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

Sponsor

Switchgear Committee
of the
IEEE Power Engineering Society

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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 prefered 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.

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

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.”

[1]ANSI 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/).

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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.

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

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

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

[5]IEEE 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/).

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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 ±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.

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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

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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.

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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.

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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 ±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.

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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 μs;
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 μs.

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 μs 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.

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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 μs.
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 μs, 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 μs ±50 μs.

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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 μs ±1500 μs.

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.

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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

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

where

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

or

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

t = contact parting time

τ = time constant

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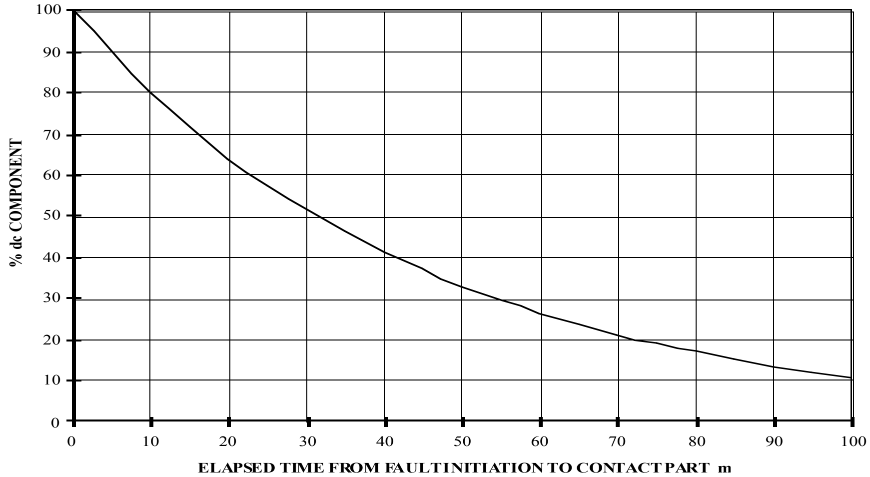

Figure 1—Percent dc required at contact part for asymmetrical tests (values based on a time constant of 45 ms equivalent to X/R of 17)

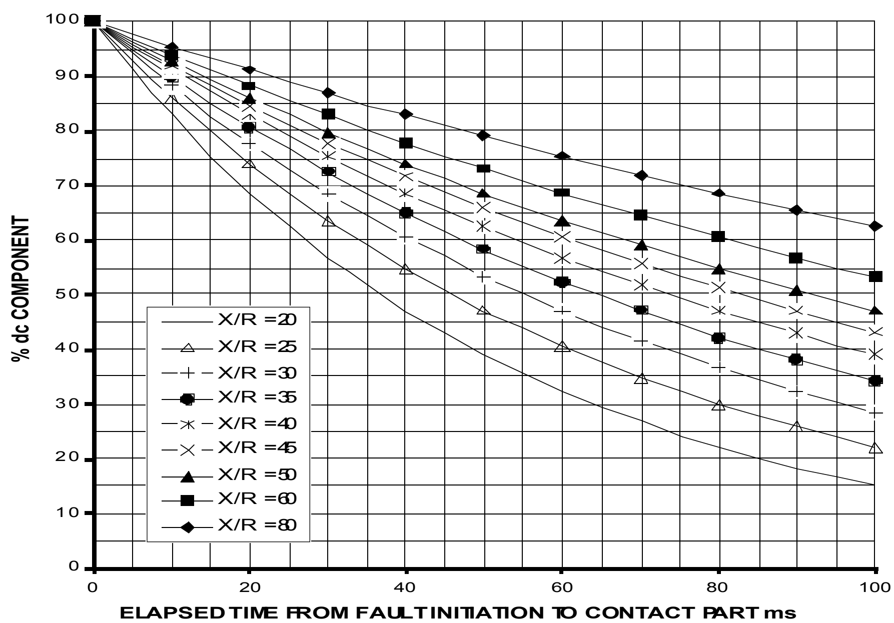

Figure 2—Percent dc required at contact part for asymmetrical tests (values based on a range of X/R factors at 60 Hz)

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.

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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

Arcing time = minimum arcing time + 0.75 × t_l (2)

where t_l = 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

Arcing time = minimum arcing time + length of major loop – 1 ms (3)

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

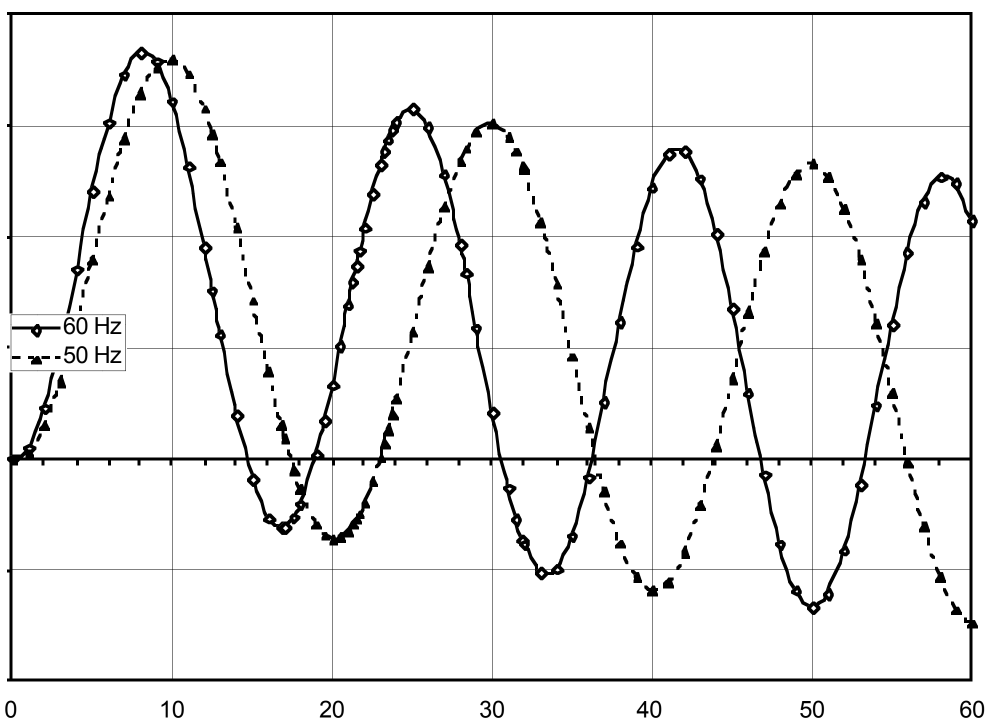

Figure 3—Single-phase asymmetrical currents with a 45 ms time constant for 50 and 60 Hz

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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.

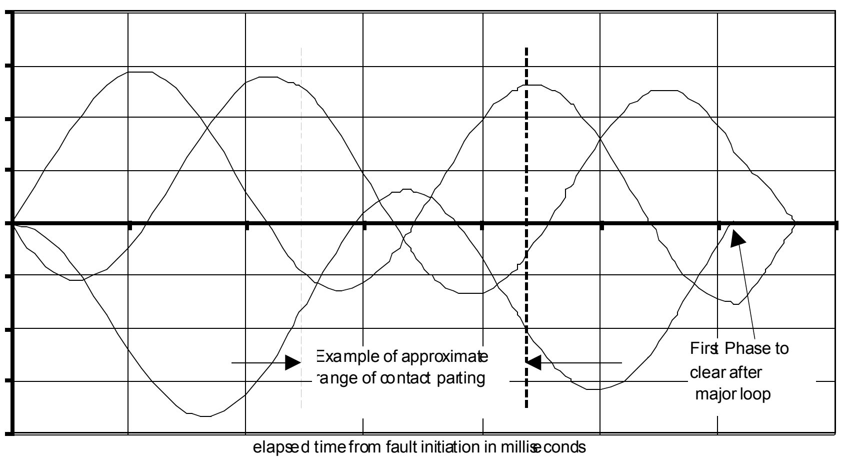

Figure 4—Three-phase asymmetrical current case, a) of 4.8.1.4.4 (example shows ungrounded system)

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).

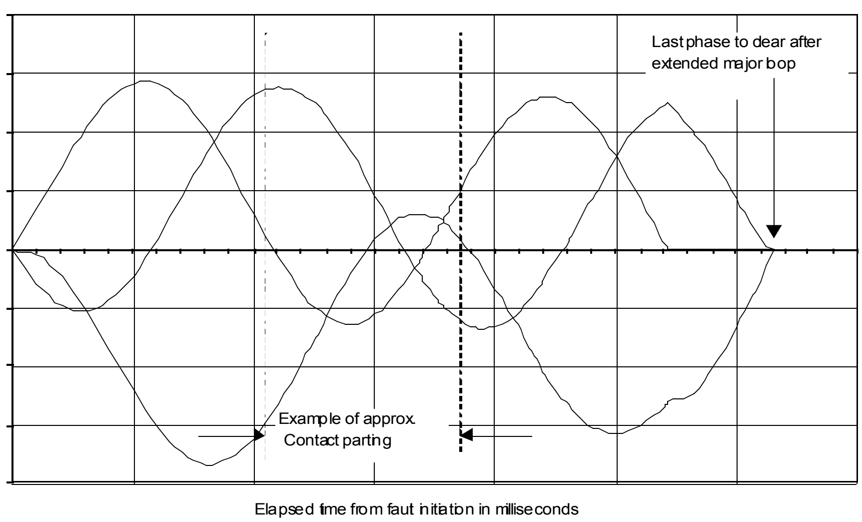

Figure 5—Three-phase asymmetrical current case, b) of 4.8.1.4.4 (example shows ungrounded system)

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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).

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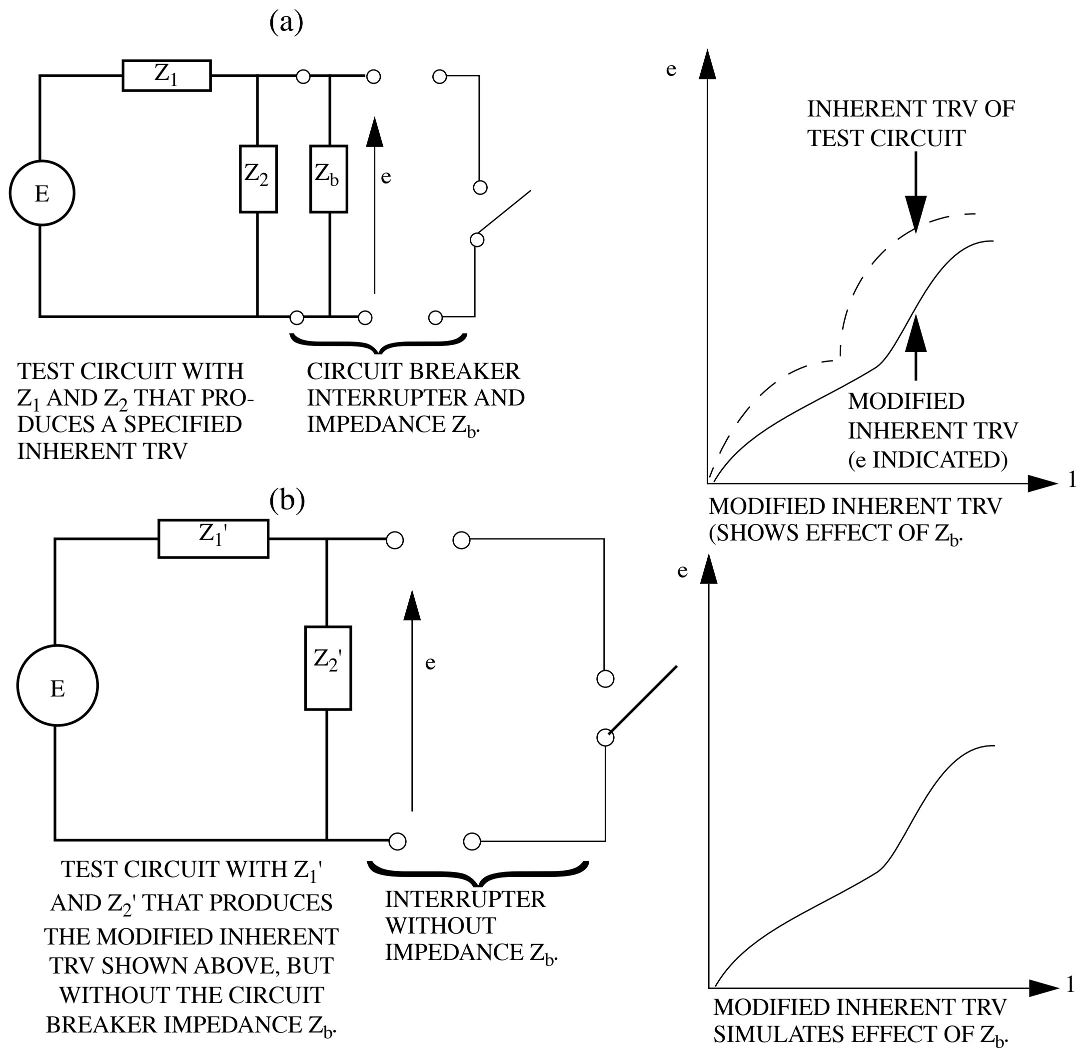

Figure 6—A test circuit designed to simulate the effect of circuit breaker modifying impedance

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 $1 + (K_a – 1)M$.

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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)	I @ contact part kA	% asymmetry
1	Three Os	E		0.1 I	see 4.8.3.1
2	Three Os	E		0.3 I	see 4.8.3.1
3	Three Os	E		0.6 I	see 4.8.3.1
4	O - t - CO - t' - CO or (4a) and (4b)	E		I	< 20
4a	C - t' - C	E	F × I		
4b	O - t - O - t' - O	E		I	< 20
5	Three Os	E		see 4.8.3.3	> 20
Single-phase tests					
6	O	.58 V		I	< 20
7	O	.58 V		see 4.8.3.4	> 20
Single-phase short-line fault tests					
8	Three Os	.58 V		.7 I to .8 I	< 20
9	Three Os	.58 V		.9 I to .95 I	< 20
Short-time test					
10	Closed position		F × I	I for T seconds	

The sawtooth line-side component of the recovery voltage can be described in terms of:

a) The line inductance $L_{L;}$

b) Frequency $f_{L;}$ and

c) An amplitude constant, d, which is the ratio of the peak of the sawtooth component to the peak of the voltage to ground, at the circuit breaker terminals, at the instant of interruption.

Let MI be the desired test current, where M represents the ratio of the test current to I. Then the line inductance L_L is:

$$L_L = \frac{0.58\ V}{M\omega I}(1 - M)\ \text{Henrys} \tag{4}$$

The TRV rate of the line-side component R_L for a short-line fault is the surge impedance Z multiplied by the slope of the current at current zero:

$$R_L = \sqrt{2}\omega MIZ \times 10^{-6}\text{kV}/\mu\text{s} \tag{5}$$

If the peak amplitude constant of the line-side component is d, the first peak, e, is:

$$e = d(1 - M)\sqrt{2}(0.58V)kV \tag{6}$$

The time T_L to the line-side peak is then:

$$T_L = \frac{e}{R_L}\ \mu s \tag{7}$$

and the frequency is:

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$$f_L = \frac{10^6}{2(e/R_L)} \text{ Hz or} \qquad (8)$$

$$f_L = \frac{0.866^{(MI)}\omega MIZ}{d(1-M)V} \text{ Hz}$$

To determine the line-side component circuit, calculate the line inductance, L_L, verify that the amplitude constant equals d, and adjust the frequency, f_L, to the desired value.

The surge impedance, as specified in IEEE Std C37.04-1999, is Z = 450 Ω, and the amplitude constant d = 1.6.

NOTE—$\omega = 2\pi f$, where f is the power system frequency. V is in kV units. I is in kA units.

The sawtooth recovery voltage on the short-line fault transient is delayed by substation capacitance adjacent to the circuit breaker and the line. The time delay t_d is 0.5 μs for breakers rated 242 kV and above, and 0.2 μs for breakers rated below 242 kV (see IEEE Std C37.04-1999). The first line-side peak voltage, e, and the line-side rate of rise of recovery voltage, R_L, are the same as previously calculated, but the time to first peak voltage is modified.

The ramp voltage rising at a rate R_L is delayed by the time delay t_d. The voltage then rises linearly to nearly peak voltage, but the peak occurs at a time ($T_L + 2t_d$) as shown in Figure 7.

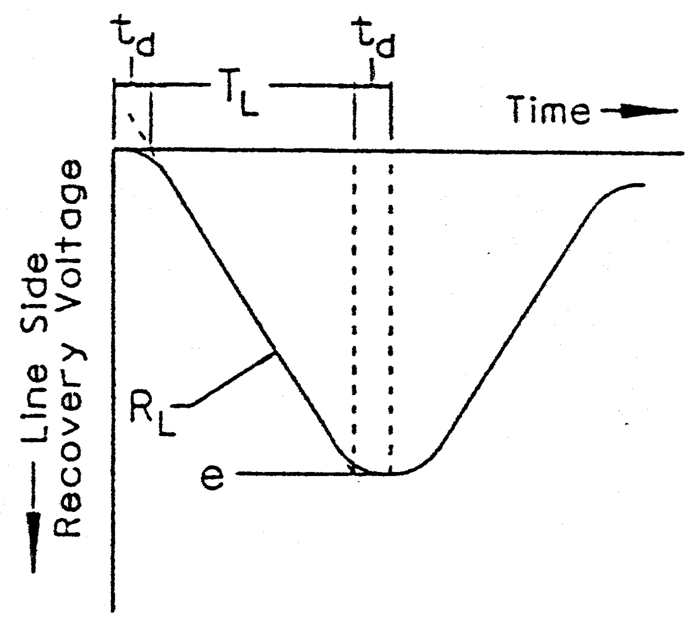

Figure 7—Short-line fault TRV with time delay

4.8.1.7 Initial TRV test conditions

The initial TRV capability may be demonstrated in conjunction with short-line fault testing. Suitable circuit impedance may be used on the source side to obtain the initial TRV as specified in IEEE Std C37.04-1999.

Testing complexity may be reduced by using an alternate test method to demonstrate the initial TRV capability as explained with the aid of Figure 8 and Figure 9.

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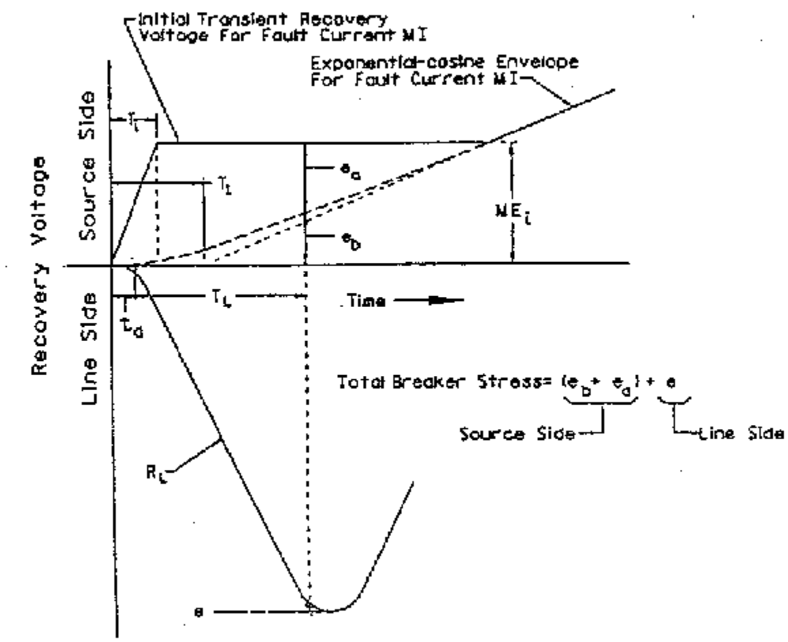

Figure 8—Illustration of initial TRV on source side with time delayed short-line fault transient voltage on the line side

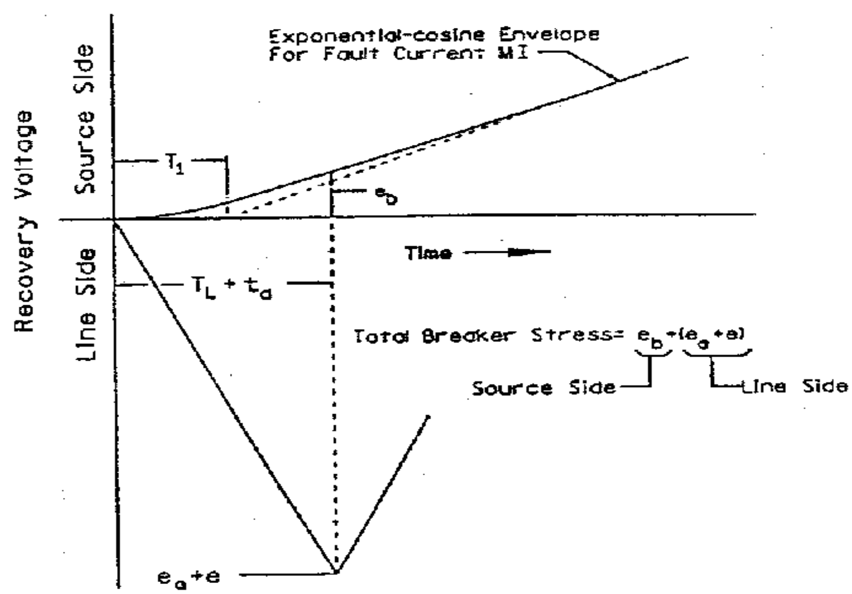

Figure 9—Illustration of equivalent short-line fault TRV on the line side without the initial TRV on the source side

In the case where the initial TRV ME_i exceeds the exponential-cosine transient for current MI at time ($T_L + t_d$), the source-side initial TRV can be simulated by a line-side linear ramp transient without time delay t_d (see Figure 8). The peak of the line-side transient shall also be increased such that the total peak voltage across the circuit breaker at time ($T_L + t_d$) is equal to the sum of the normal short-line fault peak voltage, e, and the initial TRV ME_i.

The required line-side peak voltage e and time to peak with time delay is calculated as explained previously in 4.8.1.6. The reduced initial TRV for the fault current MI and the total circuit breaker stress is then determined at the time (T_L + t_d) as shown in Figure 8. An equivalent line-side TRV is then calculated assuming only an exponential-cosine envelope for the reduced current MI for the source side transient. The peak line-side test voltage would be (e + e_a) and the voltage should rise linearly to the value at time (T_L+ t_d) without a time delay as shown in Figure 9.

In the case where the reduced exponential-cosine transient for current MI exceeds ME_i at time (T_L + t_d) then the initial TRV can be simulated by a line-side linear ramp transient without time delay t_d and the peak shall simply be e at time (T_L + t_d).

NOTE—It is considered that the combination of shortline fault (SLF) (with the standard time delay) plus initial transient recovery voltage (ITRV) is equivalent to a test of SLF performed with a line, without time delay (< 0.1 μs).

4.8.1.8 Control voltage

It is preferred that the minimum control voltage be used for all tests. However, it is acceptable to use a higher control voltage to minimize the variations in the contact making and contact parting times for the purposes of facilitating the testing procedures, provided that at least one open test is made at the maximum current and at the minimum control voltage.

4.8.1.9 Operating pressures

a) *Mechanism*. For circuit breakers operated by hydraulic or pneumatic mechanisms, the minimum operating pressure shall be used at the initiation of the operating sequence.
b) *Interrupters*. For circuit breakers whose interrupters use a pressurized gas as the interrupting medium, the minimum allowable interrupter gas pressure shall be used for all tests.

4.8.1.10 Opening times

The opening time of the circuit breaker shall be measured prior to the initiation of the short-circuit tests. These measurements shall be made with maximum control voltage and mechanism operating pressure, in order to determine the maximum asymmetry required at contact separation (at minimum contact parting time) in accordance with 4.8.1.3.

4.8.1.11 Conditions during single-pole tests and unit tests

During single-pole tests and unit tests the closing speed/travel, and the opening speed/travel of the contacts in the region of arcing, shall be approximately the same as during a corresponding test on the complete breaker. If the tests are being made on a single-pole or other part of a three-pole circuit breaker, or if the three-phase short-circuit currents exert a significant influence on the opening and closing speeds of the circuit breaker, the opening and closing forces shall be adjusted so that the contact travel characteristics obtained on the operating tests performed in accordance with 4.8.5.2 shall be within a tolerance of ±10% in speed/travel and contact gap at any instant during the opening stroke between the instant of contact separation and the instant corresponding to maximum arc duration. At lower currents, the contact velocities may be different.

If the short-circuit currents cause appreciable mechanical latch loading or velocity changes, either acceleration or deceleration during opening, or deceleration during closing, and if a single mechanism operates all poles, additional tests should be made if they can further test the ability of the circuit breaker to close and open three-phase faults successfully.

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4.8.1.12 Grounding of the circuit breaker and test circuit

The normally grounded parts of the circuit breaker shall be grounded. In all cases, either the short circuit or the neutral of the supply shall be grounded, but not both.

4.8.1.13 Reversal of test connections

Test connections to circuit breakers with a non symmetrical configuration shall be reversed during tests with the short-circuit applied in turn to each side of the circuit breaker. This requirement may be complied with by reversing the connections between tests duties 4 and 5 from Table 1.

If it can be shown that one connection is more severe than the other, then all tests may be performed under this condition, and further reversal of the connections is not required.

4.8.1.14 Test enclosures for indoor circuit breakers

Indoor circuit breakers shall be tested in a minimum volume enclosure or in the actual switchgear vertical section compartment equipped with the maximum complement of mechanism operated cell (MOC) switches. Connections to the switchgear shall be made in accordance with IEEE Std C37.20.2-1993.

4.8.2 Test methods

A three-phase short circuit, with either the source or the fault ungrounded, is usually the most desirable test method for a circuit breaker to demonstrate its short-circuit ratings, which are based primarily on the three-phase conditions. Because of limitations of the test facilities, both in a laboratory and in the field, there are ratings of circuit breakers for which interrupting tests can not be conducted up to the full rating, which includes system voltage, short circuit current, and system TRV requirements.

The test methods described below are the preferred methods. The test program shown in Table 1 shall be applicable with any test method that is used.

4.8.2.1 Method I, three-phase tests

Method I consists of switching, by means of a three-pole circuit breaker, a three-phase circuit source of reactive power, which has a recovery voltage substantially equal to the service voltage. To verify the rated short circuit current of the circuit breaker by Method I, the test procedure given in Table 1 shall be followed.

4.8.2.2 Method II, single-phase tests

Method II tests a single pole of a three-pole circuit breaker with a single-phase source of reactive power. The test is made by applying to the single pole the same currents, and substantially the same recovery voltages that would be impressed upon the most highly stressed pole during interruption of a three-phase current by the complete three pole circuit breaker under correspondingly similar conditions. The test procedure given in Table 1 shall be followed.

If there is a possibility that hot gases produced by switching may cause a flashover between poles of a completely assembled circuit breaker by mingling of the exhaust gases, adequate provisions shall be included in the single-pole tests to demonstrate that phase-to-phase flashover will not occur in service. Such a provision might be a grounded temporary screen or barrier, conducting or semiconducting, placed near the test pole in accordance with the specifications of the manufacturer.

Additionally, if the opening speed of the circuit breaker can be substantially altered due to back pressures developed by each pole during the interruption of a three-phase fault, adequate allowances shall be made to

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demonstrate that the instantaneous energy requirement relationship between the interrupter and the mechanism has been preserved.

4.8.2.3 Method III, unit tests

When the full series of short-circuit current interrupting tests can not be made by Method I or Method II, and when the pole that accomplishes the interruption incorporates several identical and relatively independent interrupting units connected in series, the unit test method may be used to verify the interrupting performance of the circuit breaker.

Similarly, if each pole that closes the circuit incorporates several identical and relatively independent making units in series, this method may be used to indicate the making capacity of the circuit breaker. The test procedure given in Table 1 shall be followed.

The validity of unit tests depends on how closely the conditions imposed on the test unit approximate the most severe conditions that would be imposed on the unit when used as an integral part of a three-pole circuit breaker subjected to the simulated voltage, current, and operating duty.

Tests made in accordance with Method III do not evaluate the possibility that hot gases produced by interruption can cause a flashover through a path other than a normal arcing path. Knowledge of the characteristics of a particular circuit breaker design may permit demonstration of its adequacy in this respect by special test arrangements, but it is impractical to prescribe tests that will be valid for any design of circuit breaker and that are within the limitations of available test facilities.

4.8.2.3.1 Conditions that make unit testing possible

a) *Nature of the units*. When all units of the circuit breaker are effectively identical in their shape, dimensions, and conditions of arc extinguishing medium (temperature, pressure, flow velocity, etc.), tests may be made on a unit or group of units under the most severe conditions of recovery voltage. These conditions would be imposed on any such unit or group in a corresponding test on the complete circuit breaker with due consideration for the effects of circuit grounding and adjacent objects and of any distortion of voltage distribution by current magnitude, recovery transient frequency, or post-arc conductivity.

   When all units are not identical, tests may be made on each type of unit up to the most severe conditions of recovery voltage that would be imposed on any unit of that type with due consideration to the effects listed in the preceding paragraph. Units may be tested in groups, provided that each unit is subjected to its required recovery voltage conditions.

b) *Simultaneity of operation*. The mechanical operation of the contacts should be such that all contacts performing the same function in a pole unit touch on closing within an interval of one quarter of a cycle of the applicable rated power frequency and separate on opening within an interval of one sixth of a cycle of the corresponding rated power frequency. If a circuit breaker uses a supply of arc-extinguishing medium, from a source external to the units, the arc-extinguishing action in all units of one pole should start within an interval of one sixth of a cycle.

c) *Supply of the arc-extinguishing medium*. For circuit breakers using a supply of arc extinguishing medium from a source external to the units specified in item b), the test should be made in such a way that neither the supply of the arc-extinguishing medium to the unit or units under test nor the freedom of exhaust of the arc products is increased as a result of the absence of arcing in other units normally connected in series with the unit or units under test.

d) *Exhaust conditions*. Ionized gases or vapors that may be present in the exhaust should be so discharged that they cannot cause malfunctioning of adjacent units in the same or other phases, or failure of the circuit breaker as a whole by flashover, either partially or totally, through exhaust gases.

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4.8.2.3.2 Determination of voltage distribution

The required test voltage is dependent upon the voltage distribution among the breaks of a multibreak circuit breaker. Consequently, this distribution should be determined for the types of tests to be made and, when the breaks are not symmetrically arranged, the voltage distribution with the connections reversed shall be evaluated. The types of tests may include making and interrupting tests that can be made on one or more interrupters as well as on complete poles.

The range of frequencies or rates of rise and amplitudes of the TRVs should be determined; these determinations may be made by suitable means, such as voltage or current injection with little or no current through the circuit breaker. Their validity may be tested by the following comparison: Three single-pole tests in which a complete pole interrupts the maximum current available at 0.87 or 0.75 (see 4.8.3) times the rated maximum voltage are compared with three single-pole tests in which the same current is interrupted by a test unit with power frequency and TRVs equal to those determined for the most highly stressed corresponding unit by the voltage distribution measurements. The performance should be equivalent. For example, if the asymmetry of the currents is the same and if the current zeros occur at the same times after contact parting, the arcing times should be equal.

If one half or another fraction of a pole unit can be tested to a higher current with full calculated recovery voltages, three interrupting tests on it can be compared with three interrupting tests on a smaller unit at the same current and with power frequency and TRVs equal to those determined for the most highly stressed unit for the test condition used for the fractional pole test. The number of breaks and the test circuits available determine the number of comparative tests that can be made to validate the measurements of voltage distribution. These validation tests may also qualify for demonstrating some of the test duties.

For short-line fault unit tests the voltage distribution shall be calculated or measured statistically on the basis of a voltage on the line side at the fundamental frequency of the line oscillation and a voltage on the source side at the equivalent frequency of the TRV for terminal faults, the common of the two voltages being at ground potential.

4.8.2.3.3 Factors modifying voltage distribution

a) *Influence of circuit grounding and adjacent objects*. For circuit breakers in which the units are not arranged symmetrically with respect to ground, the voltage distribution between the different units may vary according to the position of a fault to ground in relation to the circuit breaker.

   To take into account the influence of such an unsymmetrical arrangement, where it exists, determination of the voltage distributions should be made with each of the terminals of the pole of the circuit breaker successively connected to ground.

   Furthermore, for all circuit breakers, except those in which all units of each pole are contained in a metal enclosure connected to ground, the voltage distribution may vary with the proximity of adjacent objects.

   Unless all the parts of a pole are contained in a grounded metal enclosure or unless the units are shunted by resistors or capacitors of sufficiently low impedance to render the voltage distribution independent of the proximity of adjacent objects, the tests should be made under the following conditions:

   1) If the test is made on the center pole, all the breaks of the other poles should be shunted and their metal parts grounded.
   2) If the test is made on an outer pole or on a single pole of a circuit breaker, a conducting or semiconducting partition should be placed near the tested pole at a distance specified by the manufacturer.

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b) *Effect of post-arc conductivity*. Post-arc conductivity may influence the proper determination of the voltage distribution among the units for some ms after current zero. The validating tests specified in 4.8.2.3.2 will detect any effect of post-arc conductivity on the performance of the circuit breaker at the current at which the comparison is made.

4.8.2.3.4 Choice of units to be tested and the test voltage

A complete circuit breaker, or a complete pole of a circuit breaker, shall be available and operated during the tests.

a) Interrupting tests
   1) *Choice of the units for test*. Unit tests are usually made on the maximum number of units in series that can be tested at the testing facility, up to the currents corresponding to the required symmetrical and asymmetrical interrupting capabilities of a circuit breaker with a TRV as specified in 2).
   2) *Recovery voltage*. The recovery voltage across the terminals of the test unit or group of units in series should not be less than the highest recovery voltage recorded across the corresponding number of units in series during the determination of the voltage distribution among the units, taking into consideration the influence of adjacent objects, grounding conditions, and the influence of external pollution.

      If, when testing a group of units, the voltage distribution among the different units is more uniform than in the tests on the complete circuit breaker with reduced currents, the voltage at the terminals of the group should be increased so that the recovery voltage at the terminals of a unit is at least equal to the recovery voltage occurring on the most highly stressed unit in the complete pole of the circuit breaker.
b) Making tests
   1) *Choice of units for test*. Unit tests are usually made on the maximum number of units in series which can be tested at the testing facility, up to the current corresponding to the required making capability of the circuit breaker at the initial voltage specified in 2).
   2) *Initial voltage*. The initial voltage across the terminals of the test unit or group of units in series should be not less than the highest voltage recorded across the corresponding number of units in series during the determination of the voltage distribution among the units.

      If, during the making tests, the prestrike arc duration is shorter than in tests carried out on the complete circuit breaker, additional making tests should be made with an increased initial voltage so that the arc duration is at least equal to that obtained on the complete circuit breaker.

4.8.2.4 Method IV, pre-tripped tests

Pre-tripping may be used with any of the other methods of testing circuit breakers as a means of increasing the amount of current and voltage available on a test circuit. The tripping impulse is applied to the circuit breaker before the inception of the short circuit, so that the contacts of the circuit breaker part sooner after initiation of the short circuit than would otherwise be possible. The short-circuit current during the arcing period then has the higher ac component and, with proper timing, a higher dc component, which is available from the generator under this condition.

4.8.2.5 Method V, synthetic tests

Synthetic tests are tests in which a relatively low-voltage source supplies short-circuit current to the circuit breaker up to the time of interruption, and a source capable of supplying a high recovery voltage is applied to the circuit breaker at about the time of interruption (see IEEE Std C37.081-1981). Thus, the circuit breaker has the duty of carrying the high short-circuit current of the low-voltage source up to the time of arc

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interruption and must then withstand the high recovery voltage of the second source. In this manner, the duty of interrupting the high current at the high voltage is simulated.

The accuracy with which a synthetic test represents a test in which the same voltage causes the current to flow and provides the recovery voltage, as in Methods I and II, depends on several conditions. These are listed below and must be considered in planning and evaluating a synthetic test.

a) The arc voltage should be relatively low and should cause little or no distortion of the current wave. Since the magnitude of the arc voltage is larger with respect to the voltage of the current source than it is with respect to the voltage of the circuit being represented, the arc voltage has a greater effect in reducing the magnitude and shortening the duration of those loops of current during which arcing takes place. If the current distortion is appreciable, the interrupted current assigned to the test should be the product of the value measured in the conventional way, at contact parting, and a factor that compensates for the distortion.
b) The TRV should appear across the terminals of a pole unit in the same manner as the TRV does in the tests made in accordance with Methods I and II, and that is:
    1) It should appear at the precise instant of arc extinction.
    2) The circuit TRV should increase at least as rapidly and to at least as high a value as the circuit TRV being simulated.
    3) The parameters of the high-voltage sources should be such that the effect of post-arc conductivity on the TRV is no greater than that in the circuit being simulated; or failing this, the characteristics of the TRV should be judged on the basis of the actual voltage appearing across the circuit breaker contacts instead of the circuit TRV.
c) The arcing time should be controlled so that it covers the range of arcing time that will occur when the circuit breaker actually interrupts the power being simulated.

4.8.3 Test duties

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 (for test duties 1 through 5)
    1) For three phase tests,

        E = rated maximum voltage, V.

    2) For single phase test,

        E = 0.87 × rated maximum voltage V for circuit breakers rated 100 kV and below

        E = 0.75 × rated maximum voltage V for circuit breakers rated above 100 kV

    where V = rated maximum voltage as given in ANSI C37.06-1997.
b) Test current, I, is equal to the maximum rated rms symmetrical interrupting current.
c) Time, t, is equal to:
    1) 15 s for circuit breakers that are not rated for re closing duty; and
    2) 0.3 s for circuit breakers rated for re closing duty.
d) Time, t', is equal to 3 min.
e) Time, T, is equal to the specified time shown in IEEE Std C37.04-1999 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.

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4.8.3.1 Test duties 1, 2, and 3

Test duties 1, 2, and 3 shown in Table 1 consist of at least two symmetrical (< 20% dc) and one asymmetrical (between 40% and 60%) current interruption tests made with the appropriate current values, where I represents the rated short circuit interrupting current value. At the discretion of the manufacturer, the tests may also be performed as a O - t - CO - t' - CO, provided that for two opening operations the test current must be symmetrical at the time of contact part. In the case of three-phase tests the symmetry requirement is applicable only to one of the phases. For convenience in testing it is permissible to perform three C - O operations or a complete duty cycle O - t - CO - t' - CO instead of the O operations.

These tests demonstrate the capability of the circuit breaker for switching low magnitudes of symmetrical short-circuit currents. The circuit TRV used in test duties 1, 2, and 3 shall be in accordance with the related capability envelope given in IEEE Std C37.04-1999 and modified in accordance with the corresponding TRV multipliers given in ANSI C37.06-1997 or ANSI C37.06.1-1997.

4.8.3.2 Test duty 4

Test duty 4 in Table 1 demonstrates the standard operating duty and/or the re closing duty cycle at rated short-circuit capability by interrupting a symmetrical current I of the rated value with a power frequency recovery voltage associated with the rated maximum voltage and with a circuit TRV defined by the rated or adjusted exponential-cosine envelope for circuit breakers rated above 100 kV, or by the rated or adjusted, one minus-cosine envelope for circuit breakers rated 100 kV and below.

For these tests the current must be symmetrical (< 20% dc) at the time of contact part for all three opening operations. This requirement can be met by delaying the opening, which follows the close operation.

In the event that operating test duty 4 can not be performed as shown, due to limitations of the test laboratory, the alternate methods 4a and 4b may be applied.

Refer to 4.8.1.4 for specific requirements for demonstrating the most severe switching conditions.

4.8.3.3 Test duty 5

Test duty 5 in Table 1 consists of three asymmetrical opening operations made not more than 15 min apart. The required degree of asymmetry shall be determined in accordance with Figure 1 and where the elapsed time from fault initiation shall be equal to 1/2 cycle of rated power frequency plus the actual measured opening time of the circuit breaker with maximum control voltage.

The required dc component must be attained at the time of contact separation in one phase during one of the interruptions.

Refer to 4.8.1.4 for specific requirements for demonstrating the most severe switching conditions.

4.8.3.4 Test duties 6 and 7

Test duties 6 and 7 in Table 1 are single-phase tests made at 58% of the maximum rated voltage. These tests are intended to demonstrate the capabilities of the circuit breaker for interrupting a single phase-to-ground fault under the most severe switching condition for the circuit breaker.

Test duty 6 is performed with a symmetrical current equal to the maximum rated symmetrical rms current and with a maximum arcing time as indicated in 4.8.1.4.1.

Test duty 7 is made with an asymmetrical current having a dc component, which is determined as described in 4.8.1.3, and a maximum arcing time corresponding to those specified in 4.8.1.4.2.

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Test duties 6 and 7 are not required if test duties 4 and 5 are made on a single-phase basis.

4.8.3.5 Test duties 8 and 9

Test duties 8 and 9 in Table 1 are single-phase tests made at 58% of the maximum rated voltage. These tests are intended to demonstrate the short-line fault capability of the circuit breaker.

4.8.4 Tests for short-circuit current required related capabilities

See IEEE Std C37.04-1999.

4.8.4.1 Closing and latch tests

The required capability to close against a fault current, and to latch closed, as specified in IEEE Std C37.04-1999, is demonstrated by performing a closing test where the peak current has a value equal to 2.6 × I for 60 Hz or 2.5 × I for 50 Hz.

The test may be performed as part of test duty 4 or its alternates. The latching portion of the test is demonstrated by sustaining the current flow after the closing operation for a duration equivalent to at least 10 cycles of the rated power frequency. When closing and latching is not done as part of test duty 4, upon completion of the closing and latching test the circuit breaker shall be allowed to cool for at least five minutes and then it shall be opened under no-load conditions to demonstrate that welding of the contacts has not occurred. The circuit breaker will have passed the test provided it opens successfully.

For circuit breakers where all three poles are operated by a common operating mechanism, these tests shall be performed using either of the following two methods:

a) Using a three-phase source circuit where the maximum offset current is applied to one of the outer phase poles; or
b) Using a single-phase source circuit where two poles are connected in parallel and then in series with the third pole. The single pole in the series connection shall be one of the outside poles of the circuit breaker.

For circuit breakers whose poles are independently operated, only a single-phase test source is required.

4.8.4.2 Short-time current carrying tests

The required short-time current carrying capability of a circuit breaker is demonstrated by test duty 10 in Table 1. The duration of the current flow shall be in accordance with the requirements of IEEE Std C37.04-1999 and ANSI C37.06-1997. In some cases, the duration of the test demonstrating the short-time current carrying capability may not be exactly as specified. However, since the heating of the current carrying parts is very nearly proportional to i^2dt and the cooling time is relatively short, the test is valid if the duration of the short circuit current is within 25% of the specified time and the product of i_A^2T is equal or greater than the i_B^2T product of the originally specified parameters (see 7.1.6).

4.8.4.3 Service capability and circuit breaker condition

The capability of a circuit breaker to meet its service capabilities as required in IEEE Std C37.04-1999 is demonstrated by obtaining the summation of all the currents that have been interrupted by the same interrupter during the performance of the test duties listed in Table 1 (interruption tests for calibration and interruption tests performed at reduced voltage may be included in accumulated current summation). In some cases it may be necessary to perform additional tests to fulfill this requirement.

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4.8.5 Condition of circuit breaker tested

At the initiation of the short-circuit test program the circuit breaker shall be new and in good condition.

4.8.5.1 Circuit breaker to be used for test

The circuit breaker shall be representative of the type, style, or model, as required for all design tests.

Indoor circuit breakers shall be tested in their minimum size enclosures or in a switchgear vertical section compartment.

4.8.5.2 Circuit breaker operating characteristics prior to test initiation

The following circuit breaker characteristics shall be measured and recorded prior to the initiation of interruption tests:

a) Opening time and opening contact speed/travel with rated control voltage and mechanism operating pressure (if applicable);
b) Opening time and opening contact speed/travel with maximum control voltage and maximum mechanism operating pressure (if applicable);
c) Closing contact speed/travel with minimum mechanism operating pressure (if applicable); and
d) Contact resistance.

4.8.5.3 Reconditioning of circuit breaker during testing

The expendable parts of a circuit breaker may be replaced during a test series, except that no reconditioning is permitted until the summation of the interrupted currents in one pole equals or exceeds the required service capability (see 4.8.4.3).

4.8.5.4 Circuit breaker operating characteristics after test

The circuit breaker opening time shall be measured and recorded at the completion of interruption tests and they shall be compared to those measured and recorded at the initiation of the tests (see 4.8.5.2).

4.8.5.5 Condition of circuit breaker after test

After completion of the prescribed design tests, the circuit breaker shall be in the following condition:

a) The circuit breaker shall be in substantially the same mechanical condition as it was before the performance of the required duty cycles.
b) The circuit breaker shall be capable of withstanding its rated maximum voltage in the open position and of carrying its rated continuous current without exceeding its rated temperature rise by more than 10 °C. The circuit breaker shall be deemed to be capable of carrying its rated continuous current without exceeding its rated temperature rise if the resistance of the continuous current carrying circuit meets the limitation in item d). If this condition is not met then a continuous current carrying test in accordance with 4.3 is required.
c) The circuit breaker shall be capable of withstanding a one minute power frequency, or a modified impulse voltage test as specified below in 4.8.5.6.
d) The resistance of the continuous current carrying circuit, from terminal to terminal when measured with a dc current source where at least 100 A are flowing, shall be less than 200% of the maximum value given by the manufacturer.

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e) The opening time of the circuit breaker shall not exceed 110% of the corresponding initial value measured before the test.

4.8.5.6 Voltage withstand tests

The tests described below shall be performed after completion of short-circuit current interruption tests.

a) For circuit breakers rated below 72.5 kV:

   A one-minute power frequency withstand tests at 80% of the original rated withstand value.

b) For circuit breakers rated 72.5 kV and above, but below 362 kV:

   A withstand test applying a test voltage having a peak value equal to 80% of the product of $\sqrt{2}$ times the rated power frequency withstand voltage. The waveform shall be similar to that of the applicable rated TRV as used in test duty 1 of Table 1.

c) For circuit breakers rated 362 kV and above:

   An impulse voltage test with a peak voltage equal to 90% of the rated switching impulse withstand voltage. The waveform for this test shall be the same as that used for switching impulse tests.

The IEC 60056-1987 test method outlined below can be used as an alternate demonstration of capability.

a) For circuit breakers rated 72.5 kV and below:

   A one-minute power frequency withstand test at 80% of the original rated withstand value.

b) For circuit breakers rated above 72.5 kV, and up to 245 kV:

   An impulse voltage test with a peak voltage equal to 60% of the corresponding rated lighting impulse. The waveform shall be similar to that of the applicable rated TRV as used in test duty 1 of Table 1.

c) For circuit breakers rated above 300 kV and up to 420 kV:

   An impulse voltage test with a peak voltage equal to 80% of the corresponding rated switching impulse. The waveform shall be similar to that of the applicable rated TRV as used in test duty 1 of Table 1.

d) For circuit breakers rated 550 kV and up to 800 kV:

   An impulse voltage test with a peak voltage equal to 90% of the corresponding rated switching impulse. The waveform shall be similar to that of the applicable rated TRV as used in test duty 1 of Table 1.

4.8.6 Suggested short-circuit current interruption performance data form

Test data is preferably presented in a form with an accompanying tabulation of pertinent data similar to that shown in Annex A.

4.9 Load current

4.9.1 Load current switching test conditions

Load current switching tests shall be made under the following conditions to demonstrate the capability of the circuit breaker to switch load currents such as may be encountered in normal service:

a) The test current levels shall be at:

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1) 3 to 7% of the rated continuous current; and
2) 95 to 100% of the rated continuous current.

b) The power factor of the test circuits shall be 80% lagging or less with a parallel connected load.

NOTE—Tests at lower power factors are not required but may be made at the option of the manufacturer.

c) For three-phase tests, three close-open operations shall be made at each current level. For single-phase tests, nine close-open operations shall be made at each current level with the contact parting time to be varied by 30° intervals, on one reference phase, between tests.
d) If three-phase tests are made, they shall be made with power frequency initial and recovery voltages at least equal to the rated maximum voltage of the circuit breaker. If single-phase tests are made, they shall be made with power frequency initial and recovery voltages at least equal to 87% of the rated maximum voltage.
e) If three-phase tests are made, either the neutral of the switched circuit or of the supply shall be ungrounded except in the case of circuit breakers, which are only intended for grounded neutral service, or where otherwise specified.
f) The normally grounded parts of the circuit breaker shall be grounded.
g) If the interrupter or interrupters are not symmetrical with respect to the terminals, part of the tests shall be made with the source connected to one side of the circuit breaker and then repeated with the source connected to the other side of the circuit breaker.

NOTE—If the most severe configuration has been previously determined during short circuit testing, then that side shall be used for all tests.

h) The tests shall be made at rated power frequency.
i) All tests shall be made at rated control voltage and operating gas or oil mechanism pressure, if applicable).
j) With all interrupters using pressurized gas, all operations shall be made to demonstrate the circuit breaker capability for interrupting load currents at the minimum pressure of the interrupting medium.

4.9.2 Load current endurance switching tests

Load current endurance switching tests may be made to determine the capability of a circuit breaker of performing the number of load switching operations shown in ANSI C37.06-1997 by opening the circuit breaker and interrupting a current equal to the rated continuous current at rated maximum voltage with a power factor between 80% leading and 80% lagging and by closing circuits having making currents of 600% of rated continuous current. A demonstration of this capability is not required if the circuit breaker has successfully met the service capability requirement (see 4.8.4.3).

NOTE—The following clause covering capacitor current testing 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 that is now being prepared by a joint IEEE and IEC working group.

4.10 Capacitor switching current tests

The capacitance current switching rating of a circuit breaker may be demonstrated by laboratory or field tests. The conditions for making the laboratory tests with static capacitors are described below and in Tables 2 and 3.

If field tests are made, they shall be conducted in accordance with the applicable portions of the procedure outlined for laboratory tests insofar as practicable for the rating or capability being demonstrated.

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Design tests may be conducted at values in excess of rating. However, in conformance tests, field tests, or in service, the circuit breaker is not required to have the capability of passing tests or performing at values that exceed the applicable ratings or related required capabilities.

Table 2—Three-pole capacitance current switching tests

Test duty (see 4.10.11)	Test voltage phase-to-phase (a)[a]	Percent of rated capacitance switching current	Number and type of operations (c, h, k)	Interrupter pressure	Circuit grounding
1A Isolated capacitor bank or cable switching	$V\frac{2}{1+A}$	30	24 O	Rated	(f)
1B Isolated capacitor bank or cable switching	$V\frac{2}{1+A}$	100 (d)	24 C - O	Rated (e)	(f)
2A Back-to-back capacitor bank or cable switching	$V\frac{2}{1+A}$	30	24 O	Rated	(f)
2B Back-to-back capacitor bank or cable switching	$V\frac{2}{1+A}$	100 (b, d, j)	24 C - O	Rated (e)	(f)
3A Open wire line charging current switching	$V\frac{2}{1+A}$	30 (j)	24 O - C(i)	Rated	(g)
3B Open wire line charging current switching	$V\frac{2}{1+A}$	100 (d, j)	24 C - O	Rated (e)	(g)

[a] Letters in parentheses correspond to those in the explanatory NOTES.

NOTES—

V = Rated maximum voltage (IEEE Std C37.04-1999).
A = Voltage regulation factor (see 4.10.4.1).

a) Test circuit voltage with test circuit breaker open but with bus capacitor bank connected for back-to-back tests in test duty 2 (see 4.10.4.1).

b) Rated transient inrush current on closing.

c) Type of operations:
At 30% of ratings—Open [see NOTE i) for test duty 3A]; and
At 100% of ratings—Close-open, allow sufficient time before tripping for closing transient currents to decay.

d) For circuit breakers with non symmetrical insulation paths, reverse terminal connections for half of 100% operations (see 4.10.9).

e) Interrupter pressure shall be minimum for three operations (see 4.10.6).

f) Grounding: source neutral grounded; capacitor bank neutral grounded for circuit breakers rated 121 kV and above (see 4.10.8).

g) Grounding: source neutral grounded; neutral of one half of the capacitive load ungrounded, neutral of one half of the capacitive load grounded (see 4.10.8). The recovery voltage across the first phase to interrupt should be 2.4 times E_{max} (phase).

h) The operations specified shall include the following:

   1) Two interruptions, each with contact separation at 30° intervals over the current loop: 0°, 30°, 60°, 90°, 120°, 150° in one reference phase.

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2) Six interruptions with contact separation at the point on the current wave, ±7.5°, which, as determined above, resulted in the shortest capacitance current arcing time in the first phase to clear, not including reignition or restrike.
3) Six interruptions with contact separation at the point on the current wave, ±7.5°, which, as determined above, resulted in the longest capacitance current arcing time in the first phase to clear, not including reignition or restrike. This is considered equivalent to 50 random three-phase operations.
4) During these tests, the performance specified in performance on capacitance current switching for definite purpose circuit breakers (see IEEE Std C37.04-1999) will be considered to have been met if there is no more than one operation with an overvoltage greater than the allowable limit. For general purpose circuit breakers (IEEE Std C37.04-1999) the performance will be considered to have been met if there are no operations with overvoltages greater than the allowable limit.

i) For circuit breakers rated for instantaneous reclosing, these operations are to be made with a duty of Open - 0 s - Close to demonstrate the circuit breaker's capability during high-speed reclosing when the unfaulted phases of a line may have a trapped voltage charge. The reclosing time shall be rated reclosing time for the circuit breaker under test (IEEE Std C37.04-1999).

j) If tests are made with lumped capacitor banks to simulate transmission lines or cables, the test circuit may be modified to limit current surges on closing to those obtained when closing into the surge impedance of a line or cable.

k) For circuit breakers equipped with shunting resistors, the thermal capability of the resistors must be considered in determining the time interval between tests.

Table 3—Single-pole capacitance current switching tests

Test duty (see 4.10.11)	Test voltage (a, b)[a]	Percent of rated capacitance switching current	Number and type of operations (d, g, k)	Interrupter pressure	Circuit grounding
1A Isolated capacitor switching	$0.58BV\frac{2}{1+A_1}$	30	24 O	Rated	(h)
1B Isolated capacitor switching	$0.58BV\frac{2}{1+A_1}$	100 (e)	24 C - O	Rated (f)	(h)
2A Back-to-back cable switching	$0.58BV\frac{2}{1+A_1}$	30	24 O	Rated	(h)
2B Back-to-back cable switching	$0.58BV\frac{2}{1+A_1}$	100 (c, e, j)	24 C - O	Rated (f)	(h)
3A Open wire line switching	$0.58BV\frac{2}{1+A_1}$	30 (j)	24 O - C (i)	Rated	(h)
3B Open wire line switching	$0.58BV\frac{2}{1+A_1}$	100 (e, j)	24 C - O	Rated (f)	(h)

[a] Letters in parentheses correspond to those in the explanatory NOTES.

NOTES—

V = Rated maximum voltage (IEEE Std C37.04-1999).
A_1 = Voltage regulation factor (see 4.10.4.2).
B = Voltage multiplying factor (see 4.10.4.2).

a) Test circuit voltage with test circuit breaker open but with bus bank connected for back-to-back bank tests in test duty 2 (see 4.10.4 2).

b) Voltage multiplying factor: For shunt capacitor bank switching tests, the voltage multiplying factor is:

B = 1.5 for circuit breakers rated 72 5 kV and below; and
B = 1.0 for circuit breakers rated 121 kV and above.

For transmission line charging current switching tests, the voltage multiplying factor is B = 1.2.

c) Rated transient inrush current on closing.

d) Type of operations:

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At 30% of ratings—Open [see NOTE i) for test duty 3A]; and
At 100% of ratings—Close-Open, allow sufficient time before tripping for closing transient currents to decay.

e) For circuit breakers with non symmetrical current path, reverse terminal connections for half of 100% operations (see 4.10.9).

f) Interrupter pressure shall be minimum for three operations (see 4.10.6).

g) The operations specified shall include the following:

   1) Two interruptions, each with contact separation at 30° intervals over the current loop: 0°, 30°, 60°, 90°, 120°, 150°.
   2) Six interruptions with contact separation at the point on the current wave, ±7.5°, which, as determined above, resulted in the shortest capacitance current arcing time, not including reignition or restrike.
   3) Six interruptions with contact separation at the point on the current wave, ±7.5°, which, as determined above, resulted in the longest capacitance current arcing time, not including reignition or restrike.
   4) This is considered equivalent to 50 random three-phase operations.

   During these tests, the performance specified in performance on capacitance current switching for definite purpose circuit breakers (IEEE Std C37.04-1999) will be considered to have been met if there is no more than one operation with an overvoltage greater than the allowable limit. For general purpose circuit breakers (IEEE Std C37.04-1999) the performance will be considered to have been met if there are no operations with overvoltages greater than the allowable limit.

   The transient overvoltage factor shall be calculated by dividing the peak transient voltage by the line-to-ground peak value of the average of the open and closed circuit test voltage.

h) Circuit grounding: Test circuit may be grounded (see 4.10.8).

i) For circuit breakers rated for instantaneous reclosing, these operations are to be made with a duty of Open - 0 s - Close to demonstrate the circuit breaker's capability during high-speed reclosing when the unfaulted phases of a line may have a trapped voltage charge. The reclosing time shall be the rated reclosing time for the circuit breaker under test (IEEE Std C37.04-1999).

j) If tests are made with lumped capacitor banks to simulate transmission lines or cables, the test circuit may be modified to limit current surges on closing to those obtained when closing into the surge impedance of a line or cable.

k) For circuit breakers equipped with shunting resistors, the thermal capability of the resistors must be considered in determining the time interval between tests.

4.10.1 Demonstration of conformance with rated transient overvoltage factor

4.10.1.1 Method of demonstration by measurement of overvoltages

The ability of a circuit breaker design to meet its rated transient overvoltage factor shall be demonstrated by making the required series of capacitance current switching tests on an essentially lossless circuit (no resistance intentionally added). The peak transient overvoltage for each test shall be measured between the circuit breaker disconnected terminals and either the neutral of the capacitance bank or ground. The transient overvoltage factor for each test shall then be calculated by dividing the peak transient voltage by the phase-to-neutral peak value of the average of the open and closed circuit test voltages. Although the rated transient overvoltage factor is based on the operating line-to-neutral peak voltage prior to opening, the average value of open and closed circuit voltages must be used to properly relate test laboratory conditions to actual service conditions

4.10.1.2 Current pause method of demonstrating performance

An alternate method of demonstrating performance, on circuit breakers rated 121 kV and above, is to count restrikes and measure the time duration of intervals of zero current between circuit interruptions and restriking. This is of particular value in cases where overvoltages have not been measured or where the overvoltage measurement is in doubt. This method may be used at the option of the manufacturer. The details of this method are as follows.

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4.10.1.2.1 General-purpose circuit breakers

a) For circuit breakers not equipped with arc shunting resistors, there shall be no multiple restrikes.

b) For circuit breakers equipped with arc shunting resistors of essentially constant value, restrikes through the primary or secondary arcing contacts shall fall within the following limitations.

1) *Primary arcing contacts* (during insertion of the arc shunting resistors). For capacitance currents greater than

$$2.31\left(\frac{\text{phase-to-phase operating V}}{\text{pole-unit arc shunting resistance }\Omega}\right)\text{A} \tag{9}$$

there shall be no more than one restrike through the primary arcing contacts. For capacitance currents equal to or less than this value, multiple restrikes through the primary arcing contacts are permissible.

2) *Secondary arcing contacts*. For switching of unloaded open wire lines, there shall be no more than one restrike through the secondary arcing contacts, except that if the pole unit arc shunting resistance exceeds 110 Ω, multiple restrikes through the secondary arcing contacts are permissible.

For switching of cables and shunt capacitor banks, there shall be no more than one restrike through the secondary arcing contacts for capacitance currents less than

$$0.10\frac{(\text{phase-to-phase operating V}/\text{pole-unit arc shunting resistance }\Omega)^2\text{A}}{\text{circuit breaker rated short-circuit current A}} \tag{10}$$

For switching of cable and shunt capacitor bank currents equal to or greater than this value, multiple restrikes through the secondary arcing contacts are permissible.

4.10.1.2.2 Definite-purpose circuit breakers

a) For circuit breakers not equipped with arc shunting resistors, there shall be no more than one restrike per operation, and that restrike shall not be preceded by a current pause in excess of 1/3 cycle.

b) For circuit breakers equipped with arc shunting resistors of essentially constant value, restrike through the primary or secondary arcing contacts shall fall within the following limitations.

1) *Primary arcing contacts* (during insertion of the arc shunting resistors). For capacitance currents greater than

$$0.98\left(\frac{\text{phase-to-phase operating V}}{\text{pole-unit arc shunting resistance }\Omega}\right)\text{A} \tag{11}$$

there shall be no more than one restrike through the primary arcing contacts and that restrike shall not follow a current pause greater than that given in Figure 10.

For capacitance currents equal to or less than this value, multiple restrikes through the primary arcing contacts are permissible.

2) *Secondary arcing contacts*. For switching of unloaded open wire lines, there shall be no more than one restrike through the secondary arcing contacts and that restrike shall not follow a current pause greater than 1/3 cycle, except that if the pole unit arc shunting resistance exceeds 210 Ω, multiple restrikes through the secondary arcing contacts for capacitance currents less than

$$0.44\frac{(\text{phase-to-phase operating V}/\text{pole-unit arc shunting resistance }\Omega)^2\text{A}}{\text{circuit breaker rated short-circuit current A}} \tag{12}$$

For switching of cable and shunt capacitor bank currents equal to or greater than this value, multiple restrikes through the secondary arcing contacts are permissible.

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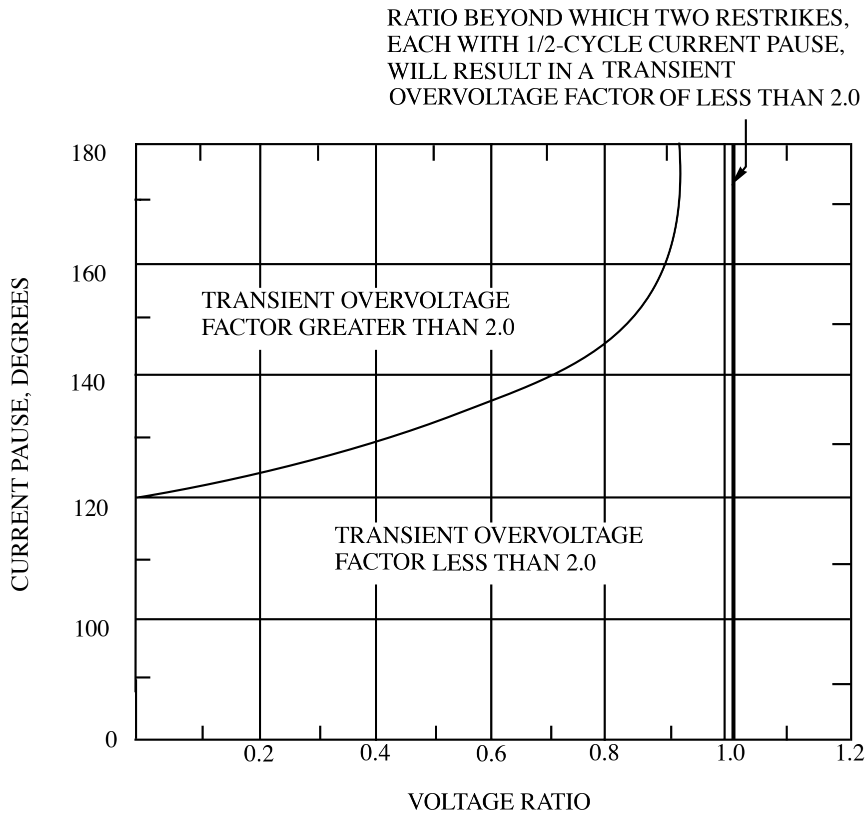

Figure 10—Allowable current pause for a transient overvoltage factor of 2.0

4.10.2 Condition of circuit breaker to be tested

The circuit breaker shall be new and in good condition. It may be reconditioned during the testing, as permitted in 4.10.2.2.

4.10.2.1 Circuit breaker to be used for test

The circuit breaker shall be representative of the type or model as required for all design tests being demonstrated.

4.10.2.2 Reconditioning of circuit breaker during testing

The expendable parts of the circuit breaker may be replaced between test duties 1, 2, and 3 listed in Tables 2 and 3. If this is done, an explanatory note shall be included in the test report.

4.10.2.3 Condition of circuit breaker after test

Following the test operations listed for test duties 1, 2, and 3 in Tables 2 and 3, the circuit breaker shall be in the condition specified in IEEE Std C37.04-1999. If any reignitions or restrikes occur, they shall take place in normal arc paths and shall cause no damage to the circuit breaker interrupter or to the associated resistors.

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4.10.3 Testing conditions

4.10.3.1 Power factor

For capacitance current switching tests, the power factor of the testing circuit shall not exceed 0.15 leading.

4.10.3.2 Frequency of test circuit

Tests demonstrating capacitance current switching capabilities of circuit breakers are to be made at the rated power frequency of 60 Hz + 5%. If tests are made outside this frequency range (for example, 50 Hz), the instantaneous recovery voltage across the current interrupting contacts of the circuit breaker, during the first 8.33 ms shall not be less than that which would occur for a 60 Hz test.

4.10.3.3 Recovery voltage

In the switching of capacitance currents, because of the charge that is trapped on the capacitive load, the recovery voltage across the circuit breaker contacts of the first phase to interrupt starts from a very low value at current interruption (determined by the system regulation when the capacitive load is removed) and then, following the fundamental frequency, increases to a value that can reach a peak value approximately between 2 E_{max} and 3 E_{max} (phase) at a time 1/2 cycle after current interruption. The actual value that the recovery voltage can attain is determined by the system and shunt capacitor bank grounding, the system regulation when the capacitive load is removed, transmission line or cable configuration or construction, whether the current is interrupted at a natural current zero (that is, not chopped), or the sequence of interruption in the second or third phases. For several typical types of capacitive loads that a circuit breaker may have to switch, the approximate maximum peak recovery voltage that can appear across the contacts of the first phase to interrupt 1/2 cycle after interruption may reach the following values:

Type of capacitive circuit	Times E_{max} phase-to-ground
Grounded shunt capacitor bank on grounded system	2
Unloaded cables (with individual ground sheaths)	2
Unloaded transmission line ($C_1 = 2\ C_o$)	2.4
Shunt capacitor bank when either bank or system, or both, is ungrounded:	
1) If second and third phases interrupt at next natural current zero	2.5
2) If second and third phases do not interrupt at next current zero	3

In general, the phenomena occurring in the switching of a grounded shunt capacitor bank or an unloaded cable on a grounded system is simply as would occur in three single-phase circuits. In the case of the unloaded transmission line, part of the capacitance is grounded and part is ungrounded, and in the ungrounded shunt capacitor bank all the capacitive load is ungrounded. Through the coupling between phases, recovery voltages greater than 2 E_{max} (phase) are produced across the contacts. In some cases, even higher recovery voltages are possible, generally resulting from wide variations in primary arcing contact parting between phases or one phase remaining connected to the system.

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These recovery voltages will be slightly lower under field conditions due to the regulation occurring when the capacitance is switched off. The system voltage regulation, or voltage change, when the capacitive load is switched, is equal to:

$$\text{Percent voltage change} = \frac{\text{kvar}_0}{\text{kVA}_0 - \text{kvar}_0} \times 100\% \quad (13)$$

where

kVA_o = symmetrical three-phase short circuit kVA at the point of the capacitive load; and
kvar_o = nominal three-phase kvar determined from open circuit voltage (same as used for kVA_o) and the capacitance of the load.

In most short-circuit test laboratories, this voltage change may be considerably larger because of lower available kVA_o than on a system, for a given amount of capacitive load.

In recognition of this generally larger voltage change during laboratory capacitance current switching tests and the variation in recovery voltage conditions depending on the type of capacitive load and grounding, factors are specified in 4.10.4 that define test voltages for three-phase and single-phase laboratory tests. Based on these factors, the recovery voltages across the circuit breaker contacts 1/2 cycle after interruption will be equivalent to those obtained under actual system conditions.

4.10.4 Test voltage

4.10.4.1 Test voltage, three-phase tests

If three-phase laboratory tests are made to demonstrate the capacitance current switching rating of a circuit breaker, the capacitive load shall be connected with its neutral either grounded or ungrounded, as required for the type of test being conducted, or for simulation of unloaded transmission lines, one-half of the total capacitive load shall be ungrounded and one-half shall be grounded. The neutral of the source may be grounded. In order to obtain a recovery voltage across the circuit breaker contacts that is equivalent to the voltage that occurs in a system operating at rated maximum voltage and having negligible voltage change when the capacitive load is removed, it may be necessary to have an open circuit test voltage that is less than rated maximum voltage depending on regulation of the laboratory circuit.

The open circuit test voltage E_o is determined as follows:

$$EC = A\,(E_o) \quad (14)$$

where

$$A = \frac{I_{sc}}{I_{sc} - I_c}$$

and

E_c = closed circuit line-to-line voltage,
E_o = open circuit line-to-line voltage,
I_{sc}= available short-circuit current, and
I_c = rms capacitance current.

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The nominal recovery voltage across the circuit breaker 1/2 cycle after current interruption will be proportional to the peak value of:

$$\frac{E_o + E_c}{2} = \frac{E_o + AE_o}{2} = \frac{E_o(1 + A)}{2} \tag{15}$$

Therefore, the proper open circuit line-to-line test voltage, E_o, to result in a recovery voltage proportional to rated maximum voltage, V, in a system where A is very close to 1.0 may be determined by:

$$E_o \frac{(1 + A)}{2} = V \tag{16}$$

$$E_o = V\left(\frac{2}{1 + A}\right)$$

4.10.4.2 Test voltage, single-phase tests

By proper choice of test voltage to produce recovery voltages equivalent to those occurring in three-phase tests, single-phase tests may be made to demonstrate the capacitance current switching ratings of circuit breakers. Because of the phenomena occurring in three-phase capacitance current switching operations described in 4.10.3.3, a factor, B, must be considered in choosing open circuit test voltage E_{o1} for single-phase tests, in addition to the factor *A* described in 4.10.4.1.

For grounded shunt capacitor bank or cable charging current switching tests on a three-phase basis:

$B = 1.0$

For ungrounded shunt capacitor bank current switching tests on a three-phase basis:

$B = 1.5$

For overhead line charging current switching tests on a three-phase basis:

$(C_1 = 2\,C_0)$, $B = 1.2$

Therefore, the open circuit phase-to-ground test voltage for single-phase tests is:

$$E_{o1} = 0.58\,V\left(\frac{2}{1 + A}\right)B \tag{17}$$

where

$$A = \frac{I_{sc}}{I_{sc} - I_c}$$

and

I_{sc} and I_c = single-phase values of available short-circuit current and capacitance current.

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NOTE—The methods described in 4.10.4.1 and 4.10.4.2 for the determination of laboratory test voltage are approximate because of the dependence of the prospective short-circuit current and, therefore, A, on the open circuit voltage. These methods, however, can be used to define conditions for reasonable test recovery voltages, particularly where laboratory short-circuit current is not large.

4.10.5 Control voltage and mechanism operating pressure

Rated values of control voltage and rated pressure for mechanical operation shall be maintained for the closing and tripping circuits.

4.10.6 Interrupter pressure

Circuit breakers that depend on external energy or pressure to drive an interrupting gas or fluid and that have a minimum permissible pressure specified, shall be capable of performing at minimum permissible pressure as specified in Table 3 and Table 4.

4.10.7 Contact speeds during single-pole and unit interrupter tests

During single-pole and unit interrupter tests, the closing and opening speeds of the contacts through the arcing zone shall be no greater than during a corresponding test on a complete circuit breaker.

4.10.8 Grounding on the circuit breaker and test circuit

The normally grounded parts of the circuit breaker shall be grounded.

During three-phase tests, the neutral of the source circuit may be grounded.

The neutral of the capacitive load shall be grounded or ungrounded as specified IEEE Std C37.04-1999, depending on the type of capacitance current switching test being made.

During single-phase tests, the test circuit may be grounded.

When single-phase tests are made on a circuit breaker with the three poles in one tank, the other poles shall be grounded.

4.10.9 Reversal of test connections

On circuit breakers that have unsymmetrical insulation paths, the connections to the source and to the capacitive load shall be reversed for half of the 100% capacitance current switching tests listed in Table 3 and Table 4.

4.10.10 Obtaining the most severe switching conditions

In capacitance current switching operations, the voltage regulation is small when the capacitance current is interrupted (that is, A is very close to 1.0, as would generally prevail on a system), the current is usually interrupted at the first or second current zero after contact separation. In circuit breakers that have a contact gap or arc path that increases in a generally linear relation to time, for example oil circuit breakers, the recovery voltage stress will be imposed on a relatively short contact gap. In a test laboratory where the voltage change at current interruption is larger, the final interruption may be delayed, allowing a larger contact gap at the time of the maximum recovery voltage than would occur on a system. In testing, it is desirable to duplicate system conditions in this respect as closely as possible. One method of increasing the probability of interruption at the first or second current zero after contact separation is by the addition of capacitance to the source side of the test circuit breaker to reduce the natural frequency, and thereby the rate-of-change of

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the voltage regulation occurring at interruption. Another method is the use of series capacitance to increase the apparent short circuit kVA of the source.

4.10.11 Methods of demonstrating capacitance switching rating

Tests that demonstrate the capacitance current switching rating of a circuit breaker may be made three-phase or single-phase. Three-phase tests are listed in Table 2 and single-phase tests are listed in Table 3. Other methods of testing may be used to demonstrate capacitance current switching rating if laboratory limitations in kVA or kvar capacity prevent complete tests by the methods in Table 2 or Table 3. These methods include unit interrupter tests, field tests, and synthetic tests and, if used, should follow insofar as possible the outline of tests in Table 2 and Table 3 to provide equivalent test results.

In Table 2 and Table 3, test duty 1 demonstrates the performance of the circuit breaker switching the current associated with its isolated cable and isolated shunt capacitor bank switch switching rating. Test duty 2 demonstrates the performance of the circuit breaker switching the current associated with its back-to-back cable and back-to-back shunt capacitor bank switching rating. Test duty 3 demonstrates the performance of the circuit breaker switching the current associated with its transmission line charging current switching rating. In each table the test voltage for all tests is based on obtaining a recovery voltage across the circuit breaker equivalent to service application at rated maximum voltage. In each of the test duties, tests are made at 30% and 100% of the respective capacitance current switching ratings.

If tests are made with lumped capacitor banks to simulate transmission lines or cables, the test circuit may be modified to limit current surges on closing to those obtained when closing into the surge impedance of a transmission line or cable.

4.10.11.1 Three-pole tests

A program to demonstrate the capacitance current switching rating of a circuit breaker by a series of three-phase tests on a three-pole circuit breaker is shown in Table 2.

Certain classes of circuit breakers are required to be able to switch ungrounded capacitance loads. Satisfactory completion of the prescribed tests on three-phase ungrounded capacitor banks will completely demonstrate this performance. If three-phase performance has been demonstrated, tests will not also be required to demonstrate conformance on the single-phase simulation at 87% of phase-to-phase voltage.

As measurement of the transient overvoltage between the disconnected terminal and neutral may prove to be difficult when testing on a three-phase ungrounded capacitor bank, a transient overvoltage measurement from disconnected terminal to ground will be accepted as an alternate measurement method.

4.10.11.2 Single-pole tests

A program to demonstrate the capacitance current switching rating of a circuit breaker by a series of single-phase tests on a single-pole of a three-pole circuit breaker is shown in Table 3.

4.10.11.3 Unit interrupter tests

In some cases, it may be necessary or desirable to make capacitance current switching tests on a unit interrupter or on a portion of the total interrupting structure of a single pole of a circuit breaker, where such total interrupting structure is composed of a number of interrupting units or breaks that operate in a relatively independent manner in capacitance current switching operations. See 4.8.2.3.1 for a discussion of conditions that should be considered in making unit interrupter tests. When capacitance current switching tests are made on a unit interrupter or on a portion of the total interrupting structure of a circuit breaker pole, the program of Table 3 shall be followed. The test voltage for such tests should be determined as given in Table 3 for the portion of the total voltage represented by the number of interrupter units or breaks tested.

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4.10.11.4 Synthetic tests

Tests to demonstrate the ability of a circuit breaker to switch capacitance currents may be made where the recovery voltage across the circuit breaker and the current through the circuit breaker are supplied from different parts of the same circuit. This is usually referred to as a synthetic circuit. With such a circuit it is generally possible to simulate a given kvar switching operation with a significantly smaller actual capacitive load.

The adequacy of a test by synthetic methods depends, among other things, on the relative timing and shape of the recovery voltage with respect to the interruption of the current through the test circuit breaker.

If a restrike or reignition should occur in a capacitance current interruption, the voltage changes or oscillations in the circuit are primary factors in determining whether subsequent restrikes or reignitions may take place. For this reason, synthetic capacitance current switching tests are generally usable only to determine if a circuit breaker will or will not have restrikes. Consequently, synthetic tests are usually considered valid for demonstration of performance only in circuit breakers that do not restrike.

If synthetic tests are made, they shall be carried out in accordance with other pertinent sections of the test procedure concerning voltage, current, operations, etc.

For comments on important considerations in making synthetic tests by short-circuit switching ability of a circuit breaker, see 4.8.2.5.

4.10.12 Test data reporting

A report of the results of capacitance current switching tests on a circuit breaker should include the following data from the tests:

a) Circuit breaker and test identification
   1) Circuit breaker identification
   2) The value of pole unit or interrupter shunting resistance (other than resistance normally applied only for interrupter voltage grading)
   3) Method of test
      i) Three-pole
      ii) Single-pole
      iii) Unit interrupter
   4) Test duty
      i) Isolated shunt capacitor bank or cable
      ii) Back-to-back shunt capacitor bank or cable
      iii) Open wire line charging
b) Test results
   1) Capacitance current switched
   2) Test circuit voltage
      i) Open circuit
      ii) Closed circuit
   3) Interrupting time, through primary arcing contacts
   4) Interrupting time, through secondary arcing contacts
   5) Number of tests
   6) Number of tests with restrikes, and whether single or multiple

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7) Time from interruption of the normal frequency load current to the first restrike
8) transient overvoltage factor
9) Inrush current characteristics in back-to-back shunt capacitor bank switching tests
10) Inherent peak inrush current
11) Natural frequency
12) Maintenance on test circuit breaker for each duty (see 4.10.2.2)

4.11 Line closing switching surge factor

For circuit breakers rated 362 kV and above, the ability of the circuit breaker design to meet its line closing switching surge factor rating shall be demonstrated by conducting a series of tests on a simulated standard reference power system consisting of a simulated standard reference power source, a simulated circuit breaker, and a simulated standard reference transmission line. The system simulation is by mathematical or physical means, and the study is conducted with a digital computer, an electronic differential analyzer (mathematical analog), a transient network analyzer (physical analog), or by accepted similar methods.

The circuit breaker characteristics, which affect the line closing switching surge maximum voltage, shall be used to perform the simulated study. These characteristics shall be verified by the manufacturer by means of electrical and mechanical tests on a circuit breaker representative of this same type, style, or model.

This method of demonstrating the ability of a circuit breaker design to perform within the limit of its rated line closing switching surge factor recognizes the fact that actual transmission system test facilities of the type required to demonstrate this rating are often unobtainable. The simulated study is accepted as the next best means of demonstration. Conformance tests may be conducted by the purchaser on an operating system to demonstrate that a circuit breaker meets the requirements of its rated line closing switching surge factor. Such conformance tests are described in 6.1.3. The rated factors are found in ANSI C37.06-1997.

The switching surge factors given in ANSI C37.06-1997 are, for the purpose of setting minimum standards for circuit breakers, specifically designed for line closing switching surge control. Systems operations or circuit configurations not in conformance with the standard reference power-system tests could result in surge factors lower or higher than those shown in ANSI C37.06-1997.

4.11.1 Standard reference power system

The standard reference power system consists of a standard reference power source and a standard reference transmission line.

4.11.1.1 Standard reference power source

The standard reference power source is a three-phase Y-connected voltage source with neutral grounded, with each of the three-phase voltages in series, and with an inductive reactance that represents the short-circuit capability of the source. The maximum source voltage, line-to-line, is the rated maximum voltage of the circuit breaker. The series inductive reactance is that which produces the rated short-circuit current of the circuit breaker, both three-phase and single-phase, at rated maximum voltage, with the short circuit applied to the circuit breaker terminals (X_1, X_2, X_0).

4.11.1.2 Standard reference transmission line

The standard reference transmission line is a perfectly transposed three-phase transmission line with balanced parameters as listed in ANSI C37.06-1997. These values have been selected to make the lines typical of anticipated service conditions.

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4.11.2 Standard conditions of simulation

4.11.2.1 Simulation of power source

The standard reference power source shall be simulated on a three-phase basis.

4.11.2.2 Simulation of transmission line

The standard reference transmission line shall be simulated on a three-phase basis.

4.11.2.3 Simulation of circuit breakers

The circuit breaker shall be simulated on a three-phase basis. The method used to simulate the circuit breaker shall include such pertinent design features as the value of closing resistor, insertion time of closing resistors, statistical spread of closing times of the three poles, and such other features as are required to simulate the means used by the manufacturer to control the line closing switching surge voltages. The statistical spread of the closing times shall include the effects of electrical prestrike as well as differences in the mechanical closing times of the three poles.

4.11.2.4 Simulation of trapped charge on the transmission line

For the standard conditions of simulation, trapped charges are assumed to be present from a previous line dropping operation performed by a circuit breaker without opening resistors and with each phase extinguishing current at successive current zeros. Trapped charge can be placed on the simulated line by simulating random time tripping of an idealized circuit breaker.

It is not intended that this standard prevent development of classes of circuit breakers with opening resistors, or other means, to substantially reduce trapped charges. For such breakers, dual-line closing switching surge factor ratings (with and without such means) could be assigned.

If shunt reactors are used on the standard line, an oscillating voltage, generally lower in frequency than the power system, will exist on the transmission line after opening the line circuit breaker. Consequently, the magnitude of the peaks of the ac voltage across the circuit breaker will vary with time (see IEEE Std C37.010-1999). The reclosing time for the simulated model tests should be adjusted ±50 ms around the specified reclosing time given in ANSI C37.06-1997 to obtain the highest magnitude of closing switching surge factor as determined from statistical distribution.

If shunt reactors are used in practice where they are not included in the standard line, or if reactors of substantially different values than in the standard line are used in practice, it may be necessary to make a special study in the application of these circuit breakers.

4.11.3 Method of conducting tests on the simulated system to establish the rated line closing switching surge factor

At least 50 three-phase tests shall be made of the simulated system with no more than one line closing switching surge factor per 50 tests exceeding the rated value. If the rated value is exceeded more than once during the first set of 50 tests, additional sets of 50 tests each may be performed until the ratio of the number of times the rated value is exceeded, to the total number of tests, decreases to 2%. If this ratio does not drop to 2% with continued tests, the circuit breaker design will be considered to have failed to meet its line closing switching surge factor rating. The closing of the three poles with relation to the phase of the applied voltage shall be at random within the specified allowance for the statistical spread of closing time.

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4.12 Out-of-phase switching current tests

The tests specified in this subclause are made only if an out-of-phase switching current rating has been assigned to the circuit breaker by the manufacturer.

These tests are outlined in Table 4 and are described in the following subclauses.

The test requirements in Table 4 demonstrate out-of-phase switching capability for the majority of out-of-phase switching conditions. Attention is called to suggested preventive measures described in IEEE Std C37.010-1999.

Table 4—Test to demonstrate out-of-phase capabilities

Test duty	Operating duty	Current I
1	Two Os	0.05 I to 0.10 I
2	O - CO	0.25 I
2a	CO	0.25 I

4.12.1 General

Tests shall be made to determine the ability of a circuit breaker to make and interrupt currents during out-of-phase conditions.

The tests may be made using any of the test methods described previously for short circuit tests and using the same guidelines for applicability specified for short-circuit testing conditions. If these conditions are not fulfilled, three-phase tests should be made.

The out-of-phase switching current capacity performance in a test shall be stated in terms of the following:

a) The value of the out-of-phase switching current;
b) The value of the out-of-phase recovery voltage; and
c) The value of the peak, time-to-peak, and wave shape of the TRV.

4.12.2 Arrangement of circuit breaker for tests

The circuit breaker subjected to out-of-phase switching current tests shall be a representative of the type being certified in all details of construction and operation as recorded in certified drawings or specifications, or both.

Circuit breaker operating mechanisms shall be operated at the specified minimum control voltage or the specified minimum operating pressure, or both.

The air or gas pressure in air or gas-blast circuit breakers shall be the minimum operating pressure for the rated (short-circuit) interrupting capacity.

Indoor circuit breakers shall be tested inside of their enclosures.

If single phase or unit tests are performed, the test unit shall be equivalent to, but not in a more favorable condition than, the complete three-phase circuit breaker with respect to the following:

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a) Speed of closing and opening
b) Arc-extinguishing medium
c) Energy output of operating mechanism
d) Rigidity of the structure

4.12.3 Test circuit

a) The power factor of the test circuit shall not exceed 0.15 lagging.
b) For single-phase tests, the test circuit shall be arranged so that approximately one half of the applied voltage and of the recovery voltage is on each side of the circuit breaker (see Figure 11).

If it is not feasible to use this circuit in the testing station, it is permissible to use either of the circuits shown in Figures 12 and 13 at the option of the manufacturer.

— Two identical voltages separated in phase by 120° instead of 180° may be used, provided the total voltage across the circuit breaker is as stated in 4.12.4 (see Figure 12).
— Tests with one terminal of the circuit breaker grounded may be used (see Figure 13).

4.12.4 Test voltage

4.12.4.1 Single phase

For single-phase tests as called for in test duties 1 and 2 of Table 4, both the applied voltage E (as shown in Figures 11 through 13) and the power frequency recovery test voltage shall be equal to or greater than:

a) For effectively grounded neutral, E shall be 2.0 times the rated maximum voltage V divided by $\sqrt{3}$.
b) For systems other than neutral grounded, the test voltage E shall be 2.5 times the rated maximum voltage V divided by $\sqrt{3}$.
c) The inherent TRV of the test circuit shall have a 1-cos wave shape with a peak value of 1.76 times the value of the test voltage E and a time to peak no greater than 2 times the time T_2 as is listed in ANSI C37.06-1997 for the circuit breaker under test.
d) For the alternate single-phase close-open test called for in test duty 2a of Table 4, the applied voltage shall be equal to or greater than 1.5 times the rated maximum voltage V divided by $\sqrt{3}$.

This corresponds approximately to limiting the out-of-phase closing angle to 90° (see IEEE Std C37.010-1999).

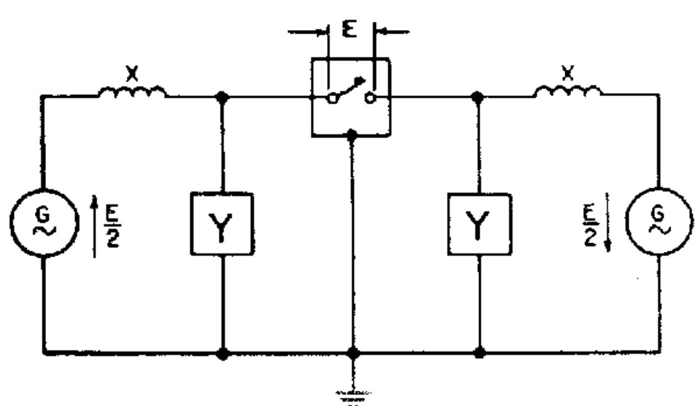

Figure 11—Dual voltage testing 180°

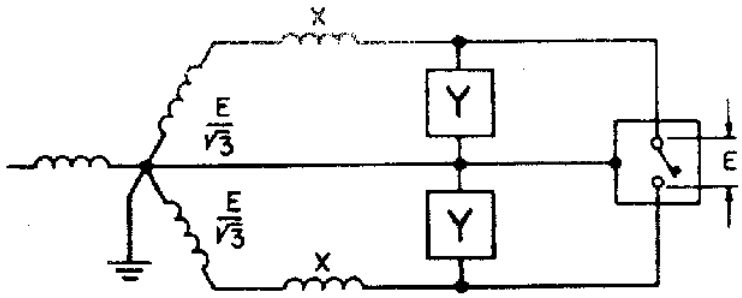

Figure 12—Dual voltage testing 120°

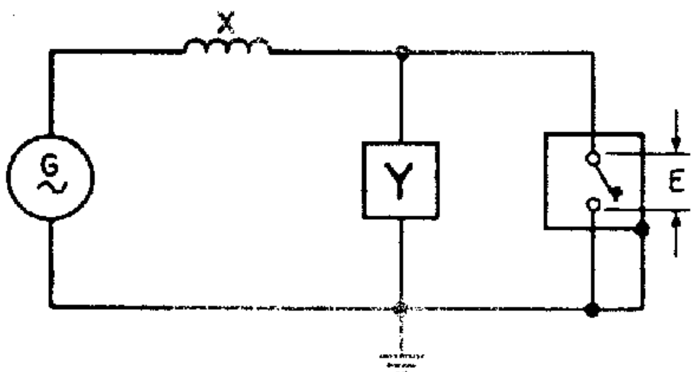

Figure 13—Single voltage testing one side grounded

NOTE—Y in Figures 11, 12, and 13 represents combinations of capacitances and resistances.

4.12.4.2 Three phase

For three-phase tests, the recovery voltage of the first pole to clear shall have the appropriate value as stated above for single-phase tests.

4.12.5 Test frequency

See 4.8.1.2.

4.12.6 Test duties

The test duties to be made are shown in Table 4. A minimum of one sequence of test duty 1 and one sequence of test duty 2 is sufficient to demonstrate the out-of-phase switching capability of the circuit breaker.

4.12.7 Condition of circuit breaker after tests

After performing the specified test, the circuit breaker shall be capable of meeting the requirements set forth in 4.8.5.4, 4.8.5.5, and 4.8.5.6.

4.12.8 Test report

The test report shall contain the data necessary to prove that the circuit breaker complies with this standard. Suggested oscillographic and other records include:

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a) Switching current in each phase
b) Voltage across each phase
c) Instant of energizing trip coil
d) Travel of moving contacts, if practicable
e) Current in closing coil
f) Timing wave
g) Gas pressure before test
h) Voltage of the supply circuit
i) Interrupting time
j) Resistor current in each phase (when applicable)

NOTE—Any deviation from this subclause shall be clearly stated in the test report.

4.13 Mechanical endurance tests

No-load mechanical operation tests are made on a complete circuit breaker to ensure its satisfactory operation in normal service without excessive maintenance.

4.13.1 Testing conditions

No load mechanical endurance tests shall be made under the following conditions:

a) The circuit breaker shall be new or reconditioned, at the option of the manufacturer.
b) The circuit breaker shall be a complete assembly, containing all major components, appurtenances, and accessories. It shall contain the maximum number of available auxiliary contacts.
c) Indoor circuit breakers shall be installed in a minimum volume test compartment, or in the appropriate vertical section compartment of the switchgear suggested by the manufacturer (see IEEE Std C37.20.2-1993).
d) When indoor circuit breakers are intended to be mounted in an upper compartment, the mechanical endurance tests shall be conducted in the upper vertical section of that compartment.
e) For indoor draw-out circuit breakers, part of the mechanical endurance testing includes racking tests in accordance with the requirements outlined in IEEE Std C37.20.2-1993.
f) At the beginning and at the end of the test, the resistance of each pole shall be measured from terminal to terminal, with at least 100 A of dc current flowing in the circuit.
g) Contact opening time, contact closing time, and travel curves or speed measurements also shall be taken at the beginning and at the end of the test.
h) The testing shall be done with rated control voltage and operating pressure, as listed in ANSI C37.06-1997. However, during the course of testing, at any interval, as determined by the manufacturer, 10 cycles shall be conducted at each of the upper and lower range of the rated control voltage and the operating pressure.
i) One cycle of operation shall consist of a close operation followed by an opening operation (C-O) for the total number of required cycles as listed in ANSI C37.06-1997. The total number of cycles may be completed at any convenient rate at the option of the manufacturer as long as overheating of bearings, coils, valves rectifiers, etc., does not occur. External forced cooling of these components is allowable if the tests are performed at a rate greater than two cycles per minute.
j) Twenty successive C-O operations (cycles) must be conducted during the course of testing at 30 s intervals at rated control voltage, without overheating to a point that would injure the insulation of coils or motors sufficiently to adversely affect the circuit breaker performance.

4.13.2 Low temperature operating tests

In order to demonstrate that circuit breakers are capable of operating at the rated ambient of –30 °C the following test procedure is required:

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a) With the circuit breaker in the closed position, the ambient temperature shall be lowered to –30 °C, for a period of 24 hours. During this period the normally installed heating elements shall be energized. At the end of the 24-hour period, 10 cycles shall be performed at rated control voltage and operating pressure, recording operating speeds of the circuit breaker.
b) Ten cycles shall be conducted at rated voltage after the equipment has been held at the ambient temperature of –30 °C, with all normally installed heater elements de-energized and the control voltage disconnected, for a period of at least two hours.
c) If testing facilities do not permit this demonstration, then performance of important components of the circuit breaker may be demonstrated individually at this temperature.

4.13.3 Performance requirements

Both during and after these tests the following performance criteria shall be met:

a) The endurance tests shall be completed, without repair or replacement of any part that will cause failure or misoperation of the circuit breaker, and in compliance with the number of operations between servicing listed in ANSI C37.06-1997.
b) The circuit breaker shall be inspected to verify that it is in operable condition and that it meets the requirements set forth in IEEE Std C37.04-1999.
c) The transient voltage produced by the control circuit associated with the circuit breaker itself did not exceed 1500 V peak when the control circuit was interrupted.
d) The travel/timing records taken before and after the test shall have substantially the same characteristics.

4.14 Control voltage

Proper operation of the circuit breaker at rated control voltage, at the minimum voltage, and at the maximum control voltage corresponding to it, is demonstrated during mechanical operation tests and the short-circuit switching tests.

4.15 Fluid operating pressure

Proper operation of the circuit breaker mechanism and of the interrupting chamber at rated fluid operating pressure and over its range is demonstrated during the mechanical operation tests and during the short-circuit switching tests.

4.16 Design tests on pressurized components

4.16.1 Pressurized porcelain components

A representative of each design of porcelain insulators, porcelain housings, or porcelain tubes having an internal or external gas gauge pressure exceeding 208 kPa (absolute pressure) (with no limitation on size) shall withstand for five minutes 4.25 times the maximum allowable working pressure after all glazing, firing, and grinding operations are completed.

When the porcelain element utilizes end flanges, the test pressure shall be applied on a complete assembly, using bolted end plates and loading the flanges in tension. If the porcelain element does not have end flanges and is used in an assembly held together by longitudinal compression (center clamping), the end plates shall be restrained by the test fixture and the porcelain element loaded only in hoop stress.

In addition to the above tests, when pressurized porcelain elements with end flanges having an internal or external gas gauge pressure exceeding 208 kPa (absolute pressure) (with no limitation on size) are subjected

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to cantilever stress in a circuit breaker application, a representative of each porcelain element, after all glazing, firing, and grinding operations are completed, shall withstand for five minutes a total stress equivalent to the end plate loading from maximum allowable working pressure plus three times the maximum rated cantilever stress.

Where applicable, the maximum rated cantilever stress shall be based on the load on the porcelain element resulting from:

a) The combination of the short-circuit forces internally of the circuit breaker plus rated line pull withstand and a 40 mi/s (90 mi/h) wind velocity withstand; and
b) From the combination of rated line pull withstand and the 0.2 g (static) earthquake shock withstand, whichever is the more severe duty; rated requirements for line pull factors will be available in a future ANSI/IEEE standard.

NOTE—1 Pascal (Pa) = 1.45×10^{-4} psi

4.16.2 Pressurized non-ceramic components.

4.16.2.1 Non-isolating vessels

Components that neither isolate nor separate high voltage elements of 1000 V or higher shall be tested in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section X, Fiberglass-Reinforced Plastic Pressure Vessels.

4.16.2.2 Isolating vessels

Non-ceramic components that electrically isolate or separate high voltage elements of 1000 V or higher and that are pressurized at a constant pressure (where the pressure typically varies only due to diurnal pressure variations and are minimal compared to the static ambient pressure) shall be tested and meet the requirements described in 4.16.1.

4.16.2.3 External components

External components that electrically isolate or separate high voltage elements of 1000 V or higher and that undergo significant pressure cycling variations due to the operation of the circuit breaker shall be tested as per 4.16.1. Additionally, a design cyclic pressure and burst tests, in accordance with applicable subclauses 4.16.3.1, 4.16.3.2, or 4.16.3.3, shall be performed.

These tests shall be made in a prototype of each design of non-ceramic vessel, insulator, or tube having an internal or external gas pressure exceeding 208 kPa (absolute pressure) (15 psig) and having an inside diameter exceeding 152 mm (6 in), after all coating, curing, and fabrication operations are completed.

Where applicable, the prototype vessel(s) shall be so loaded as to create the magnitude of bending and shear stresses expected to occur under service conditions. The maximum rated cantilever stress shall be based on the load on the plastic element resulting from:

a) The combination of the short-circuit forces internal to the circuit breaker plus the rated line pull withstand and a 40 mi/s (90 mi/h) wind velocity withstand; and
b) From the combination of rated line pull withstand and the 0.2 g (static) earthquake shock withstand, whichever is the more severe duty; rated requirements for line pull factors will be available in a future ANSI/IEEE standard.

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4.16.3 Intended pressure application

4.16.3.1 Vessels intended for internal pressure only

At least one prototype vessel shall be subjected to a cyclic pressure test followed by a hydrostatic pressure test at the maximum operating temperature but not less than 65 °C. The pressure shall be cycled from atmospheric pressure to the operating and back 100 000 times; except that the vessels with internal liners or external jackets, whether integral or not, shall be cycled for 10 000 cycles at the minimum working temperature and for 90 000 cycles at the maximum working temperature. No leakage shall occur and the vessel shall not burst during these tests.

4.16.3.2 Vessels intended for both internal and external pressure

At least one prototype vessel intended for both internal and external pressure service shall be subjected to a cyclic pressure test in accordance with 4.16.2.1 except that the pressure shall be cycled from the external maximum allowable operating pressure to the internal operating pressure and back 100 000 times. At the manufacturer's option, the cyclic pressure test may be carried out in two steps, as follows:

a) The pressure shall be cycled from the internal operating pressure to atmospheric pressure and back 100 000 times.
b) The pressure shall be cycled from the external maximum operating pressure to atmospheric pressure and back 100 000 times.

The prototype vessel, after being subjected to the external hydrostatic pressure test, shall then be subjected to an internal hydrostatic test in accordance with the requirements of 4.16.2.1.

4.16.3.3 Vessels intended for external pressure only

At least one prototype intended only for external pressure service shall be tested in accordance with 4.16.2.2 except that the internal design pressure shall not be less than 103 kPa (absolute pressure) (15 psia).

4.17 Sealed pressure systems leakage tests

This requirement applies to high voltage indoor or outdoor circuit breakers that use a gas other than air at atmospheric pressure as interrupting, insulating, or operating medium.

4.17.1 Design tests

The purpose of tightness/leakage tests is to demonstrate that the absolute leakage rate, F, does not exceed the specified value of the permissible leakage rate, F_p (see Pressurized systems in IEEE Std C37.04-1999).

Where possible, the tests should be performed on a complete system; if this is not practical, the tests may be performed on parts, components, or subassemblies. In such cases, the leakage rate of the total system shall be determined by summation of the component leakage rates. The possible leakages between subassemblies of different pressures shall also be taken into account.

— The tightness test of a circuit breaker shall be performed both in the closed and open position of the device, unless the leakage rate is independent of the position of the main contacts.
— The tightness tests shall be performed before and after the mechanical operation test or during the operation tests at extreme temperatures.

An increased leakage rate at extreme temperatures (if such tests are required) is acceptable, provided that this rate resets to a value not higher than the maximum permissible value at normal ambient air temperature.

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The increased temporary leakage rate shall not exceed three times the specified permissible value F_p.

In general, only cumulative leakage measurements allow calculation of leakage rates. In general, for the application of an adequate test method, reference is made to IEC 60068-2-17-1994.

4.17.2 Relative leakage rate

The relative leakage rate, F_{rel}, shall be checked by measuring the pressure drop, ΔP, over a time period, t, that is of sufficient length to permit a determination of the pressure drop. A correction should be made to take into account the variation of ambient air temperature. During this period the replenishment device shall be inoperative.

4.17.3 Test report

The test report for these design tests should include the following information as a minimum:

a) A description of the object under test, including its internal volume and the nature of the filling gas;
b) Whether the object under test is in the closed or open position;
c) The pressures and temperatures recorded at the beginning and end of the test, and the number of replenishments (if any needed);
d) The cut-in and cut-off pressure settings of the pressure (or density) control, or monitoring device;
e) An indication of the calibration of meters used to detect leakage rates;
f) The results of the measurements; and
g) If applicable, the test gas and the conversion factor to assess the results.

5. Production tests

5.1 Types of tests

Production tests are normally made by the manufacturer at the factory as part of the process of producing the circuit breaker. If the circuit breaker is completely assembled prior to shipment, some of the production tests are made after final assembly, but other tests can often be made more effectively on components and subassemblies during or after manufacture.

If the circuit breaker is not completely assembled at the factory prior to shipment, appropriate tests on component parts shall be made to check the quality of workmanship and uniformity of material used and to assure satisfactory performance when properly assembled at its destination. This performance may be verified by making tests after delivery.

Production tests shall be made and shall include the following as appropriate for the type of circuit breaker concerned.

a) Current and linear coupler transformer tests
b) Bushing tests
c) Gas receiver tests
d) Pressure tests
e) Nameplate check
f) Leakage tests
g) Resistors, heaters, and coils check tests

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h) Control and secondary wiring check tests
i) Clearance and mechanical adjustment check tests
j) Mechanical operation tests
k) Timing tests
l) Stored energy system tests
m) Conductivity of current path test
n) Power frequency withstand voltage tests on primary insulation components
o) Power frequency withstand voltage tests on control, secondary wiring, and components, to include motors, release coils, etc.
p) For indoor circuit breakers used in enclosures interchangeability test refer to IEEE Std C37.20.2-1993

5.2 Current and linear coupler transformer tests

All current transformers used with high voltage circuit breakers shall be designed in accordance with the ANSI/IEEE standards for transformers (IEEE Std C57.13-1993).

Current and linear coupler transformers shall receive the following tests where applicable:

a) Each transformer shall be checked for presence of correct nameplate, terminal, and polarity markings.
b) Each transformer shall be checked electrically to ensure proper direction of winding to give the correct polarity.
c) Each transformer shall be given sufficient tests to ensure that the electrical and magnetic properties are within the necessary limits to meet the ratio and accuracy classification requirements.
    1) Relaying transformers shall receive ratio or mutual reactance tests to ensure proper turn ratios. Multi-ratio transformers are given sufficient ratio tests to ensure the correctness of the winding for each tap section. For bushing current transformers, two check points on the excitation curve may be made to ensure that the unit meets its relaying accuracy classification.
    2) Metering transformers shall receive ratio and phase angle tests at 10% and 100% rated primary current at one burden to ensure that the unit meets its metering accuracy classification.
d) After installation in the circuit breaker, each transformer shall be given a 1 min power frequency withstand test of 2500 V between the shorted secondary winding (including leads) and ground (see also 5.16). In addition, each unit will receive a polarity and ratio check to ensure correct installation in the circuit breaker.

5.3 High-voltage circuit breaker bushings tests

High-voltage circuit breaker bushings for outdoor circuit breakers shall be tested in accordance with IEEE Std C57.19.00-1991.

5.4 Gas receiver tests

5.4.1 Metal vessels

All metal vessels, except those having an internal or external operating gas pressure not exceeding 208 kPa (absolute pressure) (15 psig) (with no limitation on size) or those having an inside diameter not exceeding 150 mm (6 in), (with no limitation on pressure), shall be tested in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels, and any state and local codes that apply at the point of original installation.

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5.4.2 Porcelain components

All ground surfaces of pressurized porcelain elements shall be individually dye checked after grinding to ensure freedom from cracks. Other methods are permitted by agreement between user and manufacturer.

All porcelain insulators, porcelain housings, or porcelain tubes having an internal or external gas pressure exceeding 208 kPa (absolute pressure) (15 psig) (with no limitation on size) shall individually withstand for five minutes a pressure equal to three times the maximum allowable working pressure after all glazing, firing, and grinding operations are completed. When the porcelain element utilizes end flanges, the test pressure shall be applied on a complete assembly, using bolted end plates and loading the flanges in tension. If the porcelain element does not have end flanges and is used in an assembly that is held together by longitudinal compression (center clamping), the end plates shall be restrained by the test fixture and the porcelain element loaded only in hoop stress.

5.4.3 Non-ceramic components

The under thickness deviation in any area of a production vessel shall not exceed 10% of the vessel from design tests. Each vessel shall weigh at least 95% of the weight of the prototype vessels used in design tests.

Each vessel shall be subjected to a hydrostatic leakage test. The test procedure at ambient temperature shall be 1.5 times maximum working pressure, whether internal or external, and shall be maintained for at least one minute. No leakage shall occur.

5.4.4 Assembled components

If the circuit breaker is not completely assembled at the factory prior to shipment, each major assembly shall be tested in the factory by raising the pressure to the maximum allowable working pressure and holding it for five minutes.

These assembled component tests are not required if the circuit breaker is completely assembled at the factory and the pressure test described in 5.5 is made.

5.5 Pressure tests

This test is made on assembled circuit breakers having gas receivers, associated valves, piping, and other auxiliary pressure devices. With the apparatus completely assembled, the pressure shall be raised until the safety valve operates and this pressure shall be applied to all parts of the system that can be subjected to this pressure in service.

5.6 Nameplate check

The nameplates shall be checked for accuracy and completeness of information and rating.

5.7 Leakage tests

The purpose of tightness/leakage tests is to demonstrate that the absolute leakage rate, F, does not exceed the specified value of the permissible leakage rate, F_p.

5.7.1 Relative leakage rate

The test shall be performed at normal ambient air temperature with the circuit breaker filled at a test pressure/density specified by the manufacturer. The relative leakage rate, F_{rel}, shall be checked by measuring the

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pressure drop ΔP over a time period, t, that is of sufficient length to permit a determination of the pressure drop. A correction should be made to take into account the variation of ambient air temperature. During this period, the replenishment device shall be inoperative. Sniffing may be used under controlled conditions.

5.8 Vacuum integrity tests

The purpose of vacuum integrity tests is to demonstrate that the pressure on the vacuum interrupter is still below the maximum level required for the acceptable performance of the switching and insulating functions. The vacuum level will have been checked by the vacuum interrupter manufacturer before shipping the unit to the circuit breaker manufacturer. Therefore, the tests identified in this standard are to demonstrate that the assembly of the vacuum interrupter into the circuit breaker and the operation of the circuit breaker do not affect the vacuum integrity of the interrupters.

Measuring the pressure inside of a vacuum interrupter is a very difficult task and those measurements can only be performed on a vacuum interrupter by itself, not when installed in a circuit breaker. Therefore, the requirements of this standard are limited to the use of a voltage withstand test to verify that the vacuum pressure is still within the acceptable limits.

After assembly, the vacuum circuit breaker shall be subjected to a dielectric withstand test to demonstrate its integrity. The test voltage shall be stated by the manufacturer and the final dielectric test shall be carried out after the routine mechanical production tests. These test may be combined with the requirements of 5.16.

5.9 Resistors, heaters, and coils check tests

All resistors and heaters shall be checked either by operation or resistance measurements. All closing, tripping, control valve, and relay coils shall be checked either by resistance measurement or turn counters and shall be within prescribed manufacturing limits.

5.10 Control and secondary wiring check tests

Secondary wiring shall be checked to ensure that all connections are made in accordance with the wiring diagram. Relays and other devices should be checked by actual operation, if feasible. Those circuits for which operation is not feasible should be checked for continuity.

A check shall be made for proper sequence of operation of mechanically operated auxiliary switches and devices.

5.11 Clearance and mechanical adjustment check tests

The clearances and mechanism adjustments shall be checked by closing the circuit breaker and verifying that the engagement of the contacts, positions of critical members of the operating linkage and important clearances, including positions of any latches, are within prescribed manufacturing limits.

Close the circuit breaker using control power, and repeat the checks in the preceding paragraph.

Open the unit being tested, and check that it has opened completely.

5.12 Mechanical operation tests

Mechanical operation tests are made to check the adjustments and to determine the ability of the circuit breaker or certain of its components to operate correctly over the entire range of control voltage specified for

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its rated control voltage in ANSI C37.06-1997, and, when applicable, over its entire range of operating pressure without damage to parts or substantial change in adjustments.

Following these tests, the components shall be inspected visually to determine that no critical parts have sustained damage and all are in first-class operating condition. Normally, this is accomplished without disassembly.

All mechanical operation tests shall include the following:

a) At minimum control voltage and (where applicable) maximum pressure:
   1) Five close operations; and
   2) Five open operations.
b) At maximum control voltage and (where applicable) maximum pressure:
   1) Five close operations; and
   1) Five open operations.
c) At rated control voltage and (where applicable) rated pressure:
   1) Five open operations.
   2) Five close operations.
   3) Five close-open operations with the shunt trip coil circuit electrically energized prior to giving the closing signal so that the trip coil is energized, as the circuit breaker closes, simultaneously with the closing of the auxiliary “a” contacts. During these tests, the control switch is held in the close position to demonstrate that the circuit breaker is electrically trip-free. During these tests the circuit breaker contacts are allowed to touch momentarily (see IEEE Std C37.11-1997).
   4) Five close-open operations with the mechanical trip command applied and held prior to the application of the closing signal (mechanical or electrical). For several tests, an electric close command shall be applied and several more tests shall have a mechanical close command. During these tests the contacts shall not close, even momentarily. During these tests, the control switch is held in the close position to demonstrate that the circuit breaker is electrically trip-free (see IEEE Std C37.11-1997).
   5) Five close-open operations with the closing signal applied electrically and held for a period of time. Following the closing command, an electrical trip signal is given. The closing signal shall be held for a sufficiently long period of time (15 to 20 s) after the application of the trip signal. The circuit breaker shall close in response to the initial close command, shall open in response to the trip command, and shall not close again until the closing signal is first removed and then reapplied. This test is designed to demonstrate the anti-pump function.
   6) Five reclosing operations (if the circuit breaker is intended for reclosing service).
d) Check to make certain that the closing operation will be completed after momentary contact of the closing control switch (seal-in feature) (see IEEE Std C37.11-1997).
e) The circuit breaker shall also be tripped by slowly moving the shunt trip armature manually in the direction of tripping.
f) Check to make certain that all interlocks function as intended.
g) Check to make certain that all shock absorbing devices function as intended.

5.13 Timing tests

Timing tests are made to determine the time required for circuit breakers or components to operate on open, close, close-open, and reclosing operations.

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Timing tests may be made by any of the following methods:

a) An oscillograph with suitable travel indicators connected to an appropriate point or points of the circuit breaker linkage or contacts;
b) A cycle counter or interval timer to determine the time interval after the energizing of the closing or tripping circuit to the parting, closing, or reclosing of contacts; or
c) A time-travel recorder to record graphically, as a function of time, the position of the part to which it is mechanically attached.

Oscillographs with travel indicators and time travel recorders can produce records from which the speed of the part can be calculated.

These tests, when used as production tests, are a means of checking the operation of a new circuit breaker within the speed range selected during development of this type of circuit breaker. After a circuit breaker has been in service, these tests may be used to determine whether it is still operating correctly.

Opening times shall be obtained and recorded for all circuit breakers.

Travel-time curves shall be obtained for all outdoor circuit breakers with an interrupting time of three cycles or less.

5.14 Stored energy system tests

5.14.1 Pneumatic/hydraulic mechanisms

Power operating mechanisms that store energy in compressed air or other gas shall be subjected to the following tests:

a) The pressure switches shall be set and tested for operation at the correct pressures.
b) The pressure relief valve shall open within its selected range of pressure above normal pressure and shall close before the low-pressure cut-off device operates.
c) Starting at normal pressure and without replenishing the gas in the reservoir, a compressed gas circuit breaker shall make at least two close-open operations before a low-pressure cut-off device operates.
d) Starting at normal pressure and without replenishing the gas in the reservoir, a pneumatically or hydraulically operated circuit breaker, other than gas blast, shall make at least five close and five open operations before a low-pressure cut-off device operates.

5.14.2 Spring charged mechanisms

The charging motor of a spring-driven circuit breaker operating mechanism shall replace the spring stored kinetic energy within a maximum time of 15 s after being used during a close operation when rated control voltage is maintained at the motor terminals.

5.15 Electrical resistance of current path test

The dc resistance of the primary circuit, from terminal to terminal of each pole unit, in the close position shall be measured with at least 100 A of dc current flowing in the circuit and shall not exceed the limit set for the rating of the circuit breaker by the manufacturer.

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5.16 Power-frequency withstand voltage tests on major insulation components

Power-frequency withstand voltage tests shall be made for one minute either on completely assembled circuit breakers at the voltages and conditions specified in 4.4.3.1 or on major insulation components, such as bushings, insulation braces, and operating rods.

5.17 Power-frequency withstand voltage tests on control and secondary wiring

All control wiring associated with current and linear coupler transformer secondaries and potential device secondaries shall receive a power-frequency withstand test of 2500 V for one minute. All other control wiring shall receive a power-frequency withstand test of 1500 V for one minute or 1800 V for one second.

If the circuit breaker control circuit includes a motor, the motor may be disconnected during the dielectric test on the control circuit and subsequently tested, in place, at its specified dielectric withstand voltage but at not less than 900 V.

6. Conformance test

6.1 Outdoor circuit breakers

6.1.1 Method of conducting conformance tests for lighting impulse withstand voltage

When conformance tests are required for lighting impulse voltage, the tests are to be made in accordance with 4.4.4, 4.4.4.1, and 4.4.4.2, with the following exceptions:

a) The peak voltage value shall not be required to be greater than the rated switching impulse voltage values specified.
b) The time to half-value on the tail of the wave shall not be required to be in excess of 50 μs.

6.1.2 Method of conducting conformance tests for switching impulse withstand voltage

Conformance tests are to be made in accordance with 4.4.7, with the following exceptions:

a) The peak voltage value shall not be required to be greater than the rated switching impulse voltage values specified.
b) The time to half-value on the tail of the wave shall not be required to be in excess of 2500 μs.

6.1.3 Method of conducting conformance tests for line closing switching surge factor on an operating system

A purchaser may perform a field test with the circuit breaker on an actual operating system in order to determine if its test performance conforms to requirements for its rated line closing switching surge factor. The circuit breaker will be considered to have passed its conformance test when the circuit breaker is closed on a random time basis into trapped line charges, if in 20 tests there are no overvoltage factors greater than the rated line closing switching surge factor; or only one such event out of 34 tests; or two out of 48 tests; or three out of 62 tests. Four factors greater than the rated factor, or any factor greater than 1.2 times the rated line closing switching surge factor, represent nonconformance.

If the actual system is not greatly different from the standard reference power system, it is expected that the field test results will not differ significantly from the results obtained from the simulated study used to establish the rated line closing switching surge factor. However, if the circuit breaker fails to meet the above

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criterion, and if the actual power system is significantly different from the standard reference power system, the manufacturer may conduct a simulated study (witnessed by the user) of the actual power system and thereby determine the line closing switching surge factor for the circuit breaker on the actual system. This factor may be substituted in place of the rated factor and serve as the basis for evaluation of the conformance test.

6.2 Indoor circuit breakers

See ANSI C37.54-1996 for all conformance test requirements.

7. Standard methods for determining the values of a sinusoidal current wave and a power-frequency recovery voltage

This clause describes methods for measuring oscillograms to determine the transient currents in a short circuit and the power-frequency recovery voltages following the interruption of a short circuit. These include:

a) The rms or effective value, measured from the envelope of an asymmetrical sinusoidal wave at a time such as the time of the maximum peak of the time of contact parting;
b) The rms value of a short-circuit current over several cycles; and
c) The rms value of a power-frequency recovery voltage following circuit interruption.

7.1 Currents

7.1.1 Significance of rms values used in the standards on ac high-voltage circuit breakers

RMS values of sinusoidal currents vary with the time over which the square of the current is integrated. For the purpose of current measurements on ac high-voltage circuit breakers, an rms value is used that varies with the values of the components determined from the envelope of the current wave.

When a current is specified as an rms value at a given instant determined from the envelope of the current wave, the dc component and the peak-to-peak value of the ac component are assumed to remain constant at the values existing at the given instant, and the integration is made over a time of one cycle.

When a current is specified as an rms value over a time of several cycles, the integration may be based on the instantaneous values of current over this time or, more easily, the rms current may be determined by the method in 7.1.6.

7.1.2 Classification of current wave

Sinusoidal waves may be divided into those that are symmetrical about the zero axis and those that are asymmetrical with respect to the zero axis.

7.1.3 RMS value of a symmetrical sinusoidal wave at a particular instant

A symmetrical sinusoidal wave has an rms value equal to its peak-to-peak value divided by 2.828.

To determine the rms value at a given instant, draw the envelope of the current wave (through the center of the trace), determine the peak-to-peak value, (A), at the given instant and divide by 2.828 (see Figure 14).

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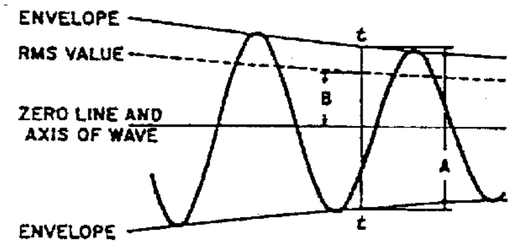
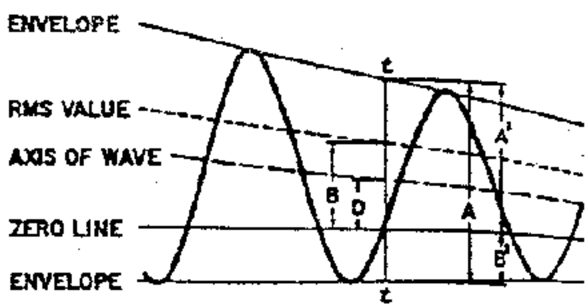


Figure 14—Measurement of the rms value of a symmetrical wave

7.1.4 RMS value of an asymmetrical sinusoidal wave at a particular instant

An asymmetrical sinusoidal wave can be considered to be composed of two components: an alternating current component and a direct current component. The rms value of such a current at a given instant is the square root of the sum of the squares of the dc and ac components of current at the instant the measurement is made (see Figure 15).



t = Instant for which measurement is made
A' = Major ordinate
B' = Minor ordinate
A = Peak-to-peak value of alternating component
= A' + B'
D = Direct component $\frac{A' - B'}{2}$

B = rms value

$$\sqrt{\left(\begin{matrix}\text{rms value of}\\\text{alternating component}\end{matrix}\right)^2 + \left(\begin{matrix}\text{direct}\\\text{component}\end{matrix}\right)^2}$$

$$\sqrt{\left(\frac{A}{2.828}\right)^2 + D^2}$$

Figure 15—Measurement of the rms value of an asymmetrical wave

7.1.4.1 Alternating component

The alternating component has a peak-to-peak value (A) equal to the distance between the upper and lower envelopes of the current, and the axis of the wave is located midway between the envelopes. The peak value of this current is given by:

$$\text{Peak value of alternating component} = \frac{\textit{Major ordinate} + \textit{Minor ordinate}}{2} = \frac{A + B}{2} \qquad (18)$$

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7.1.4.2 Direct component

The amplitude of the direct current component is measured with respect to the displaced axis of the alternating component and is equal to:

$$\frac{\text{Major ordinate} - \text{Minor ordinate}}{2} = \frac{A - B}{2} \tag{19}$$

7.1.4.3 Calculation of the rms value of an asymmetrical sinusoidal wave

See Figure 15 for the method of calculation.

7.1.5 Alternate methods of stating the making current

The making current may be stated as either an rms current, measured from the envelope of the current wave at the time of the maximum peak, or as the instantaneous value of the current at the peak. These values are equally significant in the description of asymmetrical making currents, but the units must be clearly stated to avoid confusion. The ratio of the peak value of current to the rms value varies with asymmetry (Table 5) as follows:

The ratio of the peak value to the rms value is 1.69 ±2% if the asymmetry is between 22% and 94% and 1.69 ±3% if the asymmetry is from 20% to 100%. The variation in this ratio is so small that 1.69 can be used without introducing serious error. Currents having 20% or less asymmetry are considered to be symmetrical and should not be used for demonstrating required I making capability.

Table 5—Asymmetrical currents tabulated values

% Asymmetry	Peak value	RMS value	Peak value to rms value
100	2.83	1.73	1.63
90	2.69	1.62	1.66
80	2.55	1.51	1.69
70	2.40	1.41	1.71
60	2.26	1.31	1.73
50	2.12	1.23	1.73
40	1.98	1.15	1.72
30	1.84	1.09	1.69
24	1.75	1.06	1.66
20	1.70	1.04	1.63
10	1.56	1.01	1.54
0	1.41	1.00	1.41

7.1.6 Measurement of the rms value of a current during a short circuit of several cycles duration

The oscillogram shown in Figure 16 represents a record of a short circuit of several cycles duration. Time is shown on the axis 0X and the current values on the 0Y axis. The origin 0 of the coordinates represents the beginning of the short circuit, and 0T represents the duration of the current flowing through the circuit breaker.

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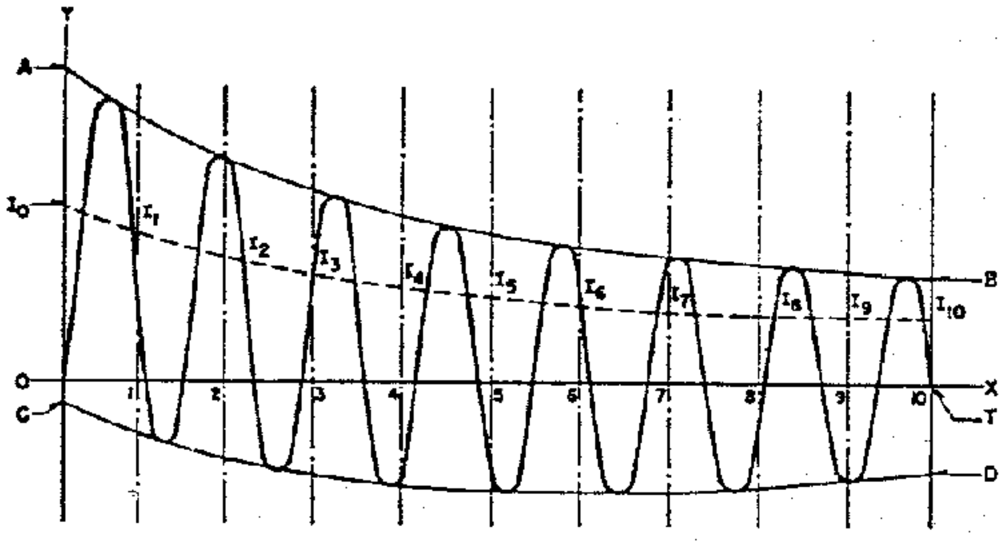

OT	=	duration of short circuit
AB	=	upper envelope of current wave
CD	=	lower envelope of current wave
I_0 - I_{10}	=	rms value of asymmetrical current at each instant

Figure 16—Determination of the equivalent rms value of a short-time current

The rms value of the current I_{rms} during the time interval 0 to T is given by the following formula:

$$I_{rms} = \sqrt{\frac{I}{T}\int_0^T \mathrm{i}^2 \mathrm{dt}} \tag{20}$$

where

i = instantaneous value of the current

The equivalent rms value of the current may be determined with sufficient accuracy by the following application of the Simpson's formula:

a) Divide the time interval OT into 10 equal parts
b) For the eleven instants 0 through 10, determine the total rms currents, I_0 through I_{10} (the method described in 7.1.4.3 may be used). The values then are substituted in the formula below:

$$I_{rms} = \sqrt{\frac{1}{30}[I_0^2 + I_{10}^2 + 4(I_1^2 + I_3^2 + I_5^2 + I_7^2 + I_9^2) + 2(I_2^2 + I_4^2 + I_6^2 + I_8^2)]} \tag{21}$$

In using this formula on currents with a dc component that decays to less than 5% of its initial value during the first time interval, it is more accurate to ignore the dc component than to consider it.

In some cases, the duration of a test demonstrating short-circuit current carrying may not be exactly as specified. However, since the heating of the current carrying parts is very nearly proportional to i^2dt, and the time for cooling is short, the rms test current I_A determined by this method is considered to demonstrate the ability of the circuit breaker to carry the specified current I_B, if the duration T_A of the short-circuit current is within 25% of the specified time T_B and if $I_a^2\, T_A$ is equal or greater than $I_B^2\, T_B$.

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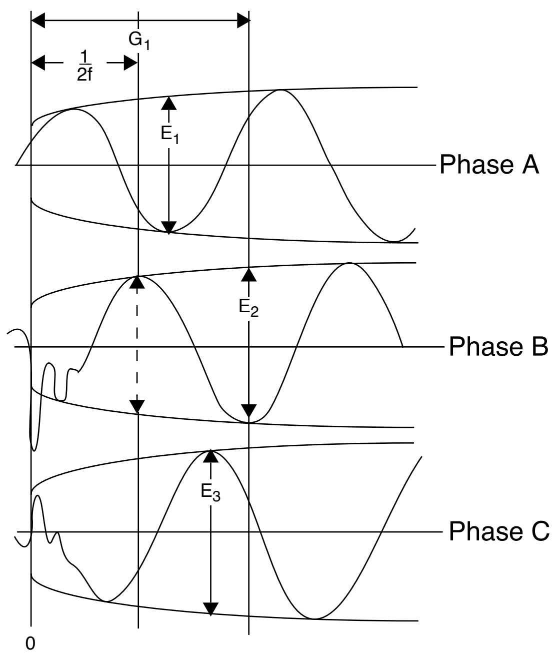
7.2 Power-frequency recovery voltage

Power-frequency recovery voltage shall be determined from the envelope of each voltage wave at a point in time coincident with that peak that occurs more than 1/2 cycle and not more than one cycle after final arc extinction in the last phase to clear. The power frequency phase-to-phase recovery voltage for a three-phase short circuit shall be taken as 1.73 times the average of the three values obtained in this manner for the three voltage waves (see Figure 17).



Phase A = first to open circuit
00 = instant of final arc extinction

G_1G_2 = instant after interval $\frac{1}{2f}$ from 00

G_2G_2 = instant after interval $\frac{1}{f}$ from 00

$\frac{E_1}{2.828}$ = power frequency recovery voltage, Phase A

$\frac{E_2}{2.828}$ = power frequency recovery voltage, Phase B

$\frac{E_3}{2.828}$ = power frequency recovery voltage, Phase C

Average power frequency pole-unit recovery voltage

$$= \frac{(E_1/2.828 + E_2/2.828 + E_3/2.828)}{3}$$

Power frequency phase-to-phase recovery voltage

$$= \sqrt{3} \left(\begin{array}{l} \text{Average power frequency} \\ \text{pole-unit recovery voltage} \end{array} \right)$$

Figure 17—Determination of the power-frequency pole unit recovery voltage

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Annex A

(informative)

Records and reports of type tests for making, breaking, and short-time current performance

A.1 Information and results to be recorded

All relevant information and results of making, breaking, and short-time current tests shall be included in the type-test report.

Typical sample oscillographic records shall be made of all short-circuit operations and included in the type-test report.

The accuracy of each measurement by oscillograph, including associated equipment, of the quantities that determine the ratings (e.g., short-circuit current, applied voltage, and recovery voltage) shall be within ± 5%.

Photographs should be taken to illustrate the condition of the circuit breaker before and after the series of tests.

The type-test report shall include a statement of the performance of the circuit breaker during each test duty and of the condition of the circuit breaker after each test duty, insofar as an examination is made, and at the end of the series of test duties. The statement shall include the following particulars:

a) Condition of circuit breaker, giving details of any replacements or adjustments made and condition of contacts and arc control devices; statement of any damage to arc shields, enclosures, insulators, and bushings; and
b) Description of performance during test duty, including observations regarding emission of oil, gas, or flame.

A.2 Information to be included in the reports

A.2.1 General

a) Date of tests
b) Reference of report number
c) Test numbers
d) Oscillogram numbers

A.2.2 Apparatus tested

a) Type or list number
b) Description (by the manufacturer), including number of poles
c) Manufacturer
d) Photograph numbers
e) Drawing numbers

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A.2.3 Rating assigned by manufacturer

a) Voltage (kV)
b) Rated continuous current (A)
c) Rated power frequency (Hz)
d) Short-circuit breaking current:
   1) RMS value of the ac component of current (kA)
   2) Percentage dc component
e) Minimum opening time (ms)
f) TRV:
   1) Peak value (kV)
   2) Rate-of-rise (kV/μs)
g) Short-line fault surge impedance (Ω and amplitude factor)
h) Short-circuit peak making current (kA)
i) Out-of-phase breaking current (kA)
j) Duration of short circuit (s)
k) Operating sequence
l) Line-charging breaking current (A)
m) Cable charging breaking current (A)
n) Capacitor bank breaking (and making) current (A)
o) Small inductive breaking current (A)
p) Supply voltages (V):
   1) Closing device
   2) Opening device
q) Operating gas pressure range (mPa or bars)

A.2.4 Test conditions for each series of tests

a) Number of poles
b) Power factor
c) Frequency (Hz)
d) Generator neutral (grounded or isolated)
e) Transformer neutral (grounded or isolated)
f) Short-circuit point or load-side neutral (grounded or isolated)
g) Diagram of test circuit including connection(s) to ground

A.2.5 Short-circuit breaking and making tests

a) Operating sequence and time intervals
b) Applied voltage (kV)
c) Making current (peak value) (kA)
d) Breaking current:
   1) RMS value of ac component for each phase and average (kA)
   2) Percentage dc component

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e) Power frequency recovery voltage (kV)
f) Prospective TRV
g) Arcing time (ms)
h) Opening time (ms)
i) Interrupting time (ms)

   Where applicable, break times up to the instant of extinction of the main arc and up to the instant of the breaking of resistance current shall be given.

j) Physical behavior:
   1) Emission of flame, gas, oil, etc.; and
   2) Behavior, conditions, and remarks.

A.2.6 Short-time current test

a) Current
   1) RMS value (kA)
   2) Peak value (kA)
b) Duration (s)
c) Physical behavior

A.2.7 No load operation

a) Before making and breaking tests
b) After making and breaking tests

A.2.8 Out-of-phase making and breaking tests

a) Breaking current in each phase (kA)
b) Voltage across each phase (kV)
c) Gas pressure before tests (when applicable) (mPa or bars)
d) Break time (ms)
e) Resistor current in each phase (when applicable) (A)

A.2.9 Capacitive current switching tests

a) Test voltage (kV)
b) Breaking current in each phase (A)
c) Peak values of the voltage between each phase and ground (kV):
   1) Supply side of circuit breaker
   2) Load side of circuit breaker
d) Number of restrikes (if any)
e) Number of test operations
f) Details of point-on-wave setting
g) Details of test circuit used
h) Behavior of circuit breaker during test
i) Condition of circuit breaker after test

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A.2.10 Oscillographic and other records

Oscillograms shall record the whole of the operation. The following parameters shall be recorded. Some of these parameters may be recorded separately from the oscillograms, and several oscillographs with different time scales may be necessary.

a) Applied voltage
b) Current in each pole
c) Recovery voltage (voltages on supply and load side of circuit breaker for charging current tests)
d) Current in closing coil
e) Current in opening coil
f) Suitable time scale
g) Travel of moving contacts (if practicable)

All cases in which the requirements of this standard are not strictly complied with and all deviations shall be explicitly mentioned at the beginning of the test report.

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Annex B

(informative)

Test tables from C37.09-1979

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Table B1—Test for demonstrating the short-circuit rating of an ac high-voltage circuit breaker by method I (testing a three-pole breaker on a three-phase circuit)

Test duty*	Operating duty (16)†	Phases	Voltages, initial and recovery, normal-frequency phase-to-phase V, rms (2) (3) (15)	Making current at first major peak (2) (4)		Current interrupted at contact separation		Tripping delay (approximate, 60 Hz base) cycles	Control voltage and operating pressure before first operation
				A, rms	A, Peak	Magnitude, A rms	% Asymmetry		
1	2	3	4	5	6	7	8	9	10
1	One O and one CO	3	V	—	—	0.07 I to 0.13 I (4)	50 to 100 (4)	1/2	Rated
2	One O and one CO	3	V	—	—	0.2 I to 0.3 I (11)	Less than 20 (11)	—	Rated
3	One O and one CO	3	V	—	—	0.4 I to 0.6 I (4)	50 to 100 (4)	1/2	Rated
4(6)(19)	O-15 s (2)-O, O-15 s (2)-CO, or CO-15 s (2)-CO	3	V	—	—	I (2) (10)	Less than 20	(5)	Rated (18)
5(6)(19)	O-15 s (2)-O, O-15 s (2)-CO, or CO-15 s (2)-CO	3	V/K	—	—	KI(2)(10)	Less than 20	(5)	Rated (18)
6-1 (8)	CO-15 s (2)-CO	3	V	1.6 KI	2.7 KI	SI(2)(4)	50 to 100 (4)	1/2	Rated (17)
6-2 (8)	C	3	V	1.6 KI	2.7 KI	—	—	—	Rated (17)
6-3 (8)	O-15 s (2)-O	3	V	—	—	SI (2)(4)	50 to 100 (4)	1/2 (5)	Rated
	For circuit breakers 121 kV and above:								
7A-1 (8)	CO-15 s-CO-15 min-CO-15 s-CO-1 h-CO	3	V/K	1.6 KI	2.7 KI	KSI (2)(4)	50 to 100 (4)	1/2	Rated (7) (17)
7A-2 (8)	C-15 s (2)-C-15 min-C-15 s (2)-C-1 h-C	3	V/K	1.6 KI	2.7 KI	—	—	—	Rated (17)
7A-3 (8)	O-15 s (2)-O-15 min-O-15 s (2)-O-1 h-O	3	V/K	—	—	KSI(2)(4)	50 to 100 (4)	1/2 (5)	Rated (7)
	For all other breakers:								
7B-1 (8)	CO-15 s-CO-1 h-CO	3	V/K	1.6 KI	2.7 KI	KSI (2)(4)	50 to 100 (4)	1/2	Rated (7) (17)
7B-2 (8)	C-15 s (2)-C-1 h-C	3	V/K	1.6 KI	2.7 KI	—	—	—	Rated (17)
7B-3 (8)	O-15 s (2)-O-1 h-O	3	V/K	—	—	KSI (2)(4)	50 to 100 (4)	1/2 (5)	Rated (7)
8 (14)	Several O and CO operations-1 h-CO	3	V/K	—	—	(14)	Random	1/2	Rated (7)
9 (12)(13)	O-0 s-CO or CO-0 s-CO	3	V	—	—	RSI (2)(4)	50 to 100 (4)	1/2	Rated
10 (12)	O-0 s-CO or CO-0 s-CO	3	V/K	—	—	$RKSI$ (2)(4)	50 to 100 (4)	1/2	Rated
11	C-T s-O	3	V/K	1.6 KI	2.7 KI	KI	0	T	Rated (17)
12	In closed position (9)	1	—	—	—	—	—	—	—
13	One O and one CO or two O	1	0.58 V	—	—	Smaller of 1.15 I or KI	Less than 20	(5)	Rated
14	One O and one CO or two O	1	0.58 V	—	—	Smaller of 1.15 SI or KSI (2)	50 to 100 (4)	1/2 (5)	Rated
15 (22)	O-15 s-O or O-15 s-CO or CO-15 s-CO	1	0.58 V	—	—	0.7 I to 0.8 I (20)	Less than 20	1/2 (5)	Rated (18)
16 (13) (22)	O-15 s-O or O-15 s-CO or CO-15 s-CO	1	0.58 V	—	—	0.9 I to 0.95 I (20)	Less than 20	1/2 (5)	Rated (18)

*See 4.5.
†Numbers in parentheses correspond to those of the explanatory NOTES on the following page.

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NOTES TO TABLE B1:

1—*V* is the rated maximum voltage. See 5.1 of ANSI/IEEE C37.04-1979.
I is the rated short-circuit current. See 4.10.1 of ANSI/IEEE C37.04-1979.
K is the voltage range factor. See 5.2 of ANSI/IEEE C37.04-1979.
S is the asymmetry factor determined from 5.10.2.2 of ANSI/IEEE C37.04-1979.
R is the factor for reclosing duty cycle determined from 5.10.2.6 of ANSI/IEEE C37.04-1979.
T is the maximum permissible tripping delay (see 5.8.1 of ANSI/IEEE C37.04-1979) and is as near *Y* as test facilities permit.

2—The voltage, current, and time values in a test must be equal to or greater than the specified values, except that the time values may be reduced at the discretion of the manufacturer.

3—If imposed by limitations in testing facilities, a tolerance of –5% is permissible in the recovery voltage. (See 4.6.5.3.1.)

4—This value is required in only one operation and in only one phase. (See 4.6.5.10.)

5—Obtain the most severe switching conditions on at least one interruption. (See 4.6.5.11.)

6—The connections from the power source shall be moved from one side of the circuit breaker to the other between Test Duties 4 and 6 and between Test Duties 5 and 7 if that changes the possibility of flashover to ground or between phases. (See 4.6.5.9.)

7—Interrupting time on the last operation may exceed the rated interrupting time by one cycle. For conditions after test, see 4.6.4.3.

8—Test Duties designated with –2 and –3 constitute an alternate for a Test Duty designated with a corresponding –1. All operations made in performing Test Duties 7A or 7B, either with the –1 Test Duty or the –2 and –3 Test Duties, are to be performed without maintenance to demonstrate that the circuit breaker will be in the condition specified after performing the number of operations required for the service capability. (See 5.10.3.3 of ANSI/IEEE C37.04-1979.)

If the evidence available from development tests on this circuit breaker shows that a standard duty cycle is more severe with the voltages and currents of Test Duty 7 than of Test Duty 6, Test Duty 6 may be omitted. If the evidence available from development tests on this circuit breaker shows that a standard duty cycle is more severe with the voltages and currents of Test Duty 6 than of Test Duty 7, a modified Test Duty 7, made with the voltages and currents specified for Test Duty 6, may be used in place of both Test Duties 6 and 7.

If the standard duty cycle is not used in either Test Duty 4 or 5 and if neither Test Duty 6-1 nor 7-1 is used as specified, the standard duty cycle shall be demonstrated by Test Duty 6-1 with the currents and recovery voltage as nearly as possible at the required values without any of the values being exceeded except with the agreement of the manufacturer. Test Duty 6-1 shall then be supplemented by either Test Duty 6-2 or Test Duty 6-3, whichever is necessary to meet the requirement not fully met by Test Duty 6-1. The other part of the alternate Test Duty need not be made.

9—In the closed position, the circuit breaker shall carry a current having an rms value over 3 s of *KI*. For measurement of current, see 7.1.6.

10—The average of the rms values of the three ac components shall be equal to or greater than the specified value. The value of the ac component in any phase shall not vary from the average by more than 10% of the average.

11—This value is required only in one operation, but in all three phases.

12—Test Duties 9 and 10 are omitted if the circuit breaker is not rated for instantaneous reclosing. The reclosing time should not exceed the rated relcosing time. See 5.9 of ANSI/IEEE C37.04-1979.

13—This test may be omitted if *K* is less than 1.2.

14—This service capability test is required only on circuit breakers demonstrated with Test Duty 7B because a duty at least equivalent is required in 7A. The sum of the currents interrupted in a combined total of 10 or less O and CO operations shall be equal to at least 400% *KSI*. In this series, except in the final operation, no individual symmetrical component should exceed 0.85 *KI*, nor should any individual total rms current exceed 0.85 *KSI*. In the final operation, the circuit breaker must clear a current having a symmetrical component at least equal to *KI*, but the interrupting time may exceed the rated interrupting time by one cycle. See 4.6.4.3. At the discretion of the manufacturer, this Test Duty may be met by running without maintenance Test Duties 1 to 3, inclusive, plus such other opening operations at any currents as may be required to make up an accumulated interrupted current of 400% *KSI* and then after 1 h making one close-open operation with a current having a symmetrical component at least equal to *KI*. See 5.10.3.3 of ANSI/IEEE C37.04-1979 for limitation on tests per hour and 4.6.4.3 for condition after test.

15—The neutral of the test circuit or the short circuit shall be grounded, but not both.

16—In the Test Duty or Test Duties used to demonstrate the standard duty cycle and service capability between 85 and 100% of the required asymmetrical interrupting capability, the 15 s time interval shall be used. Unless otherwise specified, for reclosing and service capability demonstrations, all other Test Duties may be made with longer intervals or with corresponding operations not made in sequence. Successive open or close operations require intervening switching of the testing circuit.

17—Before at least one close operation in one Test Duty, the closing and tripping test voltages shall be at their respective minimums and the operating pressures of pneumatic or hydraulic operating mechanisms shall be 106% or less of cut-off pressure.

18—A compressed gas circuit breaker shall make two close-open operations at the required interrupting capability without the arc extinguishing medium being replenished. This may be demonstrated during Test Duty 4 or 5 by shutting off the air supply before the CO-15 s-CO operating duty or before the circuit breaker is closed prior to either one of the operations with the pressure coy-responding to that of the second operation in these Test Duties. In this last case, the air may be replenished between operations.

19—Either Test Duty 4 or Test Duty 5 may be omitted if the evidence available from development tests on this circuit breaker shows that the other is the more severe condition

20—The bus should have a capability of *I* or *KI* and the test current reduced by additional line impedance to the required values.

21—All test duties should be made with transient recovery voltages as specified in 4.7.

22—This demonstration test is not required for circuit breakers rated 72.5 kV and below.

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Table B2—Test for demonstrating the short-circuit rating of an ac high-voltage circuit breaker by method II (testing a single pole of a three-pole breaker on a single-phase circuit)

Test duty *	Operating duty (16)†	Phases	Voltages, initial and recovery, normal-frequency pole-unit V, rms (2) (3) (15) (20)	Making current at first major peak (2) (4) rms	Peak	Current interrupted at contact separation: Magnitude, A, rms	% Asymmetry	Tripping delay (approximate, 60 Hz base) cycles	Control voltage and operating pressure before first operation
1	2	3	4	5	6	7	8	9	10
1	One O and one CO	1	0.87 *V*	—	—	0.07 *I* to 0.13 *I* (4)	50 to 100 (4)	1/2	(11)
2	One O and one CO	1	0.87 *V*	—	—	0.2 *I* to 0.3 *I* (4)	Less than 20 (4)	—	(11)
3	One O and one CO	1	0.87 *V*	—	—	0.4 *I* to 0.6 *I* (4)	50 to 100 (4)	1/2	(11)
4 (6) (19)	O-15 s (2)-O, O-15, s (2)-CO, or CO-15 s (2)-CO	1	0.87 *V*	—	—	*I* (10)	Less than 20	(5)	(11) (18)
5 (6) (19)	O-1 5 s (2)-O, O-1 5, s (2)-CO, or CO-15 s (2)-CO	1	0.87 *V/K*	—	—	*K* (10)	Less than 20	(5)	(11) (18)
6-1 (8)	CO-15 s (2)-CO	1	0.87 *V*	1.6 *KI*	2.7 *KI*	*SI* (2) (4)	50 to 100 (4)	1/2	(11) (17)
6-2 (8)	C	1	0.58 *V*	1.5 *KI*	2.7 *KI*	—	—	—	(11) (17)
6-3 (8)	O-15 s (2)-O	1	0.87 *V*	—	—	*SI* (2) (4)	50 to 100 (4)	1/2 (5)	(11)
	For circuit breakers 121 kV and above:								
7A-1 (8)	CO-15 s-CO-15 min-CO-15 s-CO-1 h-CO	1	0.87 *V/K*	1.6 *KI*	2.7 *KI*	*KSI* (2) (4)	50 to 100 (4)	1/2 (5)	(7) (11) (17)
7A-2 (8)	C-15 s (2)-C-15 min-C-15 s (2)-C-1 h-C	1	0.58 *V/K*	1.6 *KI*	2.7 *KI*	—	—	—	(11) (17)
7A-3 (8)	O-15 s (2)-O-15 min-O-15 s (2)-O-1 h-O	1	0.87 *V/K*	—	—	*KSI* (2) (4)	50 to 100 (4)	1/2 (5)	(7) (11)
	For all other breakers:								
7B-1 (8)	CO-15 S-CO-1 h-CO	1	0.87 *V/K*	1.6 *KI*	2.7 *KI*	*KSI* (2) (4)	50 to 100 (4)	1/2 (5)	(7) (11) (17)
7B-2 (8)	C-15 s (2)-C-1 h-C	1	0.58 *V/K*	1.6 *KI*	2.7 *KI*	—	—	—	(11) (17)
7B-3 (8)	O-1 5 s (2)-O-1 h-O	1	0.87 *V/K*	—	—	*KSI* (2) (4)	50 to 100 (4)	1/2 (5)	(7)(11)
8 (14)	Several O and CO operations-1 h-CO	1	0.87 *V/K*	—	—	(14)	Random	1/2	(11)
9 (12) (13)	O-0 s-CO or CO-0 s-CO	1	0.87 *V*	—	—	*RSI* (2) (4)	50 to 100 (4)	1/2	(11)
10 (12)	O-0 s-CO or CO-0 s-CO	1	0.87 *V/K*	—	—	*RKSI* (2) (4)	50 to 100 (4)	1/2	(11)
11	C-*T* s-O	1	0.87 *V/K*	1.6 *KI*	2.7 *KI*	*KI*	0	*T*	(11) (17)
12	In closed position (9)	1	—	—	—	—	—	—	—
15 (23)	O-15 s-O or O-15 s-CO or CO-15 s-CO	1	0.58 *V*	—	—	0.7 *I* to 0.8 *I* (21)	Less than 20	1/2 (5)	Rated (18)
16 (13) (23)	O-15 s-O or O-15 s-CO or CO-15 s-CO CO-15 s-CO	1	0.58 *V*	—	—	0.7 *KI* to 0.8 *KI* (21)	Less than 20	1/2 (5)	Rated (18)

*See 4.6.
†Numbers in parentheses correspond to those of the explanatory NOTES on the following page.

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NOTES to Table B2:

1—*V* is the rated maximum voltage. See 5.1 of ANSI/IEEE C37.04-1979.
I is the rated short-circuit current. See 4.10.1 of ANSI/IEEE C37.04-1979.
K is the voltage range factor. See 5.2 of ANSI/IEEE C37.04-1979.
S is the asymmetry factor determined from 5.10.2.2 of ANSI/IEEE C37.04-1979.
R is the factor for reclosing duty cycle determined from 5.10.2.6 of ANSI/IEEE C37.04-1979.
T is the maximum permissible tripping delay (see 5.8.1 of ANSI/IEEE C37.04-1979) and is as near *Y* as test facilities permit, but no less than 1/2 s.

2— The voltage, current, and time values in a test must be equal to or greater than the specified values, except that the time values may be reduced at the discretion of the manufacturer.

3— If imposed by limitations in testing facilities, a tolerance of –5% is permissible in the recovery voltage. (See 4.6.5.3.1.)

4—This value is required in only one operation. (See 4.6.5.10.)

5— Obtain the most severe switching conditions on at least one interruption. (See 4.6.5.11.)

6— The connections from the power source shall be moved from one side of the circuit breaker to the other between Test Duties 4 and 6 and between Test Duties 5 and 7 if that changes the possibility of flashover to ground or between phases. (See 4.6.5.9.)

7—Interrupting time on the last operation may exceed the rated interrupting time by one cycle. For conditions after test, see 4.6.4.3.

8—Test Duties designated with –2 and –3 constitute an alternate for a Test Duty designated with a corresponding –1. All operations made in performing Test Duties 7A or 7B, either with the –1 Test Duty or the –2 and –3 Test Duties, are to be performed without maintenance to demonstrate that the circuit breaker will be in the condition specified after performing the number of operations required for the service capability. (See 5.10.3.3 of ANSI/IEEE C37.04-1979.)

If the evidence available from development tests on this circuit breaker shows that a standard duty cycle is more severe with the voltages and currents of Test Duty 7 than of Test Duty 6, Test Duty 6 may be omitted. If the evidence available from development tests on this circuit breaker shows that a standard duty cycle is more severe with the voltages and currents of Test Duty 6 than of Test Duty 7, a modified Test Duty 7, made with the voltages and currents specified for Test Duty 6, may be used in place of both Test Duties 6 and 7.

If the standard duty cycle is not used in either Test Duty 4 or 5 and if neither Test Duty 6-1 nor 7-1 is used as specified, the standard duty cycle shall be demonstrated by Test Duty 6-1 with the currents and recovery voltage as nearly as possible at the required values without any of the values being exceeded except with the agreement of the manufacturer. Test Duty 6-1 shall then be supplemented by either Test Duty 6-2 or Test Duty 6-3, whichever is necessary to meet the requirement not fully met by Test Duty 6-1. The other part of the alternate Test Duty need not be made.

9—In the closed position, the circuit breaker shall carry a current having an rms value over 3 s of *KI*. For measurement of current, see 7.1.6.

10—The rms value of the ac component must be equal to or greater than the specified current.

11—Except as required by Note (16), control voltage and operating pressure shall be maintained at such values that the closing speed and the opening speed of the contacts in the region of arcing are approximately the same as is obtained with rated control voltage and rated operating pressure during a corresponding three-phase test on a three-pole circuit breaker (see 4.6.5.7).

12—Test Duties 9 and 10 are omitted if the circuit breaker is not rated for instantaneous reclosing. The reclosing time should not exceed the rated reclosing time. See 5.9 of ANSI/IEEE C37.04-1979.

13—This test may be omitted if *K* is less than 1.2.

14—This service capability test is required only on circuit breakers demonstrated with Test Duty 7B because an equivalent duty is required in 7A. The sum of the currents interrupted in a combined total of 10 or less O and CO operations shall be equal to at least 400% *KSI*. In this series, except in the final operation, no individual symmetrical component should exceed 0.85 *KI*, nor should any individual total rms current exceed 0.85 *KSI* In the final operation, the circuit breaker must clear a current having a symmetrical component at least equal to *KI*, but the interrupting time may exceed the rated interrupting time by one cycle. See 4.6.4.3. At the discretion of the manufacturer, this Test Duty may be met by running without maintenance Test Duties 1 to 3, inclusive, plus such other opening operations at any currents as may be required to make up an accumulated interrupted current of 400% *KSI* and then after 1 h making one close-open operation with a current having a symmetrical component at least equal to *KI*. See 5.10.3.3 of ANSI/IEEE C37.04-1979 for limitation on tests per hour and 4.6.4.3 for condition after test.

15—If it is desired to demonstrate the ability to interrupt three-phase grounded faults on an effectively grounded three-phase system, but not three-phase ungrounded faults, the constant 0.87 is replaced by 0.75.

16—In the Test Duty or Test Duties used to demonstrate the standard duty cycle and service capability between 85 and 100% of the required asymmetrical interrupting capability, the 15 s time interval shall be used. Unless otherwise specified, for reclosing and service capability demonstrations, all other Test Duties may be made with longer intervals or with corresponding operations not made in sequence. Successive open or close operations require intervening switching of the testing circuit.

17—Before at least one close operation in one Test Duty, the operating pressure of a fluid-operated circuit breaker shall be such as to produce contact closing speed and contact opening speed in the region of arcing equal to that produced on a three-pole circuit breaker by an operating pressure equal to cut-off pressure during a corresponding three-phase test.

Closing control voltage in a solenoid-operated circuit breaker shall be such as to produce contact closing speed and contact opening speed approximately equal to those which would be produced on a three-pole circuit breaker by a closing control voltage at the lower limit of its operating range, or in a fluid-operated circuit breaker shall be at the lower limit of its operating range, and tripping control voltage shall be at the lower limit of its operating range.

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18— A compressed gas circuit breaker shall make two close-open operations at the required interrupting capability without the arc extinguishing medium being replenished. This may be demonstrated during Test Duty 4 or 5 by shutting off the air supply before the CO-15 s-CO operating duty or before the circuit breaker is closed prior to either of the other operating duties. It may also be demonstrated by making either one of the operations with the pressure corresponding to that of the second operation in these Test Duties. If less than a three-pole circuit breaker is being operated on the test, a pressure equivalent to pressure for the second interruption in a three-pole circuit breaker shall be used for one interruption.

19—Either Test Duty 4 or Test Duty 5 may be omitted if the evidence available from development tests on this circuit breaker shows that the other is the more severe condition.

20—To avoid closing with a voltage which is required for the opening, but is higher than necessary for demonstrating closing, the CO operation may be made at 0.58/0.87 times the voltage specified in Column 4 providing it is supplemented by an opening operation at the voltage specified in Column 4.

21—The bus should have a capability of *I* or *KI* and the test current reduced by additional line impedance to the required values.

22—All Test Duties should be made with transient recovery voltages as specified in 4.7.

23—This demonstration test is not required for circuit breakers rated 72.5 kV and below.

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