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(Amendment to
IEEE Std C37.09™-1999)

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IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Amendment 1: Capacitance Current Switching

IEEE Power Engineering Society

Sponsored by the
Switchgear Committee

IEEE

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Abstract: A revision to the capacitance current switching standards is included in this amendment.
Keywords: amendment, capacitance current switching, fast transient recovery voltage, indoor, initial, mechanical endurance, operating duty, outdoor, power frequency, short-circuit current, short-line fault, single-phase testing, test data reporting, three-phase testing, unit test, voltage distribution synthetic test

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Introduction

This introduction is not part of IEEE Std C37.09a-2005, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Amendment 1: Capacitance Current Switching.

The capacitance current switching standards have been completely revised. A joint IEEE/IEC task force developed a revised approach to capacitance current switching standardization. IEC has published this task force's work as part of IEC's new circuit breaker standard, designated IEC 62271-100. IEC 62271-100 replaces the old IEC 56.

In the interest of harmonization of high-voltage circuit breaker standards, a joint meeting of the IEC 17A, the IEEE/PES Switchgear Committee, and the IEEE/PES Substations Committee was held in Vienna VA, in May 1995. One of the outcomes of that meeting was a decision to form a joint IEEE/IEC task force to revise the standards for capacitance current switching. The task force was given the IEC designation "IEC SC17A WG21 TF10." It was agreed that the work of this task force (TF10) would serve as the basis for capacitance current switching standards in IEC and IEEE. The task force had two 2-day meetings, one in Clamart, France in September 1995 and one in Berlin Germany in December 1995.

The task force was comprised of the following:

R. W. Alexander *(IEEE)*
D. Dufournet *(IEEE and IEC)*
R. Jeanjean *(IEEE and IEC)*
H. Kempen *(IEC)*
R. O' Leary *(IEEE)*
P. Riffon *(IEC)*
M. Seeger *(IEC)*
N. Trapp (*IEC)*

The work of the above task force has been incorporated into the new IEC circuit breaker standard IEC 62271-100 (formerly IEC 56) published in May 2001. The IEEE version is comprised of IEEE Std C37.04a™, IEEE Std C37.09a, and a revised set of tables in ANSI C37.06. Slight modifications to the IEC version have been made to reflect North American practice. Additionally, slight modifications to the text have been made for the North American reader, such as "Earth" is replaced by "Ground." Most of the text is the same and certain usage may be unfamiliar, but is understandable to the discriminating reader.

In keeping with IEC Circuit Breaker Standard philosophy, the capacitance current switching ratings have been "unbundled." A "basic" circuit breaker has either an overhead line switching rating (outdoor circuit breaker), or a cable switching rating (indoor circuit breaker) Capacitor bank ratings, both single bank and back to back, or additional OH or cable ratings must be specified separately.

Three classes of circuit breaker regarding restriking performance are specified. "Class C0" has a probability of restrike up to one restrike per operation, and its capacitance current switching performance can be compared to the former "general purpose circuit breaker" defined in IEEE Std C37.04™-1979. "Class C1" has a restriking performance similar to the old "definite purpose circuit breaker" defined in IEEE Std C37.04-1979 and is called "low probability of restrike." Class C2 is intended to have a very low probability of restriking, about 1/10 or less than that of a class C1 circuit breaker. A probability of restrike classification is applicable to each capacitance current switching rating.

For circuit breakers rated 362 kV and above, a single phase test voltage factor of 1.4 (recovery voltage of 2.8 p.u.) is required for the overhead line switching test duties. (This is an option in IEC 62271-100.) The purpose of this requirement is to acknowledge the long transmission lines and low coefficient of grounding, common in North America. This is an increase from the 1.2 single phase test voltage factor (2.4 p.u. recovery voltage) requirement in IEEE Std C37.04-1979. For circuit breakers rated 72.5 kV and below the same 1.4 single phase test voltage factor is required for all capacitance current switching duties. This is to allow for the many ungrounded systems that exist at 72.5 kV and below. IEC 62271-100 requires this only at

52 kV and below. This is a slight decrease in the requirement for a 1.5 single phase test voltage factor (3.0 p.u. recovery voltage) for capacitance current testing in IEEE Std C37.09-1999.

IEEE Std C37.012™ "IEEE Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis" is being revised to align with this new approach and to alert the user concerning these changes.

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Contents

IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Amendment 1: Capacitance Current Switching

NOTE—The editing instructions contained in this amendment define how to merge the material contained herein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown in bold italic. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make small corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strikethrough~~ (to remove old material) and underscore (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make large changes in existing text, subclauses, tables, or figures by removing existing material and replacing it with new material. Editorial notes will not be carried over into future editions because the changes will be incorporated into the base standard.

3. Definitions

Replace the text in Clause 3 with the following:

For the purposes of this standard, the following terms and definitions apply. These definitions are not intended to embrace all possible meanings of the terms. They are intended solely to establish the meanings of terms used in power switchgear. IEEE Std C37.100™ and IEEE Std C37.04a™[B4][1] should be referenced for terms not defined in this clause.

3.1 Close-open time: Interval of time between the instant when the contacts touch in the first pole during a closing operation and the instant when the arcing contacts have separated in all poles during the subsequent opening operation.

NOTE—Unless otherwise stated, it is assumed that the opening release incorporated in the circuit-breaker is energized at the instant when the 52a contacts close in the trip circuit during the closing operation. This represents the minimum close-open time.[2]

[1]The numbers in brackets correspond to those of the bibliography in Annex D.

[2]Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

3.2 Non-sustained disruptive discharge (NSDD): A disruptive discharge associated with current interruption that does not result in the resumption of power frequency current or, in the case of capacitance current interruption, does not result in current at the natural frequency of the circuit.

NOTE—Oscillations following NSDDs are associated with the stray capacitance and inductance local to, or of the circuit breaker itself. NSDDs may also involve the stray capacitance to ground of nearby equipment.

4. Design tests

Replace the title of 4.10 with the following:

4.10 Capacitance current switching tests

Replace the text in 4.10 with the following:

4.10.1 Applicability

Capacitance current switching tests are applicable to all circuit-breakers since line charging interrupting current is assigned to all outdoor circuit breakers, and cable charging interrupting current is assigned to all indoor breakers. Tests are required to demonstrate the following ratings when assigned:

- Rated line-charging breaking current (required for all outdoor circuit breakers, optional for indoor circuit breakers)
- Rated cable-charging breaking current (required for indoor circuit breakers, optional for outdoor circuit breakers)
- Rated single-capacitor bank breaking current (optional for all circuit breakers)
- Rated back-to-back capacitor bank breaking current (optional for all circuit breakers)
- Rated back-to-back capacitor bank inrush making current (optional for all circuit breakers)

Preferred values of rated capacitance switching currents are given in Tables 1C, 2C, 3E of ANSI C37.06 [B1].

NOTE 1—The determination of overvoltages when switching capacitor currents is not covered by this standard. See IEEE Std 1036™ [B6] for guidance.

NOTE 2—An explanatory note on capacitance current switching is given in C.3.

4.10.2 General

Re-ignitions during the capacitance current switching tests are permitted. Three classes of circuit-beakers are defined according to their restrike performances:

- Class C2: very low probability of restrike during capacitance current breaking as demonstrated by specific type tests (4.10.9.1).
- Class C1: low probability of restrike during capacitance current breaking as demonstrated by specific type tests (4.10.9.2).
- Class C0: unspecified probability of restrike during capacitance current breaking allows up to one restrike per operation. Suitability for capacitance current switching is demonstrated by successfully performing either the C1 or C2 test program with up to one restrike per operation (4.10.12.3).

NOTE 1—The probability is related to the performance during the series of design tests.

NOTE 2—Phenomena occurring after a restrike or a re-ignition event are not representative of service conditions as the test circuit does not adequately reproduce re-ignition/restrike energy or the post-event voltage conditions.

NOTE 3—A circuit breaker can be class C2 for some ratings, and class C1 for other ratings, and/or class C0 for other ratings. For example: A circuit breaker could be class C2 for line charging and cable charging, class C1 for Capacitor

bank switching, and class C0 for back-to-back capacitor bank switching; or a circuit breaker could be class C2 for "normal" switching, and class C1 when switching in the presence of a ground fault.

In laboratory tests, the lines and cables may be partly or fully replaced by artificial circuits with lumped elements of capacitors, reactors, or resistors.

The test circuit frequency shall be the rated frequency with a tolerance of ± 2%.

NOTE 4—Tests at 60 Hz may be considered to prove the breaking characteristics at 50 Hz.

NOTE 5—Tests at 50 Hz may be considered to prove the characteristics at 60 Hz, provided that the voltage across the circuit-breaker is not less during the critical portions of the first 8.3 ms than it would be during a test at 60 Hz with the specified voltage. For restrike performance, the area of interest is from about 5 ms to 8.3 ms after current zero. This means that $V_{50\ Hz}/V_{60\ Hz} = 1.3$ will be sufficient. If restrikes occur after 8.3 ms, due to the instantaneous voltage being higher than it would be during a test at 60 Hz with the specified voltage, the test-duty should be repeated at 60 Hz.

NOTE 6—The specification of the circuits may be replaced by a specification of the recovery voltage.

4.10.3 Characteristics of supply circuits

The test circuit shall fulfil the following requirements:

a) The characteristics of the test circuit shall be such that the power frequency voltage variation, when switching, shall be less than 2% for test-duty CS1 (LC1, CC1, and BC1) and less than 5% for test-duty CS2 (LC2, CC2, and BC2). Where the voltage variation is higher than that specified, it is alternatively permissible to perform tests with specified recovery voltage (see 4.10.10) or synthetic tests.

b) The impedance of the supply circuit shall not be so low that its short-circuit current exceeds the rated short-circuit current of the circuit-breaker.

For line-charging, cable-charging or single capacitor bank current switching tests the prospective transient recovery voltage of the supply circuit shall be no more severe than the transient recovery voltage specified for short-circuit test-duty 4 in Table 1.

For back-to-back capacitor bank breaking current tests, the capacitance of the supply circuit and the impedance between the capacitors on the supply and load sides shall be such as to give the rated back-to-back capacitor bank inrush making current when testing with 100% of the rated back-to-back capacitor bank breaking current.

NOTE 1—If a circuit-breaker is intended to be used in a system with appreciable lengths of cable on the supply side, a supply circuit incorporating appropriate additional capacitance should be used. An appreciable cable length is one having a charging current > 10% of the overhead line charging, or cable-charging current rating.

NOTE 2—For back-to-back capacitor bank switching current tests where separate making tests are performed, a lower capacitance of the supply circuit may be chosen for the breaking tests. The capacitance should, however, not be so low that the prospective transient recovery voltage of the supply side exceeds that specified for short-circuit in test-duty 4 in Table 1. (TRV values in Tables 1, 2, 3 of ANSI C37.06 as appropriate).

4.10.4 Grounding of the supply circuit

For single-phase laboratory tests, either terminal of the single-phase supply circuit can be grounded. However, when it is necessary to ensure that the correct voltage distribution exists between the units of the circuit-breaker, another point of the supply circuit may be connected to ground.

For three-phase tests the grounding shall be as follows:

a) For capacitor bank current switching tests, the neutral of the supply circuit shall be grounded. For capacitor banks with grounded neutral, the zero sequence impedance shall be no less than three times the positive sequence impedance. For isolated neutral capacitor banks this ratio is not relevant.

b) For line-charging and cable-charging current switching tests, the grounding of the supply circuit shall, in principle, correspond to the grounding conditions in circuits for which the circuit-breaker is to be used.

c) For three-phase tests of a circuit-breaker intended for use in grounded neutral systems, the neutral point of the supply circuit shall be grounded and its zero sequence impedance shall be no less than three times its positive sequence impedance.

d) For three-phase tests of a circuit-breaker intended for use in isolated neutral and resonant grounded systems the neutral point of the supply side shall be isolated.

NOTE—For convenience of testing, an alternative test circuit can be used as long as the testing authority can prove that equivalent values of the recovery voltage will be obtained, for example a test circuit with a grounded neutral system and an isolated capacitor bank can be replaced, in many cases, by a test circuit with an isolated neutral system and a grounded capacitor bank.

Moreover, attention should be given to the influence of TRV control capacitors on the values of the recovery voltage especially for low capacitance currents. Table 3 gives values of the required recovery voltage.

4.10.5 Characteristics of the capacitive circuit to be switched

The following abbreviations apply:

— Line-charging current, test-duty CS1 LC1
— Line-charging current, test-duty CS2 LC2
— Cable-charging current, test-duty CS1 CC1
— Cable-charging current, test-duty CS2 CC2
— Capacitor bank current, test-duty CS1 BC1
— Capacitor bank current, test-duty CS2 BC2

The characteristics of the capacitive circuit shall, with all necessary measuring devices included (such as voltage dividers) be such that the decay of the voltage across the circuit-breaker does not exceed 10% at the end of an interval of 300 ms after final arc extinction.

In case the test circuit is unable to supply the recovery voltage for 300 ms, the withstand ability of the circuit-breaker shall be demonstrated in another way. This demonstration can be done by performing an additional test without current, applying the required recovery voltage 20 ms after contact separation for circuit-breakers rated 50 Hz and 16.6 ms after contact separation for circuit-breakers rated 60 Hz. The required recovery voltage can be obtained by applying, for example, a dc voltage at one terminal and an ac voltage to the other terminal for the required time duration. The number of voltage applications shall be the same as the number of opening operations in test-duty CS1 (LC1, CC1, and BC1). When capacitance current switching tests are performed three-phase, this additional dielectric test shall be carried out on each of the three phases.

4.10.5.1 Line-charging current switching tests

There are three possibilities for line-charging current switching tests. They are as follows:

a) Three-phase tests, where it is permissible to use parallel lines or to partly, or fully, replace the real three-phase line with lumped capacitor banks. The resulting positive sequence capacitance shall be approximately twice the zero sequence capacitance for rated voltages 72.5 kV and above, and three times the zero sequence capacitance for rated voltages less than 72.5 kV.

b) Single-phase tests in a three-phase test circuit with two phases of the capacitive circuit connected directly to the three-phase supply circuit and one phase connected to the supply circuit through the circuit-breaker pole to be tested.

c) Single-phase laboratory tests, where it is allowed to replace partly or fully the real lines by lumped capacitor banks and to use any parallel connection of the conductors in the individual phases with the return current through ground or through a conductor.

When capacitors are used to simulate overhead lines, a non-inductive resistor of a maximum value of 450 Ω may be inserted in series with the capacitors. Higher values may unduly influence the recovery voltage. If, with this resistor connected, the peak inrush current is still unacceptably high, then an alternative impedance (e.g., LR) may be used instead of the resistor, provided that the current and voltage conditions at the instant of breaking and the recovery voltage do not differ significantly (i.e., by more than 2%) from the specified values.

Caution is needed when using such alternative impedances, since this impedance can generate an overvoltage after re-ignition, which may lead to further re-ignitions or restrikes.

4.10.5.2 Cable-charging current switching tests

Capacitors may be used to simulate shielded and belted cables. For three-phase tests representing three-core belted cables, the positive sequence capacitance shall be approximately twice the zero sequence capacitance.

NOTE—A belted cable has no grounded shield on the individual phase conductors. Therefore, there is a phase to phase capacitance as well as phase to ground capacitance

When capacitors are used to simulate cables, a non-inductive resistor of a maximum value of 25 Ω may be inserted in series with the capacitors. Higher values may unduly influence the recovery voltage. If, with this resistor connected, the peak inrush current is still unacceptably high, then an alternative impedance (e.g., LR) may be used instead of the resistor, provided that the current and voltage conditions at the instant of breaking and the recovery voltage do not differ significantly (i.e., by more than 2%) from the specified values.

Caution is needed when using such alternative impedances, since this impedance can generate an overvoltage after re-ignition, which may lead to further re-ignitions or restrikes.

NOTE—A short overhead line may be used in series with a cable for the tests, provided the line charging current does not exceed 1% of the cable-charging current.

4.10.5.3 Capacitor bank current switching tests

The neutral of the capacitor shall be isolated except that, for rated voltages above 72.5 kV, the grounding conditions of the test capacitor shall be the same as for the capacitor when in service if the circuit-breaker is intended for use in grounded neutral systems.

4.10.6 Waveform of the current

The waveform of the current to be interrupted should, as nearly as possible, be sinusoidal. This condition is considered to be complied with if the ratio of the r.m.s. value of the current to the r.m.s. value of the fundamental component does not exceed 1.20. However, if the capacitance current is more than 0.1 times the maximum symmetrical interrupting rating, then the rate of change of the current within 100 microseconds of current zero shall not be greater than 2 times the maximum di/dt of the power frequency component of the capacitance current.

The current to be interrupted shall not go through zero more than once per half-cycle of power frequency.

4.10.7 Test voltage

For direct three-phase tests and for single-phase tests with the capacitive circuit to be switched according to the arrangement in item b) of 4.10.5.1, the test voltage measured between the phases at the circuit-breaker location immediately prior to opening shall be not less than the rated voltage [V] of the circuit-breaker.

For direct single-phase laboratory tests, the test voltage measured at the circuit-breaker location immediately before the opening shall be not less than the product of $V/\sqrt{3}$ and the following capacitive voltage factor k_c:

a) **1.0** for tests corresponding to normal service in grounded neutral systems without significant mutual influence of adjacent phases of the capacitive circuit, typically capacitor banks with grounded neutral and shielded cables.

b) **1.2** for tests on belted cables and for line-charging current switching tests according to item c) of 4.10.5.1 corresponding to normal service conditions in grounded neutral systems for circuit breakers with rated voltages above 72.5 kV.

c) **1.4** for tests corresponding to

— Breaking during normal service conditions in systems other than grounded neutral systems.

— Breaking of capacitor banks with isolated neutral.

Moreover, the factor **1.4** will be applied for tests on belted cables (CC1) and for line-charging current switching (LC1) according to item c) of 4.10.5.1 corresponding to normal service conditions in ungrounded neutral systems for rated voltages less than or equal to 72.5 kV.

When verification of capacitance current switching is required in presence of single- or two-phase ground faults, the following factors apply (see also 4.10.9.4 for the test currents). Line charging breaking tests in the presence of single phase to ground faults are required for circuit breakers rated 362 kV and above.

d) **1.4** for tests corresponding to breaking in the presence of single- or two-phase ground faults in grounded neutral systems.

e) **1.7** for tests corresponding to breaking in systems other than grounded neutral systems in the presence of single or two-phase ground faults.

NOTE—At best, class C1 performance is expected when $k_c = 1.7$.

In summary, the voltage factors for direct single-phase laboratory tests are as follows:

k_c = **1.4** for test duties LC1, LC2, CC1, CC2, BC1, BC2 for voltage ratings 72.5 kV and below (see Note 2)

k_c = **1.4** for test duties LC1, LC2 for voltages 362 kV and above. [In this case, item a) of 4.10.9.4 applies]

k_c = **1.2** for test duties LC1, LC2 for voltages greater than 72.5 kV and less than 362 kV

k_c = **1.0** for test duties CC1, CC2, BC1, BC2 for voltages greater than 72.5 kV (unless specified higher by the user)

For special cases that may require higher values of k_c when verification of capacitance current switching is required in the presence of single or two-phase ground faults, see IEEE Std C37.012™ [B5].

For unit tests, the test voltage shall be chosen to correspond to the most stressed unit of the pole of the circuit-breaker.

The power frequency test voltage and the dc voltage resulting from the trapped charge on the capacitive circuit shall be maintained for a period of at least 0.3 s after breaking.

NOTE 1—The voltage factors in b) to c) above are applicable to single circuit line construction. Switching test requirements for multiple circuit overhead line constructions may be greater than these factors. (See IEEE Std C37.012 [B5].)

NOTE 2—When the non-simultaneity of contact separation in the different poles of the circuit-breaker exceeds one-sixth of the cycle of the rated frequency, it is recommended to raise further the voltage factor or to make only three-phase tests. (See IEEE Std C37.012 [B5].)

4.10.8 Test current

Preferred values of rated capacitance currents are specified in ANSI C37.06 [B1].

4.10.9 Test-duties

The tests for either class C0, class C1, or class C2 shall be performed on one specimen without any maintenance. The abbreviations of 4.10.5 apply.

4.10.9.1 Test conditions for class C2 circuit-breakers

4.10.9.1.1 Class C2 test-duties

4.10.9.1.1.1 Preconditioning

Capacitance current switching tests for class C2 circuit-breakers shall be made after performing short-circuit test-duty 3 in Table 1 as a preconditioning test. (Test-duty 3 is 60% of the rated breaking capability of the circuit-breaker.) The test arrangement should be such that no interference with the circuit-breaker between the tests is necessary. However, if this is not possible and local safety rules require depressurizing to enter the test cell, it is allowed to decrease the pressure in the circuit-breaker provided that the gas is reused when refilling the circuit-breaker.

As an alternative, the preconditioning test may consist of the following:

- Same current as test-duty 3 Table 1 of IEEE Std C37.09-1999
- Low voltage and no specified TRV
- Three opening operation
- Arcing time: as for test-duty 3 or expected test-duty 3 arcing time values given by the manufacturer
- Rated or lock-out conditions

NOTE 1—For practical reasons, for circuit-breakers rated less than 72.5 kV, the manufacturer may choose to add other test-duties to the test-duty 3 preconditioning tests.

NOTE 2—If several capacitance current switching tests (e.g., line-charging, cable-charging and capacitor bank current switching tests) are performed with the same circuit-breaker without reconditioning, the test-duty 3 preconditioning tests must be performed only once at the beginning of the capacitance current switching test.

4.10.9.1.1.2 Class C2 Tests

The capacitance current switching tests shall consist of the test-duties as specified in Table 2.

For sealed-for-life fluid circuit-breakers, the minimum functional pressure is replaced by the rated pressure for interruption less the pressure drop due to leakage during life duration. For vacuum circuit-breakers, the pressure conditions for interruption are not applicable.

For make-break tests, the contacts of the circuit-breaker shall not be separated until the transient currents have subsided. To achieve this, the time between the closing and the opening operations may need to be adjusted but shall remain as close as possible to the close-open time.

No appreciable charge shall remain on the capacitive circuits before the making operations.

Table 2—Class C2 test duties

Test-duty	Operating voltages of the releases	Pressure for operation and interruption	Test current as percentage of the rated capacitance breaking current %	Type of operation or operating sequence
CS1: LC1, CC1, BC1	Maximum voltage	Minimum functional pressure	10 to 40	O
CS2: LC2, CC2, BC2	Maximum voltage	Rated pressure	Not less than 100	O and CO or CO
NOTE 1—The tests are performed at maximum operating voltage of the releases in order to facilitate consistent control of the opening operation. NOTE 2—For convenience of testing, CO operations may be performed in test-duties LC1, CC1, and BC1.				

For all capacitor bank making operations, the making shall occur within ±15° of the peak value of applied voltage (on one phase for three-phase tests). The making current shall be appropriate to the capacitance current switching duty. To demonstrate back-to-back capacitor bank switching ratings, the making current shall be at least equal to the rated back-to-back capacitor bank inrush making current (I_{bb}) and the frequency shall be at least equal to the rated back-to-back capacitor bank inrush making frequency (f_{bb}).

4.10.9.1.1.3 Alternative of separate making tests

Where, due to limitations of the test plant, it is not possible to comply with the requirements during the CO operation, then it is permitted to perform the requirements of test-duty CS2 (LC2, CC2, and BC2) as a series of separate making tests followed by a series of CO tests.

The separate making tests of this test series shall comprise the following:

— The same number of operations.

— The making current shall be appropriate to the capacitance current switching duty, to demonstrate back-to-back capacitor bank switching ratings, the making current shall be equal to the rated back-to-back capacitor bank inrush making current (I_{bb}), and the frequency shall be at least equal to the rated back-to-back capacitor bank inrush making frequency (f_{bb}).

— The test voltage shall be the same as for test-duty CS2 (LC2, CC2, and BC2).

— Closing shall occur within 15° of the peak value (on the same phase for three-phase tests).

After the separate making operations, the CO operations, following the same procedure for the separate making tests described previously, shall be performed with no-load conditions on the closing.

NOTE—When switching capacitance currents, the opening operation in a CO operation is not influenced by the pre-arc of the preceding closing operation, but may be impacted by the actual behavior of the fluid for interruption caused by the closing operation (e.g., local differences in density, turbulence, fluid motion). Therefore, the closing and the opening operations may be separated as mentioned above with regard to the electrical stress but not with regard to the motion conditions of the fluid for interruption. A no-load closing operation prior to the opening operation is necessary for these reasons.

4.10.9.1.1.4 Damping factor for inrush currents

The prospective damping factor for the inrush current during back-to-back switching, i.e., the ratio between the second peak and the first peak of the same polarity, shall be equal to or greater than 0.75 for circuit-breakers having a rated voltage less than 72.5 kV and equal to or greater than 0.85 for circuit-breakers having a rated voltage equal to or greater than 72.5 kV.

4.10.9.1.1.5 Determination of minimum arcing time

For opening operations, the minimum arcing time is determined by changing the setting of the contact separation on opening by periods of approximately 300 microseconds. Using this method, several tests may be necessary to demonstrate the minimum arcing time and the maximum arcing time.

NOTE—In order to obtain more consistent opening and closing times of the circuit-breaker, by agreement of the manufacturer voltages even higher than the relevant upper tolerance limit of the supply voltages of the operating devices may be applied during these tests.

If a maximum arcing time is obtained instead of an expected minimum arcing time, this is a valid test and shall be included in the count for the total requirement. In such an event, the following will be necessary, and may have to be iterated until minimum arcing time is achieved:

— Advance the setting of the control of the tripping impulse by 300 microseconds and repeat the test. The new setting shall be kept for other tests at minimum arcing time.

— Make one less opening operation to retain the overall total count of tests.

The number of operations at minimum arcing time as stated in 4.10.9.1.2, 4.10.9.1.3, 4.10.9.1.4, and 4.10.9.1.5 shall be achieved in any case, even if the specified total number of operations is exceeded.

A re-ignition followed by interruption at a later current zero shall be treated as a breaking operation with long arcing time.

4.10.9.1.1.6 Order of testing

The preferred order for the line-charging or cable-charging current switching tests is as follows:

a) Terminal fault test-duty 3 (Table 1) (mandatory at the beginning)

b) Capacitance current switching, test-duty CS1 (LC1 or CC1)

c) Capacitance current switching, test-duty CS2 (LC2 or CC2)

The mandatory order for capacitor bank (single or back-to-back) current switching tests is as follows:

d) Terminal fault test-duty 3 (T60) (Table 1)

e) Capacitance current switching, test-duty BC2

f) Capacitance current switching, test-duty BC1

Within each test-duty, the order of the operations as written in 4.10.9.1.2 to 4.10.9.1.5 is suggested but not mandatory.

For circuit-breakers with a non-symmetrical current path, the terminal connections shall be reversed between test-duty LC1, CC1, and BC1 and test-duty LC2, CC2, and BC2.

These test-duties may be combined in order to demonstrate the performance of a circuit-breaker for covering several applications or ratings (e.g., LC and/or CC and/or BC). If such combination method is used, the following rules apply:

— The test voltage, as defined in 4.10.7, shall be equal to the highest value for which the circuit breaker performance is required to be demonstrated. For circuit breakers with rated maximum voltage 362 kV and greater, a minimum of 48 tests shall be done with $k_c = 1.4$.

— The test-duties and test currents shall be as follows:

  1) A test-duty 1, covering test-duties LC1 and/or CC1 and/or BC1, with a current between 10% and 40% of the lowest capacitive current rating to be demonstrated.

  2) A test-duty 2, covering test-duties LC2 and/or CC2 and/or BC2, with a current not less than 100% of the highest capacitive current rating to be demonstrated.

3) If the required current to be used in test-duty 2 exceeds 10 times the current value used in test-duty 1, a third test-duty (test-duty 3) shall be performed with a test current between 10% and 40% of the test current for test-duty 2. For this third test-duty, the testing procedures of the test-duties LC1 and/or CC1 and/or BC1 apply.

4) The number of operations for each of the test-duties shall be the highest of those defined for the ratings to be demonstrated (e.g., LC, CC, or BC). Where CO operations are specified for one application and O operations for a different one, CO operations are considered to cover O operations if the testing conditions are the same.

4.10.9.1.2 Three-phase line-charging and cable-charging current switching tests for class C2

Each test-duty shall comprise a total of 24 operations as follows:

4.10.9.1.2.1 Test-duty LC1 and CC1

— 4 O, distributed on one polarity (step: 15°)
— 6 O at minimum arcing time on one polarity
— 4 O, distributed on the other polarity (step: 15°)
— 6 O at minimum arcing time on the other polarity
— Additional tests to achieve 24 O, distributed (step: 15°)

4.10.9.1.2.2 Test-duty LC2 and CC2:

— 4 CO, distributed on one polarity (step: 15°)
— 6 CO at minimum arcing time on one polarity
— 4 CO, distributed on the other polarity (step: 15°)
— 6 CO at minimum arcing time on the other polarity
— Additional tests to achieve 24 CO, distributed (step: 15°)

The C operations may be no-load operations. In this case, a series of separate making tests according to 4.10.9.1.1.3 shall be performed.

During these tests, all minimum arcing times shall occur on the same phase.

NOTE—If the opening time of the circuit-breaker prevents accurate control of contact separation, the requirement for minimum arcing times to be on the same phase can be ignored.

4.10.9.1.3 Single-phase line-charging and cable-charging current switching tests for class C2

Each test-duty shall comprise a total requirement of 48 operations as follows:

NOTE—For rated voltages 362 kV and higher, where a voltage factor k_c of 1.4 is required for LC1 and LC2, the number of tests shall be reduced by one half. (See 4.10.9.4.) This means a total of 24 for LC1 and 24 for LC2.

4.10.9.1.3.1 Test-duty LC1 and CC1

— 12 O, distributed on one polarity (step: 15°)
— 6 O at minimum arcing time on one polarity
— 12 O, distributed on the other polarity (step: 15°)
— 6 O at minimum arcing time on the other polarity

— Additional tests to achieve 48 O, distributed (step: 15°)

4.10.9.1.3.2 Test-duty LC2 and CC2

— 6 O and 6 CO, distributed on one polarity (step: 30°)
— 3 O and 3 CO at minimum arcing time on one polarity
— 6 O and 6 CO, distributed on the other polarity (step: 30°)
— 3 O and 3 CO at minimum arcing time on the other polarity
— Additional tests to achieve 24 O and 24 CO, distributed (step: 30°)

The C operations may be no-load operations. In this case, a series of separate making tests according to 4.10.9.1.1 shall be performed.

4.10.9.1.4 Three-phase capacitor bank (single or back to back) current switching tests for class C2

Test-duty BC1 shall comprise a total of 24 O tests. Test-duty BC2 shall comprise a total of 80 CO tests:

4.10.9.1.4.1 Test-duty BC1

— 4 O, distributed on one polarity (step: 15°)
— 6 O at minimum arcing time on one polarity
— 4 O, distributed on the other polarity (step: 15°)
— 6 O at minimum arcing time on the other polarity
— Additional tests to achieve 24 O, distributed (step: 15°)

4.10.9.1.4.2 Test-duty BC2

— 4 CO, distributed on one polarity (step: 15°)
— 32 CO at minimum arcing time on one polarity
— 4 CO, distributed on the other polarity (step: 15°);
— 32 CO at minimum arcing time on the other polarity
— Additional tests to achieve 80 CO, distributed (step:15°)

The C operations may be no-load operations. In this case, a series of separate making tests according to 4.10.9.1.1.3 shall be performed.

During these tests, all minimum arcing times shall be obtained on the same phase.

4.10.9.1.5 Single-phase capacitor bank (single or back-to-back) current switching tests for class C2

Test-duty BC1 shall comprise a total of 48 O tests. Test-duty BC2 shall comprise a total of 120 CO tests.

4.10.9.1.5.1 Test-duty BC1

— 12 O, distributed on one polarity (step: 15°)
— 6 O at minimum arcing time on one polarity
— 12 O, distributed on the other polarity (step: 15°)
— 6 O at minimum arcing time on the other polarity

— Additional tests to achieve 48 O, distributed (step: 15°)

4.10.9.1.5.2 Test-duty BC2

— 12 CO, distributed on one polarity (step: 15°)
— 42 CO at minimum arcing time on one polarity
— 12 CO, distributed on the other polarity (step: 15°)
— 42 CO at minimum arcing time on the other polarity
— Additional tests to achieve 120 CO, distributed (step: 15°)

The C operations may be no-load operations. In this case, a series of separate making tests according to 4.10.9.1.1.3 shall be performed.

4.10.9.2 Test conditions for class C1 circuit-breakers

NOTE—This subclause closely resembles 4.10.9.1 but with the lesser requirements for class C1. Each of these groups is presented as a "stand alone" grouping.

4.10.9.2.1 Class C1 test-duties

4.10.9.2.1.1 Class C1 Tests

The capacitance current switching tests for class C1 circuit-breakers shall consist of test-duties as specified in Table 2A without preconditioning (4.10.9.1.1.1).

NOTE—Tests performed in an attempt to qualify for class-C2 certification may be applied to class-C1 certification.

Table 2A—Class C1 test-duties

Test-duty	Operating voltage of the releases	Pressure for operation and interruption	Test current as percentage of rated capacitance switching current %	Type of operation or operating sequence
CS1: LC1, CC1, and BC1	Maximum voltage	Rated pressure[a]	10 to 40	O
CS2: LC2, CC2, and BC2	Maximum voltage	Rated pressure[a]	Not less than 100	CO
NOTE 1—For convenience of testing, CO operations may be performed in test-duty CS1 (LC1, CC,1 and BC1). NOTE 2—The tests are performed at maximum operating voltage of the releases in order to facilitate consistent control of the opening operation.				

[a] If applicable, pressure for operation and interruption shall be at the minimum functional pressure conditions for at least three CO operations, one at the minimum arcing time and two at the maximum arcing time.

4.10.9.2.1.2 Making operations

For the make-break tests, the contacts of the circuit-breaker shall not be separated until the transient currents have subsided. To achieve this, the time between the closing and opening operations may need to be adjusted but shall remain as close as possible to the close-open time.

No appreciable charge shall remain on the capacitive circuits before the making operations.

For all capacitor bank making operations, the making shall occur within ±15° of the peak value of applied voltage (on one phase for three-phase tests). The making current shall be appropriate to the capacitance current switching duty. To demonstrate back-to-back capacitor bank switching ratings, the making current shall be at least equal to the back-to-back capacitor bank inrush making current (I_{bb}) and the frequency shall be at least equal to the rated back-to-back capacitor bank inrush making frequency (f_{bb}).

4.10.9.2.1.3 Alternative separate making tests

Where, due to limitations of the test plant, it is not possible to comply with the requirements during the CO operation, then it is permitted to perform the requirements of test-duty LC2, CC2, and BC2 as a series of separate making tests followed by a series of CO tests.

The separate making tests of this test series shall comprise:

— The same number of operations.

— The making current shall be appropriate to the capacitance current switching duty, to demonstrate back-to-back capacitor bank switching ratings, the making current shall be equal to the rated back-to-back capacitor bank inrush making current (I_{bb}), and the frequency shall be at least equal to the rated back-to-back capacitor bank inrush making frequency (f_{bb}).

— The test voltage shall be the same as for test-duty CS2.

— Closing shall occur within 15° of the peak value (on the same phase for three-phase tests).

After the separate making operations, the CO operations, following the same procedure for the separate making tests described previously, shall be performed with no-load conditions on the closing.

NOTE—When switching capacitance currents, the opening operation in a CO operation is not influenced by the pre-arc of the preceding closing operation but may be impacted by the actual behavior of the fluid for interruption caused by the closing operation (for example local differences in density, turbulence, fluid motion). Therefore, the closing and opening operations may be separated as mentioned above with regard to the electrical stress, but not with regard to the motion conditions of the fluid for interruption. A no-load closing operation prior to the opening operation is necessary for these reasons.

4.10.9.2.1.4 Damping factors for inrush currents

The prospective damping factor for the inrush current during back-to-back switching, i.e., the ratio between the second peak and the first peak of the same polarity, shall be equal to or greater than 0.75 for circuit-breakers having a rated voltage less than 72.5 kV and equal to or greater than 0.85 for circuit-breakers having a rated voltage equal to or greater than 72.5 kV.

4.10.9.2.1.5 Determination of minimum arcing time

For opening operations, the minimum arcing time is determined by changing the setting of the contact separation on opening by periods of approximately 300 microseconds. Using this method, several tests may be necessary to demonstrate the minimum arcing time and the maximum arcing time.

NOTE—In order to obtain more consistent opening and closing times of the circuit-breaker, by agreement of the manufacturer, voltages even higher than the relevant upper tolerance limit of the supply voltages of the operating devices may be applied during these tests.

If a maximum arcing time is obtained instead of an expected minimum arcing time, this is a valid test and shall be included in the count for the total requirement. In such an event, the following will be necessary and may have to be iterated until minimum arcing time is achieved:

— Advance the setting of the control of the tripping impulse by 300 microseconds and repeat the test. The new setting shall be kept for other tests at minimum arcing time.

— Make one less opening operation to retain the overall total count of tests.

A re-ignition followed by interruption at a later current zero shall be treated as a breaking operation with a long arcing time.

4.10.9.2.1.6 Order of testing

Within each test-duty, the order of the operations, as written in 4.10.9.2.2, is suggested but not mandatory.

For circuit-breakers with a non-symmetrical current path, the terminal connections shall be reversed between test-duty CS1 (LC1, CC1, and BC1) and test-duty CS2 (LC2, CC2, and BC2).

These test-duties may be combined in order to demonstrate the performance of a circuit-breaker for covering several applications or ratings (e.g., LC and/or CC and/or BC). If such combination method is used, the following rules apply:

— The test voltage, as defined in 4.10.7, shall be equal to the highest value for which the circuit breaker performance is required to be demonstrated. For circuit breakers with rated maximum voltage 362 kV and greater, a minimum of 48 tests shall be done with $k_c = 1.4$.

— The test-duties and test currents shall be as follows:

1) A test-duty 1, covering test-duties LC1 and/or CC1 and/or BC1, with a current between 10% and 40% of the lowest capacitive current rating to be demonstrated.

2) A test-duty 2, covering test-duties LC2 and/or CC2 and/or BC2, with a current not less than 100% of the highest capacitive current rating to be demonstrated.

3) If the required current to be used in test-duty 2 exceeds 10 times the current value used in test-duty 1, a third test-duty (test-duty 3) shall be performed with a test current between 10% and 40% of the test current for test-duty 2. For this third test-duty, the testing procedures of the test-duties LC1 and/or CC1 and/or BC1 apply.

4) The number of operations for each of the test-duties shall be the highest of those defined for the ratings to be demonstrated (e.g., LC, CC, or BC). Where CO operations are specified for one application and O operations for a different one, CO operations are considered to cover O operations if the testing conditions are the same.

4.10.9.2.2 Single-phase and three-phase capacitance current switching tests for class C1

Test-duty CS1 (LC1, CC1, and BC1) shall comprise a total of 24 O tests. Test-duty CS2 (LC2, CC2, and BC2) shall comprise a total of 24 CO tests.

NOTE—For rated voltages 362kV and higher, where a voltage factor k_c of 1.4 is required for LC1 and LC2, the number of tests shall be reduced by one half. (See 4.10.9.4.) This means a total of 12 for LC1 and 12 for LC2.

4.10.9.2.2.1 Test-duty CS1 (LC1, CC1, BC1)

— 6 O, distributed on one polarity (step: 30°)
— 3 O at minimum arcing time on one polarity
— 3 O at minimum arcing time on other polarity
— 6 O at maximum arcing time on the other polarity
— Additional tests to achieve 24 O, distributed (step: 30°)

4.10.9.2.2.2 Test-duty CS2 (LC2, CC2, BC2)

— 6 CO, distributed on one polarity (step: 30°)
— 3 CO at minimum arcing time on one polarity

— 3 CO at minimum arcing time on the other polarity

— 6 CO at maximum arcing time on the other polarity

— Additional tests to achieve 24 CO, distributed (step: 30°)

The C operations may be no-load operations. In this case, a series of separate making tests according to 4.10.9.2.1 shall be performed.

The preferred order for the tests is the following:

— Capacitance current switching, test-duty CS1 (LC1 or CC1 or BC1)

— Capacitance current switching, test-duty CS2 (LC2 or CC2 or BC2)

4.10.9.3 Test conditions for class C0 circuit breakers

See 4.10.11.3.

The test circuit used to demonstrate class C0 must be capable of producing multiple restrikes, and must provide sufficient energy for each restrike to charge the load capacitor to 3.0 per unit voltage.

4.10.9.4 Test conditions corresponding to breaking in the presence of ground faults

a) Lines and cables

Where tests corresponding to switching of line and cable-charging currents in the presence of ground faults are required, the following shall apply:

Single-phase laboratory tests shall be made with a test voltage as given in 4.10.7 and a capacitive current equal to

— 1.25 times the rated capacitance breaking current in grounded neutral systems.

— 1.7 times the rated capacitance breaking current in systems other than grounded neutral systems.

Test procedures are as given in 4.10.9.1 and 4.10.9.2, except that the total number of tests required is divided by two for each relevant test-duty.

NOTE—If the tests corresponding to breaking in the presence of ground faults are carried out using the number of operations stated in 4.10.9.1 or 4.10.9.2, respectively, these tests cover the requirements given in 4.10.9.1 or 4.10.9.2 and the tests to 4.10.9.1 or 4.10.9.2 do not need to be performed.

b) Single capacitor banks

Tests are not necessary for capacitor banks in grounded neutral systems.

Switching grounded neutral capacitor banks on systems other than grounded neutral systems can result in higher stresses. As this is not a normal system condition, such test requirements are not considered in this standard.

c) Back-to-back capacitor banks

As switching back-to-back capacitors in the presence of a fault is not a normal system condition, such test requirements are not considered in this standard.

4.10.10 Tests with specified TRV

As an alternative to using the test circuits defined in 4.10.3, switching tests may be performed in circuits that fulfil the following requirements for the prospective recovery voltage:

— With the envelope of the prospective test recovery voltage defined as

$$u'_c \geq u_c$$

$$t'_2 \leq t_2$$

where:

u'_c is the actual capacitive recovery voltage,

t'_2 is the actual time to crest of the capacitive recovery voltage.

— In addition the initial part of the prospective recovery voltage shall remain below the line from the origin to the point defined by u_1 and t_1.

u_c is the required power frequency recovery voltage in per unit crest of the single phase test voltage U_{test}.

$$U_{\text{test}} = \frac{k_c V \sqrt{2}}{\sqrt{3}}$$

where:

k_c = test voltage factor per 4.10.7,

V = Rated Maximum Voltage,

u_1 is the maximum allowed “voltage jump” on interrupting (breaking) the capacitive current, and is expressed in per unit of the single phase test voltage U_{test},

t_1 is the time to crest of the “voltage jump” recovery voltage on interrupting (breaking) the capacitance current,

t_2 is the minimum time to crest of the power frequency recovery voltage after capacitive interruption (breaking).

Specified values of u_1, t_1, u_c, and t_2 are given in Table 3.

See C.11 to derive t_1 values from ANSI C37.06.

Table 3—Specified values of u_1, t_1, u_c, and t_2

Test duties	Recovery voltage values in relation to the peak value of the test voltage $U_{test} = \frac{k_c V \sqrt{2}}{\sqrt{3}}$ *where:* k_c = test voltage factor per 4.10.7 V = Rated Maximum Voltage		Time values	
	u_c p.u.	U_1 p.u.	t_1	t_2
CS1 (LC1, CC1, BC1)	≥ 1.98	≤ 0.02 × k_{af} [a]	≥ t_3 (column 6) in Table 1A or 2A of ANSI C37.06 or t_1 (column 6) in Table 3A of ANSI C37.06, as appropriate, for a terminal fault	8.7 ms for 50 Hz
CS2 (LC2, CC2, BC2)	≥ 1.95	≤ 0.05 × k_{af} [a]	≥ t_3 (column 6) in Table 1A or 2A of ANSI C37.06 or t_1 (column 6) in Table 3A of ANSI C37.06, as appropriate, for a terminal fault	7.3 ms for 60 Hz
NOTE 1—For single-phase synthetic tests the prospective recovery voltage is calculated based on the test voltage of the corresponding single-phase direct test. A longer t_1 produces an easier initial interruption and consequently, theoretically, a shorter arcing time. This is a slightly more severe case for capacitance current breaking. NOTE 2—Even though the amplitude factor is 1.54 for 72.5 kV ≥ V, using 1.4 will give a more severe case for capacitance current breaking.				

[a] k_{af} = amplitude factor = 1.4

4.10.11 Criteria to pass the test

Where combined testing in accordance with 4.10.9.1.1.6 (class C2) or 4.10.9.2.1.6 (class C1) is carried out, the criteria to pass the test apply to each of the following combinations of test-duties:

— Test-duties 1 and 2 corresponding to items 1) and 2) of 4.10.9.1.1.6 [or 4.10.9.2.1.6 as appropriate]

— Where applicable, test-duties 2 and 3 corresponding to items 2) and 3) of 4.10.9.1.1.6 [or 4.10.9.2.1.6 as appropriate].

4.10.11.1 Criteria for class C2

The circuit-breaker shall have successfully passed the tests for class C2 (4.10.9.1) if the following conditions are met:

a) External flashover and phase-to-ground flashover shall not occur. Either no restrikes occurred during test-duties CS1 (LC1or CC1 or BC1) and CS2 (LC2 or CC2 or BC2); or if one restrike occurs during the complete test-duties CS1 and CS2 or combination test, then all test-duties shall be repeated on the same apparatus without any maintenance. No restrike shall occur during the second series of tests. The condition of the circuit-breaker after the test series corresponds to the conditions given in 4.10.11.5 If no restrike occurred during the complete test-duties CS1 and CS2, visual inspection is sufficient.

b) In the case of combined testing according to 4.10.9.1.1.6, the circuit-breaker shall have passed the test for the application or rating with the lower capacitive breaking current, if the tests to item 1) and item 2) of 4.10.9.1.1.6 were successful, and the test for the application or rating with the higher capacitive breaking current, if the tests to item 2) and item 3) of 4.10.9.1.1.6 were successful. Where due to restrikes test-duties have to be repeated, at least two test-duties shall be repeated, either the tests to item 1) and item 2) of 4.10.9.1.1.6 or the tests to item 2) and item 3), depending on in which test-duty the restrike took place. If a restrike occurred in LC2 and/or CC2 and/or BC2 [test to item 2) in 4.10.9.1.1.6], this one and any one of the tests to item 1) and item 3) shall be repeated.

4.10.11.2 Criteria for class C1

The circuit-breaker shall have successfully passed the tests if up to one restrike occurred during test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2).

If two restrikes occurred during the complete test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2), then both test-duties shall be repeated on the same apparatus without any maintenance. If no more than one additional restrike happens during this extended series of tests, the circuit-breaker shall have successfully passed the tests. External flashover and phase-to-ground flashover shall not take place.

A circuit-breaker tested in accordance with the class C2 test program (4.10.9.1) can be qualified as a class C1 circuit-breaker if at least one of the following conditions is met:

a) The criteria for class C2 to pass the test are met

b) The total number of restrikes during line charging current switching tests (LC1 and LC2) or cable-charging current switching tests (CC1 and CC2) is not greater than

   — Two in the first series of operations, i.e., 96 in case of single-phase tests and 48 in case of three-phase tests (no repetition series is carried out) or,

   — One during the first test series of operations, i.e., 96 in case of single-phase tests and 48 in case of three-phase tests, regardless of the number of restrikes observed during the repetition of the test series; the test may be stopped if a second restrike occurs during the repetition of the test series.

c) The total number of restrikes during capacitor bank switching tests (BC1 and BC2) is not greater than:

   — Five in the first series of operations, i.e., 168 in case of single-phase tests and 104 in case of three-phase tests (no repetition series is carried out) or,

   — One during the first test series of operations, i.e., 168 in case of single-phase tests and 104 in case of three-phase tests, regardless of the number of restrikes observed during the repetition of the test series; the test may be stopped, if a second restrike occurs during the repetition of the test series.

In the case of combined testing according to 4.10.9.1.1.6, the circuit-breaker shall have passed the test for the application or rating with the lower capacitive breaking current, if the tests to items 1) and 2) of 4.10.9.1.1.6 were successful, and the test for the application or rating with the higher capacitive breaking current, if the tests to items 2) and 3) of 4.10.9.1.1.6 were successful. Where, due to restrikes, test-duties have to be repeated, at least two test-duties shall be repeated, either the tests to items 1) and 2) of 4.10.9.1.1.6 or the tests to items 2) and 3), depending on in which test-duty the restrike took place. If a restrike occurred in LC2 and/or CC2 and/or BC2 [test to item 2) in 4.10.9.1.1.6], this one and any one of the tests to items 1) and 3) shall be repeated.

4.10.11.3 Criteria for class C0

Class C0 may be demonstrated by completing either the C1 test program (4.10.9.2) or C2 test program (4.10.9.1) allowing up to one restrike per operation. External flashover and phase-to-ground flashover shall not occur. The condition of the circuit-breaker after the test series must correspond to the conditions given in 4.10.11.5.

4.10.11.4 Behavior of circuit-breaker during capacitance current switching tests

If failures occur during a test series that are neither persistent nor due to defect in design, but rather are due to errors in assembly or maintenance, the faults can be rectified and the circuit-breaker subjected to the repeated test-duty concerned. In these cases, the test report shall include reference to the invalid tests.

Non-sustained disruptive discharges (NSDDs) may occur during the recovery voltage period following a breaking operation, and shall not be considered a sign of distress as long as no power frequency, or capacitive load natural frequency current flows in the capacitive load.

The occurrence of NSDDs does not affect the performance of a switching device. Therefore, their number is of no significance to interpreting the performance of the device under test and need not be remarked upon in the test report.

NOTE —An explanatory note on NSDDs is given in C.2.

4.10.11.5 Condition after a capacitance current switching test series

The circuit breaker shall, after performing the line-charging, cable-charging and capacitor bank current switching test series specified in 4.10.9, and before reconditioning, show no signs that it is not capable of any making and breaking current up to its rated short-circuit making and breaking current at rated voltage.

In addition, the circuit breaker shall meet the requirement of item b) of 4.8.5.5 of IEEE Std C37.09-1999

There shall be no evidence of puncture, flashover, or tracking of internal insulating materials, except that moderate wear of the parts of arc control devices exposed to the arc is permissible.

Degradation of the components in the current carrying path shall not reduce the integrity of the normal current carrying path.

If, during the capacitance current switching tests, any restrike occurs, the dielectric condition checking test according to 4.8.5.6 of IEEE Std C37.09-1999 shall be performed before visual inspection, provided that the tested peak recovery voltage during the capacitance current switching tests is lower than the peak voltage of the specified dielectric condition checking test. The subsequent visual inspection shall demonstrate that the restrike occurred between the arcing contacts only. There shall be no evidence of puncture, flashover, or permanent tracking of internal insulating materials. Wear of the parts of arc control devices exposed to the arc is permissible as long as it does not impair the breaking capability. Moreover, the inspection of the insulating gap between the main contacts, if they are different from the arcing contacts, shall not show any trace of a restrike.

If no restrike occurred during the capacitance current switching tests, visual inspection is sufficient. The dielectric condition checking test according to 4.8.5.6 of IEEE Std C37.09-1999 need not be performed.

Where further tests will be performed on the same pole, the dielectric condition checking test shall be performed after the capacitance current switching test. If no restrike occurred during the capacitive current switching test, this dielectric condition checking test need not be performed, and the condition checking test may be performed after the additional tests.

NOTE—If the circuit-breaker fails during the additional tests, this procedure may make the capacitance current switching tests invalid.

For circuit breakers with sealed-for-life interrupter units, the dielectric condition checking test according to 4.8.5.6 of IEEE Std C37.09-1999 shall be performed, whether a restrike occurs during testing or not, provided that the tested peak recovery voltage during the capacitance current switching tests is lower than the peak voltage of the specified dielectric condition checking test.

Annex C

(informative)

Capacitance current switching

C.1 Historical development of these standards

The capacitance current switching standards have been completely revised. A joint IEEE/IEC task force developed a revised approach to capacitance current switching standardization. IEC has published this task force's work as part of IEC's new circuit breaker standard, designated IEC 62271-100. IEC 62271-100 replaces the old IEC 56.

In the interest of harmonization of high-voltage circuit breaker standards, a joint meeting of the IEC 17A, the IEEE/PES Switchgear Committee, and the IEEE/PES Substations Committee was held in Vienna VA, in May 1995. One of the outcomes of that meeting was a decision to form a joint IEEE/IEC task force to revise the standards for capacitance current switching. The task force was given the IEC designation "IEC SC17A WG21 TF10." It was agreed that the work of this task force (TF10) would serve as the basis for capacitance current switching standards in IEC and IEEE. The task force had two 2-day meetings, one in Clamart, France in September 1995 and one in Berlin Germany in December 1995.

The task force was comprised of:

Ray O' Leary . . . . . IEEE
Roy Alexander . . . . . .IEEE
Robert Jeanjean. . . . . .IEEE & IEC
Denis Dufournet . . . . . .IEEE & IEC
Harry Kempen . . . . . .IEC
Piere Riffon. . . . . .IEC
Martin Seeger . . . . . .IEC
Norbert Trapp . . . . . .IEC

The work of that Task Force has been incorporated into the new IEC circuit breaker standard IEC 62271-100 (formerly IEC 56) published in May 2001. IEEE Std C37.04a, along with IEEE Std C37.09a, and a revised set of tables in ANSI C37.06 is the IEEE version. Slight modifications to the IEC version have been made to reflect North American practice. Additionally, slight modifications to the text have been made for the North American reader, such as "Earth" is replaced by "Ground." Most of the text is the same and certain usage may be unfamiliar, but is understandable to the discriminating reader.

In keeping with IEC Circuit Breaker Standard philosophy, the capacitance current switching ratings have been "unbundled." A "basic" circuit breaker has either an overhead line switching rating (outdoor circuit breaker), or a cable switching rating (indoor circuit breaker) Capacitor bank ratings, both single bank and back to back, or additional OH or cable ratings must be specified separately.

Three classes of circuit breaker regarding restriking performance are specified. Class C0 allows up to one restrike per operation, during either the C1 or C2 test program. Class C0 is intended to replace the former "general purpose circuit breaker." Class C1 has a restriking performance similar to the old "definite purpose circuit breaker" defined in IEEE Std C37.04-1999 and is called "low probability of restrike." Class C2 is intended to have a very low probability of restriking, about 1/10 or less than that of a class C1 circuit breaker. A probability of restrike classification is applicable to each rated capacitance current rating.

For circuit breakers rated 362 kV and above, a single phase test voltage factor of 1.4 (recovery voltage of 2.8 p.u.) is required for the overhead line switching test duties. (This is an option in IEC 62271-100.) The purpose of this requirement is to acknowledge the long transmission lines and low coefficient of grounding, common in North America. This is an increase from the 1.2 single phase test voltage factor (2.4 p.u. recovery voltage) requirement in IEEE Std C37.04-1999. For circuit breakers rated 72.5 kV and below the same 1.4 single phase test voltage factor is required for all capacitance current switching duties. This is to allow for the many ungrounded systems that exist at 72.5 kV and below. IEC 62271-100 requires this only at 52 kV and below. This is a slight decrease in the requirement for a 1.5 single phase test voltage factor (3.0 p.u. recovery voltage) for capacitance current testing in IEEE Std C37.09-1999.

C.2 Explanatory note on NSDDs (4.10.11.3)

NSDDs have been observed under laboratory test conditions but have not been identified in actual service.

An NSDD exhibits itself as a partial voltage change. Such changes can sometimes be clearly seen with normal time resolution measurements. This is particularly true in three-phase ungrounded tests when the same polarity and magnitude of voltage change is observed in all three phases as a result of a shift in the voltage of the inherent capacitance to ground of an ungrounded load produced by an NSDD. In other cases, a clear identification of an NSDD may require a short time resolution measurement to observe the high-frequency current or voltage pulse of an NSDD.

The occurrence of NSDDs should not be viewed as a sign of distress of the switching device. Therefore, their number is of no significance to interrupting performance of the device under test and need not be remarked upon in the test report.

C.3 Explanatory note regarding capacitance current switching tests (4.10.2)

C.3.1 Restrike performance

As all circuit-breakers have a certain restrike probability in service, it is not possible to define a restrike-free circuit-breaker. Instead, it appears more logical to introduce the notion of a restrike performance in service.

The level of restrike probability also depends on the service conditions (e.g., insulation coordination, number of operations per year, maintenance policy of the user), so it is impossible to introduce a common probability level related to service condition.

To classify their restrike performance, three classes of circuit-breakers are therefore introduced: class C0, class C1, and class C2.

C.3.2 Test program

In defining the test program for these three classes, the following elements have been taken into account:

— The average number of operations per year carried out by circuit-breakers switching capacitive loads.

— The ability to reduce the number of tests by performing an increased number of switching operations at the minimum arcing time, usually the most difficult capacitive switching operation for circuit-breakers, thus keeping a high level of reliability.

— The recommendations of CIGRE working group 13.04 (ELECTRA No 155 [B2]) The expected restrike probability is exclusively related to the type tests. Due to the severity of the type tests, an improved switching performance in service can be expected.

The proposed number of tests may be questioned because of different assumptions for probability calculations. Nevertheless, these values represent a good compromise (which is the role of the standard where conflicting views exist), reflecting the needs of users (in response to market demand) and above all they avoid unrealistic demands. These tests are not reliability tests, but type tests to demonstrate the satisfactory capacitance current switching capability of the equipment in service.

C.4 Referring to 4.10.3

The variation of the power frequency voltage has been chosen as 5% for test-duties (LC2, CC2, and BC2) and 2% for test-duties (LC1, CC1, and BC1). These values are a compromise, taking limitations of testing laboratories into account. Considering the design test as a whole, because of the different stresses in the individual test-duties, any undue reduction of the electric stress during the tests is avoided. The actual values for the power frequency voltage variation depending on the short-circuit power of the system and the capacitive load) is in the range of 0.1% to 5%.

C.5 Referring to 4.10.9.1.1

Close-open operations may be performed with no-load closing operations. In any case, the complete sequence shall be tested in order to test the circuit-breaker during opening in a dynamic condition, i.e., during the motion of the fluid caused by the previous closing operation.

C.6 Referring to 4.10.9.1.1 and 4.10.9.2.1

The test sequences have been tested in a laboratory (particularly the adjustment of the minimum arcing time by steps of 300 microseconds) and are well adapted to the philosophy of the tests.

Performing some tests at rated pressure is a more pragmatic approach to the notion of type testing, knowing that the circuit-breaker does not always stand under the worst functioning conditions. Additionally, flow dynamics could make testing at full pressure more susceptible to restrikes than at minimum pressure.

C.7 Referring to 4.10.9.1.2 and 4.10.9.1.3

In test-duty CS2 of single-phase line-charging and cable-charging tests (LC2 and CC2), the tests are split into open operations and close-open operations (4.10.9.1.3) to follow more or less the actual service conditions. However, for practical reasons, due to the small number of tests, in three-phase tests (4.10.9.1.2) in test-duty CS2 (LC2 and CC2), close-open operations are performed exclusively.

C.8 Referring to 4.10.9.1.2. to 4.10.9.1.5

Close-open operations are important for capacitor bank switching because of the effect of inrush current. Close-open operations are not significant for line- or cable-switching applications, therefore for line- and cable-switching tests, only a small number of close-open operations are requested (closing may be performed as a no-load operation).

A rough parity of the number of three-phase and single-phase tests has been maintained.

The mandatory order for capacitor bank switching tests is due to the necessity to introduce the effect of inrush current at the beginning of the tests.

C.9 Referring to 4.10.9.1.4 and 4.10.9.1.5

Because of the large number of operations in actual service compared with the limited number of operations during type testing, a high number (80 or 120 respectively) of close-open operations shall be carried out in capacitor bank tests to simulate the wear in service even if the close-open operation is not the normal switching sequence.

For capacitor bank switching tests test-duty CS1 (BC1) also needs to be performed, even if the actual service switching duty is always at 100% nominal current, for the following reasons:

— The tests at 10–40% nominal current cover an increased number of actual currents
— Knowledge of the capacitance current switching performance is improved

C.10 Referring to 4.10.9.2

Requirements for class C1 tests are derived from IEEE C37.09-1979 except the restrike is moved from 120 degrees to 90 degrees.

C.11 Referring to 4.10.10 and Table 3

To derive these variables from ANSI C37.06-2000

$$t_1 \geq T_2$$

where:

T_2 is taken from Table 1 column 6 for indoor circuit breakers, Table 2 column 6 for outdoor circuit breakers rated 72.7 kV and below, and Table 3 column 5 for outdoor circuit breakers rated 123 kV and above.

C.12 Summary of required number of tests and voltage factors

Capacitance current switching Rating assigned	Rated voltage range	Single-phase test voltage factor	Number of tests		
			Class C2		Class C1
			Three phase	Single phase	Single or three phase
Line Charging or Cable Charging	$V \leq 72.5$ kV	1.4	48	96	48
Line or cable Charging with ground fault present		1.7	Not applicable	Not required	24
Capacitor Bank		1.4	104	168	48
Capacitor bank with ground fault present		1.7	Not applicable	Not required	24
Line Charging	$V > 72.5$ kV and < 362 kV	1.2	48	96	48
Line or cable Charging with ground fault present		1.4	Not applicable	48	24
Capacitor Bank (or cable charging)		1.0 (1.0)	104 (48)	168 (96)	48 (48)
Capacitor bank (or cable Charging) with ground fault present		1.4	Not applicable	84	24
Line Charging	$V \geq 362$ kV	1.4	Not applicable	48	24
Line Charging with ground fault present		Covered above. This is the basic requirement.			
Capacitor Bank (or cable charging)		1.0 (1.0)	104 (48)	168 (96)	48 (48)
Capacitor bank (or Cable charging) with ground fault present		1.4 (1.4)	Not applicable	84 (48)	24 (24)

Annex D

(informative)

Bibliography

[B1] ANSI C37.06-2000, American National Standard for Preferred Ratings for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

[B2] ELECTRA No. 155, August 1994.

[B3] IEC 62271-100, High-Voltage Alternating Current Circuit Breakers.[3]

[B4] IEEE Std C37.04a-2003, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Amendment 1: Capacitance Current Switching.[4, 5]

[B5] IEEE Std C37.012-1979 (Reaff 1988), IEEE Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

[B6] IEEE Std 1036-1992, IEEE Guide for Application of Shunt Power Capacitors.

[3]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, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

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