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IEEE Standard for Shunt Power Capacitors

IEEE Power and Energy Society

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of the
IEEE Power and Energy Society

Approved 5 December 2012

IEEE-SA Standards Board

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Abstract: Power 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, are considered.
Keywords: capacitors, IEEE 18™, shunt connection, transmission and distribution systems

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Introduction

This introduction is not part of IEEE Std 18-2012, IEEE Standard for Shunt Power Capacitors.

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

As part of this revision, portions of NEMA CP1 have been incorporated into IEEE Std 18-2012. After approval and publication of this revision, NEMA plans to withdraw NEMA CP1. In the future, the NEMA working group for power capacitors will provide input to the IEEE Shunt Capacitor Standard Working Group to update IEEE Std 18.

A subclause on internal fuses for internally fused capacitors has been added to Clause 6.

Clause 7, the testing clause, has been divided into sections on design tests and production tests. Appropriate design and production tests have been added for internally fused capacitors. In addition, a significant new design test, 7.1.6 Performance test, has been added to the standard.

A new annex has been added to cover the test procedure for the disconnecting test on internal fuses for internally fused capacitors.

Contents

IEEE Standard for Shunt Power Capacitors

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1. Scope

This standard applies to power 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.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ASTM D1535, Standard Practice for Specifying Color by the Munsell System.[1]

IEEE Std 1036™, IEEE Guide for Application of Shunt Power Capacitors.[2, 3]

IEEE Std 1313.2™-1999, IEEE Guide for the Application of Insulation Coordination

[1] ASTM publications are available from the American Society for Testing Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19248-2959, USA (http://www.astm.org/).
[2] 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/).
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NEMA CC 1-2009, Electric Power Connection for Substations.[4]

NFPA 70, National Electrical Code® (NEC®).[5]

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause. [6]

ambient temperature: The temperature of the air into which the heat of the equipment is dissipated.

NOTE 1—For self-ventilated equipment, the ambient temperature is the average temperature of the air in the immediate neighborhood of the equipment.[7]

NOTE 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.

NOTE 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).

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.

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

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

discharge device: An internal or external device permanently connected in parallel with the terminals of a capacitor for the purpose of reducing the trapped charge after the capacitor bank is disconnected from the energized power system.

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

fused capacitor: A capacitor having fuses mounted on its terminals, or inside a terminal enclosure, or inside the capacitor case, for the purpose of disconnecting a failed capacitor element, unit or group.

fuseless capacitor bank: A capacitor bank without any fuses, internal or external, which is constructed of (parallel) strings of capacitor units. Each string consists of capacitor units connected in series.

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.

[4]NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http://global.ihs.com).
[5]NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA.
[6]*IEEE Standards Dictionary Online* subscription is available at:
http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.
[7]Notes within the text of a standard are given for information only and do not contain requirements needed to implement this standard.

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

internally fused capacitor unit: A capacitor unit, which includes internal fuses.

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

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**.

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

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

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.

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.

rack: A structure that supports the capacitors.

string (string of capacitors) (string of capacitor elements): 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, in effect on the date that the capacitor is manufactured.

Capacitors shall be suitable for operation at their specified rating under the following conditions:

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 (6000 ft) above sea level. See 6.5.2 and Table 4.

c) The pollution level is "Light" as defined by IEEE 1313.2-1999.

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 maximum continuous operating voltage does not exceed the rated voltage of the unit.

f) The applied voltage, including harmonics and bank unbalance, does not exceed the limit specified in 5.3.

g) 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 they may require special construction. These conditions should be brought to the attention of those responsible for the manufacture and application of the equipment. Among such abnormal service conditions are as follows:

a) Exposure to salt air, damaging fumes or vapors, steam, excessive moisture
b) Exposure to excessive, abrasive, or conductive dust
c) Exposure to explosive mixtures of dust or gases
d) Exposure to severe weather conditions
e) Exposure to abnormal mechanical shocks, tilting or vibration, including earthquakes
f) Exposure to radiated heat from surfaces (other than the sun) that are hotter than the ambient temperature limits for capacitors given in 5.7
g) Mounting and/or arrangement that prevents adequate ventilation
h) Operation in ambient temperatures outside the range specified in 5.7 or exposure to sudden changes in temperature or to radiated heat from surfaces whose temperature is higher than the applicable ambient temperature. Excessive ambient temperatures may be encountered in rooms not having normal ventilation or with unusual configurations or partitions causing hot air pockets, or in rooms containing other heat-producing apparatus
i) Altitude higher than 1800 m (6000 ft) above sea level (see 6.5.2 and Table 4)
j) Unusual transportation or storage conditions
k) Unusual space limitations
l) Unusual insulation or voltage requirements
m) Unusual operating duty, frequency of operation or difficulty of maintenance
n) Operation at unstable control voltages
o) Unusual wave form distortion or harmonics causing excessive current, voltage or kvar loading
p) Momentary power frequency overvoltage that exceeds that listed in IEEE Std 1036
q) Transient currents that exceed those listed in IEEE Std 1036
r) Transient overvoltages that exceed those listed in IEEE Std 1036
s) Service conditions other than those listed in 4.1. For pollution levels greater than “Light” reference IEEE 1313.2-1999.

5. Ratings and capabilities

5.1 Standard ratings

This standard establishes the following ratings for capacitors:

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

5.2 Capacitance tolerance

The measured 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.

NOTE—Certain applications may require a tighter tolerance of the measured capacitance. The user may specify alternate tolerance requirements for the specific application.

5.3 Maximum operating voltage, current and kvar

Capacitors are designed to be operated continuously at or below their rated voltage.

Capacitors shall be capable of 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 √2 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

NOTE 1—A reactor connected in series with a capacitor installation increases the capacitor unit voltage. (The reactor voltage resulting from the capacitive current adds to the system voltage.) The capacitor rated voltage should be equal to or greater than the sum of the maximum system operating voltage (with the capacitor in service) plus the reactor voltage rise at this system maximum operating voltage. For harmonic filters and applications with harmonic content greater than the guidelines of IEEE Std 519™, see IEEE Std 1531™ for the appropriate application guidelines.

NOTE 2—It is recognized that during switching, sudden loss of load and the like, the voltage of a system may rise momentarily above the maximum continuous operating voltage, but there is no provision for this contingency other than the factor of safety introduced by the test voltage (see IEEE Std 1036 for momentary overvoltage capabilities).

5.4 Typical voltage and reactive power ratings for capacitors

Typical voltage and reactive power ratings are given in Table 1. These voltage and kvar values are intended as a guideline and do not reflect general manufacturing or technical capabilities for all capacitor technologies.

NOTE— Capacitor units are typically made to order. A rating listed in Table 1 is not meant to imply these are standard off the shelf items. Also, the reactive rating of a unit can be any value required by the user within manufacturing capabilities.

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 ºC uniform case and internal temperature.

Table 1—Typical voltage and reactive power ratings

Volts, rms (terminal-to-terminal)	kvar	Number of phases
216	5, 7 1/2, 13 1/3, 20, and 25	1 and 3
240	2.5, 5, 7 1/2, 10, 15, 20, 25, and 50	1 and 3
480, 600	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3
2400	50, 100, 150, 200, 300, and 400	1 and 3
2770	50, 100, 150, 200, 300, 400, and 500	1 and 3
4160, 4800	50, 100, 150, 200, 300, 400, 500 and 600	1 and 3
2400	50, 100, 150, 200, 300, and 400	1 and 3
2770	50, 100, 150, 200, 300, 400, and 500	1 and 3
4160, 4800	50, 100, 150, 200, 300, 400, 500 and 600	1 and 3
6350, 6640, 7200, 7620, 7960, 8320, 9540, 9960, 11 400, 12 470, 13 280, 14 400	50, 100, 150, 200, 300, 400, 500, 600, 700, and 800	1
15 125, 15 920	50, 100, 150, 200, 300, 400, 500, 600, 700, and 800	1
19 100, 19 920	100, 150, 200, 300, 400, 500, 600, 700, and 800	1
20 800, 21 600, 22 800, 23 800, 24 940	100, 150, 200, 300, 400, 500, 600, 700, and 800	1

5.5 Insulation classes

The minimum BIL ratings of capacitors are given in Table 2. Available BIL ratings typically range from 30 kV to 200 kV. The BIL may not be applicable to indoor ratings. Not all BIL and voltage ratings are applicable to two bushing capacitor units.

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 any mounting arrangements, indoor or outdoor, at a maximum average ambient temperature of 46 °C over a 24 hour period, with a peak of 55 °C, measured in the vicinity of the unit(s) at a point where the heat generated by the unit does not appreciably affect the measurement.

5.7.2 Minimum ambient

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

For colder climates, users may specify a minimum ambient temperature of –50 °C.

NOTE—Minimum ambient temperature lower than –40 °C may affect the maximum ambient temperature at which the unit can be operated.

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.

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 7.1.3.

6.2 Basic impulse insulation level

At a minimum, capacitors shall withstand the BIL given in Table 2, as demonstrated by the tests outlined in 7.1.1. 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 2—Minimum impulse levels

Range of capacitor voltage ratings (terminal to terminal) V, rms	Minimum BIL (kV)
216–1199	30[a]
1200–5000	75[a]
5001–15 000	95
15 001–20 000	125
20 001–25 000	150

[a] Not applicable to 216 V–5000 V 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 time limits specified in Table 3 after the capacitor is disconnected from the peak of rated voltage.

Table 3—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 use of a discharge device 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 7.1.4.

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 4. At elevations higher than 1800 m (6000 ft) 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.

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 this 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 Connection provisions

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.

Table 4— Electrical characteristics of bushings

BIL (kV)	Minimum insulation creepage distance		Withstand test voltage [a]		
	mm	inches	50 Hz or 60 Hz[b] dry 1 min, kV, rms	50 Hz or 60 Hz[b] wet 10 s, kV, rms	Impulse 1.2/50 µs full wave kV crest
30	51	2	10	6	30
75	140	5.5	27	24	75
95	250	10	35	30	95
125	410	16	42	36	125
150	430	17	60	50	150
200	660	26	80	75	200

[a] Withstand test voltages are for standard temperature and humidity at mean sea level.

[b] The frequency of the 1 min and 10 s tests will be dependent on the power supply available at the manufacturer's facility.

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.

6.6.4 Metal-enclosed capacitor equipment

A bushing, cable, or conduit entrance shall be provided for outdoor metal-enclosed capacitor equipment rated above 600 V.

6.7 Internal fuses for internally fused capacitors[8]

6.7.1 General

The fuse is connected in series to the element(s) which the fuse is intended to isolate if the element(s) becomes faulty. The range of currents and voltages for the fuse is therefore dependent on the capacitor design, and in some cases also on the bank in which the fuse is connected.

The operation of an internal fuse is in general determined by one or both of the two following factors:

a) the discharge energy from elements or units connected in parallel with the faulty element or unit; or
b) the power frequency fault current

6.7.2 Disconnecting requirements

The fuse shall enable the faulty element to be disconnected when electrical breakdown of the element occurs in a voltage range, in which the lowest value of the voltage between the terminals of the unit at the instant of the fault is calculated in Equation (1)

$$v_1 = 0.9 * \sqrt{2} * V_R \tag{1}$$

and the highest (instantaneous) value is calculated in Equation (2).

$$v_2 = 2.0 * \sqrt{2} * V_R \tag{2}$$

The v_1 and v_2 values are based on the voltage that may normally occur across the capacitor unit terminals at the instant of electrical breakdown of the element.

The v_2 value is of a transient nature and allowance has been made for damping.

If the purchaser specifies v_1 and v_2 values other than those indicated, for example for filter capacitors, the lower and upper test voltage limits shall be changed according to an agreement between manufacturer and purchaser.

6.7.3 Withstand requirements

The withstand requirements are as follows:

a) After operation, the fuse assembly shall withstand full element voltage, plus any unbalance voltage due to fuse action, and any short-time transient overvoltages normally experienced during the life of the capacitor.
b) The fuses shall be capable of carrying continuously a current equal to or greater than the maximum permissible unit current divided by the number of parallel elements in each series section throughout the life of the capacitor.
c) The fuses shall be capable of withstanding the inrush currents due to the switching operations expected during the life of the capacitor.

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d) The fuses connected to the undamaged elements shall be able to carry the discharge currents due to the breakdown of elements connected in parallel with them.

e) The fuses shall be able to carry the currents due to short-circuit faults on the bank external to the unit(s) occurring within the voltage range in accordance with 6.7.2.

6.8 Information to be provided with capacitor and capacitor equipment

6.8.1 Nameplate marking for capacitor unit

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, kvar

f) Rated voltage, V rms.

g) Nominal or measured capacitance, μF.[9]

h) Number of phases
NOTE—For Y-connected 3-phase capacitors, indicate whether neutral is connected to the case.

i) Rated frequency

j) 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.

k) Flammability classification[10]

l) Volume of insulating fluid[11]

m) Statement that capacitor contains an internal discharge device

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

The information in 6.8.2.1 and 6.8.2.2 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).

[9] See 7.2.2 for measured capacitance. Nominal capacitance is calculated using the rated voltage, frequency and reactive power.
[10] In the U.S., OSHA (Occupational Safety and Health Administration) flammability classification. Elsewhere, equivalent flammability designation based on the country of manufacture, supply or use can be specified by the user.
[11] If there is no fluid in the capacitor the nameplate can state "None."

6.8.2.1 Internally fused capacitors

The internally fused configuration is provided as follows:

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.)

6.8.2.2 Capacitor units for fuseless capacitor equipment

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

6.8.3 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.

6.8.4 Nameplate for capacitor equipment

The following minimum amount of information shall be given on all nameplates for capacitor equipment:

a) Name of manufacturer
b) Identification number or type, model, style, or catalog number
c) Rated kvar
d) Number of phases and connections
e) Rated voltage
f) Rated frequency

6.9 Dimensions

6.9.1 Mounting hole spacing

The standard mounting hole spacing for capacitors rated 50 kvar 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.

6.9.2 Non-enclosed substation equipment

Figure 1, Figure 2, and Figure 3 show the most common rack arrangements of non-enclosed capacitors. Non-enclosed substation equipment using single-phase capacitors rated 50 to 600 kvar should be as shown in Figure 1, Figure 2, and Figure 3.

The dimension for the width of the rack, from the center-line to center-line of the rack support insulators, shall be 914.4 mm (36 in).

The dimension for the length of the rack will be dependent upon bus connections and the number of capacitors mounted in the rack. The user should specify any specific requirements they have for the rack length. In the absence of a specified dimension by the user, the manufacturer will determine the length of the rack required.

The maximum height of the rack is typically manufacturer dependent, but the height of externally fused, upright mounted capacitor racks shall be a maximum of 1524 mm (60 in).

At each location for a rack support insulator, the manufacturer shall provide holes as required to attach the insulator specified by the manufacturer and/or user.

The minimum spacing between center-line to center-line of the capacitors within the rack shall be as specified in Table 5, unless otherwise agreed to by the manufacturer and the purchaser.

Table 5—Minimum spacing between capacitors

Capacitor Voltage Rating (terminal to terminal) V, rms	Minimum Spacing Between Center-line to Center-line of Capacitors, mm (in)
2400–8000	203.2 mm (8 in)
8001–15000	228.6 mm (9 in)
15001–25000	279.4 mm (11 in)

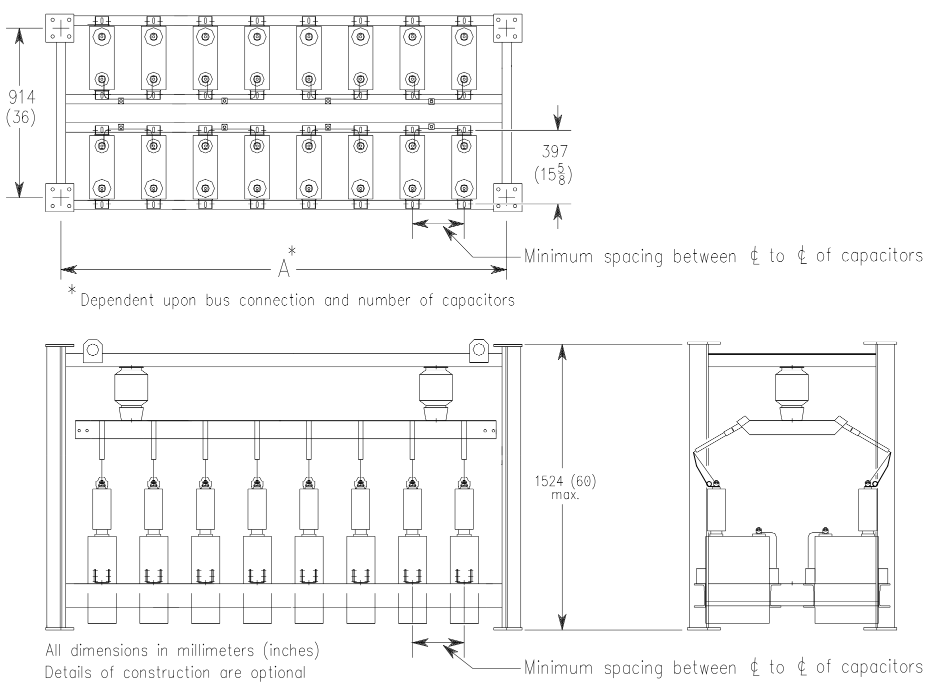

Figure 1—Dimensions, minimum spacing between and of capacitors for upright mounted, externally fused capacitor banks

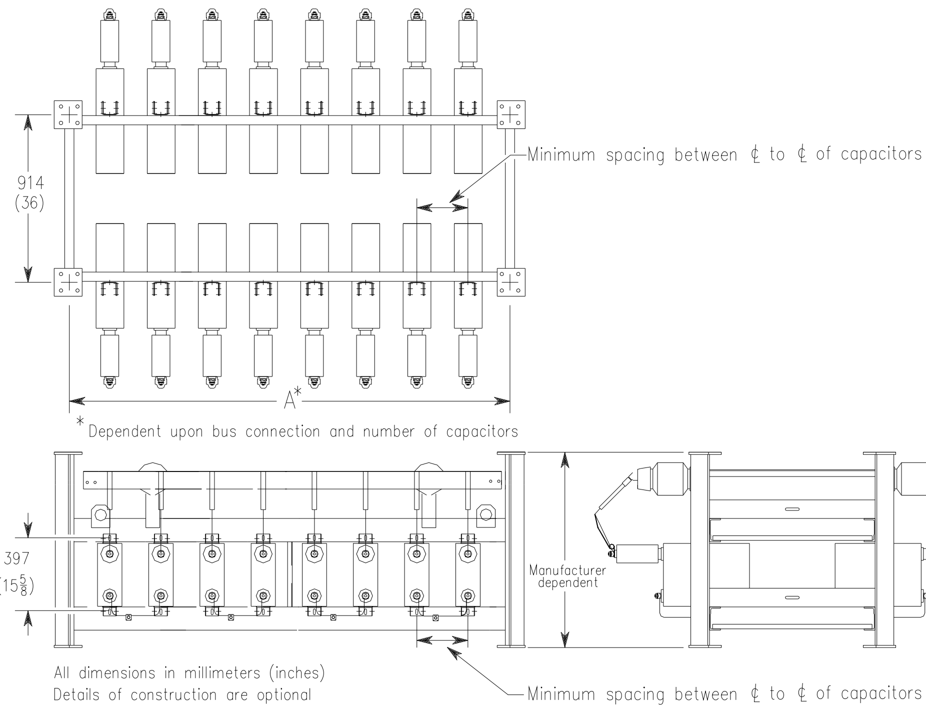

Figure 2—Dimensions, minimum spacing between and of capacitors for edge mounted, externally fused capacitor banks

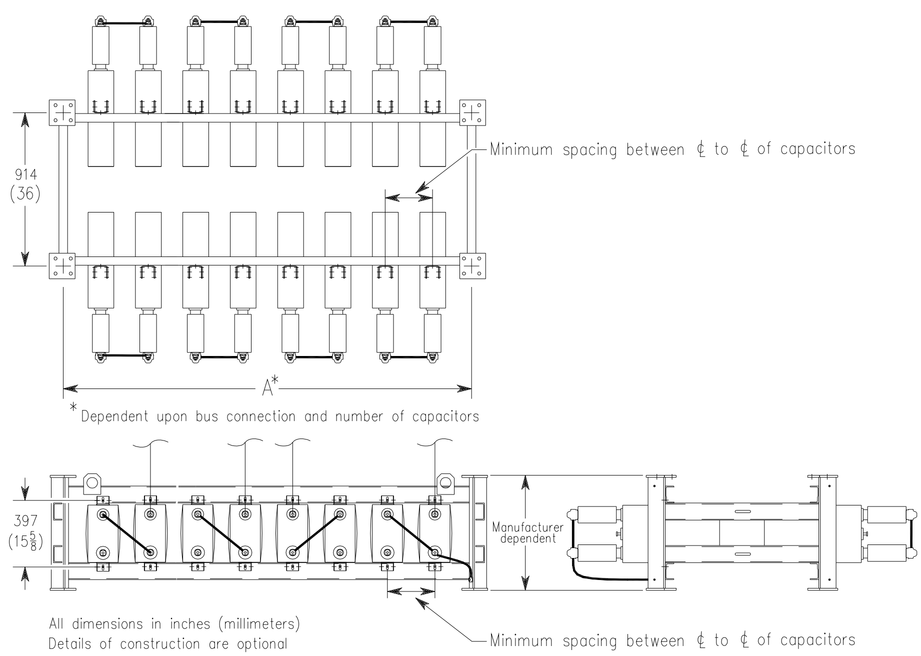

Figure 3—Dimensions, minimum spacing between and of capacitors for edge mounted, internally fused and fuseless capacitor banks

6.10 Electrical bonding provisions

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

6.11 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.

7. Testing

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

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 ± 10 °C unless otherwise specified in this standard for a specific test.
c) All alternating-current voltages shall have a frequency of 50 Hz or 60 Hz and be approximately sinusoidal in wave shape.
d) The tolerance for test measurements shall be as follows:

    1) ± 0.5% for frequency
    2) ± 0.5% for duration
    3) ± 2.5% for voltage
    4) ± 1.0 ºC

7.1 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 in 7.2 before being subjected to design tests. The design tests shall include the following:

— Impulse withstand test (see 7.1.1)
— AC voltage tests (see 7.1.2)
— Thermal stability test (see 7.1.3)
— Radio influence voltage test (see 7.1.4)
— Short circuit discharge test (see 7.1.5)
— Performance test (see 7.1.6)
— Fuse disconnect test for internally fused capacitors (see 7.1.7)

7.1.1 Impulse withstand test

Impulse tests shall be applied between terminals and case for two bushing capacitors, 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.

For single bushing capacitors, of which one principal terminal of the capacitor is connected to the case, the BIL requirements shall not apply to the internal insulation assembly. Therefore, single bushing capacitors shall not be subjected to the impulse withstand test. 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 and its internal lead assembly shall successfully pass the impulse test levels of the capacitor nameplate rating.

7.1.1.1 Impulse polarity

The capacitor shall successfully withstand three consecutive positive impulses.

7.1.1.2 Impulse waveshape

The impulse voltage shall be 1.2/50 µs full wave, as described in 7.1.1.3, with a crest value given in Table 6. The tolerance on the crest value shall be ± 3%.

7.1.1.3 Impulse measurement

The time to crest of a 1.2/50 µs 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 µs to 50 µs. 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.

Table 6—Test voltages

Range of capacitor voltage ratings (terminal-to-terminal) V, rms	BIL (kV crest)	Terminals-to-case test voltage ac voltage (50 Hz or 60 Hz) kV, rms	
		Indoor or housed equipment	Outdoor
216–300	30[a]	3	10
301–1199	30[a]	5	10
1200–5000	75[a]	11	26
1200–15 000	95	—	34
1200–20 000	125	—	40
1200–25 000	150	—	50
1200–25 000	200	—	60

[a] Outdoor units only.

7.1.2 AC voltage test

Two bushing capacitors shall pass the ac voltage tests as indicated in Table 4 for the applicable BIL rating of the unit (nameplate rating).

The bushing and internal lead assembly of single bushing capacitors shall pass the AC voltage tests as indicated in Table 4 for the applicable BIL rating of the unit (nameplate rating). If no flashover or internal electrical breakdown occurs, it shall be considered as having passed the test successfully.

7.1.3 Thermal stability 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 a minimum of 24 h, under the test conditions described in 7.1.3.1 and 7.1.3.2.

7.1.3.1 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 and frequency) 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 7.1.3.2). Resistor models having the same power loss, thermal characteristics, and physical dimensions as the test capacitor may be substituted for the barrier capacitors.

7.1.3.2 Test method

7.1.3.2.1 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 manufacturer's specified operating position that produces the highest internal temperatures.

7.1.3.2.2 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.

7.1.3.2.3 Test voltage

The test voltage calculated for this test shall be limited to a value that will result in operation of the test capacitor at 144% or greater of its kvar rating based on the unit capacitance as measured in 7.2.2. This voltage shall be maintained constant, within ± 2% throughout the last 24 h of the test period.

All three sample capacitors (or only the test capacitor if resistive barrier capacitors are used) shall be energized at the test voltage.

7.1.3.2.4 Temperature measurement

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

7.1.4 Radio influence voltage (RIV) test

7.1.4.1 Equipment

The equipment and general method used in determining the RIV shall be in accordance with NEMA CC 1-2009.

NOTE—NEMA 107, Methods of Measurement of Radio Influence Voltage (RIV) of High Voltage Apparatus, was withdrawn and the technical content was put in NEMA CC 1-2009.

7.1.4.2 Test voltage

The test voltage shall be of rated frequency and 115%, ±5%, of rated voltage rms of the capacitor.

7.1.4.3 Method

Capacitors having two or more bushings with the elements fully insulated from the case shall be tested with the case grounded and with the voltage specified in 7.1.4.2 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.

7.1.4.4 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.

7.1.4.5 RIV limits

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

7.1.5 Short circuit discharge 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. After the five discharges, the terminal-to-terminal capacitance shall be measured at rated voltage and frequency. 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.

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 m. 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.

7.1.6 Performance test

7.1.6.1 Test sample

The test sample shall be manufactured by using standard production material and processing procedures. The test sample shall pass the applicable production tests as described in 7.2.

The test sample ratings shall be no less than 30 kvar. (The test sample rating shall be agreed upon between the manufacturer and the purchaser.)

7.1.6.2 Conditioning of the sample before the test

The test sample shall be conditioned for no less than 12 hours at no less than its rated voltage. After the test, the capacitance of the test sample shall be measured at its rated voltage and frequency.

The ambient temperature range for the conditioning test shall be +15 ºC to +35 ºC.

7.1.6.3 Overvoltage test

The overvoltage test is conducted as follows:

a) Place test sample in cold chamber for no less than 12 hours at the intended low temperature ambient (–40 ºC unless otherwise specified).

   NOTE—The test temperature level has a significant impact on the severity of the test. The low temperature ambient is either specified by the purchaser or to be agreed upon between the purchaser and the equipment supplier.

b) Remove and place test sample in still air at an ambient in the range of +15 º C to +35 ºC. Within 5 min after test sample is removed from the cold chamber, apply 110% of rated voltage. Within 5 min after the voltage application, apply 225% of rated voltage for 15 cycles without any voltage interruption after which the 110% of rated voltage is maintained without any voltage interruption. After an interval of 1.5 to 2 min, the 225% of rated voltage will again be applied and the process repeated until a total of 150 applications are completed for 1 day.

c) Repeat steps a) and b) above for 1 more day. The combined application of the 225% rated voltages shall be 300 total.

d) Within 30 min of completion of step c) above, proceed to apply 140% of rated voltage for total 96 hours. The test ambient temperature shall be at +15 ºC to +35 ºC.

e) Measurement of capacitance shall be repeated at rated voltage and frequency.

7.1.6.4 Acceptance criteria

The acceptance criteria are that no break down shall occur based on the capacitance measurement. If break down should occur, two more samples shall be tested and both samples shall have no break down.

7.1.6.5 Validity of test

The performance test is a test on the capacitor unit dielectric design and composition, and on the manufacturing process of this dielectric when assembled into a capacitor unit. Each performance test will also cover other capacitor designs, which are allowed to differ from the tested design within the following stated limits.

7.1.6.5.1 Dielectric design limits

An element design is considered to be comparable with the elements in the units to be manufactured if the following requirements are satisfied:

a) The tested elements shall have the same or fewer number of layers of solid materials in the dielectric and be impregnated with the same fluid.

b) Both, the rated element voltage and the electrical stress level of the tested element shall be equal or higher.

c) The aluminum-foil (electrode) inside edge design shall be the same.

d) Element connections shall be of the same type, for example soldering, crimping, etc.

7.1.6.5.2 Test unit design limits

A test unit is considered to be comparable to the units to be manufactured if the following requirements are satisfied:

a) Test elements meeting the requirements of 7.1.6.5.1 shall be similarly assembled, have equal or thinner inter-element insulation, and be equally pressed within the manufacturing tolerance, as compared with the units to be manufactured.

b) At least four of these test elements shall be connected to give not less than 30 kvar output at rated voltage (60 Hz). All connected elements shall be placed adjacent to each other and at least one inter-element insulation shall be assembled (must have at least two series groups of elements).

c) A container to the manufacture’s standard design shall be used and the size shall be no less than 50% of the height, width and depth of the unit to be produced. (The exact case size shall be agreed upon between the manufacturer and the purchaser.)

d) The drying and impregnation process shall be identical with the normal production process.

e) The test unit shall in all other respects have the same components, such as type of discharge resistors and internal fuses, and follow the same manufacturing procedure as the units to be produced.

7.1.7 Fuse disconnect test for internally fused capacitors[12]

The fuses shall be able to withstand all design tests of the capacitor in accordance with this standard. The fuses shall also have a sufficient safety margin to allow a safe disconnection of capacitor elements in a damaged capacitor unit until the unbalance protection trips the capacitor bank and removes the unit from service.

The disconnecting test on fuses shall be performed either on one complete capacitor unit or, at the choice of the manufacturer, on two units, one unit being tested at the lower voltage limit, and one unit at the upper voltage limit, in accordance with 7.1.7.3.

NOTE—Due to testing, measuring and safety circumstances, it may be necessary to make some modifications to the unit(s) under test; e.g., those indicated in Annex B. See also the different test methods given in Annex B.

7.1.7.1 Validity of test

The fuse disconnect tests are considered valid if they are performed on capacitor(s) of a design identical with that of the capacitor offered, or on a capacitor(s) of a design that does not differ from it in any way that might affect the properties to be checked by the type tests.

7.1.7.2 Conditioning of the sample before test

The unit(s) shall have passed all production tests stated in 7.2.

7.1.7.3 Test procedures

The disconnecting test on fuses shall be performed at the lower voltage limit of 0.9 V_R voltage and at the upper voltage limit of 2.5 V_R.

If the test is carried out with dc, the test voltage shall be $\sqrt{2}$ times the corresponding ac test voltage.

If the test is carried out with ac, the triggering of the element failure with a voltage peak shall not be necessary for the test at the lower voltage limit.

Certain test methods are indicated in Annex B.

NOTE—The upper voltage limit of 2.5 V_R, defined as V_u, is considered to be the minimum required value acceptable for safe operation of the fuses under a capacitor bank trip condition. The actual upper voltage limit required is dependent upon the capacitor bank protective scheme and the internal element arrangement. The number of failed elements allowed by the manufacturer, before trip signal activation is reached, determines the level of overvoltage to consider for the upper voltage limit.

$$V_u = 1.5 * V_p \tag{3}$$

Where V_p is the maximum overvoltage that will be impressed on an individual element in a capacitor unit just after the last fuse operation allowed by the bank protection scheme. This fuse is usually considered as part of a subsequent fuse operation in the same parallel group. V_p should be agreed upon between the manufacturer and the user. The 1.5 factor is related to the potential overvoltage during breaker operation for a phase-to-ground fault with an ungrounded capacitor bank.

[12] The requirements of this section were based on IEC 60871-4 clause 5.2 and were utilized with permission from IEC. - Source: IEC 60871-4 ed. 1.0 “Copyright © 1996 IEC Geneva, Switzerland. (www.iec.ch)”

7.1.7.4 Capacitance measurement

After the test, the capacitance shall be measured to prove that the fuses have blown. A measuring method shall be used that is sufficiently sensitive to detect the capacitance change caused by one blown fuse.

7.1.7.5 Voltage test across the open fuse

A voltage test shall be carried out by applying a dc voltage of 3.5 times the element voltage for 10 s across the broken down element and the gap in its blown fuse. The element and the fuse should not be removed from the unit for this test. During the test, the gap shall be in the impregnant. No breakdown over the fuse gap or between any part of the fuse and any other part of the unit is allowed.

For units with all elements in parallel and for all units if test procedure B.2.2, B.2.3, B.2.4 or B.2.5 indicated in Annex B is used, this test can be replaced by an ac test. The test voltage between the terminals is calculated using the capacitance ratio such that the voltage across the breakdown element and the gap in its blown fuse is 3.5 times the element voltage divided by $\sqrt{2}$.

7.1.7.6 Inspection of the unit

Before opening, no significant deformation of the container shall be apparent. After opening the container, a check shall be made to verify that:

a) No significant deformation of sound fuses is apparent;

b) No more than one additional fuse (or one-tenth of fused elements directly in parallel) has been damaged (see B.1). If method B.2.2 given in Annex B is used, B.1 shall be observed.

CAUTION

Dangerous trapped charges may be present on elements disconnected either by operated fuses or by damage to their connections. All elements should be discharged with great care.

7.2 Production tests

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

— Short-time overvoltage test (see 7.2.1)
— Capacitance test (see 7.2.2)
— Leak test (see 7.2.3)
— Discharge resistor test (see 7.2.4)
— Loss determination test (see 7.2.5).
— Fuse capability test for internally fused capacitors (see 7.2.6)

7.2.1 Short-time overvoltage 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.

7.2.1.1 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 dc test voltage of 4.3 times rated (rms) voltage; or
b) An ac test voltage of 2 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 √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 ($2 \div \sqrt{3} \approx 1.16$).

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.

7.2.1.2 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.

7.2.2 Capacitance 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. Calibration of the capacitance measurement device shall be traceable to an applicable standard (e.g., the U.S. National Institute of Standards and Technology).

7.2.3 Leak test

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

7.2.4 Discharge resistor 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 $\sqrt{2}$ times rated voltage rms to 50 V or less in the time limits specified in 6.3.

7.2.5 Loss determination test

Capacitor losses shall be measured at rated voltage at a frequency of 50 Hz or 60 Hz.

If the loss test is made at a frequency other than the rated frequency of the capacitor unit, the manufacturer shall:

a) Clearly indicate the frequency at which the test was made; and

b) Indicate that the value when measured at the capacitor unit frequency will likely be different.

NOTE 1— The tangent of loss angle of impregnated low-loss dielectrics decreases during the first hours of initial energization. This decrease is not correlated to the tan δ variation with temperature. The tan δ measured in routine testing may vary significantly between identical units manufactured simultaneously. The final "stabilized" values are, however, usually within close limits, as indicated by differences recorded between routine test measurements and the value found in thermal stability testing.

NOTE 2—The user may want to consider other losses within the entire capacitor bank equipment, such as external fuses.

7.2.6 Fuse capability tests for internally fused capacitors[13]

The fuses shall be able to withstand all production tests of the capacitor in accordance with this standard.

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 close as possible to the capacitor, without any additional impedance in the circuit.

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.

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.

[13]The requirements of this section were based on IEC 60871-4 clause 5.1 and were utilized with permission from IEC. - Source: IEC 60871-4 ed. 1.0 "Copyright © 1996 IEC Geneva, Switzerland. (www.iec.ch)"

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] IEC 60871-4, Shunt capacitors for AC power systems having a rated voltage above 1 000 V - Part 4: Internal fuses.[14]

[B2] IEEE Std 519™, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.[15, 16]

[B3] IEEE Std 1531™, IEEE Guide for Application and Specification of Harmonic Filters.

[B4] IEEE Std C37.41™, IEEE Standard Design Tests for High-Voltage (>1000 V) Fuses, Fuse and Disconnecting Cutouts, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Fuse Links and Accessories Used with These Devices.

[B5] IEEE Std C37.99™, IEEE Guide for Protection of Shunt Capacitor Banks.

[B6] IEEE Std C57.19.00™, IEEE Standard General Requirements and Test Procedures for Power Apparatus Bushings.

[B7] Power Capacitor Bibliography, 1992-2011; http://grouper.ieee.org/groups/td/cap/POWCAP2.PDF.

[B8] Power Capacitor for Harmonic Filter Bibliography, 1992-1999; http://grouper.ieee.org/groups/td/cap/Harmcap1.pdf

[B9] Series Power Capacitor Bibliography, 1992-2003: http://grouper.ieee.org/groups/td/cap/Seriesca1.pdf.

[14]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.
[15] IEEE publications are available from The Institute of Electrical and Electronics Engineers (http://standards.ieee.org/).
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Annex B

(normative)

Test procedure for the disconnecting test on internal fuses[17]

B.1 General

One of the test procedures in B.2, or an alternative method, shall be used.

The capacitor voltage and current shall be recorded during the test to verify that the fuse has disconnected correctly. For dc testing, the test voltage shall be maintained for at least 30 s after breakdown to ensure that the disconnection of the fuse is unaided by disconnection of the power supply.

To verify the current-limiting behavior of the fuses when tested at the upper voltage limit, the voltage drop, excluding transient, across the blown fuse shall not exceed 30%.

If the voltage drop exceeds 30%, precaution shall be taken to make certain that the parallel stored energy and the power-frequency fault current available from the test system are representative of service conditions. A test shall then be made under these conditions to demonstrate satisfactory operation of the fuse.

At the upper voltage limit, one additional fuse (or one-tenth of the fused elements directly in parallel) connected to a sound element(s) is allowed to be damaged.

NOTE—Precautions should be taken when performing this test against the possible explosion of a capacitor unit and the explosive projection of the nail.

B.2 Test procedures

B.2.1 Capacitor preheating

The capacitor unit is preheated in a chamber before applying the ac test voltage at the lower voltage limit. Preheating temperature (100 °C to 150 °C) is chosen by the manufacturer to achieve a practical short time (some minutes to some hours) to the first breakdown.

To prevent excessive internal liquid pressure due to high temperature, the unit may be equipped with a relief tube including a valve which is closed at the instant of applying the test voltage.

A lower preheating temperature may be used when applying the test voltage at the upper voltage limit, in order to avoid breakdowns before reaching the test voltage.

B.2.2 Mechanical puncture of the element

Mechanical puncture of the element is made by a nail, which is forced into the element through a pre-drilled hole in the container. The test voltage may be dc or ac, the choice being left to the manufacturer.

[17]The requirements of this section were based on IEC 60871-4 Annex A and were utilized with permission from IEC. - Source: IEC 60871-4 ed. 1.0 “Copyright © 1996 IEC Geneva, Switzerland. (www.iec.ch)

If ac voltage is used, the timing of the puncture shall be made so that breakdown occurs close to the instant of peak voltage.

Puncture of only one element cannot be guaranteed and does not invalidate the test.

In order to limit the possibility of a flashover to the container along the nail, or through the hole caused by the nail, the punctures may be performed in the elements connected, permanently or during the test, to the container.

NOTE—DC voltage is especially suitable for capacitors having all elements in parallel.

B.2.3 Electrical breakdown of the element (first method)

Some elements in the test unit are each provided with, for example, a tab inserted between the dielectric layers. Each tab is connected to a separate terminal.

The test voltage may be ac or dc the choice being left to the manufacturer.

To obtain breakdown of an element thus equipped, a surge voltage of sufficient amplitude is applied between this tab and one of the foils of the modified element.

In the case of ac voltage, the surge shall be triggered close to the instant of peak voltage.

B.2.4 Electrical breakdown of the element (second method)

Certain elements in the test unit are each provided with a short fusible wire connected to two extra tabs and inserted between the dielectric layers. Each tab is connected to a separate insulated terminal.

The test voltage may be dc or ac, the choice being left to the manufacturer.

To obtain breakdown of an element equipped with this fusible wire, a separate capacitor charged to a sufficient voltage is discharged into the wire in order to blow it.

In the case of ac voltage, the discharge of the charged capacitor causing the wire to blow shall be triggered close to the instant of the peak voltage.

B.2.5 Electrical breakdown of the element (third method)

A small part of an element (or of several elements) in a unit is removed at the time of manufacture and replaced with a weaker dielectric.

For example: 10 cm^2 to 20 cm^2 of a film-paper-film dielectric is cut out and replaced with two thin papers.