

IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

Sponsor

**Switchgear Committee
of the
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Abstract: The testing procedures for all high-voltage circuit breakers that include all voltage ratings above 1000 V ac and comprise both indoor and outdoor types having the preferred ratings as listed in ANSI C37.06-1997 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, 1200 A, 2000 A, and 3000 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 IEEE Std C37.013-1993.

Keywords: 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 C37.09-1999, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.)

This standard is a major revision of ANSI/IEEE Std C37.09-1979 (R1996). This revision contains major substantive changes. Some editorial changes also have been included, and they are intended to eliminate duplication of words from IEEE Std C37.04-1999 and to reduce the word usage in general.

Listed here, for information and guidance, are the substantive changes.

This revision reflects the changes made in ANSI C37.06-1997 where the K factor has effectively been eliminated for all indoor circuit breakers by assigning to it a numerical value of $K = 1$. This has been done to take advantage of the newer interrupting technologies. Additionally, the traditional use of 1.6 as the multiplying factor for the asymmetrical root-mean-square (rms) current and 2.7 for the peak current has been revised to reflect the time constant of 45 ms (corresponding to an X/R ratio of 17 at 60 Hz or 14 at 50 Hz) on which the circuit breaker ratings are based, which yields the mathematically correct values of 1.55 and 2.6 respectively. With the implementation of this change, the information needed to properly test circuit breakers rated in accordance with the 1979 or earlier editions of ANSI C37.06 and IEEE Std C37.04 has been deleted from the main body of this document; however test Tables 1 and 2 from the 1979 version of ANSI/IEEE Std C37.09-1979 have been included as Annex B for reference purposes and to be used in those cases where circuit breakers designed to meet the prior standards requirement are being tested. Users must refer to the prior editions of the relevant standards for more concise information in order to properly test those earlier designs of circuit breakers. This major change has resulted in a consolidation of text and of test duty requirements for this revision.

ANSI C37.06.1-1997 is a new concept document and has been recognized and incorporated in this revision by reference and notes in applicable clauses.

All outstanding supplements of this standard have been included, with the exception of IEEE Std C37.09a-1991, Load Current Switching Tests, which has been replaced with a later revision that is included in 4.9.

Mechanical endurance (4.13) has also been upgraded.

A clause covering leakage tests (5.7) for gaseous and for vacuum interrupters has been added.

The Lightning impulse withstand testing clause (4.4.4.2) now includes the 3×9 method as part of the harmonization effort with IEC.

The Standard operating duty/standard duty cycle (4.5) for non-reclosing rated circuit breakers has been changed from CO - 15s - CO to O - t - CO - t' - CO where t and t' are defined times between tests, while the test duty O - 0.3 sec - CO has been added for circuit breakers rated for reclosing duty applications.

Short-line fault tests have now been made mandatory for all outdoor circuit breakers rated 15.5 kV and above.

ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing, is specifically referenced in this standard because its latest revision does not include critical test techniques needed for circuit breaker testing. When the latest issue of this standard is suitably revised, it will be officially recognized and will become part of this revision.

Sections of test requirements covering pressurized and non-ceramic pressurized insulating components, previously included in NEMA SG-4 Standard, have now been incorporated into this standard.

Indoor circuit breakers are recognized in this revision for their unique test and application requirements as dictated by their use in metal-clad switchgear and as covered in IEEE Std C37.20.2-1993.

Capacitor current testing (4.10) has been carried over without change, except for clause renumbering, from the 1979 publication. This clause is expected to change in the future as a result of a major harmonized revision, which is now being prepared by a joint IEEE and IEC working group.

This standard, with its companion standards, IEEE Std C37.04-1999, ANSI C37.06-1997, and IEEE Std C37.010-1999, establishes a total rating, test, and application basis for all high-voltage circuit breakers with the exception of generator circuit breakers, which are covered by IEEE Std C37.013-1997.

This standard was approved by the American National Standards Institute (ANSI) on 20 January 2000.

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1. Scope

This test procedure summarizes the various tests that are made on ac high-voltage indoor and outdoor circuit breakers, except for generator circuit breakers, which are covered in IEEE Std C37.013-1997. It describes accepted methods used in making the tests and specifies the tests that will verify assigned ratings under ANSI/IEEE standards. This procedure does not preclude the use of other equivalent or more effective methods of demonstrating ratings.

The tests are divided into the following classifications:

- a) Design tests (Referred to in IEC 60056-1987 and IEC 60694-1996 as Type Tests)
- b) Production tests (Referred to in IEC 60056-1987 and IEC 60694-1996 as Routine Tests)
- c) Tests after delivery
- d) Conformance tests

2. References

When the following standards are superseded by an approved revision, the revision shall apply.

ANSI C37.06-1997, American National Standard for Switchgear—AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities.¹

ANSI C37.06.1-1997, Trial-Use Guide for High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Designated “Definite Purpose for Fast Transient Recovery Voltage Rise Times.”

¹ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

ANSI C37.54-1996, American National Standard for Switchgear—Indoor Alternating-Current High-Voltage Circuit Breakers Applied as Removable Elements in Metal-Enclosed Switchgear Assemblies—Conformance Test Procedures.

ANSI C84.1-1982, Voltage Ratings for Electric Power Systems and Equipment (60 Hz).

ASME Boiler and Pressure Vessel Code, Section X, Fiberglass-Reinforced Plastic Pressure Vessels.²

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

IEC 60056-1987, High Voltage Alternating Current Circuit Breakers.³

IEC 60068-2-17-1994, Basic Environmental Test Procedures—Part 2: Tests—Test Q: Sealing

IEC 60694-1996, Common Specifications for High-Voltage Switchgear and Controlgear Standards.

IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.⁴

NOTE—This standard is specifically referenced because its latest revision does not include critical test techniques needed for circuit breaker testing. When the latest issue of this standard is suitably revised, it will be officially recognized and will become part of this revision.

IEEE Std 119 Aug. 1950, IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus. Test Code for Temperature Measurements.⁵

IEEE Std C37.04-1999, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers.

IEEE Std C37.010-1999, IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.011-1994, IEEE Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.013-1997, IEEE Standard for AC High-Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.015-1993, IEEE Application Guide for Shunt Reactor Current Switching.

IEEE C37.081-1981 (R1988), IEEE Guide for Synthetic Fault Testing of AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.11-1997, IEEE Standard Requirements for Electrical Control for High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.20.2-1993, IEEE Standard for Metal-Clad and Station Type Cubicle Switchgear.

²ASME publications are available from the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10016-5990, USA (<http://www.asme.org/>).

³IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://www.standards.ieee.org/>).

⁵IEEE Std 119 Aug. 1950 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://global.ihs.com/>).

IEEE Std C37.24-1986 (R1998), Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Clad Switchgear.

IEEE Std C37.100-1992, IEEE Standard Definitions for Power Switchgear.

IEEE Std C57.13-1993, IEEE Standard Requirements for Instrument Transformers.

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

IEEE C57.19.01-1991 (R1997), IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.

3. Definitions

The terms and definitions applicable to this standard and to the related standards for ac high-voltage circuit breakers shall be in accordance with IEEE Std C37.100-1992. These definitions are not intended to embrace all possible meanings of the terms. They are intended solely to establish meaning of terms used in power switchgear.

4. Design tests

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 C37.04-1999.

4.1 Maximum voltage tests

There is no specific test to demonstrate this rating. However, 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, Table 2, and Table 3 with specified values of circuit transient recovery voltage (TRV), as given in IEEE Std C37.04-1999 and ANSI C37.06-1997.

4.2 Power frequency tests

There is no specific test to demonstrate this rating. However, 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 or 60 Hz are specifically allowed by the standards to qualify for both frequencies.

4.3 Continuous current-carrying tests

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 C37.04-1999.

4.3.1 Test conditions

- a) The ambient temperature shall be between 10 °C and 40 °C, so that no correction factors need to be applied.

- b) The circuit breaker shall be tested under all other usual service conditions, except as stated in item a).
- c) Enclosed circuit breakers shall be tested in their enclosures.
- d) 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.
- e) Circuit breakers normally equipped with current transformers shall be tested with transformers in place and connected to carry rated secondary current.
- f) Circuit breakers shall be in a new condition and properly adjusted according to the product specification provided by the manufacturer.
- g) Tests demonstrating current carrying ability shall be made at rated power frequency except that where tests are performed at 60 Hz they shall be considered to be valid for the same current rating with 50 Hz rated power frequency.
- h) Outdoor circuit breakers, 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.
- i) Indoor circuit breakers 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 IEEE Std C37.20.2-1993.

4.3.2 How tests shall be made

- a) Three-phase circuit breakers shall be tested on a three-phase basis except where there is no possibility of magnetic or thermal influence between poles or modular units.
- b) Where 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.

4.3.3 Duration of continuous current tests

The continuous current test shall be continued for a period of time such that the temperature rise of any 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 specified in IEEE Std C37.04-1999 have not been exceeded in any of the last three readings.

4.3.4 How temperatures are measured

Temperatures shall be measured by any of the following methods (see IEEE Std 119 Aug.1950):

- 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. For conformance tests, if required, it is sufficient to measure accessible parts and compare the measurements with like points on the design tests. Holes that destroy the effectiveness of the test (such as in multi turn coils) shall not be drilled.

4.3.5 How ambient temperature is determined

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 indoor circuit breakers refer to the requirements outlined in IEEE Std C37.20.2-1993), 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.

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 largely upon the kind of material and the overall mass of the containing cup. The response may be further regulated by adjusting the amount of oil in the cup. The larger the apparatus under test, the larger must 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.

4.3.6 Measurements of 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 normal 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—Experience shows that an increase in the main circuit resistance may not be a reliable evidence of a bad contact or connection.

4.4 Dielectric withstand tests

The dielectric withstand capability of a circuit breaker is demonstrated by subjecting it to a power frequency, a lightning impulse test, and where required, a chopped wave lightning impulse and a switching impulse test, at voltage levels equal to or greater than those that have been specified in ANSI C37.06-1997.

4.4.1 Tests conditions

- 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 shall not have been put into commercial operation.
- c) Sealed interrupters that use a pressurized gas must 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) Correction factors shall not be used on normal power frequency dry tests, unless allowed by the specific apparatus standard. The values of correction factors for atmospheric pressure and atmospheric humidity to be used for impulse and power frequency wet tests are to be taken from IEEE Std 4-1978 curves and formulas applicable to atmospheric bushings, except where 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 where 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 4-1978 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 4-1978 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, it is necessary to apply voltage only to those terminals that produce different distributions of electric stress.
- j) Tests, as described in the following clauses, will be conducted on the complete three-pole circuit breaker. However, single-pole tests for outdoor circuit breakers are sufficient when adjacent poles have substantially no influence or are simulated by ground shields.
- k) Indoor circuit breakers shall be tested in a minimum volume enclosure or in the actual switchgear vertical section compartment.
- l) For dry switching impulse tests, which are only applicable to outdoor 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 surge impulse and for wet power frequency tests, which are only applicable to outdoor circuit breakers rated 362 kV and above, atmospheric temperature and pressure correction factors shall be applied to define the test voltage. 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 outdoor circuit breakers, at the manufacturer's option, the humidity correction factor may be applied. For indoor circuit breakers, the use of humidity correction factors is required (see IEEE Std C37.20.2-1993).

4.4.2 Insulation paths

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

- a) *Atmospheric paths*: Paths entirely through atmospheric air, such as along the porcelain surface of an outdoor bushing.

- b) *Non atmospheric paths*: All other paths, such as through a gas or vacuum sealed from the atmosphere, through a liquid such as oil, through a solid, or through a combination thereof.

4.4.2.1 Non atmospheric paths

In order to meet the requirements for non atmospheric paths, at least three dry withstand tests must be accumulated at each polarity, at the rated lightning impulse and related chopped wave voltages (in addition to one dry power frequency withstand test), all without benefit of reduction of voltages due to correction factors. The purpose is to apply full stresses to these non atmospheric 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 non atmospheric paths until conditions improve.

4.4.2.2 Atmospheric paths

There is no separate atmospheric path requirement for the dry-power frequency test.

4.4.3 Power frequency withstand voltage tests

4.4.3.1 Dry tests procedure

These tests are made to determine the ability of the circuit breaker to withstand its assigned rated power frequency withstand voltage. The test shall be made with a sinusoidal voltage having a peak value equal to 1.414 times the rated root-mean-square (rms) power frequency withstand voltage listed in ANSI C37.06-1997. The voltage test frequency shall be equal to the rated power frequency $\pm 20\%$.

The tests shall be performed in accordance with the requirements of IEEE Std 4-1978. The voltage shall be applied to the terminals of the circuit breaker for a 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.

4.4.3.2 Wet test procedure

The wet tests are made only on outdoor power circuit breakers or on external components such as bushings, in accordance with the procedure described in IEEE Std C57.19.00-1991. For those bushings, where their voltage distribution is negligibly influenced by their surroundings, and which have been tested separately as individual bushings in accordance with IEEE Std C57.19.00-1991, the tests need not be repeated in the assembled circuit breaker.

4.4.4 Full-wave lightning impulse withstand voltage tests

These tests are made 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 a peak value equal or greater than the rated full-wave lightning impulse withstand voltage, as specified in ANSI C37.06-1997, shall be applied to the terminals of the circuit breaker.

NOTE—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 (50–75% of rated value), are recommended.

4.4.4.1 Waveform for lightning impulse tests

The waveform and application of the full-wave test voltage shall be as described in IEEE Std 4-1978 and shall have the following limits:

- a) A full-wave test voltage with a virtual front time based on the rated full wave impulse test voltage, equal to or less than $1.2 \mu\text{s}$;
- b) A peak voltage equal to or exceeding the rated full wave impulse voltage; and
- c) A time to the 50% value of the peak voltage, equal to or greater than $50 \mu\text{s}$.

If the capacitance of a test sample is too high for the test equipment to be able to produce a virtual front time as short as the $1.2 \mu\text{s}$ while maintaining the peak value, the most rapid rise possible may be used, subject to agreement between the user and the manufacturer.

4.4.4.2 Test procedure

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

- a) With the circuit breaker contacts open:
 - 1) Apply three consecutive positive lightning impulse voltage waves to each terminal of the circuit breaker individually with all other terminals and frame grounded.
 - 2) Apply 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 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 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) above, a flashover 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 flashovers in the first group shall be considered a random flashover and the circuit breaker shall be considered as having successfully passed the test.

4.4.5 Impulse voltage test for interrupters and resistors

An additional impulse test is made on outdoor 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 ANSI C37.06-1997 and IEEE Std C37.04-1999 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.

4.4.6 Chopped wave lightning impulse withstand voltage tests

These tests shall be performed on outdoor circuit breakers that have a rated maximum voltage of 15.5 kV and above to verify their ability to withstand their assigned rated chopped wave lightning impulse withstand voltage.

The magnitudes of these voltages are given in ANSI C37.06-1997. They shall be applied to the terminals of the circuit breaker, without causing damage or producing a flashover, following the same procedure as described in 4.4.4.2.

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 4-1978.

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 $1.2 \mu\text{s}$.
- 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 ANSI C37.06-1997. 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 $1.2 \mu\text{s}$, while maintaining the peak value, the most rapid rise obtainable may be used, subject to agreement between the user and the manufacturer.

NOTE—Flashovers external to the circuit breaker at the specified chop times, or longer, do not constitute failure to pass the test.

4.4.7 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 4.4.4.2 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 4.4.7.1 and shall have a peak value equal to or greater than the rated switching impulse withstand voltage specified in ANSI C37.06-1997.

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 reoccurrence in the test series. Any flashovers shall cause no damage and shall be indicated in the test record.

When testing the closed circuit breaker 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—The possibility of statistically random flashovers across the contacts is not precluded.

4.4.7.1 Waveform for switching impulse voltage tests

The waveform voltage shall be as described in IEEE Std 4-1978 and shall have the following limits:

- a) A full-wave test voltage with a virtual front time, equal to $250 \mu\text{s} \pm 50 \mu\text{s}$.

- b) A peak voltage value equal to or greater than the rated switching impulse withstand voltage specified in ANSI C37.06-1997.
- c) A 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.

4.4.7.2 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 essentially 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 may 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 in excess of 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 kV rms 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.

4.4.7.3 Atmospheric correction factors for switching impulse voltage tests

The values of correction factors for atmospheric pressure and atmospheric humidity to be used for impulse and power frequency wet tests are to be taken from IEEE Std 4-1978.

4.5 Standard operating duty (standard duty cycle) tests

The standard duty cycle is demonstrated by test duty 4 of Table 1.

4.6 Interrupting time tests

The rated interrupting time is established by adding the contact opening time to the maximum arcing time 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 the rated interrupting time of IEEE Std C37.04-1999. The contact opening time corresponds to the elapsed time between the energization of the trip coil and the instant when the contacts separate. The arcing time of the circuit breaker is determined, for many different current and operating voltages, by the test duties in Table 1.

4.7 TRV tests

The ability to withstand rated TRVs, as specified in ANSI C37.06-1997 for rated symmetrical current, is demonstrated during the performance of short-circuit current interrupting tests.

4.8 Short-circuit current interrupting tests

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

4.8.1 Test conditions

4.8.1.1 Power factor

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

4.8.1.2 Frequency of test circuit

Tests demonstrating short-circuit current interrupting capabilities shall be made at 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 contains interrupters that are not affected significantly by the di/dt , then tests performed at 50 Hz can be used to demonstrate the performance at 60 Hz and vice versa. However, 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.

4.8.1.3 Current asymmetry

Interrupting tests are required with both symmetrical and asymmetrical currents. Any interrupting test in which the asymmetry of the current, in all phases at contact parting time, is less than 20% is considered a symmetrical test. Asymmetry of less than 20% is considered to have negligible influence on the performance in a circuit that has a time constant of 45 ms (corresponding to X/R values of 14 and 17 for rated power frequencies of 50 and 60 Hz respectively). At this level of asymmetry, the total current is increased by less than 4% and furthermore, the instantaneous value of the power frequency recovery voltage, at the instant of arc extinction at the end of a major current loop, is within 2% of the peak value, while at the end of a minor current loop, within 6%.

For the asymmetrical tests, the current value is determined at the instant of contact part, and since the asymmetry decreases with time, the value of the dc component at the time of contact separation shall be equal to the value obtained from Figure 1 for an elapsed time corresponding to the circuit breaker under test. This required percent of the dc component is specified in Figure 1 for a time constant of 45 ms. Figure 2 may be used to determine the required percentage of the dc component for tests where the manufacturer may want to demonstrate the asymmetrical interrupting current capability for X/R ratios other than 17 at 60 Hz.

The defining equation for these curves is

$$\%dc = 100e^{-\alpha} \quad (1)$$

where

$$\alpha = \left(\frac{X/R}{2\pi f} \right)$$

or

$$\frac{t}{\tau}$$

t = contact parting time

τ = time constant

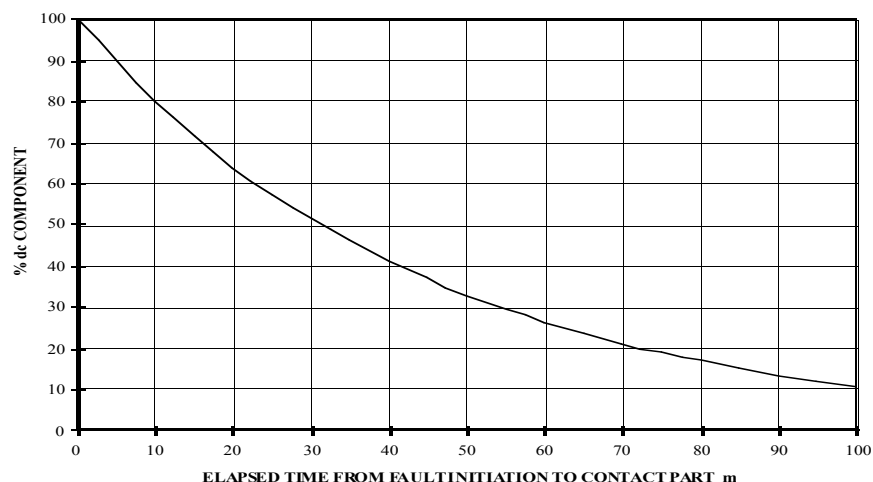


**Figure 1—Percent dc required at contact part for asymmetrical tests
(values based on a time constant of 45 ms equivalent to X/R of 17)**

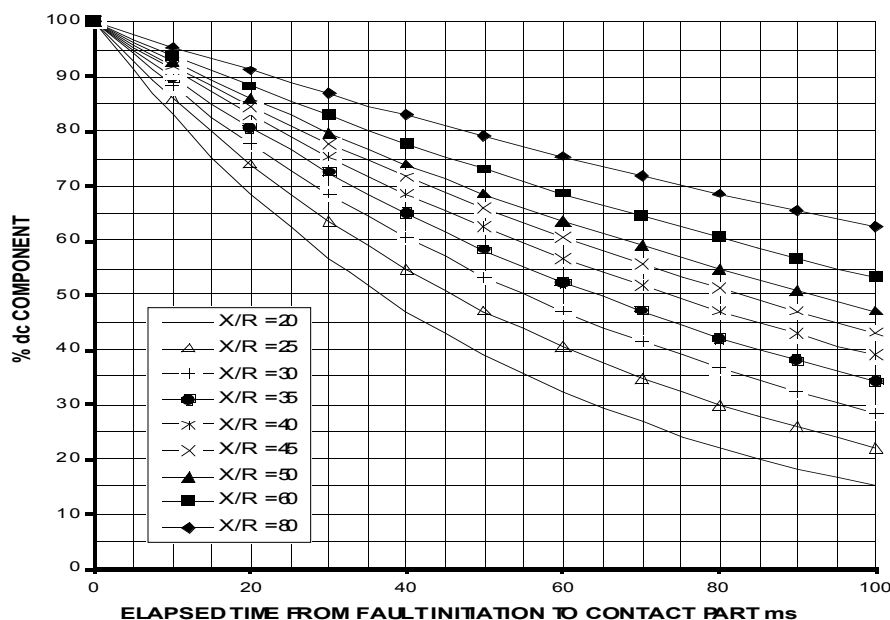


**Figure 2—Percent dc required at contact part for asymmetrical tests
(values based on a range of X/R factors at 60 Hz)**

The elapsed time as shown in Figure 1 and Figure 2 is equal to the sum of 1/2 cycle of relay time (on the basis of the applicable rated power frequency) plus the shortest contact opening time of the circuit breaker as determined in 4.8.5.2.

NOTE—To convert the 60 Hz based X/R factors to a 50 Hz base multiply the X/R factor shown in Figure 2 by 0.833. To convert X/R to time constants, multiply the 60 Hz X/R by 2.652 or the 50 Hz X/R by 3.183. The result is the time constant in ms.

4.8.1.4 Obtaining the most severe switching conditions

To demonstrate the required interrupting capability of a circuit breaker, it is necessary to show that the circuit breaker is capable of meeting the requirements for the rated interrupting time, the rated short circuit current, and related required capabilities in accordance with the requirements set forth in IEEE Std C37.04-1999 and ANSI C37.06-1997, under the most severe switching conditions. The most severe conditions are considered to be those where the maximum arcing energy input is seen by the interrupter during interruption as a result of variations of the arcing time that are due to the relationship between contact parting time of the circuit breaker and the natural current zeros of the short-circuit current. It must be shown that the circuit breaker is capable of interrupting the rated current, within its limitations for asymmetry and interrupting time, with the current zeros occurring in such relation to the contact parting as to yield approximately the longest arcing time.

To satisfy the above conditions the opening operations for test duties 4, 5, 6, and 7 of Table 1 shall have the corresponding arcing times, in ms, as outlined below. For each test duty, the minimum arcing time shall be specified by the manufacturer.

4.8.1.4.1 Single-phase symmetrical current tests

$$\text{Arcing time} = \text{minimum arcing time} + 0.75 \times t_1 \quad (2)$$

where t_1 = time for cycle of rated power frequency (10 or 8.33 ms for 50 or 60 Hz respectively)

4.8.1.4.2 Single-phase asymmetrical current tests

$$\text{Arcing time} = \text{minimum arcing time} + \text{length of major loop} - 1 \text{ ms} \quad (3)$$

(The length of major loop is shown in Figure 3.)

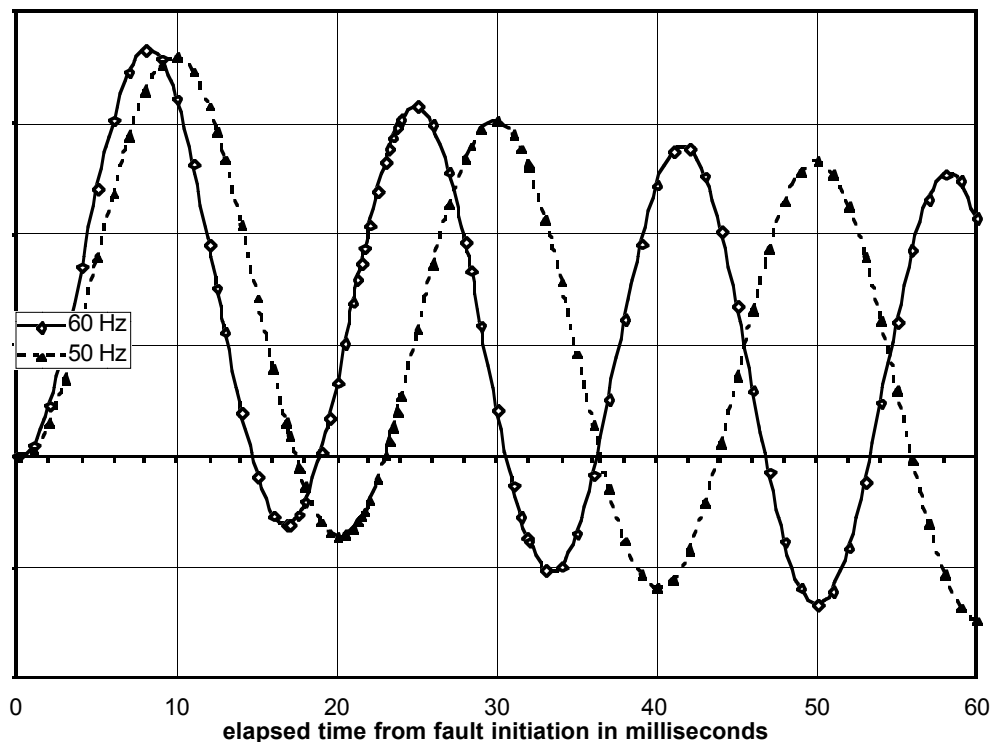


Figure 3—Single-phase asymmetrical currents with a 45 ms time constant for 50 and 60 Hz

4.8.1.4.3 Three phase symmetrical current tests

In order to obtain the most severe condition for these tests it is sufficient to modify the contact parting time of the test circuit breaker by 40 electrical degrees (approximately 2 ms) between each operation.

4.8.1.4.4 Three phase asymmetrical current test

The contact parting time shall be adjusted such that:

- a) In one test, the first phase to clear is the one with the required % dc component and where arc extinction occurs after a major loop of current (see Figure 4). Interruption at the end of a minor loop following arcing through a major loop is permissible as long as the maximum interrupting time is not exceeded.

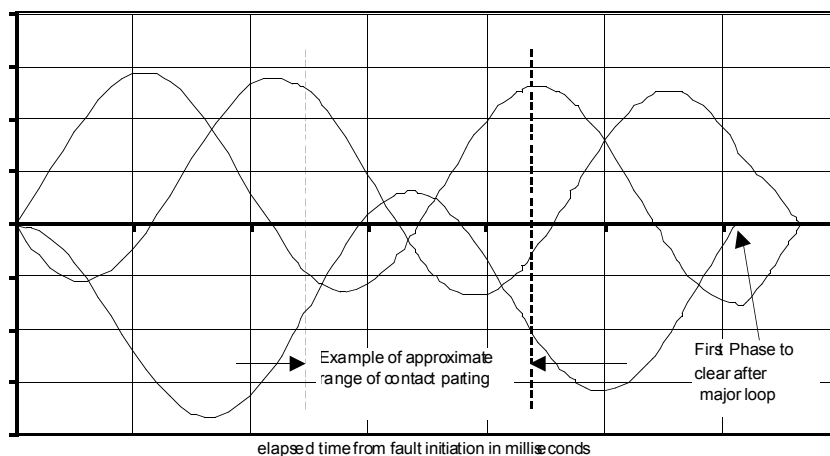


**Figure 4—Three-phase asymmetrical current case, a) of 4.8.1.4.4
(example shows ungrounded system)**

- b) In another test, arc extinction for the last phase to clear must occur in a phase that has the required % dc component and after a major extended loop or the greatest part of that loop (see Figure 5).

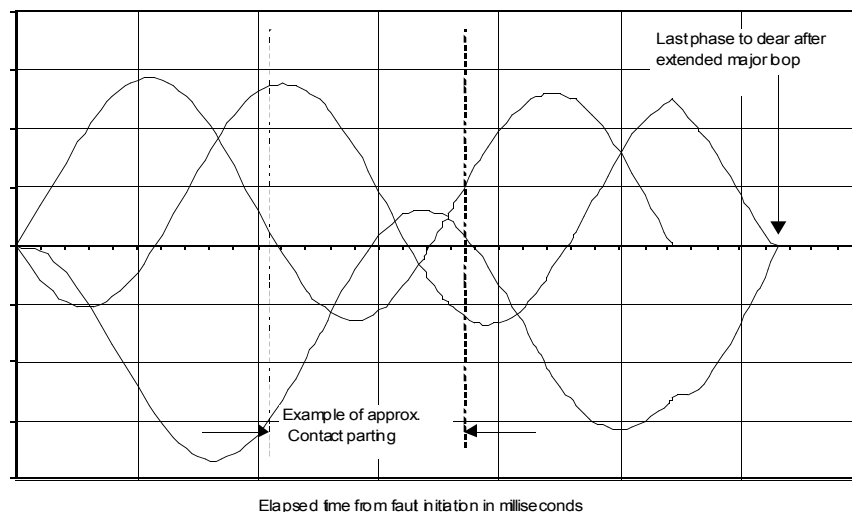


**Figure 5—Three-phase asymmetrical current case, b) of 4.8.1.4.4
(example shows ungrounded system)**

4.8.1.5 Recovery voltage

Both circuit TRV and power frequency recovery voltage must be considered when demonstrating the rating of a circuit breaker.

The determining factors are the magnitude and the shape of the circuit TRV as a function of time, and the magnitude and duration of the power frequency recovery voltage.

- a) *Power frequency recovery voltage.* The power frequency recovery voltage, where possible and unless limited by the capabilities of the test station or by the test method used, shall be equal to the specified source side recovery voltage within an allowable tolerance of minus 5%. Higher voltages may be used at the discretion of the manufacturer.

The power frequency recovery voltage shall be maintained, following current interruption, for at least 20 cycles of rated power frequency for vacuum interrupters or at least 6 cycles of rated power frequency for all other types of interrupters.

If a single-phase test is chosen for demonstrating the standard duty cycle, the test voltage, E , specified in 4.8.3 should be maintained for 1 cycle of rated power frequency, and thereafter it may be reduced to 58% of the rated phase-to-phase voltage.

- b) *TRV.* The inherent TRV of the test circuit shall meet or exceed the rated envelopes as defined in IEEE Std C37.04-1999. The rated envelopes are required for rated symmetrical short circuit currents. For short circuit currents other than rated, the envelope shall be adjusted to establish the capabilities as stated in ANSI C37.06-1997 and ANSI C37.06.1-1997.

The inherent recovery voltage may be determined before or after the interruption tests using any suitable method, including current injection or calculation.

NOTE—Care must be exercised to use a measuring technique that does not introduce transients to the circuit that can increase the apparent severity of the TRV. For example, in current injection techniques a small 60 Hz current pulse is passed through the circuit and the voltage transient is observed after the current is interrupted. The current slope should not be deformed before current zero, nor should there be residual current flow after the current is interrupted. Such modifications to the current can add spurious transients to the measured voltage and result in an inaccurate record of the inherent TRV of the circuit being tested.

The actual TRV measured during a circuit interruption may differ from the inherent TRV because of arc resistance, circuit breaker impedance, etc. These circuit breaker influences are complex functions of time, current, and voltage. The interaction between the circuit breaker and the circuit, and its modifying effects on TRV, cannot be determined by simple calculations. The differences between the actual and inherent TRV that can result from the interaction process are permissible.

Some circuit breakers, such as capacitors or resistors, have substantial amounts of shunt impedance specifically intended to modify the TRV. It may not be desirable to test the circuit breaker with this added impedance. Therefore, a test circuit that produces the modified inherent TRV may be used to test the interrupting device without its added impedance. Such a circuit without impedance Z_b is shown in Figure 6(b). This is permissible provided that the test circuit and the interrupting device interact in the same manner, as would the actual circuit interrupter with its added impedance, and that the test circuit produces the required inherent TRV. The circuit breaker shall be considered to have passed the test if the actual measured TRV meets or exceeds the modified inherent TRV (see IEC 60056-1987, Annex F).

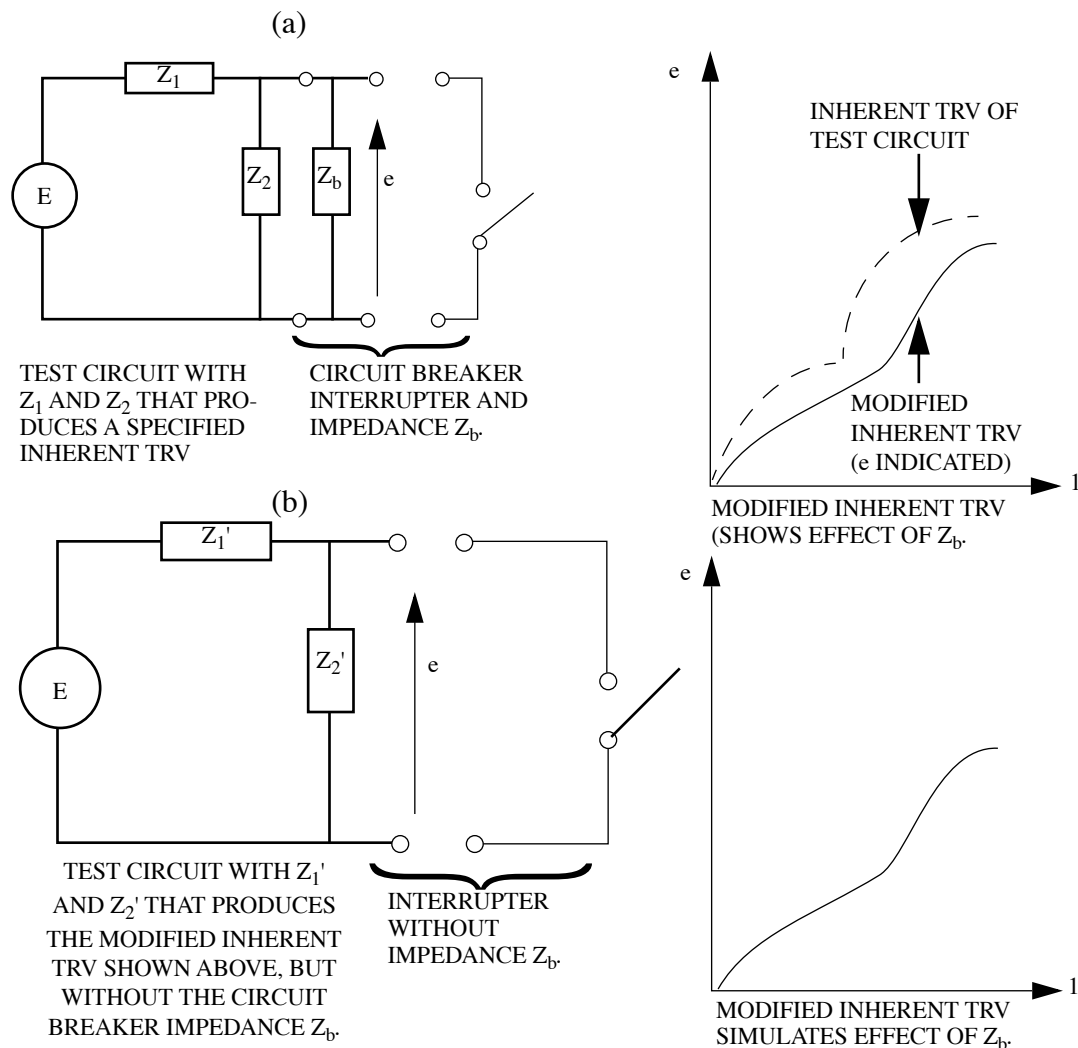


Figure 6—A test circuit designed to simulate the effect of circuit breaker modifying impedance

4.8.1.6 Short-line fault test conditions

The short-line fault tests are performed on circuit breakers that are intended to be connected directly to an overhead line.

Short-line fault tests are made on a single-phase basis. The tests may be performed on a single pole of a three-phase circuit breaker, or in the case of hermetically sealed interrupters, on a single interrupter provided that the conditions listed in 4.8.2.2 are met.

For these tests the bus (source) voltage should be equal to 0.58 V, and the magnitude of the short-circuit current at the circuit breaker terminals shall be as shown in Table 1.

The peak value E_2 for the source side component of the TRV is equal to where K_a = Amplitude factor = 1.4 for circuit breakers above 100 kV or 1.54 for circuit breakers below 100 kV. This amplitude is obtained for a grounded fault at the circuit breaker terminals only. Additional line reactance is then used to reduce the current to the test value. This reactance also reduces the amplitude of the source side component of TRV by a factor of $1 + (K_a - 1)M$.