C37.66™



IEEE Standard Requirements for Capacitor Switches for AC Systems (1 kV to 38 kV)

IEEE Power Engineering Society

Sponsored by the
Switchgear Committee

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

22 March 2006

IEEE Std C37.66™-2005
(Revision of
ANSI C37.66-1969)

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Approved 1 February 2006

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Approved 22 September 2005

IEEE-SA Standards Board

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Abstract: Required definitions, ratings, and procedures for performing design tests, production tests, and construction requirements for capacitor switches for ac systems from 1 kV to 38 kV are covered.

Keywords: back-to-back capacitor switching, capacitor load, capacitor switches, inrush current, operation, pole discrepancy, probability of restrike classification, restrike, simultaneous operation

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Introduction

This introduction is not part of IEEE Std C37.66-2005, IEEE Standard Requirements for Capacitor Switches for AC Systems (1 kV to 38 kV).

This standard has been revised and updated from the 1969 version of ANSI C37.66-1969 (R1982), incorporating significant improvements that reflect present capacitor switch technology. These improvements include changes and additions in the following areas:

a) Inclusion of solid and gas insulated switches

b) Expansion of the ratings data through 38 kV

c) Creation of probability of restrike classifications C2, C1, and C0

d) Addition of Annex A (informative)—Fault handling ratings for capacitor switches

e) Addition of Annex B (informative)—Consideration of inrush current in back-to-back capacitor switching

f) Addition of Annex C (informative)—Simultaneous opening of single-phase capacitor switches on ungrounded wye capacitor installations

g) Addition of Annex D (informative)—Altitude correction factors

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IEEE Standard Requirements for Capacitor Switches for AC Systems (1 kV to 38 kV)

1. Scope

This standard applies to single- or multi-pole ac switches for rated maximum voltage above 1 kV to 38 kV for use in switching shunt capacitor banks (see the note in this clause). This standard covers the application of capacitive load switching wherein the capacitive loads are separated by sufficient inductance to limit the high-frequency transient-making peak current to the peak values shown in Table 2 and Table 3. Switches designed and built in accordance with this standard are not intended for use as fault current or non-capacitive load current interrupting devices.

NOTE—This standard is intended to be a comprehensive standard for all "specific duty" applications of switches in the area of switching shunt capacitor banks, but it is limited in scope up to and including 38 kV. However, subject to agreement between the user and manufacturer, it may be used as a specification guide for other rated voltages.[1]

2. Normative references

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

ANSI C63.2-1996, American National Standard for Electromagnetic Noise and Field Strength Instrumentation, 10 kHz to 40 GHz—Specifications.[2]

IEC 60694-2002, Common Specifications for High-Voltage Switchgear and Controlgear Standards.[3]

IEEE Std 4™-1995, IEEE Standard Techniques for High-Voltage Testing.[4, 5]

[1] Notes in text, tables, and figures of a standard are given for information only, and do not contain requirements needed to implement the standard.
[2] This standard is 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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IEEE Std 1247™-1998, IEEE Standard for Interrupter Switches for Alternating Current Rated Above 1000 Volts.

IEEE Std C37.100™-1992 (Reaff 2001), IEEE Standard Definitions for Power Switchgear.

NEMA 107-1987 (Reaff 1993), Methods of Measurement of Radio Influence Voltage (RIV) of High-Voltage Apparatus.[6]

3. Definitions

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

The definitions of terms contained in this standard, or in other standards referred to in this document, are not intended to embrace all legitimate meanings of the terms. They are applicable only to the subject treated in this standard. For additional definitions, see IEEE Std C37.100-1992.[7]

An asterisk (*) indicates that, at the time this standard was approved, there was no corresponding definition in IEEE Std C37.100-1992. A dagger (†) indicates that the definition in this standard differs from that of IEEE Std C37.100-1992.

3.1 capacitive load: A lumped capacitance that is switched as a unit.

3.2 capacitor switch: A switch capable of making and breaking capacitive currents of capacitor banks.

3.3 operation: A closing followed by an opening.†

3.4 pole discrepancy: The time interval, in electrical degrees, between the first capacitor switch pole contact and the final capacitor switch pole contact to mechanically close or open when single-pole capacitor switches are configured as a three-phase system.*

3.5 rated capacitor switching current: The rms symmetrical value of the highest capacitive load current that a device is required to make and interrupt at a rated maximum voltage as part of its designated operation duty cycle.

NOTE—When applying a capacitor switch, the capacitive switching current rating should be at least 125% of the nominal capacitor bank current for ungrounded capacitor banks and at least 135% for grounded capacitor banks. The excess current can be caused by harmonics, overvoltage, and/or plus tolerance in the capacitance of the capacitor bank units. The current multipliers for grounded and ungrounded applications are different because the potential for harmonic current flow is higher in grounded banks when compared to the current flow in ungrounded banks.

3.6 rated high-frequency transient-making current: The peak value of the high-frequency current, with specified damping, against which a device is required to close and latch under specified conditions.

3.7 rated symmetrical-making current: The maximum peak current at rated power frequency, without dc component, against which a device is required to close and hold in the presence of two times the rated high-frequency transient-making current at a frequency equal to one-half of the rated transient inrush frequency.*

3.8 rated transient inrush frequency: The highest frequency of the transient inrush current of a designated operating duty.

[6] NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http://global.ihs.com/).
[7] For information on references, see Clause 2.

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3.9 recovery voltage: The voltage that occurs across the terminals of a pole of a circuit-interrupting device upon interruption of current.

3.10 restrike: A resumption of current between the contacts of a switching device during an opening operation after an interval of zero current of one-quarter cycle at normal power frequency or longer.

3.11 simultaneous operation: A capacitor switch is considered to have simultaneous closing or opening capability if its pole discrepancy is equal to or less than 90 electrical degrees.*

NOTE—Simultaneous operation can be achieved through electrical operation of three single-pole switches operating on a three-phase system or through mechanical joining of three single poles on a three-phase switch.

3.12 synchronous operation (opening or closing): Operation of a switching device in such a manner that the contacts are closed or opened at a predetermined point on a reference voltage or current wave.

3.13 transient overvoltage: The peak voltage condition resulting from the operation of a switching device that is measured at the source side terminals of the device and is expressed in per unit of the peak values of the operating line-to-ground voltage at the device with the load connected.†

4. Service conditions

4.1 Usual service conditions

Capacitor switches conforming to this standard shall be suitable for operation at their standard ratings provided that the following conditions are met:

a) The temperature of the air (ambient temperature) is not above 40 °C or below –30 °C.

b) The altitude does not exceed 1000 m.

4.2 Unusual service conditions

Unusual service conditions shall include, but are not limited to, service conditions that exceed those defined in 4.1 or extremes in the following:

a) Duty cycle

b) System conditions

c) Site conditions

d) Shock and/or vibration

e) Damaging fumes or vapors

f) Excessive or abrasive dust

g) Explosive mixtures of dust or gases

h) Salt air and/or extreme humidity

Unusual service conditions should be brought to the attention of those responsible for the manufacture of the equipment to define or prevent loss of performance or service life, if any, from specified values. Applicable standards such as those for altitude correction should be used when available.

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4.2.1 Abnormal ambient temperature

Capacitor switches may be applied at higher or lower ambient temperatures than specified in 4.1, but performance may be affected and special consideration shall be given to these applications.

4.2.2 Altitudes above 1000 m

Capacitor switches may be applied at altitudes higher than 1000 m; however, the rated lightning impulse withstand voltage, rated maximum voltage, and rated capacitive current shall be multiplied individually by a correction factor.[8] Users should consult the manufacturer for appropriate de-rating when the equipment is applied above 1000 m. Annex D can also be referred to for comments on altitude correction factors.

5. Ratings

5.1 General

When the interrupting medium is vacuum, the capacitor switch shall withstand the rated impulse voltage in the closed position.

However, the unique characteristics of an open vacuum interrupter or vacuum gap make it permissible to have random sparkovers of the open vacuum interrupter as much as 25% below the rated terminal-to-terminal lightning impulse withstand voltage of the capacitor switch. If such an impulse surge sparks over the open interrupter contacts, the impulse current will pass through the open contacts without damage to the interrupter unit. An impulse sparkover of the open vacuum contacts may be followed by a flow of power current that will be interrupted without damage to the capacitor switches.

Switches with interrupter mediums other than vacuum shall be rated as given in Column 5 of Table 1 for both the line-to-ground and open gap conditions.

Table 1—Preferred voltage ratings and related test requirements for capacitor switches

Line number	Rated maximum rms voltage (kV)	Power-frequency insulation level withstand tests (kV rms)		Rated lightning impulse withstand peak voltage line-to-ground (kV)	Lightning impulse withstand peak voltage terminal-to-terminal (open gap) (kV) (vacuum only[a])
		1 min dry	10 s wet		
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6
1	15.0	36	30	95	95
2	15.5	36	30	95	95
3	15.5	50	45	110	95
4	15.5	50	45	110	110
5	27	60	50	125	95
6	27	60	50	125	125
7	27	60	50	150	125
8	38	70	60	150	125
9	38	70	60	150	150
10	38	70	60	200	150
11	38	70	60	200	200

[a] It is permissible to have a lower lightning impulse withstand rating across the open gap of a vacuum interrupter since the switch is not intended to be applied as an isolation device, and a flashover across the open gap is not detrimental to the performance and power-frequency withstand capability of the vacuum interrupter device.

[8] Altitude correction factors are being studied by the Switchgear Committee and will be adopted by issuance of a supplement or revision to this standard when they are approved.

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5.2 Rating information

The rating shall include the following items:

a) Rated maximum voltage
b) Rated power frequency
c) Rated peak fault-making current
d) Rated symmetrical fault-making current
e) Rated capacitive switching current
f) Rated peak withstand current
g) Rated short-time withstand (symmetrical) current
h) Rated high-frequency transient-making current
i) Rated transient inrush frequency
j) Rated lightning impulse withstand voltage
k) Rated control voltage
l) Probability of restrike classification

5.3 Rated maximum voltage

The preferred values for maximum rated voltage of capacitor switches are shown in Column 2 of Table 1.

5.4 Rated power frequency

The rated frequency of capacitor switches is 50 Hz or 60 Hz.

5.5 Rated peak fault-making current

The preferred values for the rated peak fault-making current (asymmetrical), expressed in peak amperes, are shown in Column 4 of Table 2 and Table 3 and are defined as a multiple of the symmetrical fault-making current shown in Column 5 of the tables. For switches rated according to Table 2, the multiplication factors are 2.45 for 50 Hz and 2.50 for 60 Hz. For switches rated according to Table 3, the multiplication factors are 2.55 for 50 Hz and 2.59 for 60 Hz.

5.6 Rated symmetrical fault-making current

The preferred values for the rated symmetrical fault-making current of capacitor switches are shown in Column 5 of Table 2 and Table 3.

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Table 2—Preferred ratings for capacitor switches applied on systems with a circuit time constant less than 32 ms[a]

Line number[b]	Rated maximum voltage (kV)	Power-frequency current ratings				High-frequency inrush current ratings		
		Capacitive switching current (A)	Fault-making[c] peak current (A)	Symmetrical fault-making current (A)	Withstand[d] peak current (A)	Short-time symmetrical withstand current (A)	High-frequency transient-making peak current (A)	Rated transient inrush frequency (Hz)
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
1	15	200	9 000	6 000	9 000	4 500	6 000	6 000
2	15.5	200	15 000	6 000	15 000	4 500	9 000	6 000
3	27	200	9 000	6 000	9 000	4 500	6 000	6 000
4	27	200	15 000	6 000	15 000	4 500	9 000	6 000
5	38	200	9 000	6 000	9 000	4 500	6 000	6 000
6	38	200	15 000	6 000	15 000	4 500	9 000	6 000

[a] The preferred ratings of capacitor switches are intended for application of pole-mounted capacitor banks on a feeder circuit outside the substation where the circuit *X/R* ratio is reduced by the line impedance. The time constant of 32 ms equates to an *X/R* ratio of 12.0 at 60 Hz and 10.0 at 50 Hz. Refer to Annex A for additional background information on *X/R* ratio, circuit time constant definition, and related issues. The ratings shown represent 60 Hz values.
[b] Line numbers 1, 3, and 5 in Column 1 represent acceptable legacy values for capacitor switches that have been successfully applied in capacitor switching applications in the past and will continue to be applied in the future.
[c] The peak fault-making current is a related required capability of the symmetrical fault-making current rating as defined in 5.5.
[d] The peak withstand current ratings are based on 60 Hz. Lower ratings apply for switches rated at 50 Hz as defined in 5.8.

Table 3—Preferred ratings for capacitor switches applied on systems with a circuit time constant less than 45 ms[a]

Line number	Rated maximum voltage (kV)	Power-frequency current ratings				High-frequency inrush current ratings		
		Capacitive switching current (A)	Fault-making[b] peak current (A)	Symmetrical fault-making current (A)	Withstand[c] peak current (A)	Short-time symmetrical withstand current (A)	High-frequency transient-making peak current (A)	Rated transient inrush frequency (Hz)
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
1	15.5	200	26 000	10 000	26 000	5 000	10 000	6 000
2	15.5	200	32 500	12 500	32 500	6 250	12 000	6 000
3	15.5	400	26 000	10 000	26 000	5 000	10 000	6 000
4	15.5	400	32 500	12 500	32 500	6 250	20 000	4 000
5	15.5	600	26 000	10 000	26 000	5 000	10 000	6 000
6	15.5	600	26 000	10 000	26 000	5 000	12 000	6 000
7	15.5	600	32 500	12 500	32 500	6 250	24 000	3 400
8	27	200	32 500	12 500	32 500	6 250	8 000	6 000
9	27	400	32 500	12 500	32 500	6 250	10 000	6 000
10	27	600	32 500	12 500	32 500	6 250	10 000	6 000
11	27	600	32 500	12 500	32 500	6 250	12 000	6 000
12	38	200	32 500	12 500	32 500	6 250	8 000	6 000
13	38	300	32 500	12 500	32 500	6 250	8 000	6 000
14	38	400	32 500	12 500	32 500	6 250	10 000	6 000
15	38	600	32 500	12 500	32 500	6 250	10 000	6 000
16	38	600	32 500	12 500	32 500	6 250	12 000	6 000

[a] The preferred ratings of capacitor switches are intended for application on a feeder circuit in or close to the substation where the *X/R* ratio is higher. The time constant of 45 ms equates to an *X/R* ratio of 17.0 at 60 Hz and 14.1 at 50 Hz. Refer to Annex A for additional background information on *X/R* ratio, circuit time constant definition, and related issues. The ratings shown represent 60 Hz values.
[b] The peak fault-making current is a related required capability of the symmetrical fault-making current rating as defined in 5.5.
[c] The peak withstand current ratings are based on 60Hz. Lower ratings apply for switches rated at 50 Hz as defined in 5.8.

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5.7 Rated capacitive switching current

The preferred values for the rated capacitive switching current of capacitor switches are shown in Column 3 of Table 2 and Table 3.

5.7.1 Conditions of continuous capacitive current rating

a) Capacitor switches are used under the usual service conditions defined in 4.1.

b) Current ratings shall be based on the total temperature limits of the materials used for such parts. A temperature rise reference is given to permit testing at reduced ambient.

c) Capacitor switches installed in open-air racks shall have their ratings based on a 40 °C ambient temperature. Capacitor switches installed in enclosures shall have their ratings based on the ventilation of such enclosures and a 40 °C ambient temperature outside the enclosure.

5.7.2 Limits of observable temperature rise

At rated current, the observable hottest-spot temperature rise above ambient and the temperature of each of the various parts shall not exceed those listed in Table 4.

5.8 Rated peak withstand current

The preferred values for the rated peak withstand current at 60 Hz of capacitor switches are shown in Column 6 of Table 2 and Table 3. The preferred values for the rated peak withstand current, expressed in peak amperes, are defined as a multiple of the symmetrical fault-making current shown in Column 5 of Table 2 and Table 3. Lower values than the ones shown in Column 6 of Table 2 and Table 3 are acceptable for 50 Hz applications. For switches rated according to Table 2, the multiplication factor of the symmetrical current is 2.45 for 50 Hz. For switches rated according to Table 3, the multiplication factor is 2.55 for 50 Hz.

5.9 Rated short-time (symmetrical) withstand current and duration

The preferred values for the rated short-time (symmetrical) withstand current of capacitor switches are shown in Column 7 of Table 2 and Table 3. The rated short-time withstand current duration is 1 s.

5.10 Rated high-frequency transient-making current

The preferred values for the rated high-frequency transient-making current of capacitor switches are shown in Column 8 of Table 2 and Table 3.

5.11 Rated transient inrush frequency

The preferred values for the rated transient inrush frequency of capacitor switches are shown in Column 9 of Table 2 and Table 3.

The rated transient inrush frequency is the highest frequency the switch shall be required to close at 100% rated high-frequency transient-making current shown in Column 8 of Table 2 and Table 3. For application at less than 100% of rated high-frequency transient-making current, the product of the actual high-frequency transient-making current and the actual transient inrush frequency shall not exceed the product of the rated high-frequency transient-making current and the rated transient inrush frequency. Refer to Annex B for additional details and application examples.

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5.12 Rated lightning impulse withstand voltage

The preferred values for the rated lightning impulse withstand voltage of capacitor switches shall be the values given in Column 5 and Column 6 of Table 1 for both positive and negative test polarities. For wave shape, refer to 6.2.5.1.

Table 4—Limits of temperature and temperature rise for various parts and materials of capacitor switches

Nature of the part and material[a, b, c]		Total temperature (°C)	Temperature rise at ambient (40 °C)
1. Material used as insulation and metal parts in contact with insulation of these classes[d]	O	90	50
	A	105	65
	B	130	90
	F	155	115
	H	180	140
	C	220	180
	Oil[e]	90	50
2. Contacts[f]	Bare copper and bare-copper alloy		
	—in air	75	35
	—in SF_6 (sulfurhexaflouride)	105	65
	—in oil	80	40
	Silver-coated or nickel-coated[g]		
	—in air	105	65
	—in SF_6	105	65
	—in oil	90	50
	Tin-coated[g]		
	—in air	105	65
	—in SF_6	105	65
	—In oil	90	50
3. Connections, bolted or the equivalent[h]	Bare copper, bare-copper alloy, bare aluminum, or bare-aluminum alloy		
	—in air	90	50
	—in SF_6	115	75
	—in oil	100	60
	Silver-coated or nickel-coated		
	—in air	115	75
	—in SF_6	115	75
	—in oil	100	60
	Tin-coated		
	—in air	105	65
	—in SF_6	105	65
	—in oil	100	60
4. All other contacts or connections made of bare metals or coated with other materials		(See Footnote i)	(See Footnote i)
5. Terminals for the connection to external conductors by screws or bolts[j]	Bare copper and bare-copper alloy	90	50
	Silver-coated, nickel-coated, tin-coated	105	65
	Other coatings	(See Footnote i)	(See Footnote i)
6. Metal parts acting as springs		(See Footnote k)	(See Footnote k)

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Footnotes to Table 4

[a] According to its function, the same part may belong to several categories as listed in this table. In this case, the permissible maximum values of total temperature and temperature rise to be considered are the lowest among the relevant categories.
[b] For sealed interrupters (such as vacuum), the values of total temperature and temperature-rise limits are not applicable for parts inside the sealed interrupter. The remaining parts shall not exceed the values of temperature and temperature rise given in this table.
[c] The temperatures of conductors between contacts and connections are not covered in this table, as long as the temperature at the point of contact between conductors and insulation does not exceed the limits established for the insulating material.
[d] The classes of insulating materials are those given in IEC 60694-2002.
[e] The top oil (upper layer) temperature shall not exceed 40 °C rise or 80 °C total. The 50 °C and 90 °C values refer to the hottest-spot temperature of parts in contact with oil.
[f] When contact parts have different coatings, the permissible temperatures and temperature rises shall be those of the part having the lower value permitted in this table.
[g] The quality of the coated contacts shall be such that a layer of coating material remains at the contact area as follows: 1) After making and breaking tests (if any); 2) After short-time withstand current tests; 3) After the mechanical endurance test; and 4) According to the relevant specifications for each piece of equipment. Otherwise, the contacts shall be regarded as "bare."
[h] When connection parts have different coatings, the permissible temperatures and temperature rises shall be those of the part having the lower value permitted in this table.
[i] When materials other than those given in this table are used, their properties shall be considered in order to determine the maximum permissible temperature rises.
[j] The values of temperature and temperature rise are valid even if the conductor to the terminals is bare.
[k] The temperature shall not reach a value where the temper of the material is impaired.

5.13 Rated control voltages and ranges

When measured at the control power terminals of the operating mechanisms with the maximum operating current flowing, nominal voltages and their permissible ranges for the control power supply of switching and interrupting devices shall be as shown in Table 5.

Table 5—Rated control voltage and ranges

Nominal voltage rating (V)	Voltage range (V)
Col. 1	**Col. 2**
Direct current	
24	20–28
48	36–56
125	90–140
250	180–280
Alternating current	
120	104–127
240	208–254

6. Design tests

6.1 General

Capacitor switches shall be capable of meeting the design tests described in 6.2 through 6.10, inclusively. Once made, the design tests need not be repeated unless the design is changed so as to modify the performance characteristics of the switch.

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6.1.1 Condition of switch to be tested

The switch shall be new and in good condition, and tests shall be applied before the switch is put into commercial service, unless otherwise specified.

6.1.2 Mounting of specimen

The switch shall be mounted on its hanger or mounting means in a manner closely approximating the normal service conditions for which it is designed.

6.1.3 Grounding of specimen

The housing or hanger, or both, and all groundable parts shall be grounded by a lead or leads attached to the appropriate ground terminal points in a manner not to decrease the withstand voltage.

6.1.4 Power frequency

The frequency of the power supply voltage shall be the rated power frequency ±2%. A sine wave of acceptable commercial standards shall be applied. Such a wave shape is defined in 6.1.1 of IEEE Std 4-1995.

The following test guidelines apply for rated power frequency:

a) Tests at 60 Hz may be considered to prove the breaking characteristics at 50 Hz.

b) Tests at 50 Hz may be considered to prove the characteristics at 60 Hz when the specified voltage across the switch is not less during the first 8.3 ms than it would be during a test at 60 Hz and the making current is not less than that required for the 60 Hz test. This means that $V_{50\ Hz}/V_{60\ Hz} = 1.3$. If a restrike occurs after 8.3 ms, due to a higher instantaneous voltage than it would be during a 60 Hz test at the specified voltage, the test duty should be repeated at 60 Hz.

6.2 Insulation (dielectric) tests

Capacitor switches shall be capable of withstanding, without damage, the following test voltages when tested in accordance with 6.1 and as outlined in 6.2.1 through 6.2.5.

6.2.1 Electrical connections

Electrical connections shall be made by means of bare wire inserted in or appropriately bolted to each terminal depending on the terminal interface design. These wires shall project in such a manner as not to decrease the withstand value. Any necessary bends may be made at the terminal.

6.2.2 Points of application of test voltage

Test 1, Test 2, Test 3, and Test 4 shall be made on multi-pole switches. Test 1 and Test 2 shall be made on single-pole switches.

a) *Test 1:* With the capacitor switch closed and with tanks or groundable parts grounded, the test voltage shall be applied to all of the terminals on one side of the switch.

b) *Test 2:* With the capacitor switch open, the test voltage shall be applied simultaneously to the terminals on one side of the switch. The other terminals, tanks, or groundable parts shall be grounded. Then, reverse the terminal connections and repeat the procedure.

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c) *Test 3:* With the capacitor switch closed, the test voltage shall be applied to the middle phase of the switch. The terminals of the other phases and all tanks or groundable parts, or both, shall be grounded.

d) *Test 4:* With the capacitor switch open, the test voltage shall be applied to one of the terminals of the middle phase of the switch. The terminals of the other phases, the opposite terminal of the middle phase and all tanks or groundable parts, or both, shall be grounded. Then, reverse the middle phase terminal connections and repeat the procedure.

6.2.3 Temperature

Dielectric tests shall be made at the temperature attained under the conditions of commercial testing.

6.2.4 Dielectric test procedures and voltage measurements

The dielectric test procedures and the methods of voltage measurement shall be in accordance with IEEE Std 4-1995.

6.2.5 Withstand test voltages

6.2.5.1 Lightning impulse withstand test voltage

Lightning impulse withstand test voltage shall be a 1.2 × 50 μs voltage impulse in accordance with IEEE Std 4-1995. The peak value shall be as given in Column 5 and Column 6 of Table 1. At least three positive and three negative impulses shall be applied to the test specimen. If flashover occurs on only one test during any group of three consecutive tests, nine more tests shall be made. If the capacitor switch successfully withstands all nine of the second group of tests, the flashover in the first group shall be considered a random flashover and the capacitor switch shall be considered as having successfully passed the test. If an additional flashover occurs, the capacitor switch shall be considered to have failed.

The following tolerances shall apply during these tests, unless otherwise specified:

a) *Design Tests:* Capacitor switches shall pass a full-wave voltage impulse with the following:

   1) A virtual front time based on the rated full-wave impulse voltage, equal to or less than 1.2 μs.

   2) A peak voltage equal to or exceeding the value given in Column 5 and Column 6 of Table 1.

   3) A time to the 50% value of the peak voltage equal to or greater than 50 μs.

b) *Conformance Tests:* When lightning impulse withstand voltage tests are required for conformance tests, capacitor switches shall be capable of passing a full-wave impulse voltage test series with values and procedures as agreed to by the purchaser and the manufacturer subject to the following:

   1) Test procedures shall be in accordance with IEEE Std 4-1995.

   2) The switch shall not be expected to withstand a peak voltage that exceeds its rating.

   3) If, in the course of performing the conformance tests an individual, successful withstand test is performed that meets or exceeds the requirements of item a) of 6.2.5.1, it shall be counted as a withstand. However, an unsuccessful withstand under the same conditions shall not be counted as a failure.

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When the interrupting medium is vacuum, there is a possibility that an open vacuum interrupter or vacuum gap will have random sparkover of the open vacuum interrupter as much as 25% below the rated impulse withstand voltage of the capacitor switch. Due to the unique characteristics of vacuum interrupters, the impulse current will pass through the open contacts without damage to the interrupter unit. An impulse sparkover of the open vacuum contacts may be followed by a flow of power current that will be interrupted without damage to the capacitor switch. If a sparkover occurs during the second group of tests as outlined previously, the capacitor switch can be tested up to five times at an impulse level and sequence defined by the capacitor switch manufacturer. At the completion of these test operations, the capacitor switch must successfully withstand nine tests at the peak values given in Column 5 and Column 6 of Table 1. If the capacitor switch successfully withstands all nine of the third group of tests, the capacitor switch shall be considered as having successfully passed the test. If an additional flashover occurs, the capacitor switch shall be considered to have failed.

6.2.5.2 Power-frequency withstand test voltage

Power-frequency withstand voltages shall be applied with a peak value equal to 1.414 times the rated power-frequency withstand dry and wet values given in Column 3 and Column 4 of Table 1, with a test duration of 60 s for the dry test and 10 s for the wet test. Wet tests shall be made in accordance with IEEE Std 4-1995. If bushing coordination gaps are used, they shall be retained in place during tests and shall withstand these test voltages.

6.3 Short-time current tests

6.3.1 General

Capacitor switches shall be subjected to a single symmetrical withstand test, as specified in 5.9 of this standard and 8.4 of IEEE Std 1247-1998, for the rated short-time current duration. The condition after test shall be as identified in 6.6 and not as outlined in 8.6 of IEEE Std 1247-1998. See Table 2 and Table 3 for preferred short-time current ratings. The requirement for a peak withstand current test is satisfied by the fault-making current test without any high-frequency inrush current, specified in 6.4.

6.3.2 Condition after test

After completion of the test, the capacitor switch shall meet the conditions outlined in 6.6.

6.4 Rated fault-making current tests

6.4.1 General

Two fault-making current tests are required. The first test is to demonstrate the peak (asymmetrical) fault-making current capability specified in 5.5. This rating simulates the capacitor switch closing in on a faulted capacitor bank with full asymmetry of the fault current and without any high-frequency inrush current. It is the case of a single bank or when another source side bank is offline. The second test is to demonstrate the symmetrical fault-making current capability specified in 5.6. This rating simulates the capacitor switch closing in on a faulted bank with a source side bank online feeding a transient inrush current at a transient inrush frequency. Refer to Annex A.

6.4.2 Operating performance

A capacitor switch shall be capable of closing and holding once against the fault-making currents specified in Table 2 and Table 3 without excessive damage as defined in 6.6 and in the case of oil-filled switches, without emitting flame or any quantity of oil.

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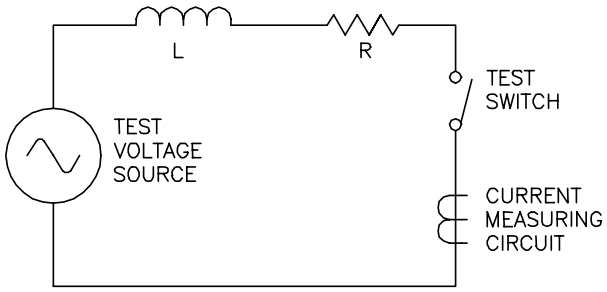
6.4.3 Test procedures

The rated fault-making current tests shall consist of closing the switch and holding once for a period of not less than ten cycles of power frequency (167 ms at 60 Hz) against the following rated peak making currents:

a) Rated peak fault-making current

b) Rated symmetrical fault-making current

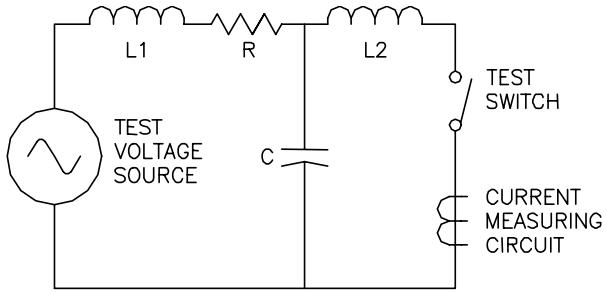
Maintenance and adjustment to the switch may be performed between the two tests. Refer to Figure 1 and Figure 2 for the test configurations.



NOTE 1—The test voltage equals the rated maximum voltage.

NOTE 2—Values of *L* and *R* are to be selected to produce the following: a) A symmetrical fault current equal to the rated symmetrical fault-making current (see Column 5 of Table 2 and Table 3) and b) At maximum asymmetry, a peak current equal to the rated peak fault-making current (see Column 4 of Table 2 and Table 3).

Figure 1—Suggested test circuit for rated making duty test (rated fault-making current test)



NOTE 1—The test voltage equals the rated maximum voltage.

NOTE 2—Values of *L*1 and *R* are the same as those used for the rated peak fault-making test.

NOTE 3—Values of *C* and *L*2 are selected to produce, upon closing the test switch, a peak discharge current equal to the inrush-making current rating (see Column 8 of Table 2 and Table 3) at a frequency equal to transient inrush frequency (see Column 9 of Table 2 and Table 3).

Figure 2—Suggested test circuit for rated making duty test (rated back-to-back fault-making current test)

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6.4.4 Condition after test

After each of these tests, the capacitor switch shall meet the conditions outlined in 6.6.

6.5 Operating duty tests

Capacitor switches shall be capable of meeting the operating duty test specified in 6.5.3.

6.5.1 Test voltages

Test voltages shall be defined for simultaneous and non-simultaneous capacitor switching systems. Refer to Clause 3 for the definition of simultaneous operation.

6.5.1.1 Simultaneous opening

A test voltage of 0.87 times the rated maximum voltage shall be used when tests are made on a single-phase switch or on a single phase of a three-phase switch when simultaneous opening of all three phases, within 90 electrical degrees, will occur. Refer to Clause 3 for the definition of simultaneous operation.

6.5.1.2 Non-simultaneous opening

A test voltage of 1.2 times the rated maximum voltage shall be used when tests are made on a single-phase switch or on a single-phase switch configured as a three-phase switch when simultaneous opening of all three phases, within 90 electrical degrees, is not assured. Refer to Annex C for additional details and explanations of ungrounded versus grounded capacitor bank configurations.

6.5.2 Inrush current

During the operations at 100% of rated switching current

a) The test circuit for non-simultaneous opening switches shall be capable of producing a high-frequency inrush current with 1.2 times rated maximum voltage at the capacitor. The high-frequency inrush current shall be equal in magnitude to the rated high-frequency transient-making current at a frequency equal to the rated transient inrush frequency, with a tolerance of ±10% for both the frequency and making current. The negative frequency tolerance is permitted only if required due to laboratory limitations.

b) The test circuit for simultaneous opening switches or single-phase switches used in solidly grounded capacitor bank applications shall be capable of producing a high-frequency inrush current, with 0.87 times rated maximum voltage at the capacitor. The high-frequency inrush current shall be equal in magnitude to the rated high-frequency transient-making current at a frequency equal to the rated transient inrush frequency with a tolerance of ±10%. The negative frequency tolerance is permitted only if required due to laboratory limitations.

c) The damping of the high-frequency current shall be such that the ratio of two successive current peaks, one transient cycle apart, shall be between 0.40 and 0.55 without arc voltage and without such damping resistors as are part of the switch.

For operations at 45% to 55% and 15% to 20% of rated switching currents, the parameters on the source side of the switch under test in the test circuit shall remain the same while the capacitance of the load being switched will be reduced to obtain the required switching current.

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6.5.3 Test requirements

6.5.3.1 Test operations

The operating duty test shall consist of 1200 operations, without adjustment or maintenance of the switch, of a capacitive switching current, which is as follows:

a) 100% of the rated switching current during the first 400 operations

b) 45% to 55% of the rated switching current during the second 400 operations

c) 15% to 20% of the rated switching current during the last 400 operations

6.5.3.2 Test requirements

The following are general requirements for all tests:

a) All 1200 operations shall be at random with respect to the point on the voltage wave at which closing or opening occurs. The manner in which the operations are representative of various voltage points on the waveform is dependent upon the design and characteristics of the switch under test and shall be at the discretion of the test laboratory and the manufacturer. It is the intention of this standard that the capacitor switch demonstrate the capability of closing with the maximum rated inrush current and opening at all points on the voltage wave during the 1200 operations. This requirement will be satisfied when all three of the following minimum results are achieved during the course of the first test of 400 operations at 100% of the rated switching current, as specified in item a) of 6.5.3.1:

   1) The maximum rated inrush current occurs in four of the closing operations for each polarity of the current wave.

   2) Four open operations occur when the switch contact separates within each 30 (±5) electrical degree segment of the voltage waveform

   3) The timing of the switch contact separation during open operations is truly random with respect to the voltage waveform.

b) The power-frequency short-circuit current of the test circuit, with rated maximum voltage at the capacitors, shall be at least equal to the rated peak withstand current.

c) The duration of time between testing intervals shall be based on an agreement between the laboratory and the manufacturer.

d) The switch shall be able to perform its designated operating duty test with the control voltage at both the maximum voltage and the minimum voltage of the rated control voltage range. This requirement shall be met by performing at least five operations at both the maximum and the minimum voltages given in Table 5.

e) The voltage must be maintained for a minimum of 0.3 s and shall be at least 90% of the voltages in 6.5.1 after 0.3 s.

f) The maximum transient overvoltage produced during the operating duty tests shall not exceed 2.5 times the peak line-to-ground voltage.

6.5.3.3 Probability of restrike classification

Based on the results of 1200 test operations performed in 6.5.3.1, capacitor switches will be classified with one of the following class designations, which will represent the probability of restrike for the switch:

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a) *Class C2*: A Class C2 switch will have a 0.2% probability of restrike in the 1200 test operations. This equates to a maximum of 2 operations with restrikes in 1200 consecutive operations. A switch with this classification is considered to have a "very low" probability of restrike.

b) *Class C1*: A Class C1 switch will have a 2.0% probability of restrike in the 1200 test operations. This equates to a maximum of 24 operations with restrikes in 1200 consecutive operations. A switch with this classification is considered to have a "low" probability of restrike.

c) *Class C0:* A Class C0 switch will have a probability of restrike greater than 2.0% in the 1200 test operations. This equates to 25 or more operations with restrikes in 1200 consecutive operations. A switch with this classification is considered to have a "moderate to high" probability of restrike.

NOTE—The probability of restrike classifications of C2, C1, and C0 presented in 6.5.3.3 are consistent in terminology with other standards that contain restrike classifications. It should be noted that the specific criteria for meeting these common classifications may vary slightly between the different standards.

6.5.3.4 Condition after test

After completion of the test, the capacitor switch shall meet the conditions outlined in 6.6.

6.5.3.5 Interpretation of test

The above test is intended to indicate the capabilities of the switch over the full range of typical loads. It does not imply, however, that the switch can successfully switch any one load up to and including its rated switching current through 1200 operations. Also, it is not inferred that the switch can meet its maximum making duty without inspection and maintenance.

6.6 Condition of capacitor switch after short-time current tests, rated fault-making current tests, and operating duty tests (see 6.3, 6.4, and 6.5)

During each of the tests, the capacitor switch shall have functioned without failure and without maintenance or replacement of parts.

After performing each of the tests, the capacitor switch shall be in the following condition:

a) *Mechanical:* The capacitor switch shall be substantially in the same mechanical condition as at the beginning and the capacitor switch shall be capable of automatic and manual operation. The arcing contacts or any other specified renewable parts may be worn. The quality of the oil, used for arc extinction in oil capacitor switches, may be impaired and its quantity reduced from the normal level. There may be deposits on the insulators caused by the decomposition of the arc-extinguishing medium.

b) *Electrical:* The capacitor switch shall be capable of withstanding 80% of the dry power-frequency insulation withstand test level for 1 min, and shall be capable of carrying rated continuous current, but not necessarily without exceeding rated temperature rise. Resistance measurements taken before and after the operating duty test shall be used to establish the ability to carry the rated continuous current.

A contact resistance check shall be made to determine the capacitor switch's current-carrying ability, with a current of at least 100 A (dc). The value of the contact resistance shall be less than 200% of that before the test sequence. If the resistance has increased more than 200%, a heat run must be performed at rated continuous current with thermocouples placed as close as practical to the main contacts, to insure the capacitor switch will not experience thermal runaway.

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6.7 Temperature rise tests

Capacitor switches shall meet the conditions of capacitive switching current rating and limits of observable temperature rise as specified in 5.7.1 and 5.7.2, respectively, when tested as specified in 6.1 and 6.7.1 through 6.7.3.

6.7.1 Test conditions

The device shall be mounted in an environment with a stable ambient temperature, and be substantially free from air currents other than those generated by heat from the device being tested. The air velocity at the start of the test shall not be above 0.5 m/s.

6.7.2 Electrical connections

The capacitor switch shall have a conductor connected to each terminal, having a minimum length of 1.2 m. For capacitor switches with terminals designed for connection to bare-copper conductors, use Table 6. For aluminum cables, use Table 7. The connection shall be made to the ends of these conductors.

Table 6—Size of copper cable leads

Rated continuous rms current (A)	Maximum size of leads		
	Area (mm^2)	AWG	MCM
200	33.6	2	66.4
300	67.4	2/0	133.1
400	107.2	4/0	211.6
600	177.3	—	350

Table 7—Size of aluminum cable leads

Rated continuous rms current (A)	Maximum size of leads		
	Area (mm^2)	AWG	MCM
200	67.4	2/0	133.1
300	135.2	—	266.8
400	170.5	—	336.4
600	282.0	—	556.5

6.7.3 Test procedure

Rated continuous current of a capacitor switch at rated frequency shall be applied continuously until the temperature becomes constant. The temperature shall be considered constant when three consecutive values of temperature rise taken at half-hour intervals at all points where readings are being taken shows a maximum variation of 1 °C. If the temperature rise after the second interval is equal to the limit of observable temperature rise (5.7.2) and if the temperature rise has increased since the last reading, the tests shall be continued. All temperature determinations shall he made as indicated in 6.7.3.1 through 6.7.3.3.

6.7.3.1 Method of temperature determination

This method consists of the determination of the temperature by thermocouples applied to various parts of the apparatus.

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6.7.3.2 Value of ambient temperature during test

a) The ambient temperature shall be taken as that of surrounding air, which should not be less than 10 °C or more than 40 °C.

b) Corrections shall not be applied for any variation in ambient temperature with the range specified in item a), listed previously.

6.7.3.3 Determination of the ambient temperature

6.7.3.3.1 Placing of thermocouples

The ambient temperature shall be determined by taking the average of the readings of three thermocouples (thermometers) placed 30 cm to one side of the device and vertically located as follows:

a) One 30 cm above the device

b) One 30 cm below the device

c) One midway between item a) and item b)

6.7.3.3.2 Use of oil cup

In order to avoid errors due to the time lag between the temperature of apparatus and the variations in the ambient temperature, all reasonable precautions must be taken to reduce these variations and the errors that arise. Thus, when the ambient temperature is subject to such variations that error in taking the temperature rise might result, the thermocouple for determining the ambient temperature should be immersed in a suitable liquid (such as oil), in a suitable cup.

The smallest size of oil cup employed in any case shall consist of a metal cylinder 2.5 cm in diameter and 5 cm high, containing not less than 20 mL of the suitable liquid (such as oil).

6.8 Radio influence voltage tests

Capacitor switches shall meet the radio influence voltage (RIV) limits when tested in accordance with 6.1 and as indicated in 6.8.1 through 6.8.3.

6.8.1 Test voltages and limits

The test voltages shall be a minimum of 110% of the line-to-ground voltage corresponding to the rated maximum voltage of the capacitor switch. The limit of conducted radio influence in all cases shall be 500 μV at 1.0 MHz. Capacitor switches having two or more voltage ratings shall be tested on the basis of the highest voltage rating given on the nameplate.

6.8.2 Test conditions

6.8.2.1 Proximity of other apparatus

Any grounded or ungrounded object or structure (except mounting structure when required) shall not be nearer any part of the capacitor switch or its terminals undergoing test than three times the longest overall dimension of the test piece with a minimum allowable spacing of l m.

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Where space requirements under test conditions do not permit the above clearances to be maintained, the test shall be considered satisfactory if the limits of the RIV obtained are equal to or less than those specified in 6.8.1. In such cases a record should be made of the object structures, etc., and their distances from the capacitor switch under test; this data is to be kept for future use.

6.8.2.2 Capacitor switch insulating mediums

The tanks of capacitor switches with insulating mediums other than air shall be filled with the correct amount of medium and, in the case of gas, pressurized to the "nominal as shipped" pressure at 20 °C.

6.8.2.3 Electrical connections

Conductors of the largest size (bare wire) intended for use with the capacitor switch under test shall be connected to each terminal. The length of the conductors, when used, shall be equal to or greater than the longest overall dimension of the capacitor switch except that the length need not exceed 1.8 m. The free end of any such conductor shall terminate in a sphere having a diameter of twice the diameter of the conductor ±0% or shall be shielded in some other suitable manner to eliminate the effect of the end of the conductor as a source of RIV.

6.8.2.4 Atmospheric conditions

Tests shall be conducted under atmospheric conditions prevailing at the time and place of test, but it is recommended that tests be avoided when the vapor pressure is below 0.67 kPa or above 2.00 kPa.

Since the effects of humidity and air density upon RIV are not definitely known, no correction factors are recommended for either at the present time. However, it is recommended that barometric pressure and dry- and wet-bulb thermometer readings be recorded so that, if suitable correction factors should be determined, they could be applied to previous measurements.

6.8.3 Test equipment and procedure

The equipment and general method used in making RIV tests shall be in accordance with the recommendations of NEMA 107-1987 and ANSI C63.2-1996.

6.8.3.1 Procedure

Tests shall be made with the capacitor switch in the closed and open positions. When tests are made with the capacitor switch in the open position, the RIV shall be determined with the pole or group of poles not being connected to the measuring apparatus either grounded and ungrounded.

6.8.3.2 Tests on multi-pole devices

In the case of multi-pole capacitor switches, one pole or terminal or groups of the same may be tested at one time.

6.8.3.3 Tests on complete switch assembly

In the case of an assembled switch, the test shall be made without removing any component part, and the lowest rated voltage of any component part shall determine the test voltage. The limiting RIV shall be identical with the highest value fixed for any of the component parts that determine the test voltage.

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6.8.3.4 Precautions

The following precautions shall be observed when making radio influence tests:

a) The capacitor switch should be approximately the same temperature as the room in which the tests are conducted.

b) The capacitor switch should be dry and clean.

c) The capacitor switch should not have been subjected to dielectric tests within 2 h prior to the RIV tests.

d) In some cases it may be found that the RIV falls off after the 60 Hz voltage has been applied for a short time. In such cases, it may be desirable to pre-excite the capacitor switch at normal operating voltage for a period not exceeding 5 min before proceeding with the tests.

6.9 Mechanical life tests

Capacitor switches shall be capable of 10 000 operations when tested at no load without any required maintenance or adjustments, and shall be capable of successfully passing dielectric and contact resistance tests at the end of the mechanical life test. Refer to Clause 3 for the definition of operation.

6.10 Control wiring tests

Control wiring of capacitor switches shall be capable of withstanding a power-frequency 1 min dielectric test of 1500 V to ground.

7. Production tests

Production tests, made on every device, shall include the following:

a) The 1 min dry withstand power-frequency test (see 6.2.5)

b) Control wiring check tests

c) Manual operation, if applicable

d) Electrical operation

e) Dielectric tests on control wiring (see 6.10)

8. Construction requirements

8.1 Grounding provision

A capacitor switch having a metal housing shall have provision for the connection of a ground lead.

8.2 Manual operating provision

Distribution line capacitor switches may have provisions for manual tripping. Capacitor switches for substation applications should have provision for manual tripping and closing.

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8.3 Position indicator

A capacitor switch shall be provided with a position indicator that clearly indicates the closed or open position. Its position shall be visible while standing on the ground with the capacitor switch mounted 12 m above the ground.

8.4 Nameplate marking

The following minimum information should be given on a nameplate:

a) Manufacturer's name.

b) Manufacturer's type or identification number to indicate the design or construction. Changes in operating characteristic, design, or construction, which affect its application or service, shall be accompanied by a change in the identification data.

c) Rated maximum voltage.

d) Rated capacitive switching current.

e) Rated lightning impulse withstand voltage. The rated open gap rating shall be provided if different than the line-to-ground rating (see Table 1).

f) Rated control voltage.

g) Month and year of manufacture designation.

h) Serial number designation.

i) Rated short-time (symmetrical) current (see Column 7 of Table 2 and Table 3).

j) Rated high-frequency transient-making current (see Column 8 Table 2 and Table 3).

k) Probability of restrike classification (see 6.5.3.3).

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Annex A

(informative)

Fault handling ratings for capacitor switches

A.1 Introduction

The purpose of this annex is to provide the background and rationale for the development of Table 2 and Table 3 in this standard. Earlier revisions of IEEE Std C37.66 used the terms "line" and "station" to describe two general classifications of a distribution capacitor switch. The terms were subjective and often misunderstood, but were used to distinguish a *line* switch used out on the distribution feeder from a *station* switch located in or near the substation. The assumption being that the station switch would be exposed to, and therefore must be rated for, a higher prospective short-circuit current than a line switch located some distance from the substation.

A.2 Quantitative distinction

The current revision of this standard provides a quantitative distinction between the two classes of distribution capacitor switch based on the following:

a) The rated short-time withstand current that is a 1 s rating given in Column 7 of Table 2 and Table 3.

b) The system *X/R* ratio at the point of application of the switch.

Table 2 defines a line switch applied on the system where the inherent short-circuit capacity is equal to or less than the rated short-time withstand current given in Column 7 and the *X/R* ratio is 12.0 or less for 60 Hz systems and 10.0 or less for 50 Hz systems (time constant of approximately 32 ms for both 50 Hz and 60 Hz). This defines in quantitative terms what was subjectively referred to as a "line switch" in earlier revisions of this standard.

Similarly, Table 3 defines a line switch applied on the system where the inherent short-circuit capacity is equal to or less than the rated short-time withstand current given in Column 7, and the *X/R* ratio is 17.0 or less for 60 Hz systems and 14.1 or less for 50 Hz systems (time constant of approximately 45 ms for both 50 Hz and 60 Hz). In quantitative terms, this defines what was subjectively referred to as a "station switch" in earlier revisions of this standard.

NOTE—If a user's *X/R* ratio is greater than 17.0, the user may wish to install current limiting reactors on the station transformer secondary to reduce the switch duty requirements, or the user may request higher ratings from the capacitor switch suppliers than the preferred ratings identified in Table 2 and Table 3.

A.3 Time constant (τ_{cc}) and *X/R* ratio

An electrical circuit may be defined by its main series components that are the inductance (L or X) ($X = 2\pi fL$) and resistance. The circuit time constant is defined by the ratio L/R. The *X/R* ratio is frequency dependent (i.e., a time constant of 45 ms will lead to an *X/R* ratio of 17.0 at 60 Hz and 14.1 at 50 Hz).

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A.4 Related required capabilities

Given the definitions described in A.2, two related and required capabilities are automatically defined as multiples of the rated short-time withstand current. They are the peak fault-making current and the peak withstand current, both expressed in peak amperes. For switches rated according to Table 2, the multiplication factor is 2.50 for 60 Hz systems and 2.45 for 50 Hz systems. For switches rated according to Table 3, the factors are 2.59 for 60 Hz systems and 2.55 for 50 Hz systems.

NOTE—Refer to Annex A of IEEE Std C37.60™-2003[9] for information on *X/R* ratios and related peak factors.

[9] IEEE Std C37.60-2003, IEEE Standard Requirements for Overhead, Pad-Mounted, Dry Vault, and Submersible Automatic Circuit Reclosers and Fault Interrupters for Alternating Current Systems up to 38 kV.

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Annex B

(informative)

Consideration of inrush current in back-to-back capacitor switching

B.1 Introduction

The purpose of this annex is to provide guidelines to design for inrush currents associated with back-to-back capacitor switching. When switching "back-to-back" or parallel capacitor banks installed on the same bus or banks that can be paralleled by closing normally open switches or breakers, consideration must be given to the maximum inrush current that can occur.

CAUTION

It may be necessary to add inductance to the system to limit these currents to values that will not damage the capacitors and switches or have other detrimental effects. An uncharged capacitor bank offers practically zero impedance when initially energized, with a resultant passage of a large, high-frequency transient inrush current. When two or more capacitor banks are paralleled within close proximity to each other, the peak transient inrush current into the uncharged bank may exceed the normal peak steady-state capacitor current by several orders of magnitude. This high-frequency release of energy can cause damage to the switching device and capacitors if it is not limited.

The only significant impedance to limit inrush current is the inherent resistance and inductance of the conductors between banks. The values of resistance and inductance of the conductors may be too low to limit the inrush current to safe values. In these cases, the addition of a current limiting impedance is required. The use of reactors for this purpose has been found to be practical for typical capacitor banks used on power systems.

B.2 General application guidelines

There are three parameters related to the transient inrush current that are of interest in the application of capacitors and capacitor switches:

— High-frequency transient-making current expressed as a peak current

— Transient inrush current frequency

— Maximum rate-of-rise of current for the transient-making current expressed as the product of the high-frequency transient-making current and the transient inrush current frequency

For longest maintenance-free life of the capacitors and capacitor switches, peak inrush current should always be limited to values below the maximum rating of the switch. For some switch designs, the rate-of-rise of the transient current must be limited. The transient inrush current frequency by itself is not a concern, except as it determines the rate-of-rise of current.

In this standard, the values for the transient inrush current shown in Column 8 of Table 2 and Table 3 are generally limited to the lesser of the following: a) the peak fault-making current rating of the switch as shown in Column 4 of Table 2 and Table 3 or b) 12 kA. Switches applied according to Table 2 are typically installed out on the line where the use of a current limiting reactor is usually not necessary. Switches

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applied according to Table 3 are typically installed close to or within substations where the use of a current limiting reactor is usually required to limit the inrush current. In both Table 2 and Table 3, the transient inrush frequency is rated at a maximum of 6000 Hz.

As noted in 5.11, a capacitor switch applied at less than the rated high-frequency transient-making current may be applied at a transient inrush frequency higher than the rated value given in Column 9 of Table 2 and Table 3 provided that the rate-of-rise of current does not exceed the product of the rated transient inrush frequency shown in Column 9 of Table 2 and Table 3 and the rated high-frequency transient-making current shown in Column 8 of Table 2 and Table 3.

Example 1:

Consider a capacitor switch rated according to Line 1 of Table 3 but applied in a location where the maximum high-frequency transient-making current is limited to 8 000 A.

Rated transient inrush frequency	= 6 000 Hz
Rated high-frequency transient-making current	= 10 000 A
Maximum rate-of-rise of current	= 6 000 Hz • 10 000 A
	= 6.0×10^7 A/s
Permissible transient inrush frequency	= 6.0×10^7 A/s • (1/8 000 A)
	= 7 500 Hz

To achieve maximum switch life when applied with the repetitive nature of capacitor switching applications, the manufacturer should be contacted for suggested limits of peak inrush current. When designing capacitor bank installations, the user needs to review the impact of all existing banks that are connected on the same bus or electrically near any new proposed bank installations.

B.3 Inrush current and frequency formulas for switching capacitor banks

The following formulas from ANSI C37.012-1979[10] enable the user to determine the inductance needed to limit peak inrush currents to acceptable values. In calculating the required inductance, it is generally appropriate to include a value of 0.984 μH per meter of overhead bus or 0.295 μH per meter of cable for the electrical separation between the capacitor banks. The resistance per meter is assumed to be negligible. IEEE Std C37.99™-2000[11] can also be referenced for specific recommended values for different system voltages. After the necessary inductance is calculated, the inductance of the conductors between the banks is subtracted from the calculated total equivalent inductance L_{EQ} yielding the size of the required current limiting reactor. Note that if reactors are installed in both capacitor banks, the L_{EQ} equals the sum of both reactors.

[10] ANSI C37.012-1979, Application Guide for Capacitor Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.
[11] IEEE Std C37.99-2000, IEEE Guide for the Protection of Shunt Capacitor Banks.

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Energizing an isolated bank:

$$I_{\text{max peak}}\ (\text{amperes}) = 1.41 \bullet \sqrt{I_{SC} \bullet I_1}$$

$$f\ (\text{hertz}) = f_s \bullet \sqrt{I_{SC} / I_1}$$

Energizing a bank with another on the same bus:

$$I_{\text{max peak}}\ (\text{amperes}) = 1747 \bullet \sqrt{\frac{V_{LL}\,(I_1 \bullet I_2)}{L_{EQ}\,(I_1 + I_2)}}$$

$$f\ (\text{kilohertz}) = 9.5 \bullet \sqrt{\frac{f_s \bullet V_{LL}\,(I_1 + I_2)}{L_{EQ}\,(I_1 \bullet I_2)}}$$

B.4 Example equations

Example 2—two banks of equal value:

To facilitate calculations, the peak inrush current formula in *Example 2* is restated to solve for L_{EQ} based on some common maximum inrush current levels.

1) Switch no. 1 ($I_{\text{max peak}} = 6\,000$ A); $L_{EQ} = \dfrac{V_{LL} \bullet I_1}{23.6}$

2) Switch no. 2 ($I_{\text{max peak}} = 8\,000$ A); $L_{EQ} = \dfrac{V_{LL} \bullet I_1}{42}$

3) Switch no. 3 ($I_{\text{max peak}} = 10\,000$ A); $L_{EQ} = \dfrac{V_{LL} \bullet I_1}{66}$

Example 3—general case:

For energizing two or more capacitor banks

Solve:

1) $$Q_{EQ} = \frac{\left(\sum_{1}^{N} Q\right) Q_1^{\,2}}{\sum_{1}^{N} Q}$$

2) $$L_{EQ} = \frac{1767\,(10^6)\,Q_{EQ}}{I_{pk}^{\,2}}$$

3) $$L_1 = L_{EQ} - \frac{1}{\frac{1}{L_2} + \frac{1}{L_3} \ldots \frac{1}{L_N}}$$

Solved Examples: Equal inductance and bank size

Bank qty.	I_{pk} = 6 kA	I_{pk} = 8 kA	I_{pk} = 10 kA
2	$L_1 = 12.27(Q_1)$	$L_1 = 6.90(Q_1)$	$L_1 = 4.18\,(Q_1)$
3	$L_1 = 21.85(Q_1)$	$L_1 = 12.27(Q_1)$	$L_1 = 7.85\,(Q_1)$
4	$L_1 = 27.61(Q_1)$	$L_1 = 15.53(Q_1)$	$L_1 = 9.94\,(Q_1)$
5	$L_1 = 31.41(Q_1)$	$L_1 = 17.62(Q_1)$	$L_1 = 11.27\,(Q_1)$

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B.5 Formula definitions

V_{LL} Rated maximum system line-to-line voltage (kilovolts)

Q Rated reactive power (Mvar)

I_{SC} Symmetrical short-circuit rms current (amperes)

$I_{max\ peak}$ A peak value calculated without damping. In practical circuit it will be about 90% of this value (amperes)

f_s System frequency (hertz)

L_{EQ} Total equivalent inductance between the capacitor bank being switched and all other banks (microhenries)

Example 4—equal inductance per phase:

$L_{EQ} = (N /(N–1)) (L_1)$

$L_1 ... L_N$ Inductance per phase in bank 1 through bank N (microhenries)

I_1 and I_2 Currents of bank being switched and bank already energized, respectively. Capacitor bank being switched is assumed uncharged with closing taking place at a voltage crest of the source voltage. The current used should include the effect of operating the capacitor bank at a voltage above nominal rating of the capacitors and the effect of a positive tolerance of capacitance. In the absence of specific information, a multiplier of 1.15 times nominal capacitor current would give conservative results.

Table B.1—Typical reactor sizes

Maximum system voltage (kV)	Reactor inductance (μH/phase)	Continuous current per reactor (A)
15.5 (15.0)	15, 30, 40, 60, 80	400 or 600
27.0	30, 40, 60, 80	400 or 600
38.0	30, 40, 60, 80	300 or 400

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Annex C

(informative)

Simultaneous opening of single-phase capacitor switches on ungrounded wye capacitor installations

C.1 Introduction

The application of individual, single-phase (non-mechanically linked) capacitor switches on ungrounded wye capacitor installations is a special application consideration if the switch manufacturer claims simultaneous opening. (Refer to Clause 3 for a definition of simultaneous opening.) In this special case, this standard allows the manufacturer to conduct the operating duty test at a reduced voltage level of 87% of the rated maximum design voltage of the three-phase switch rating versus testing at 120% in the case of non-simultaneous opening. This difference in test voltage levels is allowed in recognition of the fact that the transient recovery voltage across the switch is limited to 3.0 per unit of the peak phase-to-ground voltage of the system versus a worse case value of 4.1 per unit in a non-simultaneous case.

The practice of conducting the operating duty test on a single pole of a three-phase, mechanically linked capacitor switch at 87% of the phase-to-phase voltage rating of the switch has been accepted under IEEE Std C37.09™-1999[12] for many years. This provision is in recognition of the fact that the individual pole opening times of a gang-operated three-phase device is determined by the mechanical linkage of the three phases where opening is presumed to be simultaneous.

C.2 Application considerations

In order to qualify a switch at this reduced test voltage for use on an ungrounded wye application, the manufacturer must provide evidence of consistent opening on all three phases within one-quarter cycle of each other under realistic field conditions. The user should be aware that mixing single-phase switches of different designs might result in a non-simultaneous operating condition, which would no longer be adequately rated for the particular installation if one of the switches were rated based on simultaneous opening conditions.

Users can avoid this potential application problem by enforcing a policy of always replacing a single phase of a three-phase installation with a switch of the same design.

Users should consult the individual switch manufacturers regarding the ability to mix switches of different designs. In general, mixing solenoid operators with motor operators, or mixing solenoid operators that have different operating times should be avoided unless each of the three switches is qualified at the same test level.

[12] IEEE Std C37.09-1999, IEEE Standard Test Procedures for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

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Annex D

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Altitude correction factors

D.1 Introduction

Altitude corrections factors have been removed from this standard due to the current controversy regarding their use, particularly in the range of sea level to 1000 m. Altitude correction factors are being studied by the Switchgear Committee and will be adopted by issuance of a supplement or revision to this standard when they are approved. At that time, this informative annex will be removed. The following information presents the altitude correction factor proposal from the initial draft of IEEE PC37.100.1™.[13, 14] The information is provided for reference only.

D.2 Altitude correction factors

Most switchgear are tested with reference to normal temperature and pressure at sea level (NTP) (20 °C). An added safety factor allows normal use at altitudes up to 1000 m. For installation of switchgear, *rated for up to 1000 m*, at altitudes above 1000 m, the insulation level of external insulation under the standardized reference atmospheric conditions shall be determined by multiplying the insulation withstand voltages by a factor K.

There is no requirement to confirm the test at the required altitude.

— The factor K for the required *increase* in insulation withstand rating for *equipment already rated for up to 1000 m* is $K = e^{(M(H-1000)/8150)}$.

— The factor K for the required *decrease* in insulation withstand rating for *equipment already rated for up to 1000 m* is $K = (1/K_{1000\ m})$ in accordance with Figure D.1 and Table D.2.

NOTE 1—Switchgear rated for up to 1000 m will also be capable of higher withstand voltage when used at less than 1000 m.

NOTE 2—For insulation not exposed to ambient atmospheric pressure, the dielectric characteristics are identical at any altitude and no special precautions need to be taken.

NOTE 3—For low-voltage auxiliary and control equipment, no special precautions need to be taken if the altitude is 2000 m or less. For higher altitude see IEEE Std C37.20.1™-2002.[15]

Figure D.1 is based on the following:

$M = 1$ for power-frequency, lighting impulse, and phase-to-phase switching impulse voltages
$M = 0.9$ for longitudinal switching impulse voltage
$M = 0.75$ for phase-to-ground switching impulse voltage

[13] IEEE PC37.100.1 (June 2000), Draft Standard of Common Requirements for High Voltage Power Switchgear Rated 1000 V and Above.
[14] This IEEE standards project was not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining a draft, contact the IEEE.
[15] IEEE Std C37.20.1-2002, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

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D.3 Examples for switchgear with 110 kV lightning impulse withstand rating *already rated for 1000 m*

Example 1:

The following example, Equation (D.1), is the required *increase* in voltage withstand for installation at 2000 m:

$$K_{1000\ \mathrm{m}} = e^{\,M(H-1000)/\,8150} \tag{D.1}$$

where
e = 2.7183
M = 1
H = 2000

$$K_{1000\ \mathrm{m}} = 2.7183^{\,\mathrm{M(H-1000\ m)/(8150\ m)}} = 1.131 \text{ correction factor} \tag{D.2}$$

1.131 × 110 kV = 124.4 kV, indicating 125 kV lightning impulse withstand rating should be chosen for the required 110 kV application equivalent at 2000 m.

Example 2:

The following example, Equation (D.3), is the *decrease* in voltage withstand when installed at 2000 m for equipment with a 110 kV lightning impulse withstand rating at 1000 m:

$$1/K_{1000\ \mathrm{m}} = 1/1.131 = 0.884 \text{ correction factor} \tag{D.3}$$

0.884 × 110 kV = 97.3 kV (an 11.6% reduction of safety factor).

D.4 Examples for switchgear ratings based on 110 kV lightning impulse withstand rating *referred to sea level NTP without adjustment for 1000 m*

Example 3:

The following example, Equation (D.4), is the required *increase* in voltage withstand for installations at 2000 m:

$$K_{\mathrm{NTP}} = e^{\,M(H)/\,8150}$$

$$K_{\mathrm{NTP}} = 2.7183^{\,1(2000)/\,8150} \tag{D.4}$$

K_{NTP} = 1.278 correction factor (required equivalent increase)

1.278 × 110 kV = 140.6 kV required equivalent for 2000 m when tested at sea level NTP without 1000 m safety factor.

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Example 4:

The following example, Equation (D.5), is the decrease in voltage withstand at 2000 m for 110 kV lightning impulse withstand rated equipment tested at sea level:

$1/K_{NTP} = 1/1.278 = 0.782$ correction factor (D.5)

0.782×110 kV = 86.1 kV (a reduction of 21.8% safety factor from sea level).

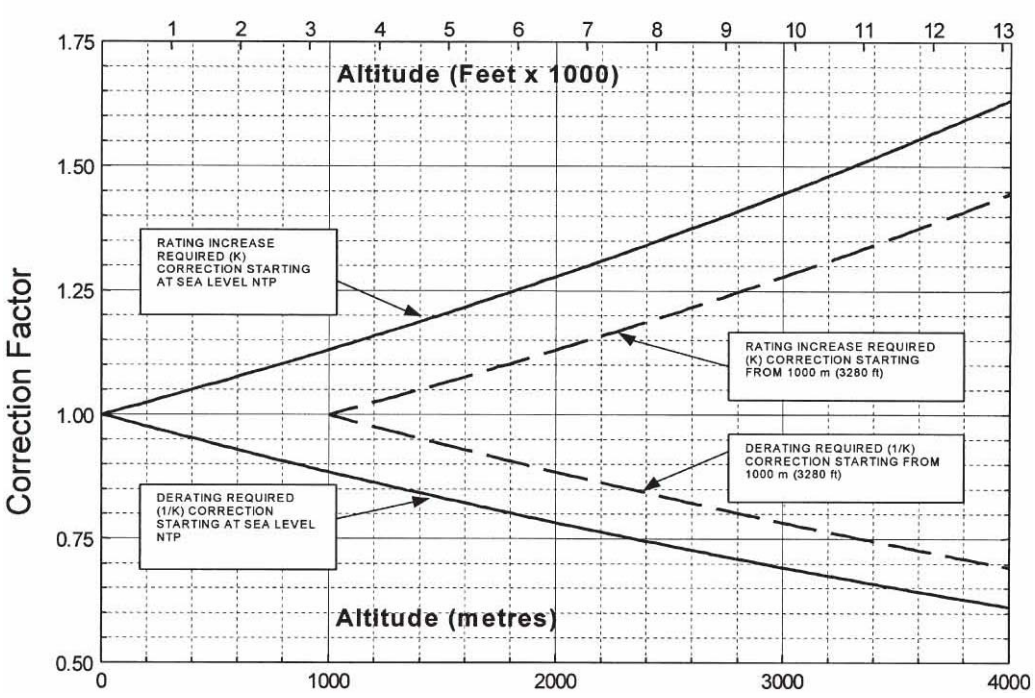

Figure D.1—Altitude correction factors

Table D.1—Correction factors

For correction factor starting at 1000 m	For correction factor starting at sea level
$k = e^{M(H-1000)/8150}$	$k = e^{M(H)/8150}$
H = altitude (meters)	
M = 1 for power-frequency, lightning impulse, and phase-to-phase switching impulse voltages	
M = 0.9 for longitudinal switching impulse voltage	
M = 0.75 for phase-to-ground switching impulse voltage	

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Table D.2—Altitude correction factors

Altitude (m)	Rating increase required starting from 1000 m (M = 1)	De-rating required starting from 1000 m (M = 1)	Rating increase required starting from sea level (M = 1)	De-rating required starting from sea level (M = 1)
0	—	—	1.000	1.000
500	—	—	1.063	0.940
1000	1.000	1.000	1.131	0.885
1500	1.063	0.940	1.202	0.832
2000	1.131	0.885	1.278	0.782
2500	1.202	0.832	1.359	0.736
3000	1.278	0.782	1.445	0.692
3500	1.359	0.736	1.536	0.651
4000	1.445	0.692	1.634	0.612

NOTE 1—At a 1000 m application altitude, if not already rated for 1000 m, there is a 13.1% increase in withstand requirement or 11.5% decrease in withstand capability from sea level NTP rating.

NOTE 2—For normal variations in barometric pressure and temperature due to weather change, the above formulas can be averaged. Where extreme weather and barometric pressure changes occur, the altitude correction factor may need to be adjusted.

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