss, or resistive component of current and power-frequency sparkover (if applicable). Tests shall be performed on samples at 20 ± 5 °C.

8.8.2 Test procedure

The samples shall be subjected to each of the following tests in the order listed:

a) Terminal torquing;
b) Thermal conditioning;
c) Seal pumping.

8.8.2.1 Terminal torquing

On each sample, install beneath one side of the terminals a length of conductor representative of the maximum diameter hard lead accommodated by the connectors. Torque the terminals of each unit 27–30 N•m (20–22 ft•lb).

8.8.2.2 Thermal conditioning

The test samples shall be placed in a circulating air oven and subjected to a temperature of 70 ±3 °C for 14 days, after which the samples shall be allowed to return to ambient temperature.

8.8.2.3 Seal pumping

The test samples shall be uniformly heated to 60 ± 3 °C and maintained at that temperature for a minimum of 1 h. The samples shall then be placed in a cold water bath having a temperature of 4 ± 3 °C for a minimum of 2 h. The transfer time between the hot and cold media shall be no more than 5 min. The test cycle shall be performed 10 times. The cold water bath shall have a water weight at a minimum of 10 times the weight of the test samples.

8.8.3 Test evaluation

Following the seal pumping portion of the test and within 24 h, the samples shall be allowed to reach ambient temperature. Then the measurement specified in 8.8.1 shall be repeated, after which each sample shall be opened for visual inspection.

The design shall be judged to conform to this standard when the test samples meet the following conditions:

a) The RIV has not increased by more than 20 mV above the value measured in 8.8.1;
b) The watts loss or resistive component of current has not increased by more than 50% above the value measured in 8.8.1;
c) The power-frequency sparkover voltage has not changed by more than 10% from the value measured in 8.8.1;
d) No moisture is found within the test samples upon visual examination of the internal parts and surfaces.

8.9 Internal-ionization voltage (IIV) and RIV tests

The equipment and general methods shall be in accordance with NEMA 107-1987.

8.9.1 Test specimens

The preparation and mounting of the specimens shall be in accordance with Clause 7, unless otherwise specified. The test specimen shall be dry and at approximately room temperature for all arresters except liquid-immersed, which shall be immersed in mineral insulating oil meeting ASTM D3487-88 (1993), at room temperature.

8.9.2 Additional shielding

For IIV tests, additional shielding of external parts is allowable as long as the inherent internal voltage grading is not affected by the external shielding. Where such shielding is not used, the RIV and IIV tests may be combined.

8.9.3 Test procedures

The RIV and IIV shall be measured at a frequency of 1.0 MHz, or as near that frequency as is practicable.

Prior to making the tests, the ambient ionization voltage shall be determined by the identical setup for determining the IIV and RIV; however, the specified power-frequency test voltage shall be applied without the arrester connected. In such cases where it is found that the IIV or RIV decreases after the power-frequency test voltage has been applied for a minimum of 10 s, the arrester shall be pre-energized for a period not exceeding 5 min.

To determine the RIV or IIV, apply to the arrester terminals a test voltage equal to 1.05 times the MCOV[7] of the arrester.

8.10 Discharge-current withstand tests

Test procedures shall comply with Clause 7. The high- and low-current withstand tests shall be made on different specimens of the same arrester type.

After completion of the tests in 8.10.1 and 8.10.2, the test specimens shall be judged by visual evidence of damage or deterioration and by the oscillograms, in addition to specific criteria given in the relevant subclauses of each test requirement.

8.10.1 High-current, short-duration tests

The tests shall be made on complete arresters or on prorated sections. The duty-cycle voltage ratings tested shall be 3 kV or more, but need not exceed 12 kV.

8.10.1.1 Test procedure

This test is performed in still air at 20 ±5 °C for all arrester classifications and types, except liquid-immersed and deadfront arresters. Liquid-immersed arresters shall be immersed in mineral insulating oil, meeting ASTM D3487-88 (1993), having a liquid temperature of 75 ± 5 °C, with the arrester having obtained thermal equilibrium at 75 ± 5 °C when subjected to the procedure. Deadfront arresters shall be preheated to 45 ± 5 °C for a sufficient time to obtain thermal equilibrium and shall be at 45 ± 5 °C when subjected to the test procedure. The test procedure shall consist of two arrester discharges of surge current having a 4/10 wave shape (–0%, +50% tolerance to accommodate test equipment), with an amplitude as specified in Table 10.

Table 10—High-current, short-duration test levels

Arrester classification	Minimum crest current (kA)
Station	65
Intermediate	65
Distribution, heavy duty	100
Distribution, normal duty	65
Distribution, light duty	40

[7]American National Standard test levels for RIV and IIV for surge arresters have not been established (see NEMA LA 1-1992).

One oscillogram of the discharge current and one oscillogram of the discharge voltage shall be obtained during the test. The test piece shall be allowed to cool to ambient temperature between discharges.

8.10.1.2 Test evaluation

Within 5 min after the second current discharge, power-frequency recovery voltage shall be applied for a minimum of 30 min. For a complete arrester, the recovery voltage shall be k_C times MCOV. For a prorated section, the recovery voltage shall be as prescribed in 7.2.2. Valve element temperature, resistive component of current, or power dissipation shall be monitored until the measured value is appreciably reduced (success) or a thermal runaway condition is evident (failure).

8.10.2 Low-current, long-duration tests

There are two test methods

a) A transmission-line discharge test for station and intermediate arresters. The switching surge duty on arresters applied to cable circuits may be evaluated by the line discharge test circuit, modified to take into account the capacitance, surge impedance, length, and charge voltage of the cable.

b) A rectangular wave test for distribution arresters.

8.10.2.1 Transmission-line discharge test for station and intermediate arresters

The test shall be made on complete arresters or on prorated sections. The duty-cycle voltage rating of the test specimens shall be 3 kV or more, but need not exceed 12 kV.

8.10.2.1.1 Preparation for test

Before making the test described in 8.10.2.1.3, a power-frequency sparkover test (see 8.2), if applicable, and a discharge-voltage test at the classifying current (see Table 7) shall be made on the test specimen.

8.10.2.1.2 Test circuit

The constants of a distributed constant generator, as shown in Figure 2, used in making the discharge test shall be based on the following transmission-line characteristics, where:

D_L is the transmission-line length;
V_M is the maximum system line-to-line rms voltage;
V_{LG} is the maximum system line-to-ground voltage crest;
E_L is the transmission-line charge voltage;
Z_L is the transmission-line surge impedance;
C_L is the transmission-line capacitance per unit length.

The values shown in Table 11 shall be used in deriving the constants of a test generator. The constants of the test generator shall be derived by using either of the following prorating factors:[8]

K is the rms arrester duty-cycle voltage in kilovolts/rms specimen duty-cycle voltage in kilovolts; or
K is the rms arrester MCOV in kilovolts/rms specimen MCOV in kilovolts.

[8]This allows the manufacturer to proportion the transmission-line generator parameters to be consistent with the manufacturer's arrester prorating technique, either by MCOV or duty-cycle ratings.

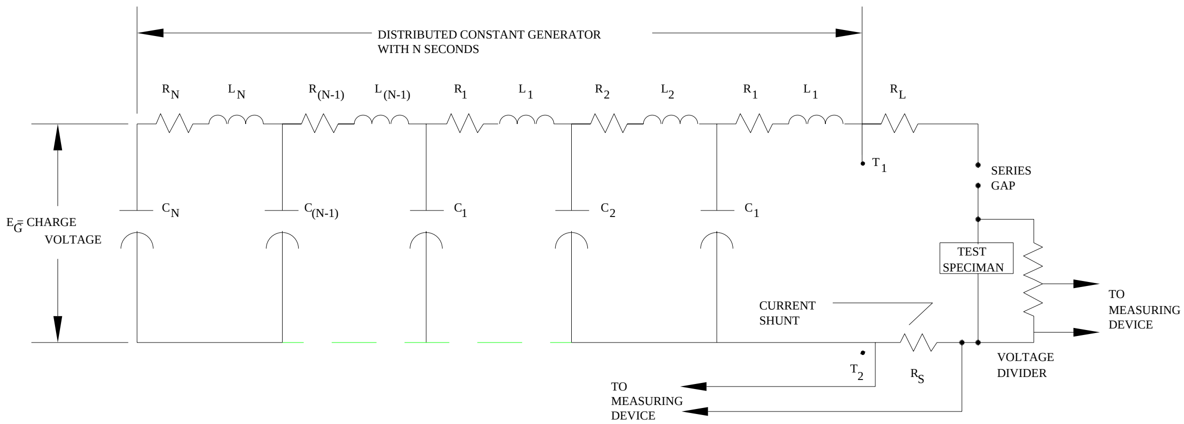

Figure 2—Transmission-line discharge test generator and setup

Table 11—Values for deriving test generator constants for transmission line discharge tests

V_M (kV)	Z_L (Ω)	C_L		E_L (kV)	Number of oper-ations	D_L			
						Station arresters		Intermediate arresters	
		μF/km	μF/mi			km	mi	km	mi
3–72	450	0.0075	0.012	2.6 V_{LG}	20	240	150	160	100
72.5–150	450	0.0075	0.012	2.6 V_{LG}	20	240	150	160	100
151–325	400	0.0087	0.014	2.6 V_{LG}	20	280	175	—	—
326–400	350	0.0093	0.015	2.6 V_{LG}	20	320	200	—	—
401–600	325	0.011	0.0177	2.0 V_{LG}	20	320	200	—	—
601–900	300	0.0177	0.0188	2.0 V_{LG}	20	320	200	—	—

Generator charge voltage in kilovolts dc

$$E_G \geq E_L / K \tag{9}$$

Generator surge impedance in ohms

$$Z_G \leq Z_L / K \tag{10}$$

Total generator inductance in microhenries

$$L_G = \sum^{i = N} L_i \tag{11}$$

Total generator capacitance in microfarads

$$C_G \geq K D_L C_L \quad (12)$$

$$L_G C_G \geq (Z_L C_L D_L)^2 \quad (13)$$

where

N is the number of generator sections and $N \geq 10$;
The subscript i designates the generator section requirements (see Figure 2);
R_i is the resistance, in ohms, of the i^{th} generator section. (This is the measured value that depends on the resistance of the section elements and connections.)

Generator connecting lead resistance plus current shunt resistance in ohms is (see Figure 2)

$$R_A = R_L + R_S \text{ (This is a measured value.)} \quad (14)$$

Generator section capacitance

$$C_i \leq 0.1 C_G \quad (15)$$

(As a first approximation, this is C_G divided by the number of sections chosen; however, the values for each section may be modified as shown below.) Generator section surge impedance in ohms

$$Z_i = \sqrt{(L_i / C_i)} \quad (16)$$

(As a first approximation, $Z_i = Z_G$; however, the sections may be modified as shown below.)

To determine the exact values of capacitance, C_i, and surge impedance, Z_i, the following requirements shall be met:

$$Z_j + R_A + \sum_{i=1}^{i=N} R_i = Z_G \pm 5\% \quad (17)$$

If

$$R_A + \sum_{i=1}^{i=N} R_i < 0.05 \; Z_G \quad (18)$$

then the first approximations for C_i and Z_i, as well as L_i, are correct. C_i may be C_G divided by the number of sections; Z may be equal to Z_G, and $Z_i = \sqrt{(L_i / C_i)}$.

If

$$R_A = \sum_{i=1}^{i=N} R_i > 0.05 \; Z_G \quad (19)$$

then Z_i shall be adjusted section by section to agree with the given equation; that is, for the third section

$$Z_3 + R_A + R_1 + R_2 + R_3 = Z_G \pm 5\% \quad (20)$$

and for the fifth section

$$Z_5 + R_A + R_1 + R_2 + R_3 + R_4 + R_5 = Z_G \pm 5\% \quad (21)$$

The surge impedance of the sections may be adjusted by adjusting L or C provided that

$$\text{Total } C_G \geq K D_L C_L \quad (22)$$

and

$$\text{Total } L_G C_G \geq (Z_L C_L D_L)^2 \quad (23)$$

The time duration in microseconds, T_D, of the initial surge of the generator, as measured by an oscilloscope, can be checked by

$$T_D = 2 Z_L C_L D_L \quad (24)$$

The voltage divider used to measure the voltage of the test specimen shall have an impedance of at least 100 times the minimum impedance of the test specimen during discharge.

If an auxiliary impulse generator is used to initiate the discharge of the distributed constant generator, then the stored energy of the auxiliary impulse generator shall not exceed 0.5% of the stored energy of the distributed constant generator.

8.10.2.1.3 Test procedure

The test shall consist of subjecting the test specimen to a number of operations, as defined in Table 11.

These operations shall be applied in three groups of six consecutive operations followed by one group of two operations, with a time interval between consecutive operations of 50–60 s. Specimens may be permitted to cool to ambient temperature after the sixth, twelfth, and eighteenth operations. Prior to the nineteenth operation, heat the sample to 60 ± 3 °C. Within 10 min after removing the sample from the oven, apply the nineteenth and twentieth operations. Testing shall occur with an ambient temperature between 20 °C and 60 °C. Within 5 min after the twentieth operation, power-frequency recovery voltage shall be applied for a minimum of 30 min. For a complete arrester, the recovery voltage shall be k_C times MCOV (8.5.2). For a prorated section, the recovery voltage shall be as prescribed in 7.2.2. Valve element temperature, resistive component of current, or power dissipation shall be monitored until the measured value is appreciably reduced (success) or a thermal runaway condition is evident (failure).

One wave shape record of the discharge voltage and discharge current through the test specimen shall be made during both the first two and last two operations of the series. Current and voltage records need not be made simultaneously.

8.10.2.1.4 Test evaluation

Following the test, and after the specimen has demonstrated thermal stability per 8.10.2.1.3, the specimen shall be allowed to cool to ambient temperature. Then the tests specified in 8.10.2.1.1 shall be repeated. The design shall be considered adequate when

a) Thermal recovery has been demonstrated;
b) No physical damage is evident;
c) Power-frequency sparkover (if applicable) and discharge voltage have not changed more than 10% from the values measured in 8.10.2.1.1.

The transmission-line discharge capacity of a designated arrester rating shall be considered to have met the requirements of this standard when tests have been made in accordance with this standard, the evaluation conditions have been met, and the following conditions have also been met:

a) The transmission-line length of D_L used in deriving the constants of the test generator in 8.10.2.1.2 is equal to or greater than the length of line specified in Table 11;

b) For the same system voltage, the rating of the designated arrester is equal to or greater than the rating of the arrester on which the test was based; or for the designated system voltage, it is less than the system voltage on which the test was based.

8.10.2.2 Low-current, long-duration test for distribution arresters

The test shall be made on complete arresters or on prorated sections. The duty-cycle voltage ratings tested shall be 3 kV or more, but need not exceed 9 kV. The discharge current shall be as specified in 8.10.2.2.2.

8.10.2.2.1 Preparation for test

Before making the test described in 8.10.2.2.2, power-frequency sparkover (see 8.2), if applicable, and discharge-voltage tests at the classifying current (see Table 6) shall be made on the test specimen.

8.10.2.2.2 Test procedure

The discharge current for this test shall have an approximately rectangular wave shape, and shall be maintained at or greater than the minimum values of current for the time as specified in Table 12.

Table 12—Low-current, long-duration test levels for distribution class arresters

Arrester classification	Minimum surge current (crest A)	Minimum duration (μs)
Distribution, heavy duty	250	2000
Distribution, normal duty	75	2000
Distribution, light duty	75	2000

The test consists of 20 operations applied in the following manner.

The test specimen shall be subjected to three groups of six consecutive operations followed by one group of two operations, with a time interval between consecutive operations of 50–60 s. The ambient conditions for the first 18 operations shall be in still air at 20 ± 5 °C, except that liquid-immersed arresters shall be in mineral insulating oil meeting ASTM D3487-88 (1993), at a liquid temperature of 20 ± 5 °C. Specimens shall be permitted to cool to ambient after the sixth, twelfth, and eighteenth operations. Prior to the nineteenth operation the test specimen shall be heated to 60 ± 5 °C, except that liquid-immersed arresters shall be in mineral insulating oil meeting ASTM D3487-88 (1993), at 120 ± 5 °C, and deadfront arresters shall be preheated to 85 ± 5 °C.

Samples shall be maintained at the prescribed temperature for a sufficient time to obtain thermal equilibrium. With the sample at the required thermal equilibrium temperature, apply the nineteenth and twentieth operations. Within 5 min after the twentieth operation, power-frequency recovery voltage shall be applied for a minimum of 30 min. For a complete arrester, the recovery voltage shall be k_C times MCOV. For a prorated section, the recovery voltage shall be determined as prescribed in 7.2.2. Valve element temperature, resistive component of current, or power dissipation shall be monitored until the measured value is appreciably reduced (success) or thermal runaway condition (failure) is evident.

One wave shape record of the discharge voltage and discharge current through the test specimen shall be made during both the first two and last two operations of the series. Current and voltage records need not be made simultaneously.

8.10.2.2.3 Test evaluation

Following the test, and after the specimen has demonstrated thermal stability per 8.10.2.2.2, the specimen shall be allowed to cool to ambient temperature. Then the tests specified in 8.10.2.2.1 shall be repeated. The design shall be considered adequate when

a) Thermal recovery has been demonstrated;
b) No physical damage is evident;
c) The power-frequency sparkover, if applicable, and the discharge voltage of the test specimen shall not have changed more than ±10% from the values measured in 8.10.2.2.1.

8.11 Duty-cycle tests

8.11.1 General

Tests procedures shall comply with Clause 7. Duty-cycle tests shall be made on a complete arrester or on a prorated section of an arrester. The duty-cycle voltage rating of the prorated section shall be not less than 3 kV, but need not exceed 12 kV.

8.11.1.1 Preparation for test

Before making the tests, sparkover tests (appropriate to the gap design) (see 8.2) and discharge-voltage tests (see 8.3) at a classifying current per Table 6 shall be made on the test specimen at 20 ± 5 °C.

8.11.1.2 Test circuit

The arrester or prorated section shall be connected across a power supply having a frequency within the range of 48–62 Hz. The crest values of power-frequency voltage measured at the arrester terminals shall not be less than the values specified in 8.11.1.3 during the flow of 60 Hz current. The crest voltage shall not increase by more than 1% when the sample is disconnected.

8.11.1.3 Test procedure

Tests shall be made in still air at 20 ± 5 °C for all arrester types except liquid-immersed, which shall be tested in mineral insulating oil meeting ASTM D3487-88 (1993), at a liquid temperature of 20 ± 5 °C. The test sample shall be energized at k_R times the rated duty-cycle voltage and maintained at this voltage for the time required to perform 20 operations, with a time interval between operations of 50–60 s. If the sample is a prorated section, its duty-cycle voltage shall be determined as prescribed in 7.2.2. The initiating surges shall be timed to occur approximately 60 °C before the crest of power-frequency voltages having the same polarity as the impulse. The initiating surges shall be 8/20 µs current waves of constant polarity and of crest value, as shown in Table 6.

After the twentieth unit operation, the sample shall be heated to 60 ± 5 °C for all arresters, except liquid-immersed arresters shall be heated in mineral insulating oil, meeting ASTM D3487-88 (1993), to 120 ± 5 °C; and deadfront arresters shall be in still air at 85 ± 5 °C for a time sufficient to obtain thermal equilibrium.

With the sample at the required thermal equilibrium temperature, it shall be subjected to two impulses of the magnitude specified in Table 6, except for distribution heavy duty classification, which shall be subjected to two 40 kA, 8/20 µs impulses, timed to occur 50–60 s apart while energized at k_C times MCOV.

8.11.1.4 Test evaluations

Within 5 min after the 20 s operation, power-frequency recovery voltage shall be applied for a minimum of 30 min. For a complete arrester, the recovery voltage shall be k_C times MCOV. For a prorated section, the recovery voltage shall be as prescribed in 7.2.2. Valve element temperature, resistive component of current, or power dissipation shall be monitored until the measured value is appreciably reduced (success) or a thermal runaway condition is evident (failure). After demonstration of thermal stability, the specimen shall be allowed to cool to approximately ambient temperature. Then the tests specified in 8.11.1.1 shall be repeated. The design shall be considered adequate when

a) Thermal recovery has been demonstrated;
b) No physical damage is evident;
c) Power-frequency sparkover (if applicable) and discharge voltage have not changed more than 10% from the values measured in 8.11.1.1.

8.12 TOV tests

8.12.1 General

The purpose of this procedure is to determine TOV capability of the arrester. Manufacturers' published data shall include curves with abscissa scaled in time and ordinate in per unit of MCOV. In addition, the manufacturer shall publish a table of TOV values listed in per unit of MCOV to three significant digits, for times 0.02, 0.1, 1, 10, 100, and 1000 s. The table values shall be taken from the curves and shall include data for "No Prior Duty" (8.12.2) and for "Prior Duty" (8.12.4). The published curve and table shall state the range of arrester ratings for which they apply.

Test procedures shall comply with Clause 7. TOV tests shall be made on complete arresters or on prorated sections in time ranges stated in items (a) and (f) and any three time ranges stated in items (b), (c), (d), or (e) below. The time ranges in seconds are

a) 0.01–0.1;
b) 0.11–1.0;
c) 1.1–10;
d) 10.1–100;
e) 101–1000;
f) 1001–10 000.

The duty-cycle voltage rating of the prorated section (used for intermediate and station arresters) shall be not less than 3 kV, but need not exceed 12 kV.

For distribution arresters, the tests shall be run on complete arresters with duty-cycle voltage ratings of 9–12 kV. Connection wire shall not be larger than AWG # 12.

For a given arrester type and design, when various size blocks are used, the blocks selected for the TOV test section shall have the minimum material volume per unit of MCOV.

8.12.1.1 Preparation for test

Before making the tests, power-frequency sparkover (see 8.2), if applicable, and discharge voltage at the classifying current (per Table 6) shall be measured at 20 ± 5 °C.

8.12.1.2 Test circuit

The arrester or prorated section shall be connected across a power supply having a frequency within the range of 48–62 Hz. Nominal test frequency (50 Hz or 60 Hz) shall be stated with published data. The crest values of power-frequency voltage shall be measured at the arrester terminals during the overvoltage. The minimum measured crest value divided by $\sqrt{2}$ times V_C [9] is the per unit value that shall be used for data display.

8.12.1.3 Test procedure

Tests shall be made in still air at 20 ± 5 °C. The sample shall be heated for a time sufficient to obtain thermal equilibrium and shall be at 60 ± 5 °C, except for deadfront arresters, which shall be at 85 ± 5 °C, and liquid-immersed arresters, which shall be in mineral insulating oil meeting ASTM D3487-88 (1993), at 120 ± 5 °C, when the test is initiated per 8.12.2.

8.12.2 “No Prior Duty” test

Apply a power-frequency overvoltage in one of the time ranges per 8.12.1. Within 1 s after the overvoltage, apply recovery voltage[10] for a minimum of 30 min. Valve element temperature, resistive component of current, or power dissipation shall be monitored until the measured value is appreciably reduced (success) or a thermal runaway condition is evident (failure). Repeat the procedure for five specimens, each to be tested in all five selected time ranges. The specimen shall be allowed to stabilize at 60 ± 5 °C, except for deadfront arresters, which shall be at 85 ± 5 °C, and liquid-immersed arresters, which shall be in mineral insulating oil meeting ASTM D3487-88 (1993) at 120 ± 5 °C, before testing at each time range.

8.12.3 Test evaluation

After the specimens have been tested in each of the five selected time ranges and have been allowed to cool to 20 ± 5 °C, repeat the measurement in 8.12.1.1. A specimen has passed when the following have occurred:

a) Sparkover (if applicable) has not changed more than 10%;
b) Discharge voltage has not changed more than 10%;
c) No physical damage is evident.

The manufacturer’s published curve has been verified when all five specimens have been tested at TOV voltages and corresponding durations that are equal to or greater than the values indicated on the curve, and have passed the evaluation criteria. All test points shall be displayed on the curve.

8.12.4 “Prior Duty” data

This requirement is applicable to station and intermediate class arresters only. Based on the above listed tests and manufacturer's data showing energy absorption during transmission-line discharge tests, the manufacturer shall either test or calculate, and publish, prior duty data. The relevant prior duty is the energy in two

[9] V_C is defined in 7.2.2 as the maximum continuous operating voltage of a prorated section.
[10] Recovery voltage of the prorated section is defined in 7.2.2.

transmission-line discharges under the conditions most severe for the design being tested and assuming no cooling between discharges. If prior duty testing is performed, the energy in two transmission-line discharges shall be applied in not less than 4000 μs nor more than 60 s, followed immediately by application of TOV. The energy associated with the two transmission-line discharges must be identified and referenced to the prior duty TOV curve on a kilojoule per kV MCOV basis.

8.13 Pressure-relief tests for station and intermediate class arresters

All station and intermediate arresters, except the liquid-immersed type, shall have pressure-relief capability and shall be tested in accordance with this standard. General test procedures shall conform to Clause 7. The high-current and low-current tests shall be made on different specimens of the same arrester type.

8.13.1 Test specimens

The high-current test shall be made on the highest voltage rating of a complete single arrester unit of a given type and design. Low-voltage units of the same type and design need not be tested unless the lower-voltage unit is required to withstand a higher current. The test on high-voltage arresters, comprised of several individual units in series, need only be made on the highest voltage rating of an individual unit. The low-current test may be made on any voltage rating of a single unit of a given type and design.

8.13.1.1 Test specimen preparation

If used, the gaps of test specimens may be reduced in spacing or shorted with a fusewire. Valve elements shall be externally fused with a wire that follows the contour of the elements in close proximity to the surface. The fusewire used for the high-current test shall melt within a time corresponding to 30° after current initiation.[11] The fusewire for the low-current test may be of any convenient size [see 8.13.4, item (d)].

8.13.1.2 Test specimen mounting

The test specimen shall be mounted to simulate service conditions. The upper end shall be terminated with the base of another unit of the same arrester design or the terminal cap, whichever is the more restrictive to pressure relief. The base of the test specimen shall be mounted on a pedestal at least 300 mm (12 in) high. An enclosure the height of the pedestal shall concentrically encircle the specimen. The diameter of the enclosure shall be equal to the specimen diameter plus twice the specimen height, with a minimum diameter of 1.8 m (6 ft).

8.13.2 High-current pressure-relief rating

Station and intermediate arresters shall be given a symmetrical rms high-current pressure-relief rating. Compliance with these ratings shall be demonstrated by the design tests specified in 8.13.3.

8.13.3 High-current pressure-relief test procedure

Several alternative procedures are given for demonstrating the compliance of arrester high-current pressure-relief venting with the rating class.

8.13.3.1 General requirements

The following general requirements apply to all of the methods for performing the high-current pressure-relief tests:

[11]On the basis of a sine wave cycle at supply frequency.

a) The test circuit power frequency shall be between 48 Hz and 62 Hz.
b) For intermediate arresters, the minimum test current duration shall be 0.2 s.
c) For station arresters with duty-cycle voltage ratings of 3–72 kV, the minimum test current duration shall be 0.2 s.
d) For station arresters with duty-cycle voltage ratings above 72 kV, the minimum test current duration shall be 0.1 s.
e) The maximum time for the arrester to vent shall be 0.085 s.
f) The high test current shall be measured at the crest of the highest asymmetrical current loop while the current is through the arrester.[12]

The rms value of the asymmetrical current shall be determined in accordance with IEEE Std C37.09-1979.

8.13.3.2 Tests at full voltage

Tests at full voltage should be made whenever test facilities permit this test procedure.

a) The open-circuit voltage, E_T, of the test circuit shall be not less than 77% of the voltage rating of the arrester tested.
b) The impedance of the test circuit shall be adjusted to produce not less than the symmetrical rms fault current of the pressure-relief rating of the arrester (see Table 13), with the arrester replaced by a bolted fault. The adjustment of the current shall be verified by measuring the symmetrical and completely asymmetrical short-circuit currents of the circuit. These currents shall be termed the prospective currents of the circuit. It is permissible to determine the prospective currents by making the bolted fault test with reduced excitation on the generator. (This reduces the duty on the test equipment.) The short-circuit currents and the open-circuit voltage, E_R, with the reduced excitation shall be measured. The prospective currents of the test circuit are the measured short-circuit currents multiplied by E_T / E_R.
c) The current shall be initiated as close as possible to voltage zero, with a permissible deviation from zero to 20° after the zero crossing of the wave.[13]
d) The *X/R* ratio of the test circuit, without the arrester connected, shall be at least 15. The ratio of the complete asymmetrical to the symmetrical rms currents for this *X/R* ratio is 1.55. This corresponds to a ratio of the crest asymmetrical current to the rms symmetrical current of 2.6.
e) The test on the arrester shall be made with the circuit adjusted in accordance with items (a)–(d). Fault-current limitation by the arrester is permissible provided that other criteria for a successful test described in 8.13.5 are met. External flashover of the arrester as a result of pressure-relief venting is permissible at any time during the test.

8.13.3.3 Compensated tests at reduced voltage

Where test stations capable of making full-voltage tests on high-voltage arresters are not available, tests at less than full voltage are necessary. The compensated reduced-voltage tests are for those arresters that exhibit considerable arc resistance during fault-current flow through the arresters. Experience has shown that the resistance of arcs inside an arrester does not appreciably increase the impedance of the circuit and, thereby, limits the symmetrical current through the arrester. However, arc resistance can cause a considerable reduction in the *X/R* ratio of a circuit, thereby reducing the current asymmetry that can be obtained.

[12]The current in an arc over the exterior of an arrester may be higher than the current through the arrester, for those arresters that transfer the arc to the outside. An external arc does not contribute to pressure inside of an arrester; therefore, the current in the external arc is not a measure of test severity.
[13]On the basis of a sine wave cycle at supply frequency.

Table 13—Pressure-relief test currents for station and intermediate class arresters

Arresters	Symmetrical rms amperes	
	High current	Low current
Station arresters[a,b]	40 000–65 000	600 ± 200
Intermediate arresters[a]	16 100	600 ± 200

[a]Test values for arresters with porcelain tops have not been standardized.
[b]For test currents above 40 kA, the values shall be in 5 kA increments.

The general procedure for the compensated reduced-voltage test is to make a test on a rating that can be tested at full voltage to determine the current that will flow through the arrester. The test on the higher voltage rating is then made, adjusting the test circuit so as to obtain the same crest asymmetrical current, and not less than the same symmetrical current, through the low-voltage unit.

a) The arrester tested at full voltage shall be of the same type and design as the high-voltage arrester to be tested.
b) The procedure for the full-voltage test is the same as described in 8.13.3.2. In this case, it is imperative to obtain an oscillographic record of the current through the arrester.
c) The test on the high-voltage rating shall be made by adjusting the test circuit so as to obtain the same crest magnitude for the first current half-cycle as was obtained during the full-voltage test on the lower rating.
d) Test circuits adjusted to comply with item (c) will often produce a higher symmetrical current through the high-voltage rating than was obtained during the full-voltage test on the lower rating. This higher symmetrical current may impose a more severe pressure-relief venting duty. It is permissible to synthetically reduce current, not less than 2.5 cycles after current initiation, to the symmetrical magnitude measured during the full-voltage test.

8.13.3.4 Reduced-voltage test

Some arrester designs having very low fault-arc resistance may be tested at reduced voltage with a fault current having crest asymmetrical and rms symmetrical values not less than those specified in Table 13 and 8.13.3.2, item (d). If the circuit that produces the required asymmetrical current results in a higher than required symmetrical value, current may be synthetically reduced, not less than 2.5 cycles after initiation, to the required symmetrical value.

8.13.4 Low-current pressure-relief test procedure

The low-current pressure-relief test shall be conducted as follows on arresters of all high-current pressure-relief ratings. Since there are no variations in low-current rating, this value need not be indicated on the arrester nameplate.

a) The test circuit power frequency shall be between 48 Hz and 62 Hz.
b) This test may be made at any test circuit voltage that will provide the current specified.
c) The rms current for the low-current test may be between the limits of 600 ± 200 A rms. The current shall be the average for the duration of current flow.

d) The test current duration, measured from the time that the fusewire melts, shall be until venting occurs. Maximum time-to-vent shall be 1 s.
e) Test current initiation may be at random with respect to the power-frequency voltage waves.
f) Any convenient value of *X/R* may be used for the low-current test circuit.

8.13.5 Test evaluation

Conformance of the test specimen with this standard shall be judged from the following:

a) The oscillograph recordings showing test current magnitude and duration;
b) The evidence of the time at which venting occurred;
c) The confinement of all components of the specimen within the enclosure specified in 8.13.1.2. Fracture of the housing by thermal shock shall, in itself, not constitute a failure of the specimen to pass the test.

8.14 Short-circuit test for porcelain-housed distribution surge arresters

All porcelain-housed distribution arresters for which a fault-current withstand rating is claimed shall be tested in accordance with this standard. General test procedures shall conform to Clause 7. Tests shall preferably be performed at full voltage (85% of duty-cycle rating). In cases where test facilities do not permit full-voltage testing, the tests may be made at reduced voltage.

8.14.1 Test specimens

The tests shall be made on the highest voltage rating of a complete single arrester unit of a given type and design. These tests shall be considered to substantiate conformance to this standard of lower voltage ratings of the same type and design. Tests need not be made on the lower voltage units, except where a higher current withstand capability is claimed for a lower voltage rating. The lower voltage rating shall then be tested at the current withstand capability claimed.

8.14.1.1 Test specimen preparation

The test specimen shall be prepared in one of two manners

a) Full voltage (85% of duty-cycle voltage rating);
b) Reduced voltage.

8.14.1.1.1 Tests at full voltage (85% of duty-cycle voltage rating)

If gaps are utilized, the gap structure may be shunted by a fusewire, or each gap spacing may be reduced so that the 60 Hz sparkover of the test specimen shall be 50% or less of the test voltage. Each valve element shall be faulted (electrically punctured) to offer a minimum resistance to the power current, or shall be externally fused. When faulted by electrical puncture, the puncture shall be visible at each end and extend the length of the valve element. When externally fused, the fusewire shall follow the contour of the valve element and be in close proximity to its surface. The fusewire shall melt within 30 electrical degrees after current initiation.

When the test is made with surge initiation of the fault current, the gap structure need not be modified. Each element of the test specimen shall be modified by breaking away a section of the collar insulating material at least 6 mm (0.25 in) wide along the entire length of the valve element.

8.14.1.1.2 Tests at reduced voltage

When required to test at reduced voltage, gaps (if used) may be fused, or their spacing may be reduced so that their sparkover is below the test voltage. The valve element shall be externally fused. The fusewire shall follow the contour of the valve element and be in close proximity to its surface. The fusewire shall melt within 30 electrical degrees after current initiation.

8.14.1.2 Test specimen mounting

The test specimen shall be mounted to simulate normal service conditions. The arrester shall be centrally located above a circular enclosure 300 mm (12 in) high and 1.8 m (6 ft) in diameter. The bottom of the arrester shall be at a minimum height of 1.2 m (4 ft) from the top of the enclosure. For those designs incorporating a disconnector, the ground lead size and attachment shall be in accordance with the manufacturer's published recommendations using the maximum size, stiffness, and shortest length.

8.14.2 Test procedures

The following procedures shall apply to all tests:

a) The test circuit power frequency shall be between 48 Hz and 62 Hz.

b) The open-circuit test voltage shall not be less than 85% of the duty-cycle voltage rating of the arrester tested. Tests at reduced voltage shall apply when conducted at test facilities that do not have sufficient capacity to test at full 85% of rating. For reduced voltage tests, the specimen shall be prepared per 8.14.1.1.2.

c) The test current, whether the prospective current of the test circuit or the current through the test specimen, shall be initiated close to voltage crest, with a maximum permissible deviation of 10 electrical degrees on either side of crest.

d) The minimum test duration for the fault-current withstand claimed for the arrester shall be 0.1 s.

e) For tests at full 85% of duty-cycle voltage rating, the impedance of the test circuit shall be adjusted to produce not less than the symmetrical rms fault-current withstand claimed for the arrester with the test specimen replaced by a bolted fault. This current shall be termed the prospective current of the circuit. For tests at less than 85% of duty-cycle voltage rating, the impedance of the test circuit shall be adjusted to produce through the specimen not less than the symmetrical rms fault-current withstand claimed for the arrester.

f) For tests at full 85% of duty-cycle voltage rating, the arrester specimen, as prepared in 8.14.1.1.1, shall be tested in the identical circuit used to determine the prospective current, but connected in place of the bolted fault. Where surge initiation is used, the surge shall be of sufficient magnitude to cause the modified valve elements to flashover, as indicated by the oscillographic record. The prospective current, as determined in item (e), shall be considered the test current. For tests at reduced voltage, using an arrester specimen prepared per 8.14.1.1.2, the test current shall be the actual current through the arrester as determined from oscillographic records.

8.14.3 Test evaluation

Conformance of the test specimen with this standard shall be judged from the following:

a) The oscillographic recordings showing test current magnitude and duration;
b) The confinement of all components of the specimen within the enclosure specified in 8.14.1.2.

Fracture of the housing by thermal shock shall, in itself, not constitute a failure of the arrester to pass the test.

8.15 Short-circuit test for polymer-housed distribution class arresters

All polymer-housed distribution arrester designs shall have a manufacturer-claimed fault-current withstand capability and shall be tested in accordance with the procedures of this section to demonstrate the claimed capability. Tests shall be performed at three fault-current levels: high, intermediate, and low. Tests shall be made on specimens which have been "pre-faulted" by means of a fusewire or by overvoltage (see 8.15.1.2). High-current tests shall be performed on two "fusewire faulted" samples and two "overvoltage faulted" samples. Intermediate- and low-current tests shall each be performed on two "overvoltage faulted" samples. Table 14 summarizes the test requirements.

Table 14—Mode-of-failure test parameters for polymer-housed distribution class arresters

Test	High current		Intermediate current	Low current
Preparation method	Fusewire	Overvoltage	Overvoltage	Overvoltage
Number of samples	2	2	2	2
Symmetrical rms current	Not less than maximum claimed	Not less than maximum claimed	0.5 ± 0.05 times maximum claimed	600 ± 200 A
Min. duration of current (s)	0.2	0.2	0.2	1.0

8.15.1 Test specimens

Tests shall be made on samples which represent the longest mechanical section of the design.

8.15.1.1 Preparation of fusewire faulted samples

The valve elements and gaps, if used, shall be externally shorted by means of a fusewire that follows the contour of the elements immediately adjacent to the surface of the elements. The size of the fusewire shall be selected such that it will melt within a time corresponding to 30 electrical degrees after fault-current initiation. In all other respects, the samples shall be representative of normal production.

8.15.1.2 Preparation of overvoltage faulted samples

Samples representative of normal production shall be subjected to a voltage exceeding MCOV that will cause the valve elements to fail in a time of 5 ± 3 min.

NOTE—Adjustment of the voltage to obtain an initial current density in the range of 5–10 mA/cm^2 will typically result in valve element failure in the prescribed time.

The short-circuit current of the voltage source may be less than or equal to 30 A. The originally applied voltage may be reduced, but to a level not less than MCOV, to cause the valve elements to fail in the specified time. The valve elements are considered to be failed when the voltage across the elements falls to below 10% of their MCOV.

8.15.1.3 Test specimen mounting for short-circuit tests

The test specimens shall be mounted vertically on an insulating crossarm, with the crossarm mounting bracket electrically isolated from the test circuit and from ground. The arrester shall be centrally located above a circular enclosure 300 mm (12 in) high and 1.8 m (6 ft) in diameter. Alternatively, a square enclosure 300 mm (12 in) high and 1.8 m (6 ft) wide may be used. The bottom of the arrester shall be at a minimum height of 1.2 m (4 ft) from the top of the enclosure. For those designs incorporating a disconnector, the ground lead size and attachment shall be in accordance with the manufacturer's published recommendations using the maximum size, stiffness, and shortest length. The line and ground lead shall be insulated to prevent arc movement along the lead and away from the test sample during the fault-current flow.

8.15.2 Test procedure

The test circuit power frequency shall be between 48 Hz and 62 Hz. High- and intermediate-current tests may be performed at either full or reduced voltage. Different requirements apply to each. Low-current tests may be performed at any test circuit voltage that will provide the required short-circuit current.

8.15.2.1 Tests at full voltage (high and intermediate fault-current levels)

The open circuit voltage of the short-circuit power source shall be no less than the MCOV of the test specimen.

A test to determine the prospective fault current shall be performed with the test specimen replaced by a solid link of negligible impedance.

For the high-current tests, the *X/R* ratio of the test circuit shall be at least 15. The ratio of the complete asymmetrical to symmetrical rms currents for this *X/R* ratio is 1.55, corresponding to a ratio of crest asymmetrical to rms symmetrical current of 2.6. The impedance of the test circuit and the timing of the fault closing shall be adjusted to produce the symmetrical rms fault current appropriate for the test being conducted (see Table 14). The magnitude and asymmetry of the current shall be confirmed by oscillographic measurement.

For the intermediate-current tests, no asymmetry is required. It is necessary only that the symmetrical rms fault current is within the range specified in Table 14. This shall be confirmed with oscillographic measurement.

Tests on arrester specimens shall be made with the circuit and timing adjusted as prescribed above. "Overvoltage faulted" samples shall be tested between 3 and 5 min after completion of the pre-fault preparation (see 8.15.1.2).

The prospective fault current, established as described within this subclause, is used to determine the claimable capability of the arrester. Fault-current limitation by the test specimen is permissible, provided that other criteria for a successful test described in 8.15.3 are met.

8.15.2.2 Tests at reduced voltage

Reduced voltage tests are typically performed in cases where the capabilities of the testing station are not sufficient to perform tests at full voltage on the longest mechanical unit of a given arrester type and design. Requirements for reduced voltage testing are described in 8.15.2.2.1 as "non-compensated." For the high fault-current tests only, requiring current asymmetry, an alternative "compensated" test may be performed (see 8.15.2.2.2).

8.15.2.2.1 Non-compensated tests at reduced voltage (high and intermediate fault-current levels)

Current through the arrester specimen during the fault-current test is used to determine the claimable capability of the arrester. The fault current shall be measured by oscillographic means.

For the high-current tests, the impedance of the test circuit shall be adjusted such that

a) The symmetrical rms current meets the requirements of Table 14 appropriate for the test being conducted.
b) The crest of the first half-cycle of current is not less than 2.6 times the symmetrical rms current.
c) The asymmetrical value of the first half-cycle of current is not less than 1.55 times the symmetrical rms current. If the circuit that produces the required asymmetrical current results in higher than the required symmetrical value, the current may be synthetically reduced, not less than 2.5 cycles after initiation, to the required symmetrical value.

For the intermediate-current tests, no asymmetry is required. It is necessary only that the symmetrical rms current through the arrester is within the range specified in Table 14.

"Overvoltage faulted" samples shall be tested between 3 and 5 min after completion of the pre-fault preparation (see 8.15.1.2).

The circuit test voltage may be any level for which the above requirements are met.

8.15.2.2.2 Compensated tests at reduced voltage (high fault current only)

The general procedure for compensated tests at reduced voltage is to first make a test on a shorter unit that can be tested at its full voltage to determine the current that will flow through the arrester. The test on the longest mechanical unit is then made, adjusting the test circuit to obtain the same asymmetrical current, and not less than the same symmetrical current, as that obtained on the test of the shorter unit. The following conditions shall apply:

a) The arrester unit tested at its full voltage shall be of the same type and design as the higher voltage arrester that is tested at the reduced voltage.
b) The procedure for the test on the shorter unit is the same as described in 8.15.2.1 for the high-current tests.
c) The test on the longer unit shall be made by adjusting the test circuit to obtain a crest magnitude for the first half-cycle of the current at least equal to that obtained during the test on the shorter unit.

Tests circuits adjusted to comply with condition (c) will often produce a higher symmetrical current through the longer unit than was obtained during the test on the shorter unit. In such a case, the current may be synthetically reduced, not less than 2.5 cycles after initiation, to the required symmetrical value.

"Overvoltage faulted" samples shall be tested between 3 and 5 min after completion of the pre-fault preparation (see 8.15.1.2).

8.15.2.3 Low-current tests

The tests may be made at any test circuit voltage that will provide the specified current (see Table 14). Test current initiation may be at random with respect to the power-frequency voltage wave. Any convenient *X/R* ratio may be used for the test circuit.

8.15.3 Test evaluation

Any flame established during the test on the test samples, or on any ejected parts of the arresters falling within the enclosure, shall self-extinguish within 2 min after the test.

Parts or fragments are permitted to fall outside the enclosure, provided that they meet the following criteria:

a) There shall be no visible flame on any part or fragment.
b) Parts or fragments weighing more than 10 g must be flexible.

Structural failure of the test samples is permitted, provided that the criteria above are satisfied.

8.16 Failure mode test for liquid-immersed arresters

Valve-type, liquid-immersed arresters may be designated as either fail-open or fail-short types, and must be tested in accordance with this standard. General test procedures shall conform to Clause 7. The fail-open current rating is the fault-current level above which the arrester is claimed to evolve into an open circuit upon failure. The fail-short current rating is the fault-current level below which the arrester is claimed to evolve into a short circuit upon failure. It is recognized that a fail-open type arrester will not always fail in an open-circuit mode for available fault currents below its fail-open current rating, and that a fail-short type arrester will not always fail in a short-circuit mode for available fault currents above its fail-short current rating.

NOTE—Fail open does not imply that the arrester is self-protecting. All arrester failures initiate a short-circuit current that must be interrupted by an overcurrent protective device. After fault clearing, the fail-open arrester allows re-energization of the device (with, of course, no overvoltage protection).

8.16.1 Test specimens

Tests shall be made on three each of the lowest and highest voltage ratings of a complete single arrester unit for a given type and design for which a failure mode current rating is claimed. These tests shall be considered to substantiate conformance to this standard of an intermediate voltage rating of the same type and design.

8.16.1.1 Test specimen preparation

The test specimens shall be modified in the following manner. The valve elements shall be faulted (electrically punctured) to offer low resistance to power-frequency current. This shall be done on all valve elements simultaneously in the assembled arrester. The valve elements must be faulted in a circuit with an available current of no less than 2 A rms and no more than 10 A rms. A sufficiently high voltage shall be applied to fail the valve elements within a period of not more than 5 min. Failure is denoted by a rapid increase in the conducted current from a fairly low but steadily increasing value to the full available current of the circuit. This current shall be permitted to flow through the valve elements for 1 min after the failure is detected.

8.16.1.2 Test specimen mounting

The test specimens shall be mounted in a manner simulating the intended service condition. The arrester under test shall be immersed in mineral insulating oil meeting ASTM D3487-88 (1993), in a container that is sufficiently large such that it does not become involved in arcing activity.

8.16.2 Test procedures

8.16.2.1 General requirements

The following general requirements apply to both fail-open and fail-short types of arresters:

a) The test circuit power frequency shall be between 48 Hz and 62 Hz.
b) The test current shall be initiated at an instant when the voltage crest is 80% or more of its crest value.
c) The test current duration shall be nominally 0.2 s, with a maximum deviation of 0.04 s from this nominal value.
d) The failure mode current shall be the current that actually flows through the test specimen. The fail-open current shall be the highest value measured while current is flowing through the arrester. The fail-short current shall be the lowest value measured while current is flowing through the arrester.

8.16.2.2 Test for fail-open mode

The impedance of the test circuit shall be adjusted to produce through the specimen not more than the fail-open current rating of the arrester.

8.16.2.3 Test for fail-short mode

The impedance of the test circuit shall be adjusted to produce through the specimen not less than the fail-short current rating of the arrester.

8.16.3 Test evaluation

Conformance of the test specimens with this standard shall be judged by the following:

a) The oscillographic recordings showing test current magnitude and duration.
b) The results of a voltage withstand test following the test described in 8.16.2.2 or 8.16.2.3. The specimens shall be tested in a circuit with limited but known available current, at a voltage not less than MCOV for a period of 1 min, during which time no current flows in the case of a fail-open type arrester or available current flows in the case of a fail-short type arrester.
c) The visual evidence of damage or deterioration of the specimens after the test.

All three tested specimens at each of the voltage ratings must meet these requirements.

8.17 Deadfront arrester failure mode

All deadfront arresters should be able to withstand valve block failures without ejecting arrester parts through the body of the housing. To demonstrate this capability, the deadfront arrester shall be tested in accordance with this standard.

8.17.1 Test specimens

Tests shall be made on the highest voltage rating of complete arrester units of a given type and design. Three specimens shall be tested per fault current. These tests shall be considered to substantiate conformance to this standard of lower voltage ratings of the same type and design.

8.17.2 Test specimen mounting

The test specimen shall be mounted on a standard load break interface to simulate normal service conditions.

8.17.3 Test procedure

This test procedure shall apply the following:

a) The test circuit power frequency shall be between 48 Hz and 62 Hz.

b) The open-circuit test voltage applied to the prefaulted deadfront arrester shall not be less than the MCOV rating of the deadfront arrester tested.

c) To electrically fail the arrester, higher than rated voltage shall be applied to the arrester with a low-current source (potential transformer) until the current increases to the source short-circuit current level, indicating failure of the valve elements.

d) The open-circuit test voltage shall then be applied to the faulted specimens within 5 min of the pre-fault mode. Three deadfront arresters shall be tested with a fault current of 500 A rms for a minimum duration of 0.3 s (20 cycles), and three more deadfront arresters shall be tested at a fault current of 10 000 A rms for a minimum duration of 0.17 s (10 cycles).

8.17.4 Test evaluation

Conformance of the test specimens with this standard shall be judged from oscillographic recordings showing test current magnitude and duration. Fracture of the housing with the valve elements ejected through the body shall constitute failure of the arrester to pass the test. Ejection of the valve elements with the release of the grounded bottom cap is considered acceptable.

8.18 Distribution arrester disconnector tests

General test procedures shall conform to Clause 7. This test shall be conducted on disconnectors that are designed as an integral part of the arrester, as an attachment to the arrester, or as an accessory for insertion into the line or ground lead. The test shall be made on arresters that are fitted with arrester disconnectors, or on the disconnector assembly alone, if its design is such that it will be unaffected by the heating of adjacent parts of the arrester in its normally installed position.

8.18.1 Test specimens

The test shall be made on each type and design of disconnector.

8.18.1.1 Test specimen preparation

The disconnector test specimen shall not have modifications made to it.

For tests on disconnectors that are affected by the internal heating of the associated arresters, the nonlinear resistors and series gaps of the arrester shall be bypassed with a bare copper wire 0.08–0.13 mm (0.003–0.005 in) in diameter in order to start the internal arcing.

For tests on disconnectors that are unaffected by the internal heating of the associated arresters, the arrester, if it is used for mounting the disconnector, shall have its nonlinear resistors and series gaps shunted or replaced by a conductor of sufficient size so that it will not be melted during the test. If convenient, it is permissible to conduct this test with the disconnector separated from the arrester and mounted in an appropriate fixture.

8.18.1.2 Test specimen mounting

The test specimen shall be mounted and connected in accordance with the manufacturer’s published recommendations, using a connecting lead of the maximum recommended size and stiffness and the shortest recommended length. In the absence of published recommendations, the conductor shall be hard-drawn bare copper, approximately 5 mm (0.2 in) in diameter and 300 mm (12 in) long, arranged to allow freedom of movement of the disconnector when it operates.

8.18.2 Test procedures

8.18.2.1 Discharge-current and duty-cycle tests

In the case of built-in disconnectors, these tests shall be made at the same time as the tests on the arrester. In the case of disconnectors that are designed for attachment to an arrester or for insertion into the line or ground lead as an accessory, the discharge-current tests may be made separately or in conjunction with tests on the arrester samples. To simulate the duty-cycle test, it may be necessary to test the disconnector in series with a specific arrester. Three disconnector samples shall withstand, without operating, each of the following distribution arrester tests, with new samples being used for each test:

a) High-current, short-duration test (8.10.1);
b) Low-current, long-duration test (8.10.2);
c) Duty-cycle test (8.11.1).

8.18.2.2 Contamination tests

For any disconnector incorporated in an arrester or intended for attachment to a specific arrester design, the contamination test (see 8.7) shall be repeated on a specimen with the mounting bracket disconnected from ground, so that all external arrester surface leakage current flows through or across the disconnector to its ground terminal. The disconnector shall withstand this test without operating.

8.18.2.3 Time-current characteristic test

An operation test shall be made on arrester disconnectors to determine a time-current characteristic; that is, the relation between the time in seconds and the current in rms symmetrical amperes required to cause the disconnector to operate. It is permissible for the actual operation of the disconnector to occur after the current has ceased.

Data for the time-current curve shall be obtained at a minimum of four different levels: 20 A, 80 A, 200 A, and 800 A rms, ±20%.

8.18.2.3.1 Test circuit and conditions

The 60 Hz test voltage shall be any convenient value that is sufficient to maintain the required current level in the arc over the arrester elements and to cause and maintain the arcing of any gaps upon which operation of the disconnector depends. The circuit initiation shall be timed to produce approximately symmetrical current.

Because the disconnector is not a fault-clearing device, the test circuits shall include devices with interrupting capabilities.

NOTE—One method of preparing the test circuit is to first adjust the parameters of the test circuit with the test sample shunted by a link of negligible impedance to produce the required value of current. A closing switch can be timed to close the circuit within a time corresponding to a few degrees of voltage crest to produce approximately symmetrical current. An opening device, such as a fuse or switch, may be used with provision for adjusting the duration of current through the test sample. After the test circuit parameters have been adjusted, the link shunting the test sample should then be removed.

8.18.2.3.2 Tests for operation and plotting of time-current characteristics

For disconnectors that operate without an appreciable time delay, the current shall be maintained at the required level until operation of the disconnector occurs. At least five new samples that have not previously been subjected to any other test shall be tested at each of the four current levels. The rms value of current through each test specimen and the duration to the first movement of the disconnector shall be plotted, using time and current as coordinates. The time-current characteristic curve shall be drawn through the maximum test points.

For disconnectors that operate with an appreciable time delay, the time-current characteristic test may be made by subjecting test samples to controlled durations of current flow at each of the required levels to determine the minimum duration that will consistently result in the operation of the disconnector. Operation of the disconnector shall occur in five tests out of five trials; or if one disconnector fails to operate, five additional tests at the same current level and duration shall result in five disconnector operations. The rms value of current through the test specimen, and the applied time duration that will result in operation subsequent to termination of the current, shall be plotted using time and current as coordinates. The time-current characteristic curve shall be drawn through the established test points.

For each disconnector type tested, there shall be clear evidence of effective and permanent disconnection by the device of the associated line or ground lead. If there is any question of this, a power-frequency voltage equal to 1.2 times the MCOV rating of the highest rated arrester with which the disconnector is designed to operate, shall be applied for 1 min without current flow in excess of 1 mA rms.

8.19 Maximum design cantilever load-static (MDCL-static) test

Any polymer-housed arrester for which a maximum design cantilever load is specified by the manufacturer shall be evaluated by this procedure. Each combination of housing design and end fitting design shall be evaluated.

8.19.1 Specimens

Tests may be made on specially prepared samples provided that each combination of housing design and end fitting design is included. The length of each test sample shall be at least the lesser of the following:

a) The longest electrical unit of the arrester;
b) Four times the outside diameter of the housing at the end fitting.

The internal construction of the test sample shall be representative of the internal construction used in the arrester being evaluated.

8.19.2 Test procedure

The test consists of the following steps:

a) Secure one end fitting of the test sample to the floor or to a rigid platform.

b) Apply the test load in any chosen radial direction (referenced as 0°) to the upper end of the test sample. With the test sample under load, measure the horizontal deflection of the upper end. Measure the IIV, RIV, or partial discharge (PD) at 1.05 times the MCOV of the test sample.

   NOTE—The test load is that load which would result in the same moment at the test sample end fitting as would be produced by MDCL-static loading at that fitting on the complete arrester. In the event that the same combination of housing and end fitting design is used at more than one location in the arrester being evaluated, it is necessary to test only the highest determined loading for that combination. Figure 3 provides examples for determining moments to be reproduced for evaluation of a three-unit arrester.

c) Repeat step (b), except with loads applied in successive directions of 0°, 90 ± 5°, 180 ± 5°, and 270 ± 5° from that of the first applied load.

d) Apply cantilever loading during temperature cycling in air in an environmental chamber for a total duration of 96 h, according to Figure 4.
The thermal variations consist of two 48 h cycles of heating and cooling. The time at each of the temperature extremes (two hot and two cold) shall be at least 16 h. For the first, second, third, and fourth 24 h periods, apply the test load in the 0°, 90 ± 5°, 180 ± 5°, and 270 ± 5° directions, respectively.

e) Within 24 h of the conclusion of thermocycling, repeat steps (b) and (c).

f) Repeat steps (a) through (e) for each different combination of housing and end fitting design, with the test load modified to obtain the required moment at the secured lower end fitting. Only one test sample need be prepared for one housing design and two end fitting designs, with the second test sequence being performed on the test sample inverted from the first sequence.

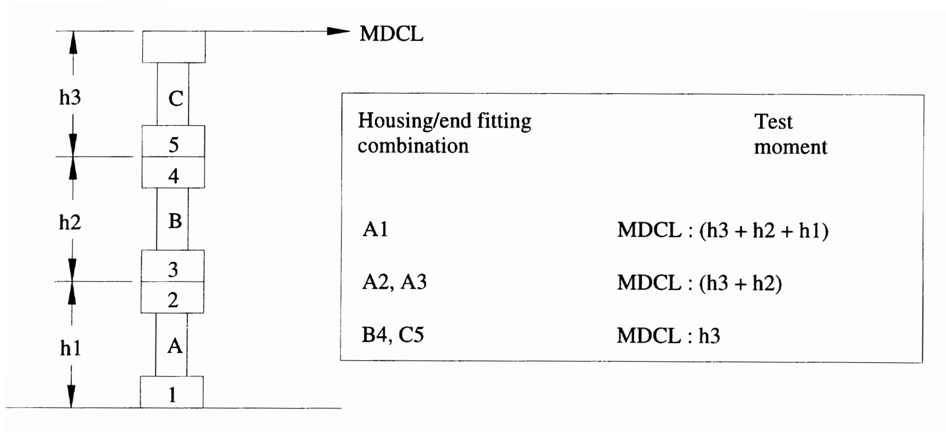

Figure 3—Example of determining moment to reproduce in test for evaluation of a multiunit arrester

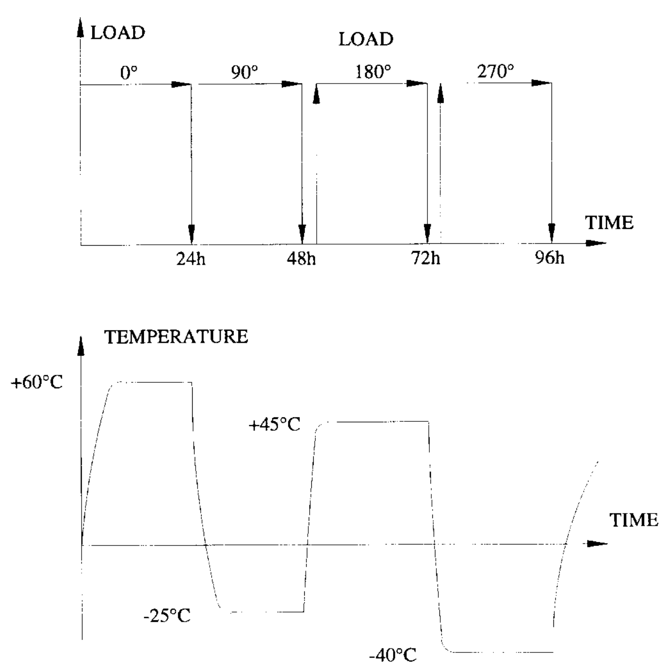

Figure 4—Thermal-mechanical cycles

8.19.3 Test evaluation

The design shall be considered adequate when for each test sequence

a) The IIV, RIV, or PD in steps (b), (c), and (e) (in 8.19.2) is within the manufacturer's specified routine test limits;
b) The deflections measured in step (e) are within 10% of the deflections measured in steps (b) and (c) (in 8.19.2) in each of the four loading directions;
c) There is no evidence of mechanical damage to the test sample.

8.20 Ultimate mechanical strength-static (UMS-static) tests for porcelain-housed arresters

8.20.1 Validating design test for UMS-static

Three housings shall be tested. For multiunit arresters having identical porcelain cross-sections and attached mounting hardware, only the longest lower unit needs to be tested. For multiunit surge arresters having differing porcelain and hardware, the longest housing assembly of each porcelain-hardware configuration shall be tested.

8.20.2 Test procedure

Tests shall be made with the test specimen adequately secured to the testing machine. The load shall be applied normal to the axis of the test specimen at the specified point of application. Specifically, the load shall be applied as follows:

a) Toward and away from pressure-relief vents;
b) Toward and away from one of the mounting bolt holes.

In demonstrating stack ratings, the equivalent lever arm may be obtained by bolting a bar or pipe of proper length and thickness to the test specimen.

8.20.3 Test evaluation

Failure of the average strength of the three specimens to meet the specified cantilever strength shall constitute failure to meet the requirement. It should be noted that normally these products are worked to 40% of the minimum breaking strength.

9. Conformance tests of valve arresters

Conformance tests as defined in Clause 3 shall include the tests described in 9.1 through 9.4.

9.1 Power-frequency sparkover test

This test applies only to gapped arrester designs and shall be made in accordance with 8.2, except that the test shall be made dry only.

The test shall be made on the complete arrester unless the arrester consists of a series of complete arrester units, in which case it may be made on the individual units.

9.2 Front-of-wave impulse protective level

This test applies only to gapped arrester designs and shall be made in accordance with 8.4.2.

9.3 Discharge-voltage test

The discharge voltage shall be determined as described in 8.3.1 using a discharge current of 8/20 wave shape with a crest amplitude of not less than 1500 A. Where the option of part testing rather than tests on the complete arrester is chosen, all test waves shall have the same nominal crest and waveform within the tolerance limits of 7.4. The test shall be made using any of the following options:

a) Tests on the complete arrester;
b) Tests on each individual unit of the arrester;
c) Tests on all of a number of unhoused prorated sections, not necessarily of the same rating, that have been assembled from the interior gap and valve elements so that
   1) All elements have been used;
   2) No element is used in more than one of the prorated sections.

For options (b) or (c), arrester discharge voltage is the arithmetic sum of the individual measurements. Oscillograms shall be made of the discharge currents and voltages.

9.4 IIV and RIV tests

These tests shall be made in accordance with 8.9.

10. Construction

10.1 Identification data

The type and identification number shall indicate the design or construction of the complete arrester. Any change in operating characteristics, design, or construction that is likely to affect the arrester application or performance shall be accompanied by a change in identification. The following minimum information shall be firmly attached to or made an integral part of each arrester:

a) Arrester classification;
b) Manufacturer's name or trademark;
c) Manufacturer's type and identification number;
d) Duty-cycle voltage rating of the arrester;
e) MCOV rating of the arrester;
f) Setting of the external series gap, if used;
g) Year of manufacture;
h) For intermediate and station arresters, excluding the liquid-immersed type, the pressure-relief rating in amperes.

10.2 Standard mountings

This subclause does not apply to deadfront or liquid-immersed arrester types.

10.2.1 Station and intermediate class arresters

Standard mountings shall be provided so that

a) Arresters with duty-cycle voltage ratings of 100 kV or less shall not require bracing; however, arresters with duty-cycle voltage ratings higher than 100 kV may require bracing.
b) Arresters shall have provision for bolting to a flat surface.
c) When required, arresters shall have provision for suspension mounting.

10.2.2 Distribution class arresters

Distribution arresters shall be so designed that they may be mounted on the mounting bracket described in ANSI C37.42-1996.

10.3 Iron and steel parts

Exposed iron and steel parts, excepting threaded parts 6 mm (0.25 in) and smaller, shall be coated with zinc or a material having equivalent protection against atmospheric corrosion. If coated by the hot dip galvanizing method, the coating shall be in accordance with ASTM A153/A153M-98.

10.4 Terminal connections

Terminal connections, excluding liquid-immersed or deadfront type arresters, shall be provided as described in 10.4.1 and 10.4.2.

10.4.1 Station and intermediate class arresters

Station and intermediate arresters shall be provided with solderless clamp-type line and ground terminals capable of securely clamping conductor diameters of 6–20 mm (0.25–0.75 in). Line terminals shall provide horizontal or vertical conductor entrance. Ground terminals shall accommodate horizontal conductor entrance only. The terminals and terminal pads for station class arresters, except those with porcelain tops, shall have two, three, or four holes to accommodate 0.5 in bolts, with holes spaced on 4.5 cm (1.75 in) centers arranged in a line, a right angle, or a square for the two, three, or four holes, respectively.

10.4.2 Distribution arresters

Distribution arresters shall be provided with either terminals or flexible insulated leads for line or ground connections. When terminal connectors are provided, and unless otherwise specified, they shall be solderless, clamp-type terminals capable of securely clamping conductor sizes from AWG # 6 (solid) to AWG # 2, stranded 4.1–7.2 mm (0.162–0.283 in) in diameter. When flexible line or ground leads are provided, and unless otherwise specified, they shall be 455 ± 25 mm (18 ± 1 in) long and have a current-carrying capability equal to or greater than that of AWG # 6 solid copper.

10.5 Housing leakage distance

Intermediate and station arresters, excluding the liquid-immersed type, with duty-cycle voltage ratings of 54 kV and above, shall have a minimum external leakage distance of 25.4 mm (1 in) for each 1 kV rms of duty-cycle voltage rating.

11. Protective characteristics

For the protective characteristics of arresters conforming to this standard, it is recommended that reference be made to the manufacturer's published information.

12. Certification test procedures for arresters applied to unit substations[14]

12.1 General

The purpose of this subclause is to explicitly state

a) Test and evaluation procedures;
b) Monitoring and retest timing, which are required for certification of arresters with voltage ratings (duty cycle) from 3–36 kV.

Tests shall be run on three samples or prorated sections that are 3 kV or greater, but need not exceed a 12 kV voltage rating.

12.2 Tests

Certification tests shall consist of the following:

a) Discharge voltage;
b) Duty-cycle tests;
c) High-current, short-duration test.

12.2.1 Discharge voltage

Test using the general principles of 8.3 at the single-current level given in Table 15. Compare the measured maximum voltage obtained to the manufacturer's published values. An individual sample has passed the test if the measured voltage is not greater than the appropriate published value.

The test results shall be evaluated as described in 12.3.

Table 15—Test currents

Arrester class	Test current (kA)
Distribution, heavy duty	10
Distribution, normal duty	5
Distribution, light duty	5
Intermediate	5
Station	10

[14]Certification tests are not required if the arresters are purchased by and used under the exclusive control of electric utilities.

12.2.2 Duty-cycle tests

Determine elevated voltage factors per 8.5; then test and evaluate individual samples in accordance with 8.11. Evaluate overall design performance per 12.3.

12.2.3 High-current, short-duration test

Test and evaluate individual samples in accordance with 8.10.1. Evaluate overall design performance per 12.3.

12.3 Evaluation procedure

Evaluation shall be on a three and three basis as follows:

a) If all samples pass, the design has passed.
b) If two or more samples fail, the design has failed.
c) If one sample fails, test three more
   1) If all three samples pass, the design has passed;
   2) If one or more samples fail, the design has failed.

12.4 Certification

The design shall be certified if the following occurs:

a) The design passes tests per 12.2 and 12.3;
b) Manufacturer's typical test data and certification are available for those design tests (per Clause 8) that were not specifically checked in 12.2 and 12.3.

12.5 Production monitoring and product retest requirements

12.5.1 General

Subsequent to certification of an arrester in accordance with this procedure, production units shall be monitored, and there shall be periodic retesting to demonstrate that certified performance capability is maintained.

12.5.2 Production monitoring

Monitoring of production units shall be done quarterly or at shorter intervals, at the discretion of the certifying agency, to verify that production tests and the product design conform to those in effect at the time the design was certified.

12.5.3 Product retest requirements

For each arrester class, retesting shall be initiated at the end of specific periods measured from time of certification. The periods are defined in Table 16 by elapsed time intervals or by the total number of units of each class produced in the 3–36 kV duty-cycle voltage range, whichever comes first. Even if the number of units produced exceeds the number listed in Table 16, retest series shall not be required less than 24 months after prior tests.

The tests to be performed at the end of each period are specified by subclause number in Table 16.

Table 16—Retest series

Arrester class	Units	Years	Test required
Distribution	500 000	5	12.2.1
	1 300 000	10	12.2.2, 12.2.3
Intermediate	40 000	5	12.2.1
	107 000	10	12.2.2, 12.2.3
Station	36 000	5	12.2.1
	96 000	10	12.2.2, 12.2.3

13. Routine tests

The following tests shall be applied to 100% of production output, except where otherwise specified. These tests do not apply to arresters rated below 1000 V.

13.1 Current-sharing test

For arresters consisting of two or more parallel columns of valve elements, measurements shall be made to confirm that the columns share "critical discharge" current within tolerances specified by the manufacturer. Critical discharge current is that associated with the highest energy discharge that the arrester would sustain in its application, as specified by the user. In the absence of a user-specified current, the critical discharge current shall be either

a) The switching surge classifying current for station and intermediate class arresters with duty-cycle ratings of 54 kV and above; or
b) The lightning impulse classifying current for all other arresters.

Measurements shall be made on each connected section in the arrester. A connected section is any section of the arrester in which there exists common electrical connections at the top and bottom of the parallel columns, with no common electrical connection at an intermediate point. If the columns in a connected section each contain more than one valve element (i.e., the parallel columns consist of a number of "layers" of valve elements), measurements may be made on each individual layer, which together make up the connected section).

Measurements may be either current or voltage according to the requirements described in 13.1.1 and 13.1.2.

13.1.1 Current measurements

The connected sections or valve element layers shall be subjected to a discharge current of any convenient wave shape having a magnitude of 0.5–2 times the critical discharge current. The difference between the currents of any two columns shall not exceed the limit specified by the manufacturer. (For connected sections having more than two columns, the test may be performed on pairs or other subdivisions of the total number of columns, with appropriately adjusted current levels, provided that the current division in all possible pairs of columns can be determined.)

13.1.2 Voltage measurements

Discharge voltages shall be determined for each column in the connected section by measuring the discharge voltage on each column or on individual valve elements within the column. Voltages shall be measured for a discharge current of any convenient wave shape having a magnitude of 0.5/N–2/N times the critical discharge current, where *N* is the number of columns in the connected section. The highest and lowest column discharge voltages, V_{max} and V_{min}, taking into account measurement accuracy, shall be such that

$$V_{max} / V_{min} \leq S^{1/\alpha} \tag{25}$$

where

S is the manufacturer's specified maximum ratio of currents between any two columns;
α is the maximum non-linear exponent of the valve elements in the current range specified above.

13.2 Discharge-voltage test

The test shall be applied to individual elements, sections, or complete arresters. The discharge voltage, when corrected for inductive component effects, shall not exceed the maximum or be less than the minimum values specified by the manufacturer. The current magnitude shall be in the range of 0.1–2 times the lightning impulse classifying current. The wave shape shall be from 4/10–8/20. When the classifying current or wave shape is not used, the manufacturer shall provide the information on the derivation method used to calculate the voltage levels.

13.3 Ionization voltage test

This test applies to complete arresters or arrester units, but does not apply to liquid-immersed arresters. The applied power-frequency voltage during this test shall be at least 1.05 times the MCOV of the arrester. Satisfactory absence from PD and contact noise shall be checked on each unit by PD or RIV methods.

13.4 Seal test

This test does not apply to liquid-immersed arresters, or to polymer-housed arresters that retain less than 10% of their volume in the form of gas. The arrester shall be tested to verify that the environmental seal meets the manufacturer's specifications.

Acceptable test methods are as follows:

a) Vacuum over water;
b) Helium-mass spectrometer;
c) Pressure or vacuum decay;
d) Halogen detection.

13.5 Power-frequency test

The test shall be performed on completely assembled arresters or arrester units. For distribution arresters, the power-frequency voltage applied must be at least 1.25 × MCOV. For intermediate and station arresters, the test voltage must be at least 1.20 × MCOV. The measured values of resistive current or watts loss shall not exceed the manufacturer's specified limits. The voltage shall be applied for a minimum of 1s, and need not exceed 30 s.[15]

13.6 Power-frequency sparkover

This test applies only to gapped arrester designs that utilize grading currents of less than 1.0 A to cause power-frequency sparkover. This test shall be performed on completely assembled arresters or arrester units. The arrester sparkover must meet the manufacturer's specifications.

[15]Users should consult the manufacturer before exceeding 30 s.

Annex A

(informative)

Basis for accelerated aging procedure

Based on Arrhenius life tests of metal-oxide block designs that increase in watts loss with time

a) 40 °C is a conservative weighted average use temperature for all except deadfront and liquid-immersed arresters.
b) The block aging process is accelerated by elevated temperature.
c) The temperature acceleration rate is reasonably estimated by an acceleration factor, AF_T

$$AF_T = 2.5^{(\Delta T)/(10)} \quad \text{(A-1)}$$

where

ΔT is the difference between test temperature and weighted average use temperature.

The weighted average use temperature is chosen to be the continuous maximum ambient temperature in the general vicinity of the arrester, as indicated in 4.1.1. Weighted average use temperature and accelerated aging tests are given in Table A.1.

Table A.1—Use conditions and test duration

Use	Continuous use temperature (°C)	Test time hours (at 115 °C test temperature)
Liquid-immersed	95	7000
Deadfront	65	2000
All others	40	1000

Using the above formula, for a 40 °C average use temperature, a 1000 h test time case is calculated in Table A.2 for illustration. Results of similar calculations for all three cases are shown in Table A.2 as equivalent time at continuous use temperature.

For the 40 °C case

$$AF_{115} = 2.5^{[(115-40)/10]} = 965 \quad \text{(A-2)}$$

The 1000 h test at 115 °C is thus equivalent to

$$\text{Equivalent 40 °C time} = 1000 \text{ (h test)} \times 965 \text{ (acceleration)}/24 \times 365 \text{ (h/year)} = 110 \text{ yr} \quad \text{(A-3)}$$

.

Table A.2—Equivalent time by type

Use	AF_T	Equivalent time at continuous use temperature (yr)
Liquid-immersed	6.25	5
Deadfront	97.70	22
All others	965.00	110

Per the standard test describing accelerated aging procedure, watts loss readings are taken at 2–5 h and compared to final readings at 1000 h, 2000 h, or 7000 h. The reason for not using readings at time zero is explained as follows.

On initial energization at temperature, various compositions of metal-oxide blocks may change rapidly and differently from their long-term character. Some compositions rapidly increase and some rapidly decrease to a more stable stage and, thereafter, display their long-term characteristic. It is the long-term characteristic that is of use for extrapolation to service life at continuous temperature. Based on this logic, the initial phenomena are ignored.

Annex B

(informative)

Surge arrester classification prescribed test requirements

Table B.1 summarizes, for each arrester class, the minimum design test requirements for selected key design tests.

Table B.1—Surge arrester classification prescribed test requirements

Class	Rate voltage (kV)		Impulse classifying current (kA)	Table 7 and switching surge classifying current (A)	Min. high-current withstand (kA)	Min. LC-DC (A/μs)	Min. TL discharge capability	Min. high-current pressure relief (kA)[a]	Low-current pressure relief (A)[a]
	Duty cycle	MCOV							
Station	3–48	2.55–39	10	500	65	NA	Table 11	40–65	600 ± 200
	54–312	42–245	10	500–1000	65	NA	Table 11	40–65	600 ± 200
	396–564	318–448	15	2000	65	NA	Table 11	40–65	600 ± 200
	576–612	462–485	20	2000	65	NA	Table 11	40–65	600 ± 200
Intermediate	3–144	2.55–115	5	500	65	NA	Table 11	16.1	600 ± 200
Distribution, heavy duty[b]	3–36	2.55–29	10	NA	100	250/2000	NA	NA	NA
Distribution, normal duty[b]	3–36	2.55–29	5	NA	65	75/2000	NA	NA	NA
Distribution, light duty[b]	3–36	2.55–29	5	NA	40	75/2000	NA	NA	NA

[a]Test values for arresters with porcelain tops have not been standardized.
[b]Riser pole, liquid-immersed, and deadfront are arrester types, not classifications.