

IEEE Standard Test Procedures for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V

IEEE Power and Energy Society

Sponsored by the
Switchgear Committee

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

IEEE Std C37.09™-2018
(Revision of
IEEE Std C37.09-1999)

IEEE Standard Test Procedures for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V

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Approved 5 December 2018

IEEE-SA Standards Board

Abstract: The testing procedures for all high-voltage circuit breakers that include voltage ratings above 1000 V ac and comprise both indoor and outdoor types having the preferred ratings as listed in IEEE Std C37.04™ are covered. Typical circuit breakers covered by these standards have maximum voltage ratings from 4.76 kV through 800 kV, and continuous current ratings of 600 A through 5000 A associated with the various maximum voltage ratings. The test procedures verify all assigned ratings, including continuous current, dielectric withstand voltages, short-circuit current, transient recovery voltage, and capacitor switching, plus associated capabilities such as mechanical endurance, load current, and out-of-phase switching. Production test procedures are also included. This standard does not cover generator circuit breakers as these are covered in IEC/IEEE 62271-37-013.

Keywords: arcing time, direct test, IEEE C37.09™, mechanical endurance, operating duty, power frequency, short-circuit current, short-line fault, single-phase testing, synthetic test, test data reporting, three-phase testing, transient recovery voltage, unit test

The Institute of Electrical and Electronics Engineers, Inc.
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PDF: ISBN 978-1-5044-5437-7 STD23486
Print: ISBN 978-1-5044-5438-4 STDPD23486

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Introduction

This introduction is not part of IEEE Std C37.09-2018, IEEE Standard Test Procedures for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V.

This standard is a major revision of IEEE Std C37.09™-1999 [B23]¹ that includes IEEE Std C37.09a™-2005 [B25] and IEEE Std C37.09b™-2010 [B26]. This standard is coordinated with IEEE Std C37.017™ and with the revisions to IEEE Std C37.04™ (in progress)² that incorporate amendments IEEE Std C37.04a™-2003 [B20] and IEEE Std C37.04b™-2008 [B21], rating information previously in IEEE Std C37.06™-2009 [B22], and information previously in NEMA SG4-2009 [B37]. In addition, the requirements have been, when appropriate, harmonized with the most recent IEC standards. Most of the figures are updated with improved quality. This revision is not intended to imply or require that any additional tests or retesting of existing ac high-voltage circuit breakers tested and qualified to the previous edition of this standard are necessary.

For information and guidance, some clauses with substantive changes are listed as follows:

- Interrupting time tests (4.7)
- Demonstration of arcing times (4.8.2.3)
- Single-phase or three-phase test duties for short-circuit current tests (Table 1)
- Splitting of test duties (4.8.3.4)
- Multipart testing (4.8.3.7)
- Load current switching tests (4.9)
- Capacitance current switching tests (4.10)
- Out-of-phase switching current tests (4.12)

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Color is essential to the understanding of the graphics.

¹ The numbers in brackets correspond to those of the bibliography in Annex E.

² Information on references can be found in Clause 2.

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IEEE Standard Test Procedures for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V

1. Scope

This standard applies to ac high-voltage circuit breakers with rated maximum voltage above 1000 V. It defines various tests that are made on ac high-voltage circuit breakers, except for generator circuit breakers, which are covered in IEC/IEEE 62271-37-013:2015 [B14]³ (formerly IEEE Std C37.013™-1997 [B29]). It specifies the tests and describes the accepted methods used to verify assigned ratings defined in IEEE Std C37.04™.⁴ It also describes the test procedures associated with production and field installation.

The test procedures are divided into the following classifications:

- a) Design tests
- b) Production tests
- c) Conformance tests
- d) Field tests

NOTE—Design tests are referred to as “Type” tests, and Production tests are referred to as “Routine” tests in IEC standards.⁵

2. Normative references

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

ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels.⁶

³ The numbers in brackets correspond to those of the bibliography in Annex E.

⁴ Information on references can be found in Clause 2.

⁵ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

⁶ ASME publications are available from the American Society of Mechanical Engineers (<http://www.asme.org/>).

IEC 60068-2-17, Basic Environmental Testing Procedures—Part 2: Tests—Test Q: Sealing.⁷

IEC 62271-4, High-voltage Switchgear and Controlgear—Part 4: Handling Procedures for Sulfur Hexafluoride (SF₆) and Its Mixtures.

IEC 62271-100, High-Voltage Switchgear and Controlgear—Part 100: Alternating-Current Circuit Breakers.

IEC 62271-101, High-voltage Switchgear and Controlgear—Part 101: Synthetic Testing.

IEC 62271-110, High-voltage Switchgear and Controlgear—Part 110: Inductive Load Switching.

IEC/IEEE 62271-37-082, High-Voltage Switchgear and Controlgear—Part 37-082: Standard Practice for the Measurement of Sound Pressure Levels on Alternating Current Circuit Breakers.^{8, 9}

IEEE Std 4™, IEEE Standard for High-Voltage Testing Techniques.

IEEE Std C37.04™, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers.

IEEE Std C37.06.1™-2017, IEEE Recommended Practice for Preferred Ratings for High-Voltage (>1000 volts) AC Circuit Breakers Designated Definite Purpose for Fast Transient Recovery Voltage Rise Times.

IEEE Std C37.012™, IEEE Guide for the Application of Capacitance Current Switching for AC High-Voltage Circuit Breakers Above 1000 V.

IEEE Std C37.017™, IEEE Standard for Bushings for High-Voltage [Over 1000V (AC)] Circuit Breakers and Gas-Insulated Switchgear.

IEEE Std C37.20.2™, IEEE Standard for Metal-Clad Switchgear.

IEEE Std C37.20.3™, IEEE Standard for Metal-Enclosed Interrupter Switchgear (1 kV–38 kV).

IEEE Std C37.100.1™-2007, IEEE Standard of Common Requirements for High Voltage Power Switchgear Rated Above 1000 V.

IEEE Std C57.13™, IEEE Standard Requirements for Instrument Transformers.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹⁰

These definitions are not intended to embrace all possible meanings of the terms. They are intended solely to establish the meaning of terms used in power switchgear.

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¹⁰ *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org/>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

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.

interrupting window: Range of arcing times for which a circuit breaker or a pole of circuit breaker is required to interrupt.

loop: Part of the wave of the current embraced by two successive current zero crossings. Note that a distinction is made between a major loop and a minor loop depending on the time interval between two successive current zero crossings being longer or shorter than the half-period of the alternating component of the current.

minimum arcing time: Shortest interval of time between the instant of the initiation of an arc and the instant of arc extinction.

minimum clearing time: Sum of the minimum opening time, minimum relay time (0.5 cycle), and the shortest arcing time of a minor loop interruption in the phase with intermediate asymmetry that starts with a minor loop at short-circuit current initiation. Note that this definition is applicable only for the determination of the test parameters during short-circuit breaking tests according to test duty T100a in a circuit with a time constant of 45 ms.

minimum opening time: Shortest possible interval of time between the initiation of the opening command signal and the instant when the arcing contacts have separated in all poles under defined operating conditions.

4. Design tests

4.1 General

The design tests described in this test procedure provide methods of demonstrating the capability of a circuit breaker to meet the ratings listed in IEEE Std C37.04. This revision is not intended to imply or require that any additional tests or retesting of existing ac high-voltage circuit breakers tested and qualified to the previous edition of this standard are necessary.

4.2 Maximum voltage tests

The ability of the circuit breaker to operate successfully at rated maximum voltage is demonstrated by performing short-circuit current interruption and other current switching rating tests in accordance with Table 1 and specified values of circuit transient recovery voltage (TRV), as given in IEEE Std C37.04.

4.3 Power frequency tests

The ability of a circuit breaker to operate successfully at rated power frequency is demonstrated by performing all tests at rated power frequency $\pm 10\%$ or when tests at either 50 Hz or 60 Hz are specifically allowed by the standards to qualify for both frequencies.

4.4 Continuous current-carrying tests

4.4.1 General

Continuous current-carrying tests demonstrate that the circuit breaker can carry its rated continuous current, at its rated power frequency, without exceeding any of the temperature limitations given in IEEE Std C37.04.

4.4.2 Test conditions

The following test conditions shall be met:

- a) The ambient temperature shall be between 10 °C and 40 °C, so that no correction factors need to be applied.
- b) If ambient air flow can affect the test results, the air velocity should be limited to no more than 0.5 m/s.
- c) The circuit breaker shall be tested under all other usual service conditions (refer to IEEE Std C37.04), except as stated in item a).
- d) Enclosed circuit breakers shall be tested in their enclosures.
- e) Other accessories normally connected in series and closely associated with the circuit breaker, such as current transformers, primary disconnecting contacts, cell-mounted auxiliary switches, buses, and connectors, shall be mounted in their regular position.
- f) Circuit breakers normally equipped with current transformers shall be tested with transformers in place and connected to carry rated secondary current.
- g) Circuit breakers shall be in a new condition and properly adjusted according to the product specification provided by the manufacturer.
- h) Tests demonstrating current-carrying ability shall be made at rated power frequency except when tests are performed at 60 Hz; they shall then be considered to be valid for the same current rating with 50-Hz rated power frequency.
- i) Circuit breakers installed outdoors, which are normally installed in such a manner that other connected apparatus have no appreciable effect on the circuit breaker temperature, shall be tested with cables or buses of a size corresponding to the circuit breaker current rating connected to the circuit breaker terminals by means of typical terminal connectors of corresponding rating. External conductors connected to the test specimen for continuous current tests shall be such that no significant amount of heat is conducted away from or to the test object, compared with the connections intended to be used for service. The temperatures at the terminals of the main circuit and at the temporary connections at a distance of 1 m from the terminals shall be measured. The difference in temperature rise shall not exceed 5 K. The type and size of temporary connections shall be recorded in the test report.
- j) Circuit breakers for use in metal-enclosed or metal-clad switchgear shall be tested in a minimum volume enclosure or in the actual switchgear vertical section compartment. Connections to the switchgear shall be made in accordance with the appropriate switchgear standards.

4.4.3 Test circuit breaker configurations

The following test circuit breaker configurations shall be met:

- a) Three-phase circuit breakers shall be tested on a three-phase basis except when there is no possibility of magnetic or thermal influence between poles or modular units.
- b) When there is no possibility of magnetic influence, but there may be thermal influence from other phases of the circuit breaker, tests may be made with single-phase current passed through the three poles in series.
- c) Single-phase tests may be made on a single pole of a circuit breaker or in a single component of modular units.

4.4.4 Duration of continuous current tests

The continuous current shall be maintained for a period such that the temperature rise of every monitored point in the assembly has not changed by more than 1.0 °C as indicated by three successive readings at 30-min intervals.

The equipment is considered to have passed the test if the established temperature limits and temperature rise limits specified in IEEE Std C37.04 have not been exceeded in any of the last three readings.

4.4.5 Measurement of temperatures

Temperatures shall be measured by any of the following methods:

- a) Thermocouple
- b) Thermometer (allowed method only for ambient temperature measurements; not acceptable for temperature measurement of current-carrying components)
- c) Resistance (preferred method for measuring coil temperatures)

The measuring device shall be located at a point where measurement of the hottest accessible spot can be made. Measurements shall be made at junction points of insulation and conducting parts to prevent exceeding temperature limits of the insulation. Holes that destroy the effectiveness of the test (such as in multiturn coils) shall not be drilled.

4.4.6 Determination of ambient temperatures

The ambient temperature is the average temperature of the surrounding air, external to the circuit breaker enclosures.

The ambient temperature shall be between 10 °C and 40 °C, so that no correction factors need be applied. The ambient temperature shall be determined by taking the average of the readings of three measurements that are made at locations unaffected by drafts approximately 300 mm (12 in), away, horizontally, from the projected periphery of the circuit breaker or enclosure (for circuit breakers used in metal-enclosed or metal-clad switchgear, refer to the requirements in IEEE Std C37.20.2™ or IEEE Std C37.20.3™, as applicable), and approximately in line, vertically, as follows:

- a) One approximately 300 mm (12 in) above the circuit breaker or enclosure (including bushings).
- b) One approximately 300 mm (12 in) below the circuit breaker or enclosure. In the case of floor-mounted circuit breakers or enclosures, it shall be 300 mm (12 in) above the floor or mounting base.
- c) One approximately midway between the above two positions.

To avoid errors that are due to the time lag between the temperature of large apparatus and the variations in the ambient temperature, the measuring device used for determining the ambient temperature shall be immersed in a suitable liquid, such as oil, which is contained in a suitable heavy metal cup; or bonded directly to a heavy metal plate of at least 6 mm of thickness and 25 mm on each side or bolted between two plates of at least 6 mm of thickness and 12 mm on each side.

A convenient form of such an oil cup consists of a metal cylinder with a hole drilled partly through it. The hole is filled with oil, and the sensing portion of the measuring device is then fully immersed in it. The response of this method to various rates of temperature change will depend primarily on the kind of material and the overall mass of the containing cup. The response may be further regulated by adjusting the amount of liquid in the cup. The larger the apparatus under test, the larger shall be the metal cylinder employed as an oil cup. The smallest size oil cup employed in any case shall consist of a metal cylinder, 25 mm (1 in) in diameter and 50 mm (2 in) in height.

4.4.7 Measurement of the resistance of the main circuit

The measurement of the resistance of the main circuit shall be made for future comparison between the circuit breaker originally design tested and all other circuit breakers of the same type subjected to routine tests.

The measurement shall be made with a dc source by measuring the voltage drop or resistance across the terminals of each pole. The current during the test shall have any convenient value between 100 A and the rated continuous current.

The measurement of the dc voltage drop or the resistance shall be made before the temperature rise test, with the circuit breaker at the prevailing ambient temperature, and then again after completion of the temperature rise test when the temperature of the test circuit breaker has returned to within 10 °C of ambient temperature.

NOTE—Resistance measurement is not a pass–fail criterion, but it is important for establishing references for production and field tests. Experience shows that an increase in the main circuit resistance may not be a reliable evidence of a bad contact or connection.

4.5 Dielectric withstand tests

4.5.1 General

The dielectric withstand capability of a circuit breaker is demonstrated by subjecting it to a power frequency, a lightning impulse test, and when required, a chopped wave lightning impulse and a switching impulse test, at an average voltage level equal to or greater than those that have been specified in IEEE Std C37.04.

4.5.2 Tests conditions

The following dielectric withstand test conditions shall be met:

- a) Withstand tests on circuit breakers shall be made under atmospheric pressure, temperature, and humidity conditions normally prevailing at the testing facility.
- b) The circuit breaker shall be clean and in good condition, and it shall not have been put into commercial operation.
- c) Sealed interrupters that use a pressurized gas shall be tested at the minimum specified operating pressure of the interrupter.
- d) If gaps are to be permanently mounted in parallel with the insulation structure, they shall be in place during all dielectric tests.
- e) The values of correction factors for atmospheric pressure and atmospheric humidity to be used for impulse and power frequency tests shall be taken from IEEE Std 4™ curves and formulas, except when otherwise noted.
- f) The bushing and rod gap correction factors will not always have the optimum accuracy for a specific design of circuit breaker. In cases when more accurate correction factors can be made available for a specific design or class of designs, they may be used.
- g) When revisions in correction factors in IEEE Std 4 are made, they shall be applicable to new designs only and it shall not be necessary to repeat design tests on designs for which such tests have been completed.
- h) Dielectric test voltages shall be measured in accordance with IEEE Std 4 voltage measurement standards.
- i) The configuration of the circuit breaker may cause a test on one terminal to produce the same electric stress distribution as a test on one or more of the other terminals. When this situation prevails, and test procedure B of IEEE Std 4 (e.g., “15/2 method”) is being used, it shall be necessary to apply voltage only to those terminals that produce different distributions of electric

stress. When test procedure C of IEEE Std 4 (e.g., “3 × 9 method”) is being used, all three poles must be tested.

- j) Tests, as described in the following clauses, shall be conducted on the complete three-pole circuit breaker. However, single-pole tests for outdoor circuit breakers shall be sufficient when adjacent poles have substantially no influence or are simulated by ground shields.
- k) Circuit breakers for use in metal-enclosed or metal-clad switchgear shall be tested in a minimum volume enclosure or in the actual switchgear vertical section compartment. The exact compartment location shall be denoted in the test report if multiple vertical compartments are used.
- l) For dry switching impulse tests, which are only applicable to circuit breakers rated 362 kV and above, atmospheric temperature and pressure correction factors shall be applied to define the test voltage. At the manufacturer’s option, the humidity correction factor may be applied.
- m) For wet switching impulse and wet power frequency tests, atmospheric temperature and pressure correction factor shall be applied to define the test voltage. However, the humidity correction factor shall not be applied.
- n) For lightning impulse and chopped wave tests, atmospheric temperature and pressure correction factors shall be applied to define the test voltage. For circuit breakers intended for installation outdoors, at the manufacturer’s option, the humidity correction factor may be applied. For circuit breakers for use in metal-enclosed or metal-clad switchgear, the use of humidity correction factors is required (see appropriate switchgear standard). When applicable, IEEE Std 4 method 2 may be followed.
- o) Handling and use of sulfur hexafluoride (SF₆) gas during manufacture test, and related operations shall be in accordance with IEC 62271-4.
- p) Tolerance of ±3% in the peak shall be allowed for a single impulse test. The test shall be valid as long as the average corrected test voltage peak is on the positive tolerance side.

4.5.3 Insulation paths

4.5.3.1 General

When performing dielectric tests, the following two classes of insulation paths are to be considered:

- a) **Atmospheric paths:** Paths entirely through atmospheric air, such as along the insulator surface of an outdoor bushing.
- b) **Nonatmospheric paths:** All other paths, such as through a gas or a vacuum sealed from the atmosphere, through a liquid such as oil, through a solid, or through a combination thereof.

4.5.3.2 Atmospheric paths

There is no separate atmospheric path requirement for the dielectric tests.

4.5.3.3 Nonatmospheric paths

No correction factors shall be used for testing nonatmospheric paths dielectric withstand capabilities. The purpose is to apply full stresses to these nonatmospheric paths. Therefore, tests in which a flashover occurs through an atmospheric path may be ignored. It is permissible to raise the dielectric strength of the atmospheric paths by artificial means, such as an extra high-voltage shield or a corona ring.

In some atmospheric conditions, it may be desirable to delay testing of the nonatmospheric paths until conditions improve.

4.5.4 Power frequency withstand voltage tests

4.5.4.1 Dry tests procedure

The dry tests are conducted to determine the ability of the circuit breaker to withstand its assigned rated power frequency withstand voltage. The rated root-mean-square (rms) power frequency withstand voltage values are listed in IEEE Std C37.04. The voltage test frequency shall be between 45 Hz and 65 Hz.

The tests shall be performed in accordance with the requirements of IEEE Std 4. The voltage shall be applied to the terminals of the circuit breaker for duration of 1 min, in any desired order, under the following conditions:

- a) With the circuit breaker contacts open, apply the specified test voltage to each terminal of the circuit breaker individually with all other terminals and the frame of the circuit breaker grounded.
- b) With the circuit breaker contacts closed, apply the specified test voltage to each phase of the circuit breaker individually with the other phases and the frame of the circuit breaker grounded.

There shall be no flashovers during the tests, and no damage to the insulation shall be observed after the tests.

4.5.4.2 Wet tests procedure

The wet tests are conducted only on circuit breakers intended for installation outdoors or on external components such as bushings, in accordance with the procedure described in IEEE Std C37.017™. For those bushings, when their voltage distribution is negligibly influenced by their surroundings, and when they have been tested separately as individual bushings in accordance with IEEE Std C37.017, the tests need not be repeated in the assembled circuit breaker.

4.5.5 Full-wave lightning impulse withstand voltage tests

These tests are conducted on circuit breakers, under dry conditions, to verify their ability to withstand their rated full-wave lightning impulse withstand voltages. In these tests, both positive and negative, lightning impulse voltages having an average peak value equal to or greater than the rated full-wave lightning impulse withstand voltage, as specified in IEEE Std C37.04, shall be applied to the terminals of the circuit breaker.

Note that some insulating materials retain a charge after an impulse test. For these cases, care should be taken when reversing the polarity of the test voltage. To allow the insulating materials to discharge, the use of appropriate methods, such as the application of impulses of the reverse polarity at lower voltages (50% to 75% of rated value), are recommended.

When testing switchgear incorporating an open vacuum interrupter, for each polarity, a maximum of 25 preliminary impulse tests may be performed at up to and including the rated withstand voltage. The number and level of preliminary impulses is to be stated by the manufacturer. Breakdowns that are observed during these preliminary tests shall be disregarded for the purposes of the withstand statistics used to determine the pass or fail performance of the equipment.

4.5.5.1 Waveform for lightning impulse tests

The waveform and application of the full-wave test voltage shall be as described in IEEE Std 4 and shall have the following limits:

- a) Full-wave test voltage with a virtual front time based on the rated full wave impulse test voltage, equal to or less than 1.2 μ s
- b) Average peak voltage equal to or greater than the rated full wave impulse voltage
- c) Time to the 50% value of the peak voltage, equal to or greater than 50 μ s

If the capacitance or resistance of the test circuit breaker prevents obtaining the standard impulse waveform, the closest obtainable waveform should be used, subject to agreement between the user and the manufacturer.

4.5.5.2 Test procedure

The test procedure shall consist of the following tests performed in any order:

- a) With the circuit breaker contacts open:
 - 1) Apply a group of three consecutive positive lightning impulse voltage waves to each terminal of the circuit breaker individually with all other terminals and frame grounded.
 - 2) Apply a group of three consecutive negative lightning impulse voltage waves to each terminal of the circuit breaker individually with all other terminals and frame grounded.
- b) With the circuit breaker contacts closed:
 - 1) Apply a group of three consecutive positive lightning impulse voltage waves individually to each phase of the circuit breaker with the other phases and the frame grounded.
 - 2) Apply a group of three consecutive negative lightning impulse voltage waves individually to each phase of the circuit breaker with the other phases and the frame grounded.

If, during the first group of three consecutive tests as applied in item a) and item b), a disruptive discharge occurs on one test of a group, a second group of nine tests shall be made. If the circuit breaker successfully withstands all nine of the second group of tests, the disruptive discharge in the first group shall be considered a random disruptive discharge and the circuit breaker has passed the test. If another disruptive discharge occurs in the second group of the test, the test is failed.

NOTE 1—This is the preferred procedure. It is often referred to as the 3×9 procedure or procedure C in IEEE Std 4.

As an alternative to the test described in this subclause, 15 consecutive lightning or switching impulses at the rated withstand voltage may be applied for each test condition and each polarity. The equipment has passed the impulse tests if all the following conditions are fulfilled:

- Each series has at least 15 tests.
- No disruptive discharges on non-self-restoring insulation shall occur. This is confirmed by five consecutive impulse withstands following the last disruptive discharge.
- The number of disruptive discharges shall not exceed two for each complete series.

This procedure leads to a maximum possible number of 25 impulses per series.

NOTE 2—This procedure is referred to as the 15/2 procedure or procedure B in IEEE Std 4 and IEC 60060-1:2010 [B8].

The determination of the location of the observed disruptive discharges can be done by the laboratory by dismantling and inspecting the equipment. If punctures of non-self-restoring insulation or tracking marks on the nonatmospheric paths of an insulator are observed, the equipment has failed the test.

4.5.6 Impulse voltage test for interrupters and resistors

An additional impulse test is made on circuit breakers that have a rated maximum voltage above 100 kV and that have isolating gaps in series with the interrupting gaps, or have additional gaps in the resistor or capacitor circuits.

An impulse voltage having a value and a waveform as specified in IEEE Std C37.04 shall be used. With all isolating gaps and with the gaps in the resistor and capacitor circuits closed, positive and negative waves shall be applied three times to each terminal of a pole unit with the other terminal grounded. No damage of the solid interrupter insulation, associated resistors, or capacitors shall occur.

4.5.7 Chopped wave lightning impulse withstand voltage tests

These tests shall be performed on circuit breakers intended for installation outdoors that have a rated maximum voltage of 15.5 kV or greater to verify their ability to withstand their assigned rated chopped wave lightning impulse withstand voltage.

The magnitudes of these voltages are given in IEEE Std C37.04. They shall be applied to the terminals of the circuit breaker, without causing damage or producing a flashover, following the same procedure as that described in 4.5.5.2.

The waveform and application of the chopped wave test voltage, and the type of rod gap and its location, shall be as described in IEEE Std 4.

The chopped wave shall have the following limits:

- a) The virtual front time, based on the rated chopped wave test voltage, shall be equal to or less than 1.2 μ s.
- b) The peak voltage shall be equal to or greater than the rated chopped wave test voltage.
- c) The time to the point of chop on the tail of the wave shall be no less than the times specified in IEEE Std C37.04. If the capacitance of a test sample is too high for test equipment to be able to produce a virtual front time as short as 1.2 μ s, while maintaining the peak value, the most rapid rise obtainable may be used, subject to agreement between the user and the manufacturer.

Note that flashovers external to the circuit breaker at the specified chop times, or longer, do not constitute failure to pass the test.

4.5.8 Switching impulse voltage withstand tests

Tests are made under wet and dry conditions on circuit breakers rated 362 kV and above to verify their ability to withstand their assigned rated switching impulse withstand voltages to ground and across the open gap of the circuit breaker. The test procedure is identical to that described in 4.5.5.2 for the open and closed circuit breaker, except that instead of a lightning impulse wave, a switching impulse wave of both polarities shall be used. The waveform shall be as defined in 4.5.8.1 and shall have a peak value equal to or greater than the rated switching impulse withstand voltage specified in IEEE Std C37.04.

When testing the open circuit breaker on the first group of three consecutive tests, any external flashover to ground at the energized terminal of the circuit breaker will be considered to be a withstand across the open break. One flashover across the circuit breaker, either external or internal across the open contacts, is allowed within the first three tests, provided there is no recurrence in the test series. Any flashovers shall cause no damage and shall be indicated in the test record.

When testing the closed circuit breaker on the first group of three consecutive tests, the one permissible flashover shall be external to the circuit breaker and from any energized metallic part to ground or to grounded parts of adjacent phases. Any flashovers shall be indicated in the test record.

Note that the possibility of statistically random flashovers across the contacts is not precluded.

4.5.8.1 Waveform for switching impulse voltage tests

The waveform voltage shall be as described in IEEE Std 4 and shall have the following limits:

- a) Full-wave test voltage with a virtual front time, equal to 250 μ s $\pm$ 50 μ s.
- b) Peak voltage value equal to or greater than the rated switching impulse withstand voltage specified in IEEE Std C37.04.

- c) Time to the 50% value on the tail of the wave equal to $2500 \mu\text{s} \pm 1500 \mu\text{s}$.
- d) This waveform shall be obtained with the circuit breaker in the circuit.
- e) When flashovers occur on the front of the wave, the peak voltage value is defined as the peak of the voltage wave that would have been obtained if no flashover had occurred.

4.5.8.2 Condition of circuit breaker to be tested

Switching impulse voltage tests shall be made with the circuit breaker mounted at an elevation above the ground plane not exceeding the elevation of the actual installation. Supporting frames shall be the same as those used in service: they shall be grounded and the exposed metallic surface area shall be no less than the area used in service.

Conductors shall be connected to both circuit breaker terminals, and unless specifically indicated otherwise, the connecting conductors shall be mounted horizontally. The diameter of these conductors shall not be more than that which is normally used in service. The conductors may be terminated in spheres or rings that have a diameter whose dimension in meters does not exceed an equivalent numerical value that is equal to the circuit breaker rated maximum voltage (in kilovolts) divided by 655.

No additional rings and shielding shall be employed if they are not a permanent part of the circuit breaker in its application.

4.6 Standard operating duty (standard duty cycle) tests

The standard duty cycle is demonstrated by test duty T100s of Table 1.

4.7 Interrupting time tests

The interrupting time is established by adding the maximum contact opening time when measured at rated control voltage and rated operating pressure for mechanical operation to the maximum determined arcing time [t_{bm} , as calculated in Equation (1)] of the circuit breaker. The contact opening time of the circuit breaker shall be measured prior to the initiation of the short-circuit tests, under the pressures and control voltages specified in IEEE Std C37.04. The contact opening time corresponds to the elapsed time between the energization of the trip coil and the instant when the contacts separate.

The interrupting time of a circuit breaker is the maximum interval between the instant of initialization of the opening operation (i.e., energizing of the trip circuit) and the instant of interruption of the current in all three phases during terminal fault test duties T30, T60, and T100s specified in Table 1 under the following conditions:

- Rated auxiliary supply voltage and frequency
- Rated pressures for operation, insulation, and interruption

The operating times of some circuit breakers may vary with the auxiliary supply voltage. To verify the interrupting time during these test duties, the maximum interrupting time should be amended to take account of the lower auxiliary supply voltage and pressures as follows:

$$t_{b \max} = t_{bm} + t_w - (t_{om} - t_{or}) - T \times \frac{18^\circ}{360^\circ} \quad (1)$$

where

$t_{b \max}$ is the maximum determined interrupting time.

- t_{bm} is the longest of the three recorded minimum interrupting times of T30, T60, and T100s.
Note that t_{bm} corresponds to the last pole-to-clear in the case of a three-phase test. For single-phase tests done in substitution for three-phase tests, t_{we} is computed differently to account for this difference.
- t_w is the necessary interrupting window expressed in ms.
 $t_w = T \times t_{we} / 360^\circ$.
 T is the period of power frequency (20 ms for 50 Hz, 16.7 ms for 60 Hz).
 t_{we} is expressed in electrical degrees.
— for single-phase tests in substitution for three-phase conditions
— noneffectively grounded neutral systems: $t_{we} = 150 - d\alpha$.
— effectively grounded neutral systems: $t_{we} = 180 - d\alpha$.
— for three-phase tests
— $t_{we} = 60 - d\alpha$.
 $d\alpha$ is the tripping impulse step in the search for the minimum arcing time, it is equal to 18 electrical degrees.
- t_{om} is the maximum recorded opening time on no-load, with minimum auxiliary supply voltage and pressures for operation or interruption.
- t_{or} is the maximum recorded opening time on no-load, with rated auxiliary supply voltage and pressures for operation.

The determined interrupting time is reduced by $T \times 18^\circ / 360^\circ$ to take into account the precision in the determination of the minimum arcing time. The interrupting time is defined based on the minimum arcing time because the longest recorded arcing time during the tests can be longer than under the actual field condition.

If the maximum determined interrupting time ($t_{b \max}$) found in this procedure exceeds the interrupting time, then the test duty that has given the longest interrupting time may be repeated with auxiliary supply voltage and pressure for operation and interruption at their rated values.

NOTE—The interrupting time during a make-break operation may be longer than that of a single-break operation for some circuit breaker designs. Such longer interrupting times may impact system protection strategy and stability if the delay is longer than the relay time. Users should advise the manufacturer of the maximum allowable interrupting time during make-break operations.

4.8 Short-circuit current making and breaking tests

4.8.1 General

The short-circuit current interrupting rating of a circuit breaker is demonstrated by a series of tests. These tests demonstrate the rated short-circuit current and the related required capabilities of the circuit breaker for applications in either effectively and noneffectively grounded systems.

The test duties used to demonstrate the performance of a circuit breaker are listed in Table 1, where the test parameters are identified as follows:

- a) Test voltage E takes different values depending on the test conditions for duties T10 through T100a, where
 - 1) The power frequency recovery voltage during breaking tests with k_{pp} as the first pole-to-clear factor and U_r as the rated maximum voltage

$$E = \frac{k_{pp}}{\sqrt{3}} \times U_r$$

- 2) The applied phase-to-phase voltage during three-phase making tests on a three-pole circuit breaker

$$E = U_r$$

- 3) The applied voltage during single-phase making tests on a three-pole circuit breaker

$$E = \frac{U_r}{\sqrt{3}}$$

NOTE—With the manufacturer's consent, it is permissible, for convenience of testing, to apply a voltage equal to the product of the phase-to-ground voltage and the first-pole-to-clear factor (1.3 or 1.5) of the circuit-breaker.

- b) Test current I is equal to the maximum rated rms symmetrical interrupting current
c) Time t_r is equal to
1) 15 s for circuit breakers that are not rated for reclosing duty
2) 0.3 s for circuit breakers rated for reclosing duty
d) Time t_r' is equal to 3 min
e) Time T is equal to the specified time shown in IEEE Std C37.04 under the subclause for “Rated closing, latching, and short-time current-carrying capability”
f) $F = 2.6$ for 60 Hz or 2.5 for 50 Hz

Table 1—Single-phase or three-phase test duties for short-circuit current tests

Test duty	Operating duty	Test voltage (kV)	Making I [kA (pk)]	Short-circuit current (kA)	% asymmetry @ contact part
T10	O– t_r –CO– t_r' –CO	E		0.1 I	<20
T30	O– t_r –CO– t_r' –CO	E		0.3 I	<20
T60	O– t_r –CO– t_r' –CO	E		0.6 I	<20
T100s	O– t_r –CO– t_r' –CO or T100s(a) and T100s(b)	E	$F \times I$	I	<20
T100s(a)	C– t_r' –C	E	$F \times I$		
T100s(b)	O– t_r –O– t_r' –O	E		I	<20
T100a	Three Os	E		see 4.8.4.4	>20
Single-phase fault tests					
T100s 1ph	O				<20
T100a 1ph	O	$\frac{U_r}{\sqrt{3}}$		see 4.8.4.5	>20
Single-phase, short-line fault tests					
L75	Three Os	$\frac{U_r}{\sqrt{3}}$		0.7 I to 0.8 I	<20
L90	Three Os	$\frac{U_r}{\sqrt{3}}$		0.9 I to 0.95 I	<20
Short-time current test					
STC	Closed position		$F \times I$	I for T seconds	

Note that test duties T10, T30, T60, T100s, and T100a were formerly test duties 1, 2, 3, 4, and 5 in IEEE Std C37.09™-1999 [B23]. Test duties T100s 1ph and T100a 1ph were formerly test duties 6 and 7 in IEEE Std C37.09-1999. Test duties L75 and L90 were formerly test duties 8 and 9 in IEEE Std C37.09-1999. Test duty short-time current (STC) was formerly test duty 10 in IEEE Std C37.09-1999. The requirements for these tests have changed in some respects.

Circuit breakers previously tested to the requirements of the tests in IEEE Std C37.09-1999 [B23] do not require retesting unless the design changes in a manner that would affect performance.

The test method given in 4.8.2.3 for the demonstration of arcing times is for the direct test method, meaning that one test circuit provides both the test current and the voltage. However, due to the limitation on short-circuit capacities of some test laboratories, many interrupting tests are performed using synthetic test circuits when the test current and the voltage are from separate test circuits. IEC 62271-101 provides the procedure for synthetic testing.

4.8.2 Test conditions

4.8.2.1 Power factor

For short-circuit current interrupting tests, the power factor of the testing circuits shall not exceed 5.9% lagging, which is equivalent to $X/R = 17$ at 60 Hz, or 7.1% lagging, which is equivalent to $X/R = 14$ at 50 Hz.

4.8.2.2 Frequency of test circuit

Tests demonstrating short-circuit current interrupting capabilities shall be made at a rated power frequency. When performing tests at a frequency other than the rated power frequency, special consideration shall be given to the rate of change of current at current zero since performance of some interrupters is strongly influenced by the rate of change of current (di / dt) at the instant of current zero.

If a circuit breaker has been completely type-tested for a terminal fault at a given rated power frequency (50 Hz or 60 Hz), its terminal fault making and breaking capability at the other rated power frequency is demonstrated, for the same rated maximum voltage and the same first-pole-to-clear factor, if the additional tests indicated as follows are performed successfully:

- a) If a circuit breaker has been type-tested as defined in 4.8.2 to 4.8.6 for terminal fault making and breaking and a rated power frequency of 50 Hz:
 - 1) Test duty T100s shall be performed to prove the terminal fault breaking capability at 60 Hz if the SLF breaking capability has not been demonstrated at 60 Hz and if the peak making current during the T100s test at 50 Hz is less than 2.6 p.u.
 - 2) Test duty T100a shall be performed at 60 Hz unless the requirements on current asymmetry (peak value and duration of the major loop before interruption) and arcing time for 60 Hz are met during the tests at 50 Hz.
- b) If a circuit breaker has been type-tested as defined in 4.8.2 to 4.8.6 for terminal fault making and breaking and a rated power frequency of 60 Hz, test duties T100s and T100a shall be repeated at 50 Hz to prove the terminal fault making and breaking capability at 50 Hz.

For rated power frequencies above 60 Hz or below 50 Hz, which are beyond the scope of this standard, other test considerations may be required.

4.8.2.3 Demonstration of arcing time

4.8.2.3.1 General

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The procedures described in this subclause are relevant for the adjustment of prospective arcing times. The actual arcing times may vary from the prospective ones.

NOTE 1— The arcing times prescribed in this subclause are adequate to cover the effect of the unintentional nonsimultaneity of the circuit breaker poles.

NOTE 2— The test requirements are based on network conditions and are related to direct tests only. For synthetic tests, more detailed requirements may be applicable; see IEC 62271-101.

4.8.2.3.2 Arcing time for three-phase test duties T10, T30, T60, T100s, T100s(b), OP1, and OP2

For these tests, the tripping impulse shall be advanced by 40 electrical degrees (40°) between each opening operation.

NOTE—The intent of these requirements is to demonstrate performance over the full arc extinguishing window with three interruptions.

An example of a graphical representation of the three valid breaking operations for the first-pole-to-clear factor 1.5 is given in Figure 1 and for the first-pole-to-clear factor 1.3 in Figure 2. These figures are examples to illustrate short-circuit current waveforms only. The current and time values on the coordinates are not of significance.

The prospective short-circuit current to be interrupted by a circuit breaker shall be determined at the instant of contact separation.

For T100s, the average prospective rms current of the ac component obtained during three valid tests shall be equal to or greater than the required value. When three-phase tests are performed, the average prospective rms current of the ac component in all three phases shall be equal to or greater than the required value. To avoid overstressing the circuit breaker, the prospective current shall not exceed 110% of the required value.

For T10, T30, and T60 test duties, the average prospective rms current of the ac component obtained during three valid tests shall be within 5% of the required value. When three-phase tests are performed, the average prospective rms current in all shall not vary from the required value by more than 10%.

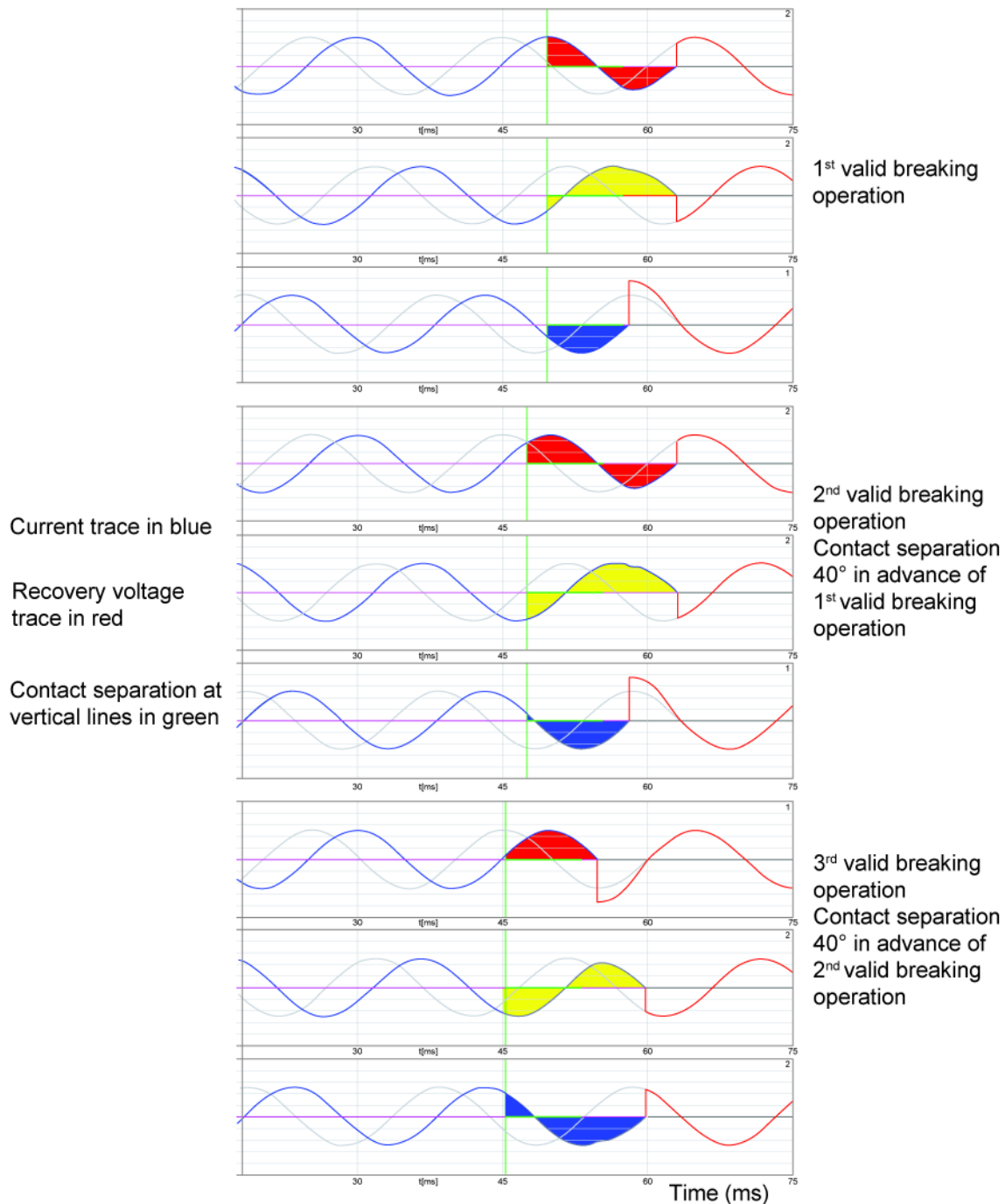


Figure 1—Example of three valid symmetrical operations for three-phase tests in a noneffectively grounded neutral system (first-pole-to-clear factor 1.5)

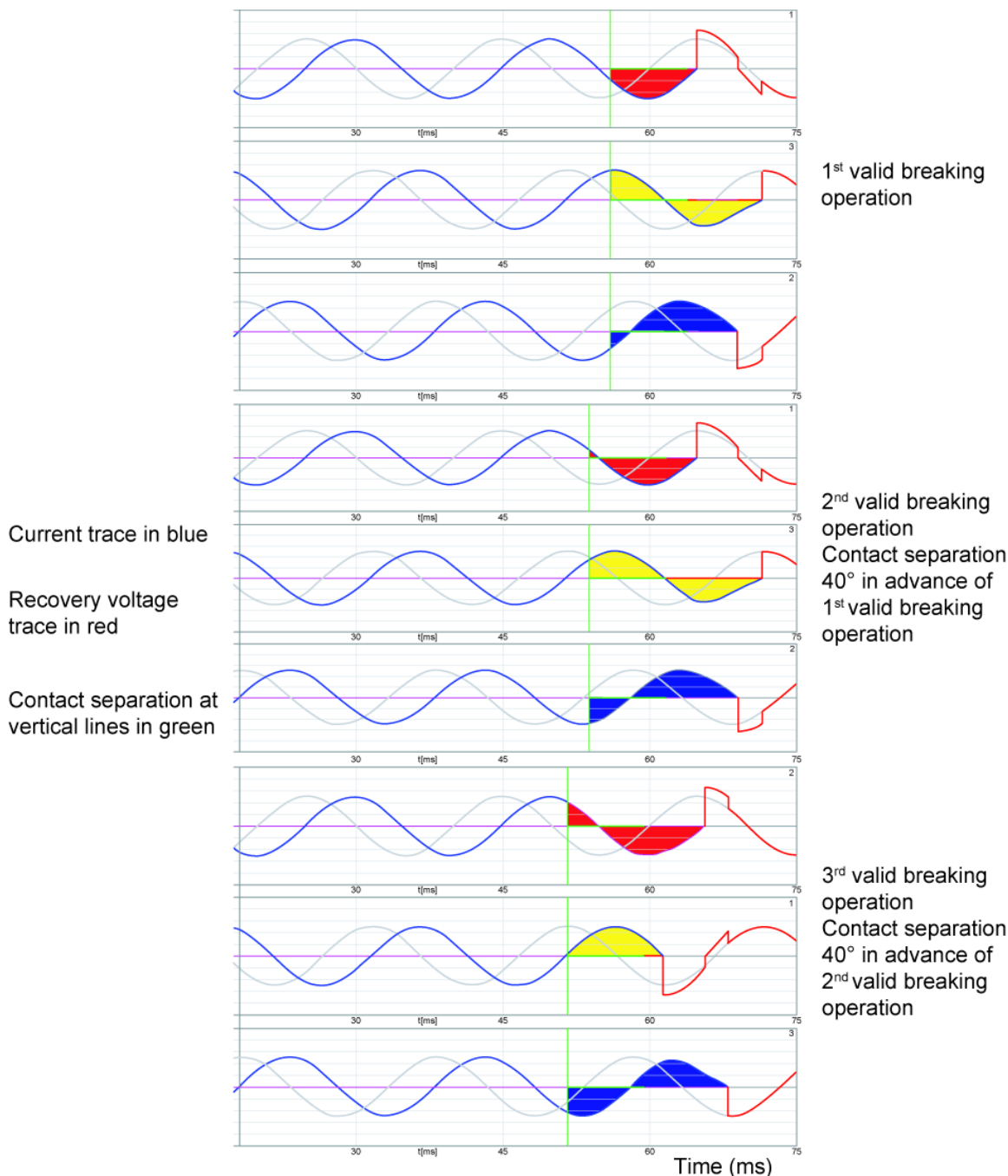


Figure 2—Example of three valid symmetrical operations for three-phase tests in an effectively grounded neutral system (first-pole-to-clear factor 1.3)

4.8.2.3.3 Arcing time for three-phase test duty T100a

Since the severity of the tests for this test duty can vary widely depending on the moment of contact separation, a procedure has been developed to arrive at realistic stresses on the circuit breaker under test. Annex C provides an explanation on the test procedure for T100a. The initiation of the short circuit is changed between tests to transfer the required asymmetry criteria from phase to phase.

The breaking operations are valid if the prospective current meets the following asymmetry criteria:

- The peak short-circuit current during the last loop prior to the interruption is between 90% and 110% of the required value.
- The duration of the short-circuit current loop prior to the interruption is between 90% and 110% of the required value.
- The product of the prospective short-circuit current peak value and the loop duration must be equal to or higher than 100% of the product of the specified values. Refer to Table 2 and Table 3.

Table 2 and Table 3 give the required values of the peak short-circuit current and loop duration that should be attained by the last loop prior to the interruption.

When the last current loop parameters are within the prescribed tolerances, the resulting deviations on the dc component at current zero, the associated di/dt and the following TRV peak value are within acceptable limits compared with those calculated with rated values.

The intention is to achieve a series of three valid tests, and the duty is satisfactory if the following conditions are met. There is no preferred order to demonstrate the three valid tests:

- a) One operation when arc extinction occurs in the first-pole-to-clear at the end of a major current loop in the first phase with the required asymmetry criteria and with the longest possible arcing time.
- b) The longest possible arcing time t_{arc1} for the first-pole-to-clear is achieved when the following condition is met:

$$t_{arc1} = \left(t_{a100s} - T \times \frac{d\alpha}{360^\circ} \right) + \Delta t_{a1}$$

- c) One operation when arc extinction occurs at the end of an extended major current loop in the second phase with the required asymmetry criteria and with the longest possible arcing time.
- d) The longest possible arcing time t_{arc2} for the last-pole-to-clear for circuit breakers intended to be used in noneffectively grounded neutral systems is achieved when the following condition is met:

$$t_{arc2} = \left(t_{a100s} - T \times \frac{d\alpha}{360^\circ} \right) + \Delta t_{a2}$$

- e) The longest possible arcing time t_{arc3} for the second-pole-to-clear for circuit breakers intended to be used in effectively grounded neutral systems is achieved when the following condition is met:

$$t_{arc3} = \left(t_{a100s} - T \times \frac{d\alpha}{360^\circ} \right) + \Delta t_{a3}$$

- f) If the required conditions of item a) and item b) are fulfilled, in the third operation, arc extinction may occur at the end

- 1) Of a major current loop for first-pole-to-clear conditions
- 2) Of an extended major current loop for last-pole-to-clear conditions for circuit breakers rated for $k_{pp} = 1.5$
- 3) Of an extended major current loop for second-pole-to-clear conditions for circuit breakers rated for $k_{pp} = 1.3$

There are no further requirements regarding the arcing times.

t_{a100s} is the minimum arcing time of terminal fault test duty T100s
 $\Delta t_{a1}, \Delta t_{a2}, \Delta t_{a3}$ are the relevant time parameters to be selected from Table 2 and Table 3
 $d\alpha$ is 18°

The conditions for current interruption in test duty T100a for the last-pole-to-clear for circuit breakers intended to be used in effectively grounded neutral systems are covered by the tests in test duty T100s. Therefore, no further requirements for the last-pole-to-clear conditions exist.

Some circuit breakers will not clear at the end of a major loop. Arcing then continues during the subsequent minor current loop. However, this test is considered valid if during a subsequent test, it is proven that the longest possible arc duration is achieved.

If the behavior of the circuit breaker is such that the required conditions of item c1) and item c2) are not fulfilled and the circuit breaker has not interrupted after a subsequent minor loop (case mentioned in the previous paragraph), the relevant tests shall be continued by changing the tripping of the circuit breaker in steps of 18° . If during tests the required arcing times are not achieved because of minimum arcing times differing from t_{a100s} , the maximum achievable arcing times shall be demonstrated. The total number of tests is limited to 6 when attempting to meet the earlier mentioned requirements. The test duty is valid no matter which arcing times have been obtained.

The circuit breaker may be reconditioned with renewable parts before the extended operations. An additional test sample can also be used for the extended operations.

A graphical representation of the three valid breaking operations for the first-pole-to-clear factor 1.5 is given in Figure 3 and for the first-pole-to-clear factor 1.3 in Figure 4. These figures are examples to illustrate short-circuit current waveforms only. The current and time values on the coordinates are not of significance.

Note that the amplitude and the duration of the last major or major extended current loop shall meet the applicable values in Table 2 and Table 3.

Note that in the second breaking operation, current in the blue phase is interrupted after a major extended loop.

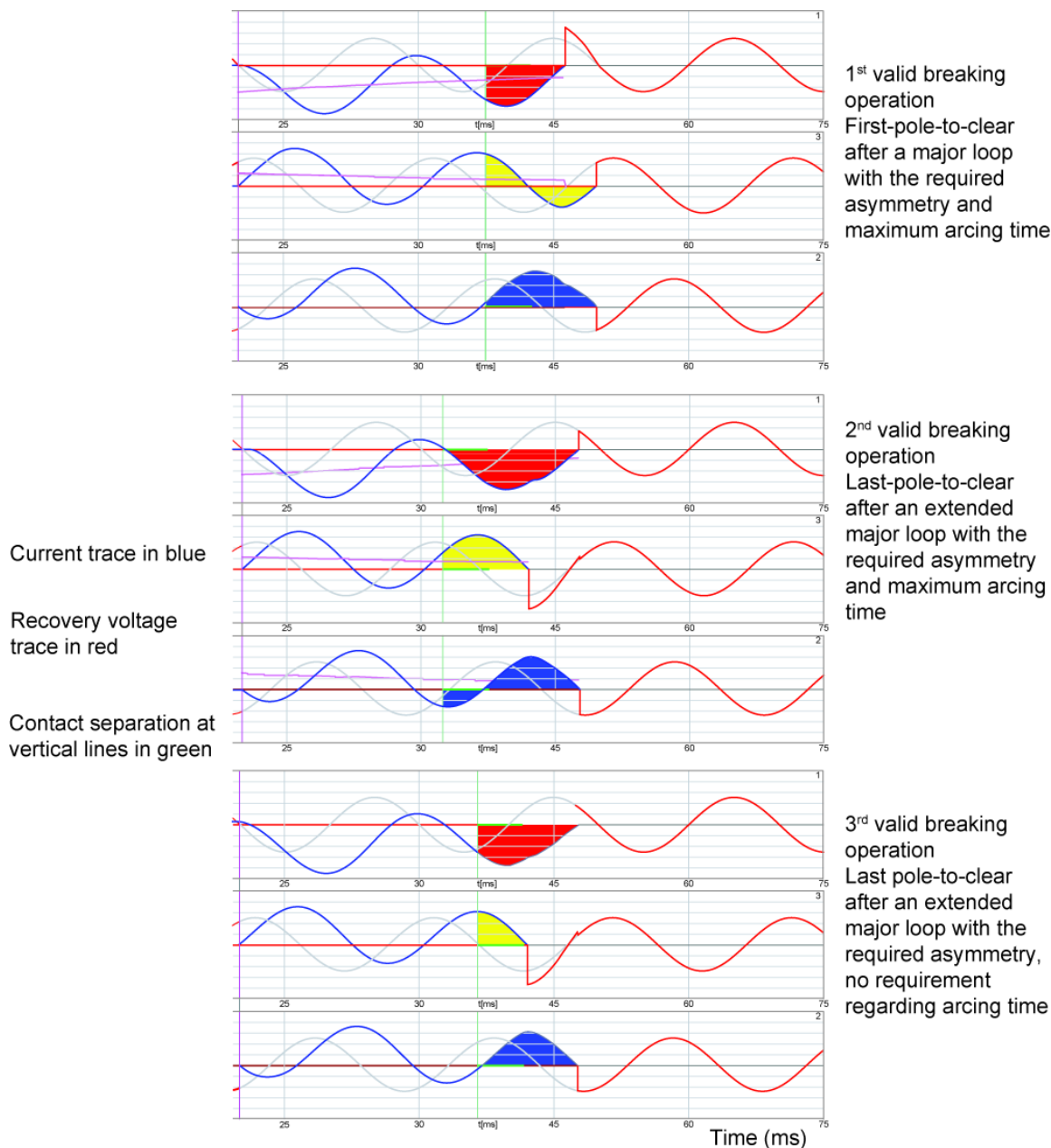


Figure 3—Example of the three valid asymmetrical operations for three-phase tests in a noneffectively grounded neutral system (first-pole-to-clear factor 1.5)

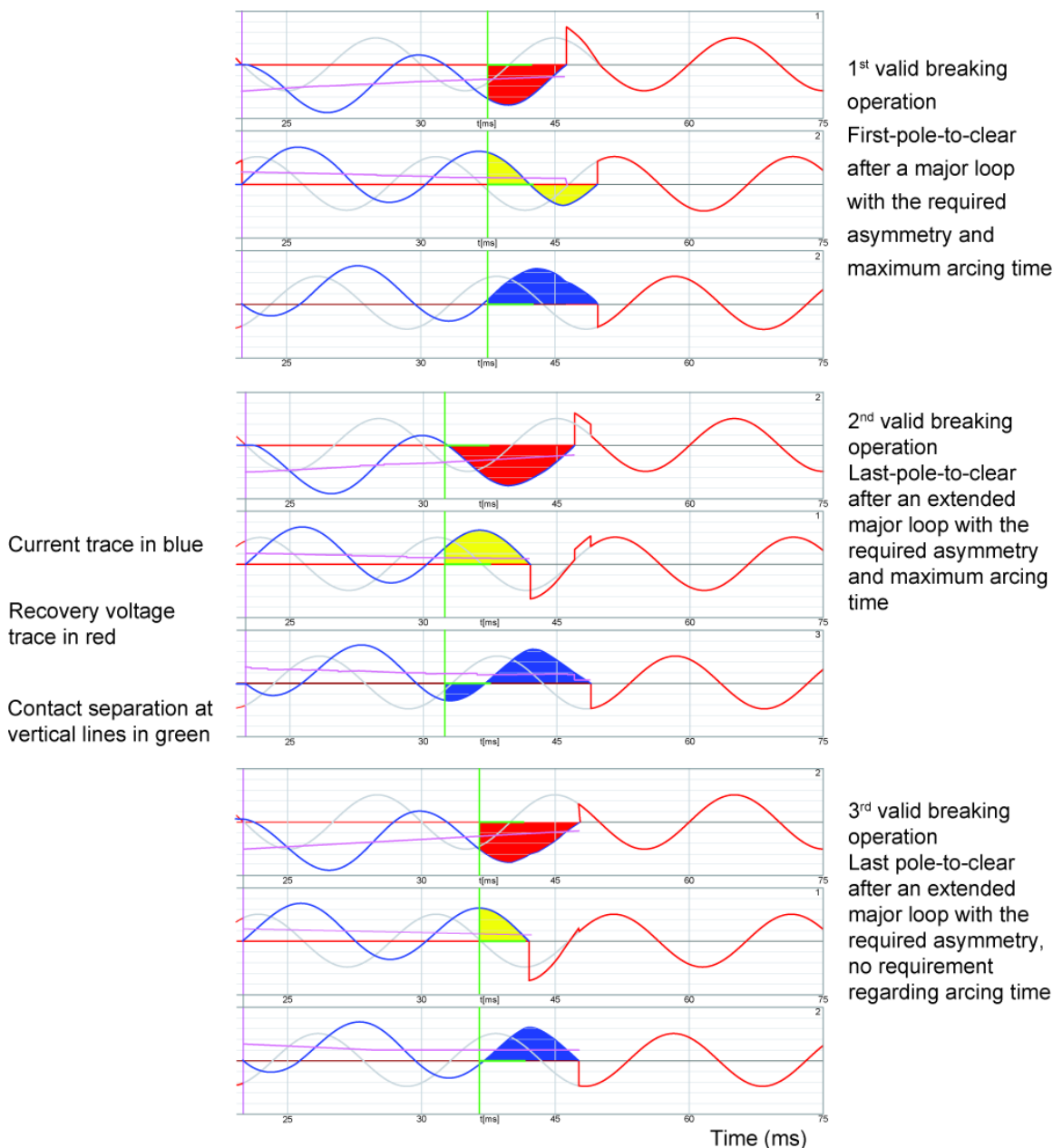


Figure 4—Example of the three valid asymmetrical operations for three-phase tests in an effectively grounded neutral system (first-pole-to-clear factor 1.3)

Note that the amplitude and the duration of the last major or major extended current loop shall meet the applicable values in Table 2 and Table 3.

**Table 2—Last current loop parameters in three-phase tests and in single-phase tests in substitution for three-phase conditions in relation with short-circuit test duty T100a—
Tests for 50-Hz operation**

τ ms	Minimum clearing time ms	$\hat{I}$ p.u.	$k_{pp} = 1.5 \text{ or } 1.3$		$k_{pp} = 1.5$		$k_{pp} = 1.3$	
			Δt_1 ms	Δt_{a1} ms	Δt_2 ms	Δt_{a2} ms	Δt_3 ms	Δt_{a3} ms
45	$10.0 < t \leq 27.0$	1.52	13.6	4.1	15.0	10.6	14.4	10.0
	$27.0 < t \leq 47.5$	1.33	12.2	3.8	13.7	9.8	13.1	9.1
	$47.5 < t \leq 68.0$	1.21	11.4	3.7	12.9	9.2	12.3	8.6
60	$10.0 < t \leq 27.0$	1.61	14.2	4.3	15.6	11.1	15.1	10.5
	$27.0 < t \leq 47.5$	1.44	12.9	4.0	14.3	10.2	13.8	9.6
	$47.5 < t \leq 67.5$	1.31	12.1	3.8	13.6	9.7	12.9	9.1
	$67.5 < t \leq 88.0$	1.22	11.4	3.7	13.0	9.3	12.3	8.6
75	$10.0 < t \leq 27.0$	1.67	14.8	4.4	16.1	11.3	15.6	10.8
	$27.0 < t \leq 47.5$	1.51	13.4	4.2	14.9	10.6	14.3	10.0
	$47.5 < t \leq 67.5$	1.39	12.6	3.9	14.1	10.1	13.4	9.4
	$67.5 < t \leq 87.5$	1.30	12.0	3.8	13.5	9.7	12.8	9.0
	$87.5 < t \leq 108.0$	1.23	11.5	3.7	13.1	9.3	12.4	8.7
120	$10.0 < t \leq 27.0$	1.78	15.7	4.8	17.0	11.9	16.6	11.4
	$27.0 < t \leq 47.0$	1.66	14.6	4.4	15.9	11.3	15.3	10.8
	$47.0 < t \leq 67.5$	1.56	13.8	4.3	15.2	10.8	14.6	10.3
	$67.5 < t \leq 87.5$	1.47	13.2	4.1	14.6	10.4	14.0	9.8
	$87.5 < t \leq 108.0$	1.40	12.6	4.0	14.1	10.1	13.5	9.5
τ DC time constant of the rated short-circuit breaking current $\hat{I}$ p.u. value of the peak current of the first-pole-to-clear, the last-pole-to-clear for $k_{pp} = 1.5$ and the second-pole to-clear for $k_{pp} = 1.3$ related to the peak value of the symmetrical short-circuit current Δt_1 duration of the major loop of the first-pole-to-clear Δt_2 duration of the extended major loop of the last-pole-to-clear for $k_{pp} = 1.5$ Δt_3 duration of the extended major loop of the second-pole-to-clear for $k_{pp} = 1.3$ Δt_{a1} time parameter for determination of the arcing time to be demonstrated for the first-pole-to-clear conditions Δt_{a2} time parameter for determination of the arcing time to be demonstrated for the last-pole-to-clear conditions for $k_{pp} = 1.5$ Δt_{a3} time parameter for determination of the arcing time to be demonstrated for the second-pole-to-clear conditions for $k_{pp} = 1.3$								

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**Table 3—Last current loop parameters in three-phase tests and in single-phase tests in substitution for three-phase conditions in relation with short-circuit test duty T100a—
Tests for 60-Hz operation**

τ ms	Minimum clearing time ms	$\hat{I}$ p.u.	$k_{pp} = 1.5 \text{ or } 1.3$		$k_{pp} = 1.5$		$k_{pp} = 1.3$	
			Δt_1 ms	Δt_{a1} ms	Δt_2 ms	Δt_{a2} ms	Δt_3 ms	Δt_{a3} ms
45	$8.5 < t \leq 22.5$	1.58	11.6	3.5	12.8	9.1	12.4	8.6
	$22.5 < t \leq 39.5$	1.40	10.5	3.3	11.8	8.4	11.2	7.9
	$39.5 < t \leq 56.5$	1.27	9.8	3.1	11.1	7.9	10.6	7.4
	$56.5 < t \leq 73.0$	1.19	9.3	3.0	10.7	7.6	10.1	7.1
60	$8.5 < t \leq 22.5$	1.66	12.2	3.7	13.3	9.4	12.9	9.0
	$22.5 < t \leq 39.5$	1.50	11.1	3.4	12.4	8.8	11.8	8.3
	$39.5 < t \leq 56.5$	1.38	10.4	3.3	11.7	8.3	11.2	7.8
	$56.5 < t \leq 73.0$	1.29	9.9	3.1	11.2	8.0	10.6	7.5
	$73.0 < t \leq 90.0$	1.22	9.5	3.1	10.8	7.7	10.2	7.2
75	$8.5 < t \leq 22.5$	1.72	12.6	3.8	13.7	9.6	13.3	9.2
	$22.5 < t \leq 39.5$	1.57	11.6	3.6	12.8	9.1	12.3	8.6
	$39.5 < t \leq 56.0$	1.46	10.9	3.4	12.1	8.6	11.6	8.1
	$56.0 < t \leq 73.0$	1.37	10.3	3.2	11.6	8.3	11.1	7.8
	$73.0 < t \leq 90.0$	1.30	9.9	3.1	11.2	8.0	10.7	7.5
	$90.0 < t \leq 106.5$	1.24	9.6	3.1	10.9	7.8	10.4	7.3
120	$8.5 < t \leq 22.5$	1.81	13.4	4.1	14.4	10.1	14.1	9.7
	$22.5 < t \leq 39.0$	1.71	12.5	3.8	13.6	9.6	13.2	9.2
	$39.0 < t \leq 56.0$	1.62	11.8	3.7	13.0	9.3	12.5	8.8
	$56.0 < t \leq 73.0$	1.54	11.3	3.5	12.5	8.9	12.0	8.5
	$73.0 < t \leq 89.5$	1.47	10.9	3.4	12.1	8.7	11.6	8.1
	$89.5 < t \leq 106.5$	1.41	10.6	3.3	11.8	8.4	11.3	7.9
τ DC time constant of the rated short-circuit breaking current $\hat{I}$ p.u. value of the peak current of the first-pole-to-clear, the last-pole-to-clear for $k_{pp} = 1.5$ and the second-pole-to-clear for $k_{pp} = 1.3$ related to the peak value of the symmetrical short-circuit current Δt_1 duration of the major loop of the first-pole-to-clear Δt_2 duration of the extended major loop of the last-pole-to-clear for $k_{pp} = 1.5$. Δt_3 duration of the extended major loop of the second-pole-to-clear for $k_{pp} = 1.3$ Δt_{a1} time parameter for determination of the arcing time to be demonstrated for the first-pole-to-clear conditions Δt_{a2} time parameter for determination of the arcing time to be demonstrated for the last-pole-to-clear conditions for $k_{pp} = 1.5$ Δt_{a3} time parameter for determination of the arcing time to be demonstrated for the second-pole-to-clear conditions for $k_{pp} = 1.3$								

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4.8.2.3.4 Arcing time for three-phase tests covering both conditions for $k_{pp} = 1.3$ and $k_{pp} = 1.5$

To cover the performance for $k_{pp} = 1.3$ and $k_{pp} = 1.5$, two separate series of duties with their specific grounding of test circuits should be performed.

If a complete series of test duties demonstrating the circuit-breaker performance for $k_{pp} = 1.5$ is already performed, it is not necessary to repeat all terminal fault test duties prescribed by this standard for demonstrating the performance of the circuit-breaker for $k_{pp} = 1.3$. In that case, test duties T100s and T100a shall be repeated with a test circuit simulating the grounding condition of an effectively grounded neutral system ($k_{pp} = 1.3$).

The repetition of test duties T100s and T100a with a three-phase circuit for an effectively grounded neutral system can, as an alternative, be replaced by additional single-phase tests specified in item a) and item b) as follows. Single-phase tests are allowed for all types of circuit breakers except for metal-enclosed circuit breakers with three phases in one enclosure when direct gas dynamic interaction between phases is involved.

- a) Additional single-phase test with symmetrical current:
- 1) A first test shall demonstrate the performance of the second-pole-to-clear under symmetrical fault conditions in an effectively grounded neutral system. The arcing time shall be set to

$$t_{\text{arc}} = t_{\text{a100s}} - T \times \frac{119^\circ}{360^\circ}$$

The TRV parameters shall be adjusted in accordance with Table 4.

The TRV parameters for the single-phase tests are $u_{c,\text{sp}}$ and $t_{3,\text{sp}}$ for a two-parameter TRV and $u_{1,\text{sp}}$, $t_{1,\text{sp}}$, $u_{c,\text{sp}}$, and $t_{2,\text{sp}}$ for a four-parameter TRV.

The test voltage is

$$1.26 \times \frac{U_r}{\sqrt{3}}$$

and it may be reduced to $U_r / \sqrt{3}$ after one half cycle of rated frequency after current interruption.

Table 4—TRV parameters for single-phase tests in substitution for three-phase tests to demonstrate interruption of second-pole-to-clear and third-pole-to-clear for $k_{pp} = 1.3$

	Rated voltage					
	$U_r < 100 \text{ kV}$ 2-parameter-TRV		$U_r \geq 100 \text{ kV}$ 4-parameter-TRV			
	$u_{c,\text{sp}}$	$t_{3,\text{sp}}$	$u_{1,\text{sp}}$	$t_{1,\text{sp}}$	$u_{c,\text{sp}}$	$t_{2,\text{sp}}$
Second pole-to-clear	$1.26 \times k_{\text{af}} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$	$t_3 \times u_{c,\text{sp}} / u_c$	$0.95 \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$	$t_1 \times u_{1,\text{sp}} / u_1$	$1.26 \times k_{\text{af}} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$	$4 \times t_{1,\text{sp}}$
Third-pole-to-clear	$k_{\text{af}} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$	$t_3 \times u_{c,\text{sp}} / u_c$	$0.75 \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$	$t_1 \times u_{1,\text{sp}} / u_1$	$k_{\text{af}} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$	$4 \times t_{1,\text{sp}}$

- 2) A second test shall demonstrate the performance of the third-pole-to-clear under symmetrical fault conditions in an effectively grounded neutral system. The arcing time shall be set to

$$t_{\text{arc}} = t_{\text{a100s}} - T \times \frac{162^\circ}{360^\circ}$$

The TRV parameters have to be adjusted according to Table 4.

The single-phase tests with symmetrical currents can be combined using the prospective TRV peak value required for the second-pole-to-clear with the arcing time prescribed for the third-pole-to-clear.

- b) Additional single-phase test with asymmetrical current:

An additional single-phase fault test with an asymmetrical current that fulfills the asymmetry criteria as defined in 4.8.2.3.30 shall be performed. This additional test demonstrates the performance of the second- and third-pole-to-clear under asymmetrical fault current on the extended major loop.

The test voltage to be applied is

$$1.26 \times \frac{U_r}{\sqrt{3}}$$

for the verification of $k_{pp} = 1.3$ and may be reduced to $U_r / \sqrt{3}$ after one quarter of a cycle of rated frequency after current interruption.

When the last current loop parameters are within the prescribed tolerances, the resulting deviations on the dc component at current zero, the associated di / dt and the following TRV peak value are within acceptable limits compared with those calculated with rated values.

The arcing time shall be the maximum arcing time calculated for a three-phase condition considering the minimum arcing time value found during test-duty T100s performed for $k_{pp} = 1.5$

$$t_{\text{arc}} = \left(t_{\text{a100s}} - T \times \frac{d\alpha}{360^\circ} \right) + \Delta t_{\text{a3}}$$

where Δt_{a3} is the relevant time parameter to be selected from Table 2 and Table 3.

4.8.2.3.5 Arcing time for single-phase tests in substitution for three-phase conditions and short-line fault tests

The procedure for establishing a minimum arcing time might result in a test with maximum arcing time or with an arcing time in excess of the maximum arcing time. The aim of the following single-phase tests is to satisfy the conditions of the first-pole-to-clear, the second-pole-to-clear, and the last pole-to-clear for each test duty in one test circuit.

The following procedures are applicable if all operations of the rated operating sequence fulfill the requirements for simultaneity of poles in IEEE Std C37.04. If not, caution shall be exercised when using Table 2 and Table 3.

- a) Arcing time for single-phase test duties T10, T30, T60, T100s, and T100s(b); OP1 and OP2; and L90, L75, and L60:

To demonstrate the capability of the circuit breaker to interrupt fault currents, the design tests need to prove three successful interruptions with minimum, maximum, and medium arcing times.