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IEEE Standard for Shunt Power Capacitors

IEEE Power Engineering Society

Sponsored by the
Transmission and Distribution Committee

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Abstract: Capacitors rated 216 V or higher, 2.5 kvar or more, and designed for shunt connection to alternating-current transmission and distribution systems operating at a nominal frequency of 50 Hz or 60 Hz, within the guidelines of IEEE Std 1036-1992, are considered.
Keywords: capacitors, shunt connection, transmission and distribution systems

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Introduction

(This introduction is not part of IEEE Std 18-2002, IEEE Standard for Shunt Power Capacitors.)

This standard's principal objective is to provide a basis for uniformity in design and testing of shunt power capacitors.

This standard was revised in response to a need created by the continuous changes in capacitor technology, primarily in the areas of internally fused and fuseless capacitors, and the need to move capacitor application information previously contained in this standard to IEEE Std 1036-1992, IEEE Guide for Application of Shunt Power Capacitors. It was also the aim of this revision to coordinate the information contained in this standard, whenever possible, with other pertinent national and international standards.

Participants

This standard was revised by a working group sponsored by the Capacitor Subcommittee of the Transmission and Distribution Committee of the IEEE Power Engineering Society. At the time this standard was approved, the Capacitor Subcommittee consisted of the following membership:

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Contents

IEEE Standard for Shunt Power Capacitors

1. Overview

1.1 Scope

This standard applies to capacitors rated 216 V or higher, 2.5 kvar or more, and designed for shunt connection to alternating current transmission and distribution systems operating at a nominal frequency of 50 Hz or 60 Hz, within the guidelines of IEEE Std 1036™-1992[1].

2. References

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 When the following standards are superseded by an approved revision, the revision shall apply.

ASTM D1535-01, Standard Practice for Specifying Color by the Munsell System.[2]

IEEE Std 1036™-1992, IEEE Guide for Application of Shunt Power Capacitors.[3, 4]

IEEE Std C37.41e™-1996, IEEE Standard Design Tests for External Fuses for Shunt Capacitors.

IEEE Std C37.99™-2000, IEEE Guide for Protection of Shunt Capacitor Banks.

IEEE Std C57.19.00™-1991 (R1997), IEEE Standard General Requirements and Test Procedures for Outdoor Power Apparatus Bushings.

NEMA 107-1993, Methods of Measurement of Radio Influence Voltage (RIV) of High-Voltage Apparatus.[5]

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

[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/).

[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://standards.ieee.org/).

[4]The IEEE standards referred to in Clause 2 are trademarks belonging to the Institute of Electrical and Electronics Engineers, Inc.

[5]NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

NEMA CP 1-2000, Shunt Capacitors.

NFPA 70-2002, National Electrical Code® (NEC®).[6]

3. Definitions

The meaning of other terms used in this standard shall be as defined in *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B1][7].

3.1 ambient temperature: The temperature of the medium, such as air, water, or earth, into which the heat of the equipment is dissipated.

NOTES

1—For self-ventilated equipment, the ambient temperature is the average temperature of the air in the immediate neighborhood of the equipment.

2—For air- or gas-cooled equipment with forced ventilation or secondary water cooling, the ambient temperature is taken as that of the ingoing air or cooling gas.

3—For self-ventilated enclosed (including oil-immersed) equipment considered as a complete unit, the ambient temperature is the average temperature of the air outside of the enclosure in the immediate neighborhood of the equipment (see 5.7 and Table 2).

3.2 capacitor bank: An assembly at one location of capacitors and all necessary accessories, such as switching equipment, protective equipment, controls, etcetera, required for a complete operating installation. It may be a collection of components assembled at the operating site or may include one or more piece(s) of factory-assembled equipment.

3.3 capacitor element: The basic component of a capacitor unit consisting of two electrodes separated by a dielectric.

3.4 capacitor equipment: A complete assembly of capacitors, including accessories such as buses, connectors, dischargers, and fuses, suitable for connection to a power system.

3.5 discharge device: An internal or external device intentionally connected in shunt with the terminals of a capacitor for the purpose of reducing the residual voltage after the capacitor is disconnected from a network.

3.6 externally fused capacitor bank: A capacitor bank with fuses external to the (power) capacitors.

3.7 fused capacitor: A capacitor having fuses mounted on its terminals, or inside a terminal enclosure, or inside the capacitor case, for the purpose of interrupting current flow to a failed capacitor.

3.8 fuseless capacitor bank: A capacitor bank without any fuses, internal or external, which is constructed of (parallel) strings of capacitor units.

3.9 indoor (prefix): Not suitable for exposure to the weather.

NOTE—For example, an indoor capacitor unit is designed for indoor service or for use in a weatherproof housing. (*See also:* **outdoor**.)

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[6]NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA.

[7]The numbers in brackets correspond to those of the bibliography in Annex A.

3.10 internal fuse of a capacitor: A fuse connected inside a capacitor unit, in series with an element or a group of elements.

3.11 internally fused capacitor (unit): A capacitor unit which includes internal fuses.

3.12 internally fused capacitor bank: A capacitor bank with internally fused capacitor units.

3.13 metal-enclosed equipment: A capacitor equipment assembly enclosed in a metal enclosure or metal house, usually grounded, to prevent accidental contact with live parts. (*Syn:* **metal-housed equipment**.)

3.14 metal-housed equipment: *See:* **metal-enclosed equipment**.

3.15 outdoor (prefix): Designed for use outside buildings and to withstand exposure to the weather.

3.16 power capacitor (capacitor, capacitor unit): An assembly of dielectric and electrodes in a container (case), with terminals brought out, that is intended to introduce capacitance into an electric power circuit.

NOTE—The abbreviated term "capacitor" or "capacitor unit" is used interchangeably with "power capacitor" throughout this standard.

3.17 proof (suffix): An apparatus is designated as dustproof, splashproof, etc., when so constructed, protected, or treated that its successful operation is not interfered with when subjected to the specified material or condition.

3.18 string (string of capacitors): Capacitors connected in series between two terminals without parallel connection(s).

4. Service conditions

4.1 Normal service conditions

Capacitors 2400 V and higher are expected to operate as indicated in the revision of IEEE Std 1036-1992, in effect on the date that the capacitor is manufactured.

Capacitors shall be suitable for operation at their specified rating when

a) The ambient temperature is within the limits specified in 5.7. (Capacitors may be exposed to the direct rays of the sun.)
b) The altitude does not exceed 1800 m above sea level. See 6.5.2 and Table 5.
c) The voltage applied between terminals does not exceed the rated voltage by more than the tolerance specified in 5.3.
d) The impulse voltage applied between each terminal and the case does not exceed the basic impulse insulation level (BIL) of that terminal.
e) The applied voltage including harmonics does not exceed the limit specified in 5.3.
f) The nominal operating frequency is equal to the rated frequency.

4.2 Abnormal service conditions

If capacitors are required to operate under abnormal service conditions, such as the following, the application should be brought to the attention of the manufacturer:

a) Exposure to damaging fumes or vapors
b) Exposure to conducting or explosive dust
c) Exposure to abnormal mechanical shock or vibration, including earthquakes
d) Exposure to radiated heat from surfaces (other than the sun) that are hotter than the ambient temperature limits for capacitors given in 5.7
e) Mounting and/or arrangement that prevents adequate ventilation
f) Operation in ambient temperatures outside the range specified in 5.7
g) Altitude higher than 1800 m[8] above sea level (see 6.5.2 and Table 5)
h) Momentary power frequency overvoltage that exceeds that listed in IEEE Std 1036-1992
i) Transient currents that exceed those listed in IEEE Std 1036-1992
j) Transient overvoltages that exceed those listed in IEEE Std 1036-1992
k) Service conditions other than those listed in 4.1

5. Ratings and capabilities

5.1 Standard ratings

This standard establishes the following ratings for capacitors:

a) Voltage, rms (terminal-to-terminal)
b) Terminal-to-case (or ground) insulation class
c) Reactive power
d) Number of phases
e) Frequency

5.2 Capacitance tolerance

The capacitance of a unit shall not vary more than –0% to +10% of the nominal value based on rated kvar, voltage and frequency, measured at 25 °C uniform case and internal temperature.

5.3 Maximum continuous operating voltage, current, and kvar

Capacitors are intended to be operated at or below their rated voltage. Capacitors shall be capable of continuous operation under contingency system and bank conditions provided that none of the following limitations are exceeded:

a) 110% of rated rms voltage
b) 120% of rated peak voltage, i.e. peak voltage not exceeding 1.2 x (square root of two) x rated rms voltage, including harmonics, but excluding transients
c) 135% of nominal rms current based on rated kvar and rated voltage
d) 135% of rated kvar

[8] 6000 ft.

5.4 Typical voltage and reactive power ratings for capacitors

Typical voltage and reactive power ratings are given in Table 1. Capacitors shall not give less than rated reactive power at rated sinusoidal voltage and frequency, and not more than 110% of this value, measured at 25 ˚C uniform case and internal temperature.

Table 1—Typical voltage and reactive power ratings

Volts, rms (terminal-to-terminal)	kvar	Number of phases	BIL kV*
216	5, 7 1/2, 13 1/3, 20, and 25	1 and 3	30**
240	2.5, 5, 7 1/2, 10, 15, 20, 25, and 50	1 and 3	30**
480, 600	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3	30**
2400	50, 100, 150, 200, 300, and 400	1 and 3	75, 95, 125, 150, and 200
2770	50, 100, 150, 200, 300, 400, and 500	1 and 3	75, 95, 125, 150, and 200
4160, 4800	50, 100, 150, 200, 300, 400, 500, 600, 700, and 800	1 and 3	75, 95, 125, 150, and 200
6640,7200,7620,7960, 8320, 9540, 9960, 11 400, 12 470, 13 280, 13 800, 14 400	50, 100, 150, 200, 300, 400, 500, 600, 700, and 800	1	95, 125, 150, and 200
15 125	50, 100, 150, 200, 300, 400, 500, 600, 700, and 800	1	125, 150, and 200
19 920	100, 150, 200, 300, 400, 500, 600, 700, and 800	1	125, 150, and 200
20 800, 21 600, 22 800, 23 800, 24 940	100, 150, 200, 300, 400, 500, 600, 700, and 800	1	150 and 200

*See 7.7.
**Not applicable to indoor ratings.

5.5 Insulation classes

The BILs of typical rating capacitors are given in Table 1.

5.6 Frequency

Power capacitors shall be designed for operation at the rated nominal frequency of either 50 Hz or 60 Hz.

5.7 Ambient temperature

5.7.1 Maximum ambient

Capacitors shall be designed for continuous operation and frequent switching operations in outdoor locations with unrestricted ventilation and direct sunlight for the maximum ambient temperatures for each mounting arrangement shown in Table 2. For applications with restricted air flow, ventilation must be adequate so that the maximum ambient air temperatures as given in Table 2 for metal-enclosed or metal-housed equipment are not exceeded.

Table 2—Maximum ambient

Mounting arrangement	Ambient air temperature—°C 4-h average*
Isolated capacitor	46
Single row of capacitors	46
Multiple rows and tiers of capacitors	40
Metal-enclosed or -housed equipment	40

*The arithmetic average of the four consecutive highest hourly readings during the hottest day expected at that location.

5.7.2 Minimum ambient

Capacitors shall be capable of both continuous operation and switching operations at a minimum ambient temperature of –40 °C.

5.8 Overvoltage and overcurrent withstand capabilities

Capacitors shall be capable of withstanding, with full life expectancy, switching transients having crest voltages up to two times the peak of the capacitor rated voltage, and other transient overvoltages and overcurrents normally associated with the operation of shunt power capacitors on electric power systems as outlined in IEEE Std 1036-1992.

The continuous and short time overvoltage capabilities of any capacitor element of a capacitor unit shall be considered to be its share of the total unit voltage capability.

6. Manufacturing

6.1 Thermal stability

Capacitors shall be thermally stable in accordance with the definition and operating conditions outlined in 7.9.

6.2 Basic impulse insulation level

At a minimum, capacitors shall withstand the BIL given in Table 3, as demonstrated by the tests outlined in 7.7. For capacitor units having bushings with different BIL ratings, the BIL of the internal terminal to case insulation must be equal to the highest BIL rating given on the capacitor unit nameplate.

Table 3—Minimum impulse levels

Range of capacitor voltage ratings (terminal to terminal) V, rms	Minimum BIL (kV)
216–1199	30*
1200–5000	75*
5001–15000	95
15001–20000	125
20001–25000	150

*Not applicable to 216–5000 indoor capacitors or housed equipment.

6.3 Internal discharge devices

Capacitors shall be equipped with an internal discharge device that will reduce the residual voltage to 50 V or less within the following time limits after the capacitor is disconnected from the peak of rated voltage:

Table 4—Discharge times

Range of capacitor voltage ratings (terminal-to-terminal) V, rms	Maximum time limit (minutes)
600 V or less	1
Over 600 V	5

NOTE—The internal discharge device provided in capacitors should not be considered as a substitute for the recommended practice of manually discharging the residual stored charge before working on capacitors.

6.4 Radio influence voltage (RIV)

Radio influence voltage generated by a capacitor shall not exceed 250 μV, as determined in accordance with 7.10.

6.5 Bushings

6.5.1 Number of bushings

Single-phase capacitors shall have either one or two bushings. Three-phase capacitors shall have three or four bushings.

6.5.2 Electrical characteristics

The bushings of outdoor capacitors shall have minimum electrical characteristics in accordance with Table 5. At elevations higher than 1800 m[9] above sea level, and/or in locations with severe contamination, increased insulation withstand and/or creepage may be required to prevent bushing flashovers or excessive leakage current.

[9]6000 ft.

Table 5—Electrical characteristics of bushings

BIL (kV)	Minimum insulation creepage distance (mm)***	Withstand test voltage*		
		60 Hz dry 1 min, kV, rms	60 Hz wet 10 s, kV, rms	Impulse 1.2/50 μs full wave kV crest
30**	51	10	6	30
75**	140	27	24	75
95	250	35	30	95
125	410	42	36	125
150	430	60	50	150
200	660	80	75	200

*Withstand test voltages are for standard temperature and humidity at mean sea level.
**Not applicable to indoor or housed equipment.
***The values in this column are based on 2, 5.5, 10, 16, 17, and 26 inches respectively.

Some capacitor equipment (such as some fuseless and internally fused banks) may have different voltage requirements on the two bushings of a capacitor unit. For these equipment, capacitors may have bushings with different BIL ratings; one bushing shall be rated for the highest voltage to rack and the other for the lower voltage to rack.

6.6 Terminals

6.6.1 Terminal size

Outdoor capacitors shall be provided with the following types of terminals, as specified by the user:

a) Clamp connector to accommodate a minimum range of conductor sizes from Number 8 solid through Number 2 stranded, AWG, or
b) Threaded stud with 3/8 in x 16 or 1/2 in x 13 threads suitable for bolting directly to bus bars, or
c) Threaded stud with M12 or M16 (metric) threads suitable for bolting directly to bus bars.

6.6.2 Single bushing capacitors

Single-bushing outdoor capacitors shall have the bushing terminal as specified under 6.6.1 and the case shall have a suitable connection point as the other terminal.

6.6.3 Indoor capacitors

Indoor capacitors shall be provided with terminals consistent with current-carrying requirements in NFPA 70-2002.

6.7 Information to be provided with capacitor

6.7.1 Nameplate marking

Each (power) capacitor shall be provided with a permanent nameplate that includes, but is not limited to, the following information:

a) Name of manufacturer.
b) Unique serial number.
c) Manufacturer's type, model, style, or catalog number.
d) Year of manufacture.
e) Rated reactive power.
f) Rated voltage, rms.
g) Number of phases.
h) Rated frequency.
i) BIL (if applicable). For capacitors having bushings with two different BIL ratings, the nameplate shall show both BIL ratings, e.g. 150/95 kV BIL.
j) Flammability classification and volume of insulating fluid.[10]
k) Statement that capacitor contains an internal discharge device.

6.7.2 Information to be supplied with internally fused capacitors or capacitor units for fuseless capacitor equipment

The information in 6.7.2.1 and 6.7.2.2 shall be provided as follows:

a) On the capacitor unit nameplate, and/or
b) On the capacitor equipment nameplate, and/or
c) On the instructions provided with the capacitor(s).

6.7.2.1 Internally fused capacitors

a) The number of series groups between the terminals and the number of parallel elements in each series group.
b) Maximum number of individual fuse operations in one series group of the capacitor unit before the capacitor unit must be removed from service, when the capacitor unit is operated at 110% of rated voltage across its terminals. (Overvoltages on unfaulted capacitor units also need to be considered in the setting of the protective relays.)

6.7.2.2 Capacitor units for fuseless capacitor equipment

The number of series groups between the terminals of the capacitor unit.

6.7.3 Non-PCB impregnant identification

Additional marking (decal or stick-on label) shall be visible from the ground. A blue marking shall be used to designate non-polychlorinated biphenyl (non-PCB) liquid.

[10]In the U. S., OSHA (Occupational Safety and Health Administration) flammability classification. Elsewhere, equivalent flammability designation based on the country of manufacture or supply.

6.8 Mounting hole spacing

The standard mounting hole spacing for capacitors rated 50 to 600 kvar and 2400 V or higher shall be 397 mm ± 1.6 mm (15 5/8 in ± 1/16 in) between centers of 11.1 mm (7/16 in) minimum-diameter holes. Cantilever-mounted capacitors (both brackets on one surface of the capacitor case) shall accommodate M16 (or 5/8-in) mounting bolts at 457.2 mm ± 1.6 mm (18 in ± 1/16 in) between centers. Mounting hole dimensions that differ from these, such as for capacitor units larger than 600 kvar may be agreed between the manufacturer and purchaser.

6.9 Grounding provisions

Capacitors shall have provision for effective electrical bonding of the case to capacitor hangers or mounting frame.

6.10 Color

Colors for capacitor cases and bushings shall be light gray per Munsell Notation 5.0BG 7.0/0.4 as defined in ASTM D1535-01.

7. Testing

7.1 General

Capacitor tests are designated as either production tests or design tests.

7.1.1 Production tests

Production tests shall be performed by the manufacturer on each capacitor and shall include the following:

a) Short-time overvoltage test (see 7.2).
b) Capacitance test (see 7.3).
c) Leak test (see 7.4).
d) Discharge resistor test (see 7.5).
e) Loss determination test (see 7.6).
f) Fuse capability tests for internally fused capacitors (see 7.12).

7.1.2 Design tests

Design tests shall be performed by the manufacturer to demonstrate compliance of the design with various parts of this standard. Capacitors shall first meet production test requirements before being subjected to design tests. The design tests shall include the following:

a) Impulse withstand test (see 7.7).
b) Bushing tests (see 7.8).
c) Thermal stability test (see 7.9).
d) Radio influence voltage test (see 7.10).
e) Voltage decay test (see 7.11).
f) Short circuit discharge test (see 7.13).

7.1.3 Test practices

The following conditions for testing shall be used:

a) New and clean capacitors shall be used for each test.
b) Ambient temperature shall be 25 °C ± 5 °C.
c) All alternating-current voltages shall have a frequency of 50 Hz or 60 Hz and be approximately sinusoidal in wave shape.

7.2 Short-time overvoltage tests (production test)

Each capacitor shall withstand the following test voltages for at least 10 s. Test voltages shall be applied in such a manner as to avoid transients.

7.2.1 Terminal-to-terminal test

Each capacitor shall, with its case and internal temperature at 25 °C ± 5 °C, withstand for at least 10 s a terminal-to-terminal insulation test at a standard test voltage of either of the following:

a) A direct current test voltage of 4.3 times rated (rms) voltage, or
b) An alternating sinusoidal voltage of two times rated (rms) voltage.

For three-phase wye-connected units where there is a neutral bushing or the neutral is connected to the case, the above testing for terminal-to-neutral shall be followed by a test at the square root of 3 times the above standard test voltage between each pair of bushings (not including any neutral bushing) to test the phase-to-phase insulation.

For three-phase wye-connected units where there is no neutral bushing and the neutral is not connected to the case, the rated voltage is the phase-to-phase voltage of the capacitor unit. In order to test both the phase-to-phase insulation and each leg of the wye at the appropriate voltage, the test voltage shall be 1.16 times the above standard test voltage between each pair of bushings (2 ÷ square root of three ≈ 1.16).

For three-phase delta connected units, the rated voltage is the phase-to-phase voltage of the capacitor unit. The test voltage shall be the above standard test voltage between each pair of bushings.

The capacitance shall be measured on each unit both before and after the application of the test voltage. The initial capacitance measurement shall be at low voltage. The change in capacitance, as a result of the test voltage, shall be less than either a value of 2% of the originally measured capacitance or that caused by failure of a single element of the particular design, whichever is smaller.

7.2.2 Terminals-to-case test (not applicable to capacitors having one terminal common to the case)

Terminals-to-case tests shall be made on capacitors having all terminals insulated from the case. The appropriate test voltage from Table 6 shall be applied for at least 10 s between all insulated terminals connected together and the case.

For capacitors having bushings with two different BIL ratings, this test shall be based on the bushing with the lower BIL. The nameplate shall show both BIL ratings, e.g. 150/95 kV BIL.

Table 6—Test voltages*

Range of capacitor voltage ratings (terminal-to-terminal) V, rms	BIL (kV crest)	Terminals-to-case test voltage AC voltage V, rms	
		Indoor or housed equipment	Outdoor
216–300	30**	3000	10 000
301–1199	30**	5000	10 000
1200–5000	75**	11 000	26 000
1200–15 000	95	—	34 000
1200–20 000	125	—	40 000
1200–25 000	150	—	50 000
1200–25 000	200	—	60 000

*For 216–5000 V indoor capacitors or housed equipment, this table is only used to determine the terminals to case ac test voltage.
**Outdoor units only.

7.3 Capacitance test (production test)

Capacitance tests shall be made on each capacitor to demonstrate that it will deliver not less than rated reactive power and not more than 110% of rated reactive power at rated voltage and frequency, corrected to a capacitor case and internal temperature of 25 °C. Measurements made at other than 25 °C are corrected by adjusting for temperature difference according to the established temperature relationship for the capacitor tested. Capacitance measurements shall be traceable to the National Institute of Standards and Technology.

7.4 Leak test (production test)

A suitable test shall be made on each capacitor to ensure that it is free from leaks.

7.5 Discharge resistor tests (production test)

A suitable test shall be performed on each capacitor to ensure that the internal discharge device will reduce an initial residual voltage equal to the square root of 2 times rated voltage rms to 50 V or less in the time limits specified in 6.3.

7.6 Loss determination test (production test)

Loss measurement shall be made by the manufacturer on each capacitor to demonstrate that the capacitor losses are equal to or less than W_M as defined in 7.9.2.3.

7.7 Impulse withstand test (design test)

Impulse tests shall be applied between terminals and case, with the terminals connected together. For capacitors having bushings with two different BIL ratings, this test shall be based on the bushing with the lower BIL. The nameplate shall show both BIL ratings, e.g. 150/95 kV BIL.

Single bushing capacitors, of which the case forms one electrode, shall not be subjected to the impulse withstand test. When one principal terminal of the capacitor is connected to the case, the BIL requirements shall not apply to the internal insulation assembly. The internal insulation assembly shall assure that the capacitor will meet the requirements of 7.2.1 in order to demonstrate that the insulation is adequate for the highest terminal-to-case (or terminal-to-terminal) voltage in the intended equipment. However, the bushing shall meet all the requirements of 6.5 and the nameplate shall carry the applicable BIL.

7.7.1 Impulse polarity

The capacitor shall successfully withstand three consecutive positive impulses.

7.7.2 Impulse waveshape

The impulse voltage shall be 1.2/50 microsecond full wave, as described in 7.7.3, with a crest value given in Table 5. The tolerance on the crest value shall be ± 3%.

7.7.3 Impulse measurement

The time to crest of a 1.2/50 microsecond impulse wave shall be measured as 1.67 times the time for the voltage to rise from 30% to 90% of crest value. The tolerance on the time to crest shall be ± 30%. The time to 0.5 crest value point on the tail of the wave shall be measured from the virtual time zero and shall be 40 to 50 microseconds. The virtual time zero shall be taken at the intersection of the zero voltage line and a line drawn through points on the front of the wave at 30% and 90% of the crest value.

7.8 Bushing test (design test)

Bushing test voltages shall be applied in accordance with the test procedures specified in IEEE Std C57.19.00-1991.

7.8.1 50-Hz or 60-Hz withstand test

If no flashover occurs, the bushings shall be considered as having passed the test successfully.

7.8.2 Impulse withstand test

The bushing passes the impulse test if no flashover occurs with the first three applications of the test voltage. If any one, but not more than one, of three applications of the test voltage causes flashover, three additional impulses shall be applied. If no additional flashover occurs, the bushings shall be considered as having passed the test successfully.

7.9 Thermal stability test (design test)

The test capacitor shall be considered thermally stable if the hot-spot case temperature reaches and maintains a constant value within a variation of 3 °C for 24 h, under the test conditions described in 7.9.1 and 7.9.2.

7.9.1 Selection of samples

One sample shall be selected as the test capacitor. Two other capacitors of the same ratings and having approximately the same power factor and capacitance (at rated voltage, rated frequency, and case and internal temperatures at t_S) as the test capacitor shall be selected for barrier capacitors (barrier capacitors are capacitor units to be mounted adjacent to the test capacitor during the thermal stability test, as described in 7.9.2). Resistor models having the same power loss, thermal characteristics, and physical dimensions as the test capacitor may be substituted for the barrier capacitors.

7.9.2 Test method

7.9.2.1 Mounting conditions

The test capacitor, selected as above, shall be mounted in an enclosure between the two barrier capacitors at the manufacturer's minimum recommended center-to-center spacing. The mounting position selected shall be the recommended operating position that produces the highest internal temperatures.

7.9.2.2 Ambient temperature

The air inside the test enclosure shall be maintained at an average temperature of 46 °C and shall not be force-circulated. The inside wall temperature of the enclosure shall be within ± 5 °C of the ambient temperature in the enclosure. The ambient temperature shall be measured by means of a thermocouple on the case or within the dielectric of an isolated unenergized capacitor, supported and positioned so that it is subjected to the minimum possible thermal radiation from the three energized samples.

7.9.2.3 Test voltage

All three sample capacitors (or only the test capacitor if resistive barrier capacitors are used) shall be energized at a test voltage to be determined as follows:

$$V_T = 1.1\ V_R \sqrt{\frac{W_M}{W_A}}$$

where

V_T is the test voltage
V_R is the capacitor rated voltage rms
W_M is the manufacturer's maximum allowable power loss. This loss shall be calculated using 110% of rated voltage rms and the manufacturer's established maximum product of measured capacitance and power factor, at rated voltage and frequency and at a stated case and internal temperature t_S.

NOTE—W_M does not correspond to an exact limit on either capacitance or power factor but does correspond to an exact limit on their product. The quantity W_M/W_A reduces to a ratio of

(Maximum product of capacitance and power factor):(Measured product of capacitance and power factor)

W_A is the actual power loss of the test capacitor. This loss shall be calculated using 110% of rated voltage rms and the actual capacitance and power factor of the test capacitor measured at rated voltage and frequency and at a stated case and internal temperature t_S.
t_S is the manufacturer's dielectric temperature limit under the conditions of this thermal stability test.

The test voltage (V_T) calculated for this test shall be limited to a value that will result in operation of the test capacitor at a maximum of 144% of its kvar rating. This voltage shall be maintained constant, within ± 2% throughout the last 24 h of the test period.

7.9.2.4 Temperature measurement

The temperature of the test capacitor shall be measured by means of thermocouples attached to the case sidewall and cover. All temperature measurements shall be accurate to within ± 1 °C.

7.10 Radio influence voltage (RIV) test (design test)

Radio influence voltage (RIV) tests on capacitors shall be conducted in accordance with 7.10.1 through 7.10.5.

7.10.1 Equipment

The equipment and general method used in determining the RIV shall be in accordance with the recommendations of the Joint Coordination Committee on Radio Reception of the Edison Electric Institute (EEI), the Electronic Industry Association (EIA), and the National Electrical Manufacturing Association (NEMA) as set forth in NEMA 107-1993.

7.10.2 Test voltage

The test voltage shall be of rated frequency and 115% of rated voltage rms of the capacitor.

7.10.3 Method

Capacitors having two or more bushings with the windings fully insulated from the case shall be tested with the case grounded and with the voltage specified in 7.10.2 applied between all bushings connected together and the case. Capacitors having only one bushing per phase with the case as the other terminal should not be tested, as this type of construction precludes any meaningful RIV measurement due to the high capacitance.

7.10.4 Precautions

The following precautions should be observed when measuring the RIV of capacitors:

a) The capacitor shall be at approximately the same temperature as the room in which the tests are made.
b) The capacitor bushings shall be dry and clean.
c) The capacitor shall be mounted in its recommended position with the manufacturer's recommended minimum clearance between the live parts and grounded surfaces.

7.10.5 RIV limits

The RIV, when measured in accordance with the foregoing at a frequency of 1 MHz, shall not exceed 250 μV.

7.11 Voltage decay test (design test)

The capacitor shall be energized at a direct current voltage equal to the peak of rated ac voltage. The decay of the voltage, when de-energized, shall be measured by suitable means. The time for decay of residual voltage to 50 V or less shall not exceed 5 min for capacitors rated higher than 600 V or 1 min for capacitors rated 600 V or less.

7.12 Fuse capability tests (internally fused capacitors) (production test)

Internally fused capacitors shall be subjected to one short-circuit discharge test, from a dc voltage of 1.7 times rated voltage through a gap situated as closely as possible to the capacitor, without any additional impedance in the circuit (see note below).

The capacitance shall be measured before and after the discharge test. The difference between the two measured values shall be less than an amount corresponding to one internal fuse operation.

The discharge test may be made before or after the voltage test between terminals. However, if it is made after the voltage test between terminals, a capacitance measurement at rated voltage shall be made after the discharge test to detect fuse operation.

If, by agreement with the purchaser, capacitors are accepted with operated fuses, the voltage test between terminals shall be made after the discharge test.

NOTE—It is permitted that dc charging voltage be generated by initially energizing with an ac voltage having a peak value of 1.7 times rated voltage and disconnecting at a current zero. The capacitor is then immediately discharged from this peak value. Alternatively, if the capacitor is disconnected at a slightly higher voltage, the discharge may be delayed until the discharge resistor reduces the voltage to 1.7 times rated voltage.

7.13 Short circuit discharge test (design test)

The purpose of the short-circuit discharge test is to verify the integrity of the internal connections and conductors of the capacitor operating under normal service conditions. The test shall be carried out by the manufacturer for a particular design that is to be manufactured or on a similar design that has equal or smaller size conductors and equal or higher energy level, as compared to the design to be manufactured, when subjected to this test. As such, the testing of a particular rating will be applicable to a wide range of capacitor ratings.

One unit shall be charged to a dc voltage 2.5 times rated rms voltage and then discharged. It shall be subjected to five such discharges. Before and after the five discharges, the terminal-to-terminal capacitance shall be measured at low voltage.

The discharge circuit shall have no inductive or resistive devices included. The discharge device may be a switch or spark gap and may be situated up to one meter from the capacitor such that the total perimeter of the external discharge loop is less than 3 meters. The conductors used to connect the capacitor to the discharge device shall be of copper and shall have a cross-section of at least 10 mm^2.

The difference in capacitance between the initial and final measurements shall be less than an amount corresponding to either the shorting of an element or operation of an internal fuse.

Annex A

(informative)

Bibliography

[B1] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.[11]

[11]The IEEE products referred to in Annex A are trademarks belonging to the Institute of Electrical and Electronics Engineers, Inc.