An American National Standard

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

Sponsor
Switchgear Committee of the
of the
IEEE Power Engineering Society

Secretariat

Institute of Electrical and Electronics Engineers
National Electrical Manufacturers Association

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ANSI/IEEE C37.09-1979
Change notice 1
22 February 1985

Change Notice to Adoption Notice

To all holders of Adoption Notice dated April 19, 1984 for ANSI/IEEE C37.09-1979, Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis:

1) IEEE issued Supplement ANSI/IEEE C37.09c-1984 to the above document on March 30, 1984. It is hereby approved for use by the Department of Defense.
2) Holders of the above document will verify that Supplement ANSI/IEEE C37.09c-1984 has been incorporated in the basic document.
3) This change notice page, together with the ANSI/IEEE Supplement C37.09c-1984, will be retained as a check sheet and is a separate publication. Each change notice is to be retained by stocking points until the Military Coordinating Activity issues a new Adoption Notice superseding the Adoption Notice for the above document.

Custodians:

Army - ME

Navy - YD

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Foreword

(This Foreword is not a part of ANSI/IEEE C37.09-1979, American National Standard, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.)

This standard is a revision of ANSI C37.09-1964 (R 1969). This revision contains both substantive revisions and editorial changes as the result of the general power circuit breaker consolidation efforts. Supplement ANSI/IEEE C37.09a-1970 is included as part of the consolidation.

The substantive changes involve atmospheric correction factors, control circuit tests, and duration of tripping delay. These revisions were balloted as C37.09b and C37.09c, but the supplemental notations have been dropped as they have been incorporated into this revision. The atmospheric correction factors (see 4.5) were prepared by a working group of the Power Circuit Breaker (PCB) Subcommittee and were developed to fill a need for rules concerning the application of atmospheric correction factors during dielectric tests on circuit breakers. The requirements for low-frequency withstand tests on control and secondary wiring (see 5.16) have been modified to allow a motor to be disconnected during the tests and tested separately at its specified level. A change has also been made in the notes for Tables 1 and 2, stating that the tripping delay, T, be no less than $^1/_2$ s.

The remainder of the changes are editorial changes resulting in the consolidation of test procedures of various supplemental standards into this one test procedure.

A number of engineering and manufacturers trade organizations were interested in standards for high-voltage circuit breakers as well as other types of electrical equipment and worked to develop standard requirements for capabilities, sizes, and testing procedures. Among these groups were the AIEE[1], the National Electric Light Association (NELA), the Electric Power Club (a predecessor of NEMA — the National Electrical Manufacturers Association), the Association of Edison Illuminating Companies (AEIC), and the Edison Electric Institute (EEI).

During the years up to 1940, these organizations adopted and published a number of standardization proposals concerning rating, testing, and other requirements for high-voltage circuit breakers.

In 1941, a unified series of standards for circuit breakers, based on those of AIEE, AEIC, and NEMA, were published for trial use by the American Standards Association (ASA). This comprised the first American Standard for high-voltage circuit breakers. In 1945, this series was issued as an approved American Standard with the familiar C37 number identification. This series included sections on rating, preferred sizes, testing, and application of circuit breakers. In 1952 and 1953, this series of standards was revised and supplemented by additional sections, forming the complete, basic group of American Standards for high-voltage circuit breakers. At the time of publication this group of standards included:

ANSI C37.4-1953	AC Power Circuit Breakers (included definitions, rating basis, and some test requirements)
ANSI C37.5-1953	Methods for Determining the RMS Value of a Sinusoidal Current Wave and Normal-Frequency Recovery Voltage, and for Simplified Calculation of Fault Currents
ANSI C37.6-1953	Schedules of Preferred Ratings for Power Circuit Breakers
ANSI C37.7-1952	Interrupting Rating Factors for Reclosing Service
ANSI C37.8-1952	Rated Control Voltages and their Ranges
ANSI C37.9-1953	Test Code for Power Circuit Breakers
ANSI C37.12-1952	Guide Specifications for Alternating Current Power Circuit Breakers

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[1] AIEE (American Institute of Electrical Engineers) merged with IRE (Institute of Radio Engineers) January 1, 1963 to form the joint organization IEEE (Institute of Electrical and Electronics Engineers).

Under these original standards, the basis of the interrupting rating was established by 6.11 of ANSI C37.4-1953 as the highest current to be interrupted at the specified operating voltage and was the "… rms value including the dc component at the instant of contact separation as determined from the envelope of the current wave." Since this standard based the interrupting rating on the total current including dc component at the instant of contact separation, it has become known as the "Total Current Basis of Rating."

For circuit breaker application, a simplified method was available in ANSI C37.5-1953, which listed multiplying factors for use with the system symmetrical fault current to derive a maximum possible total rms current which could be present at contact separation. This current was used to choose the required circuit breaker rating from those listed in ANSI C37.6-1953, or subsequent revisions. The factors recognized typical system characteristics and circuit breaker operating times.

In 1951, the AIEE Switchgear Committee began to give consideration to the development of a circuit breaker rating method based on symmetrical interrupting currents. This work was initiated with the goal of:

1) Simplifying application where high-speed relaying and fast clearing circuit breakers are used
2) Bringing American standards into closer agreement with accepted international standards (IEC-International Electrotechnical Commission) to avoid confusion on rating differences
3) Requiring that circuit breakers are proven to demonstrate a definite relationship between asymmetrical interrupting capability and symmetrical ratings

During the course of this work, principally in a working group of the AIEE Power Circuit Breaker Subcommittee, numerous reports of the proposals on the new rating, testing, and application methods were made to the industry as a whole through committee sponsored papers at AIEE meetings in 1954, 1959, and 1960. Suggestions made in discussions were considered by the working group and incorporated where practicable. The principal change from the 1953 "Total Current" standard was in the basis of rating. 4.5.1 of ANSI C37.04 established the Rated Short Circuit Current as "the highest value of the symmetrical component of the … short-circuit current in rms amperes, measured from the envelope of the current wave at contact separation, which the circuit breaker is required to interrupt at rated maximum voltage …". Certain related capabilities were also required, including operation under specified conditions of asymmetry based on typical circuit characteristics and circuit breaker timing. This rating structure became known as the *Symmetrical Current Basis of Rating* as compared to the previous *Total Current Basis of Rating*. However, as the new ratings were developed, it became apparent that changes from the older to the newer standard could not occur overnight due to requirements for rerating and retesting of many PCBs. It was, therefore, decided to retain both rating structures, with the understanding that all new circuit breaker developments would be directed toward the *symmetrical* standards. The circuit breakers based on the *total current* standards would be transferred to the new standards as work progressed in rerating programs. This transfer is being carried out and ANSI C37.6 and ANSI C37.06 have been revised accordingly a number of times.

The *symmetrical current* group of standard sections was published in 1964 and was given ANSI C37.04, C37.05, C37.06, etc, designations. These sections and the corresponding 1953 sections were:

Total Current Standard	Symmetrical Current Standard	Subject
ANSI C37.4	ANSI C37.03 ANSI C37.04 ANSI C37.04a	Definitions Rating Structure
ANSI C37.5	ANSI C37.05	Measurement of Voltage and Current Waves
ANSI C37.6	ANSI C37.06 ANSI C37.06a	Preferred Ratings
ANSI C37.7	ANSI C37.07	Reclosing Factors
ANSI C37.8	(included in ANSI C37.06)	Control Voltages
ANSI C37.9	ANSI C37.09 ANSI C37.09a	Test Code
ANSI C37.5 (Section 3.)	ANSI C37.010	Application Guide (expansion of material previously in C37.5)

Sections .04a, .06a, and .09a, also issued in 1964, were addenda concerned with supplemental dielectric capability requirements.

In ANSI C37.06-1964 and subsequent revisions prior to 1971, circuit breaker symmetrical current interrupting ratings were derived from ratings in ANSI C37.6-1961 by a relationship following a middle ground position between the total (asymmetrical) current of the former rating method and the full range of related requirements of the new rating method. For a given breaker this derivation was expressed by the formula:

$$\text{rated short circuit current} = I_{1961}\left(\frac{\text{nominal voltage}}{\text{rated maximum voltage}}\right)F$$

where

I_{1961} = interrupting rating in amperes appearing in ANSI C37.6-1961
F = 0.915 for 3 cycle breakers
0.955 for 5 cycle breakers
1.0 for 8 cycle breakers

Rated short circuit current was tabulated for rated maximum voltage rather than for nominal voltage as had been the case under the total current basis of rating.

It was stressed that this derivation was for the numerical conversion only and that a given circuit breaker, designed and tested under the total current basis of rating, could not be assumed to have these capabilities under the symmetrical current basis of rating without approval of the manufacturer.

In the revision of ANSI C37.06 published in 1971, several simplifications were introduced, including the use of a new method for selection of interrupting current ratings for outdoor circuit breakers 121 kV and above. Values for rated short circuit current were chosen from the R-10 preferred number series, and the use of a reference nominal 3-phase MVA identification was discontinued. Also the rated voltage range factor K was changed to unity, 1.0, to simplify rating and testing procedures.

In the intervening years since the official publication of the primary sections of the symmetrical basis of rating standard for high-voltage circuit breakers, a number of revisions, additions, and improvements have been developed and published. Many of these additions were in subject areas of major importance in the rating, testing, and application of circuit breakers and were published as complete standards containing appropriate definitions, rating performance criteria, rating numbers, test procedures, and application considerations. This was done to avoid delay in publication and the necessity of reprinting other existing standards as each of these was completed. The result has been the publication of a substantial number of individual supplementary standards. The basic subject areas considered in these supplementary standards, and their initial publication dates, are shown below:

ANSI C37.071-1969	Requirements for Line Closing Switching Surge Control
ANSI C37.072-1979	Requirements for Transient Recovery Voltage
ANSI C37.0721-1971	Application Guide for Transient Recovery Voltage
ANSI C37.0722-1971	Transient Recovery Voltage Ratings
ANSI C37.073-1972	Requirements for Capacitance Current Switching
ANSI C37.0731-1973	Application Guide for Capacitance Current Switching
ANSI C37.0732-1972	Preferred Ratings for Capacitance Current Switching
ANSI C37.074-1972	Requirements for Switching Impulse Voltage Insulation Strength
ANSI C37.076-1972	Requirements for Pressurized Components
ANSI C37.078-1972	Requirements for External Insulating
ANSI C37.0781-1972	Test Values for External Insulation
ANSI C37.079-1973	Method of Testing Circuit Breakers When Rated for Out-of-Phase Switching

A goal of work recently completed, and represented by the 1979 publication of these standards, has been the editorial incorporation of all the supplementary standards listed above into the proper primary standards documents. For circuit breakers rated on a symmetrical current basis, the consolidated standards sections are:

ANSI/IEEE C37.04-1979	Rating Structure
ANSI C37.06-1979	Preferred Ratings and Related Required Capabilities
ANSI/IEEE C37.09-1979	Test Procedure
ANSI/IEEE C37.010-1979	Application Guide — General
ANSI/IEEE C37.011-1979	Application Guide — Transient Recovery Voltage
ANSI/IEEE C37.012-1979	Application Guide — Capacitance Current Switching

The present ANSI C37.05, Measurement of Current and Voltage Waves, is incorporated into ANSI/IEEE C37.09; ANSI C37.07, Interrupting Capability Factors for Reclosing Service, is incorporated into ANSI/IEEE C37.04, ANSI C37.06, and ANSI/IEEE C37.09. Definitions which have been in C37.03-1964 are now in ANSI C37.100-1972.

Standards are presently being developed in a number of additional subject areas, which will be initially published as supplementary standards and incorporated into the primary subject document at some future date. Included among these subjects are requirements for current transformers, a guide for synthetic testing, sound level measurements, and seismic capability requirements.

For circuit breakers still rated on a total current basis, as listed in ANSI C37.6, the existing standards ANSI C37.4, ANSI C37.6, ANSI C37.7, and ANSI C37.9 will continue to be applicable.

Documents pertaining to guide specification and control schemes, which apply to both groups of ratings, are included in the ANSI C37 series as shown below:

ANSI C37.11-1972	Requirements for Electrical Control on AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis and a Total Current Basis
ANSI C37.12-1969	Guide Specifications for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis and a Total Current Basis

Periodic review of all these standards takes place through the normal ANSI procedure thatstandards are reaffirmed, revised, or withdrawn within no more than five year intervals from the original publication date.

Suggestions for improvement gained in the use of this standard will be welcome. They should be sent to the

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The basic data included in this consolidated document is the result of contributions made by many individuals over many years. At the time of approval, however, the American National Standards Committee on Power Switchgear, C37, which reviewed and approved this standard, had the following personnel:

C. L. Wagner, *Chair*
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J. E. Beehler *(Executive Vice-Chairman of High-Voltage Switchgear Standards)*
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The basic source documents used in this consolidated document were prepared by various Working Groups of the Power Circuit Breaker Subcommittee of the IEEE Switchgear Committee. The personnel of the subcommittee at the time of consolidation were as follows:

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CLAUSE PAGE

An American National Standard

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 which are made on ac high-voltage circuit breakers, describes accepted methods used in making the tests, and specifies the tests which will demonstrate ratings under ANSI/IEEE standards. It does not preclude the use of other equivalent or more effective methods of demonstrating ratings.

The tests are divided into the following classifications:

1) Design tests
2) Production tests
3) Tests after delivery
4) Field tests
5) Conformance tests

1.1 Design Tests

Design tests are those tests made to determine the adequacy of the design of a particular type, style, or model high-voltage circuit breaker to meet its assigned ratings and to operate satisfactorily under normal service conditions or under special conditions, if specified. Design tests are made only on representative breakers to substantiate the ratings assigned to all other breakers of basically the same design, the same interrupters, the same contact speeds, and at least as good dielectric strength. These tests are not intended to be used as a part of normal production.

The applicable portions of these design tests may also be used to evaluate modifications of a previous design and to assure that performance has not been adversely affected. Test data from previous similar designs may be used for current designs, where appropriate.

1.2 Production Tests

Production tests are those tests made to check the quality and uniformity of the workmanship and materials used in the manufacture of high-voltage circuit breakers.

1.3 Tests After Delivery

Tests made by the purchaser after delivery of the circuit breaker supplement inspection in determining whether the breaker has arrived in good condition. These tests may consist of timing tests on closing, opening, and close-open no-load operations and low-frequency voltage withstand tests at 75% of the rated low-frequency withstand voltage.

1.4 Field Tests

Field tests are usually made on operating systems for the purpose of investigating the performance of circuit breakers under conditions which cannot be duplicated in the factory. They are usually supplementary to factory tests and therefore may not provide a complete investigation of the breakers' capabilities. Emphasis is usually placed upon performance under the particular conditions for which the tests are made rather than upon a broad investigation and the schedule and instrumentation adapted accordingly.

1.5 Conformance Tests

Conformance tests are those tests made specifically to demonstrate the conformance of a circuit breaker with these standards.

2. Purpose

The purposes of the test procedure are:

1) To establish that a circuit breaker of the design on test can perform satisfactorily, both electrically and mechanically, up to the ratings assigned to it
2) To establish that production breakers have been adequately tested during manufacture and after assembly and that the breakers have characteristics essentially the same as the breaker of identical design which was subjected to design tests

3. Conditions of Test

3.1 Usual Service Conditions

Breakers designed for usual service conditions shall be tested under the conditions prevailing at the test site, provided they are within the defined usual service conditions.

3.2 Unusual Service Conditions

Breakers designed for unusual service conditions should be tested under conditions conforming as nearly as possible to the conditions under which they are applied.

3.3 Breaker Condition

The breaker undergoing tests shall be new and in good condition.

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 Section 5. of ANSI/IEEE C37.04-1979, Rating Structure for AC High-Voltage Circuit Breakers.

4.1 Rated Maximum Voltage

The ability of the circuit breaker to operate successfully at rated maximum voltage is demonstrated by making short-circuit and other current switching rating tests in accordance with Tables 1, 2, 4, 5, and 6 at rated maximum voltage and with specified values of circuit transient recovery voltage.

4.2 Rated Voltage Range Factor

The ability of a circuit breaker to operate successfully at voltages within the operating range specified by the voltage range factor is demonstrated by making short-circuit rating tests in accordance with Tables 1 and 2 at both the upper and lower limits of this range.

4.3 Rated Frequency

The ability of a circuit breaker to operate successfully at rated frequency is demonstrated preferably by making all current tests at rated frequency.

To demonstrate the rated low-frequency withstand voltage and the required making and interrupting capabilities of a breaker, the tests shall be made at a frequency within ±20% of rated frequency. Tests demonstrating current-carrying ability which are not made at rated frequency may need correction factors because the heat released varies with the frequency of the current, the relation depending on dc resistance, skin effects, eddy currents, and hysteresis losses.

4.4 Rated Continuous Current-Carrying Tests

Rated continuous current-carrying tests demonstrate that the circuit breaker can carry its rated continuous current (see 5.4 of ANSI/IEEE C37.04-1979) at its rated frequency without exceeding any of the temperature limitations in 5.4.2 of ANSI/IEEE C37.04-1979.

4.4.1 Conditions of Test

(1) The ambient temperature shall be between 10°C and 40°C, inclusive, so that no correction factors need be applied.

(2) The circuit breaker shall be tested under the usual service conditions. Enclosed breakers shall be tested in their enclosures.

Other apparatus connected in series and closely associated with the circuit breaker, such as current transformers, primary disconnecting contacts, buses, and connections, shall be mounted in their regular position.

(3) Outdoor breakers, which are normally installed in such a manner that other connected apparatus has no appreciable effect on the breaker temperature, shall be tested with cables or buses of a size corresponding to the breaker current rating connected to the breaker terminals by means of typical terminal connectors of corresponding rating. Breakers normally equipped with current transformers shall be tested with transformers in place and connected to carry rated secondary current.

(4) Circuit breakers shall be in a new condition and properly adjusted.

4.4.2 How Tests Shall Be Made

Three-phase circuit breakers shall be tested three-phase except in the following cases.

(1) Where there is no possibility of magnetic or thermal influence between poles or modular units, single-phase tests may be made on a single-pole or modular unit.

(2) Where there is no possibility of magnetic influence, but there may be thermal influence from other phases of the breaker, tests may be made with single-phase current passed through the three poles in series.

4.4.3 Duration of Rated Continuous Current Tests

The rated continuous current test shall be continued for such period of time that the temperature rises of all parts of the circuit breaker are substantially constant as indicated by three successive readings at 30 min intervals.

4.4.4 How Temperatures are Measured

Temperatures shall be measured by the following methods (See IEEE Std 119-1974, IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus. Test Code for Temperature Measurement, Aug 1950):

1) Thermocouple
2) Thermometer (preferred method for ambient temperatures)
3) Resistance

The measuring device shall be located where measurement of the hottest spot can be made even though it may involve drilling holes that destroy some parts on a design test. This will require the use of thermocouples in locations inaccessible to thermometers in order to obtain the hottest spot measurement. It is recognized that thermocouples cannot be located in the actual contact point of line or point contacts without destroying the effectiveness of such line or point contacts.

Measurements shall be made at junction points of insulation and conducting parts to prevent exceeding temperature limits of the insulation. Thermocouples shall be located so as to obtain the hottest spot measurement. For conformance tests, if required, it is sufficient to measure accessible parts and compare the measurements with like points on the design tests. Holes which destroy the effectiveness of the test (such as in multiturn coils) shall not be drilled.

The bulbs of the thermometers used for taking apparatus temperatures shall be covered by felt pads cemented to the apparatus or by oil putty. Dimensions of felt pads for use with large apparatus shall be $1\,{}^{1}/_{2}$ in × 2 in × ${}^{1}/_{8}$ in (4 cm × 5 cm × 0.3 cm). The use of smaller pads is permissible on small apparatus.

4.4.5 How Ambient Temperature is Determined

The ambient temperature shall be taken as that of the surrounding air. The ambient shall be between 10°C and 40°C, inclusive, so that no correction factors need be applied. The ambient temperature shall be determined by taking the average of the readings of three thermometers placed in locations unaffected by drafts, horizontally 12 in (575 mm) from the projected periphery of the breaker or enclosure, and approximately on a vertical line as follows:

1) One approximately 12 in (575 mm) above the circuit breaker or enclosure (including bushings)
2) One approximately 12 in (575 mm) below the circuit breaker or enclosure. (In the case of floor-mounted breakers or enclosures, it shall be 12 in (575 mm) above the floor or mounting base.)
3) One approximately midway between the above two positions

In order to avoid errors due to the time lag between the temperature of large apparatus and the variations in the ambient temperature, all reasonable precautions must be taken to reduce these variations and the errors arising from them. Thus, the thermometer for determining the ambient temperature shall be immersed in a suitable liquid, such as oil, and in a suitable heavy metal cup when the ambient temperature is subject to such variations that error in taking the temperature rise might result.

A convenient form for such an oil cup consists of a metal cylinder with a hole drilled partly through it. This hole is filled with oil and the thermometer is placed in it with its bulb well immersed. The response of the thermometer to various rates of temperature change will depend largely upon the size, kind of material, and mass of the containing cup, and may be further regulated by adjusting the amount of oil in the cup. The larger the apparatus under test, the larger the metal cylinder employed as an oil cup in determining the cooling-air temperature should be. The smallest size oil cup employed in any case shall consist of a metal cylinder, 1 in (25 mm) in diameter and 2 in (50 mm) high.

4.5 Rated Dielectric Strength

The dielectric strength of a circuit breaker is demonstrated by subjecting it to high potentials, both normal frequency and impulse.

Withstand tests on circuit breakers shall be made at the factory under temperature and humidity conditions normally obtained in commercial testing. The circuit breaker shall be clean and in good condition and shall not have been put into commercial operation.

The values for correction factors for atmospheric pressure and atmospheric humidity for impulse and low-frequency wet tests are to be taken from the IEEE Std 4-1978, Standard Techniques for High-Voltage Testing, curves and formulas applicable to atmospheric bushings, except where otherwise noted.

The bushing and rod gap correction factors will not always be of optimum accuracy for a specific design of circuit breaker. In cases where more accurate correction factors can be established for a specific design or class of designs, they may be used.

Furthermore, when refinements in correction factors in IEEE Std 4-1978 are made from time to time, it shall not be necessary to repeat design tests on designs for which such tests have been completed. Correction factors shall not be used on low-frequency dry tests.

Two classes of insulation paths are to be considered:

1) *Atmospheric paths*: Paths entirely through atmospheric air, such as along the porcelain surface of an outdoor bushing.
2) *Nonatmospheric 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 a combination thereof.

4.5.1 Atmospheric Paths

On dry switching impulse tests, humidity and atmospheric pressure correction factors must be applied to modify the test voltage. On wet switching surge and on wet low-frequency tests, humidity factors are not applied, but atmospheric pressure factors must be applied. On impulse and chopped wave tests, humidity and atmospheric pressure correction factors may be applied if external flashovers due to unfavorable atmospheric conditions would otherwise cause failure of the test series. There is no separate atmospheric path requirement for the dry low-frequency test.

4.5.2 Nonatmospheric Paths

In order to meet the requirements for nonatmospheric paths, at least three dry withstand tests must be accumulated at each polarity at the rated and related impulse and chopped wave voltages (in addition to one dry low-frequency withstand test), all without benefit of reduction of voltages due to correction factors. The purpose is to apply full stresses to these nonatmospheric paths; therefore, tests in which flashover occurs through an atmospheric path may be ignored. It is permissible to raise the dielectric strength of the atmospheric paths by artificial means, such as an extra high-voltage shield or a corona ring.

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

The voltage for dielectric tests shall be measured in accordance with voltage measurements. See IEEE Std 4-1978.

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.

Tests as described in the following sections will be conducted on the complete circuit breaker, except that single-pole tests are sufficient when adjacent poles have substantially no influence or are simulated by ground shields.

4.5.3 Rated Low-Frequency Withstand Voltage

4.5.3.1 Dry

Tests are made to determine the ability of the circuit breaker to withstand the rated low-frequency withstand voltage. See 5.5.2 of ANSI/IEEE C37.04-1979. The frequency of the low-frequency test voltage shall be in accordance with 5.5.2.3 of ANSI/IEEE C37.04-1979. The wave shape should be as close to a sine wave as practical. The test shall be made with alternating voltage having a crest value equal to 1.414 times the rated low-frequency withstand voltage. In these tests, an alternating voltage shall be applied to the terminals of the circuit breaker for 60 s without damage or flashover in each of the following methods:

1) With circuit breaker contacts open, apply low-frequency high potential to each terminal of the circuit breaker individually, with all other terminals and frame of the circuit breaker grounded.
2) With breaker contacts closed, apply low-frequency high potential to each phase of the circuit breaker individually, with other phases and frame of the circuit breaker grounded.

4.5.3.2 Wet

The wet tests are made in accordance with the procedure described in ANSI/IEEE Std 21-1976, General Requirements and Test Procedures for Outdoor Apparatus Bushings, only on outdoor power circuit breakers or on external components thereof. Bushings, the voltage distribution of which is influenced negligibly by their surroundings and which have been tested separately as bushings in accordance with ANSI/IEEE Std 21-1976, need not be retested in the assembled circuit breaker.

4.5.4 Rated Full Wave Impulse Withstand Voltage

Tests under dry conditions are made on circuit breakers to determine their ability to withstand their rated full wave impulse withstand voltages. See 5.5.3 of ANSI/IEEE C37.04-1979. In these tests, both positive and negative impulse voltages having a crest value equal to the rated full wave impulse withstand voltage of the circuit breaker and a wave shape of 1.2×50 µs, shall be applied to the terminals of the circuit breaker without damage or flashover in each of the following methods (see ANSI/IEEE C37.04-1979).

1) With breaker contacts open:
    a) Apply positive impulse voltage three consecutive times without flashover to each terminal of the circuit breaker individually with all other terminals and frame grounded.
    b) Apply negative impulse voltage three consecutive times without flashover to each terminal of the circuit breaker individually with all other terminals and frame grounded.

2) With breaker contacts closed:
    a) Apply positive impulse voltage three consecutive times without flashover to each phase of the circuit breaker individually with the other phases and frame grounded.
    b) Apply negative impulse voltage three consecutive times without flashover to each phase of the circuit breaker individually with the other phases and frame grounded.

If, during the first group of three consecutive tests as applied to (1) and (2) above, flashover occurs on one test of a group, a second group of three tests shall be made. If the circuit breaker successfully withstands all three of the second group of tests, the flashover in the first group shall be considered a random flashover and the circuit breaker shall be considered as having successfully passed the test.

The wave form and application of the 1.2 × 50 µs full wave test voltage shall be as described in IEEE Std.4-1978 and shall have the following limits:

1) 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
2) A crest voltage equal to or exceeding the rated full wave impulse voltage
3) A time to the 50% value of the crest 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 crest value, the most rapid rise possible may be used.

In the previous edition of this standard the impulse voltage wave limit was 1.2 × 40 µs, as defined above. Circuit breakers designed and tested in accordance with the previous 1.2 × 40 µs impulse wave may be assigned a 1.2 × 50 µs rating on the basis of a prior design, tested with a 20% tail tolerance.

NOTE — Previous editions of this standard referred only to a 1.5 × 40 µs wave shape. However, a given wave shape may be specified as either a 1.5 wave (2 times the actual time between the $0.3E$ and $0.9E$ points) or as a 1.2 wave (1.67 times the actual time between the same points). The wave shape is the same, but the manner of specifying its front of wave rise time has been changed. Therefore, any wave which previously met the requirements for a 1.5 × 40 wave may also now be called a 1.2 × 40 wave.

4.5.5 Impulse Voltage Test for Interrupters and Resistors

An additional impulse test is made on outdoor circuit breakers having a rated maximum voltage of 121 kV and above, having isolating gaps in series with the interrupting gaps or additional gaps in the resistor or capacitor circuits.

All isolating gaps and gaps in resistor and capacitor circuits are closed. An impulse voltage having a value and shape specified in ANSI C37.06-1979 and in 5.5.4 of ANSI/IEEE C37.04-1979 shall be used. Positive and negative waves shall be applied three times to each terminal of a pole unit with the other terminal grounded. No damage of the solid interrupter insulation, associated resistors, or capacitors shall occur.

4.5.6 Rated Chopped Wave Impulse Withstand Voltage

Tests are made on outdoor circuit breakers having a rated maximum voltage of 15.5 kV and above to determine their ability to withstand their rated chopped wave impulse withstand voltage.

These voltages of magnitudes, given in ANSI C37.06-1979, shall be applied to the terminals of the circuit breaker, without damage or flashover, in the same manner as the full wave impulse withstand voltage in 4.5.4.

The wave form 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:

1) The virtual front time, based on the rated chopped wave test voltage, equal to or less than 1.2 µs
2) The crest voltage equal to or greater than the rated chopped wave test voltage

3) The time to the point of chop on the tail of the wave not less than the times specified in ANSI C37.06-1979

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 crest value, the most rapid rise possible may be used.

External flashover of the circuit breaker at the specified chop times or longer does not constitute failure to pass the test.

4.5.7 Rated Switching-Impulse Voltage Withstand Tests

Tests under both wet and dry conditions are made on circuit breakers to determine their ability to withstand their rated switching-impulse withstand voltages to ground and across the circuit breaker. The test method is identical to that of 4.5.4 for the open and closed circuit breaker, except that instead of an impulse wave, a switching-impulse wave of both polarities shall be used with a wave shape as defined in 4.5.7.1 and with a crest value equal to or greater than the rated switching-impulse withstand voltage.

When testing the open breaker on the 3-3 switching-impulse voltage series, any external flashover to ground at the energized terminal of the circuit breaker will be considered as a withstand on the open circuit breaker. One flashover across the 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 on the 3-3 switching-impulse voltage withstand series, 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.

4.5.7.1 Wave Shape for Switching-Impulse Voltage Tests

The definition of the unidirectional switching-impulse voltage wave shape is as follows: The time from the instant of actual voltage zero on the front of the wave to the actual voltage crest will be 250 µs ±50 µs; to the half voltage value on the tail of the wave will be 2500 µs ± 1500 µs. The actual voltage crest is defined by the tangent to the wave parallel to the time axis.

When flashovers occur on the front of the wave, the crest voltage value is defined as the crest of the voltage wave that would have been obtained if no flashover had occurred.

The above wave shape shall be obtained with the circuit breaker in the circuit.

4.5.7.2 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 those used in service, having not less than the exposure of metallic surface area used in service, and shall be grounded.

Conductors may be connected to both circuit breaker terminals and may be of a diameter not in excess of that normally used in service. They may be terminated in spheres or rings having diameters in feet not in excess of the circuit breaker rated maximum voltage, kV rms divided by 200. Unless specifically indicated otherwise, the connecting conductors above shall be mounted horizontally.

Porcelain surfaces shall be relatively clean of dirt, film, or grease.

No additional rings and shielding shall be employed which are not a permanent part of the circuit breaker in application. If gaps are to be permanently mounted in parallel with the vertical insulation structure, they shall be in place during all dielectric tests.

4.5.7.3 Atmospheric Correction Factors for Switching-Impulse Voltage Tests

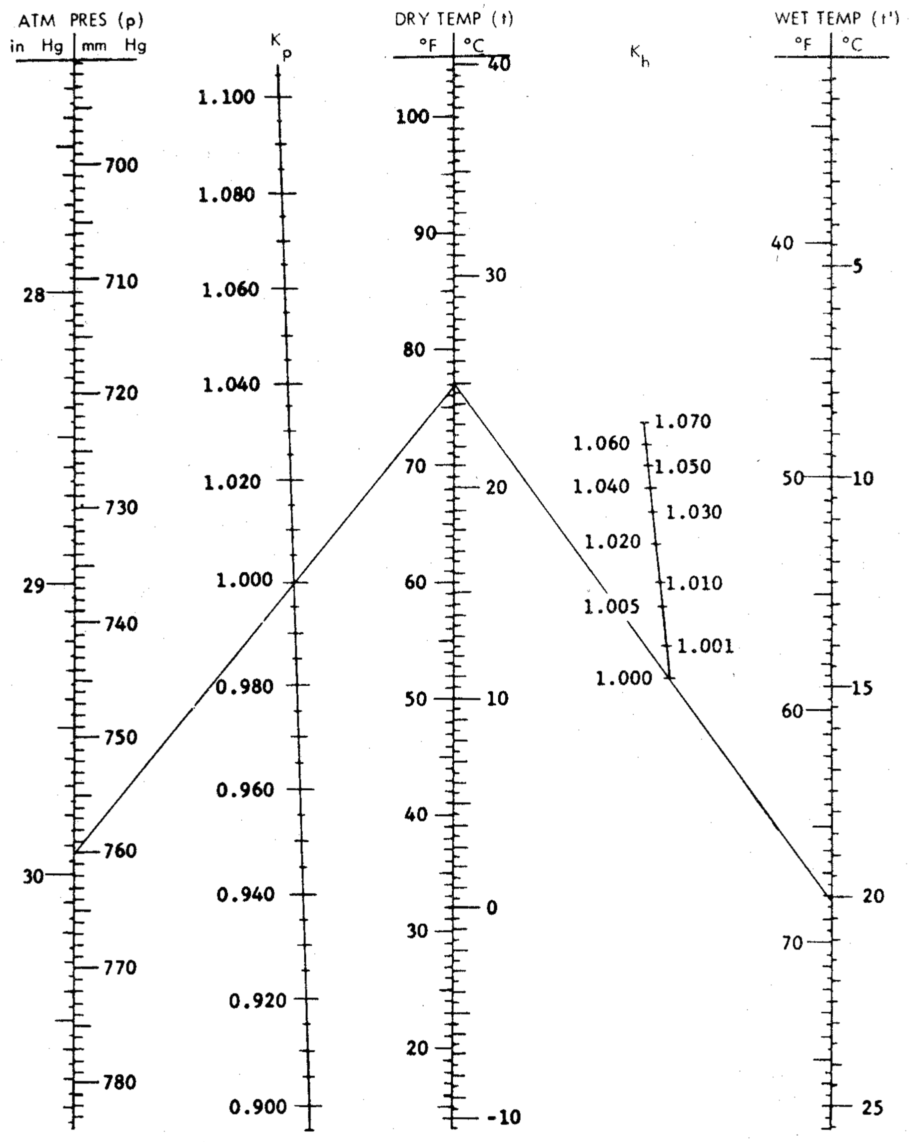
Correction factors for the atmospheric conditions surrounding the external insulation shall be made as follows:

1) *Dry Tests*. To obtain the test voltage V_{dt}, divide the rated withstand voltage V_w by K_p (Fig 1) for air density correction and K_h (Fig 2) for humidity correction.

$$V_{dt} = \frac{V_w}{K_h \cdot K_p}$$

2) *Wet Tests*. To obtain the test voltage V_{wt}, divide the rated withstand voltage V_w by K_p (Fig 1).

$$V_{wt} = \frac{V_w}{K_p}$$



$$V_{dt} = \frac{V_w}{K_h \cdot K_p}$$

$$V_{wt} = \frac{V_w}{K_p}$$

Fig 1
Air Density Correction Factor (K_p)

Fig 2
Humidity Correction Factor (K_h)

V_{dt} = dry test voltage
V_w = rated withstand voltage
K_h = humidity correction factor
K_p = air density correction factor
V_{wt} = wet test voltage
ρ_r = relative air density

Figures 1 and 2 are derived from the following data:

(1) Standard Conditions. Refer to 1.3.4.1 of IEEE Std 4-1978.

(2) *Relative Air Density*. Refer to 1.3.4.3 of IEEE Std 4-1978.

The correction K_p for air density may be read directly from Fig 1 using the air pressure (*p*) and ambient temperature (*t*) at test conditions.

Figure 1 is derived from the following equation:

$$K_p = \frac{1}{\rho r^{0.7}}$$

NOTE — The 0.7th power of the relative air density ρ_r is based on the data presented by T. A. Phillips, L. M. Robertson, A. F. Rohlfs, and R. L. Thompson in Influence of Air Density on Electrical Strength of Transmission Line Insulation, *IEEE Transactions on Power Apparatus and Systems*, Vol PAS-86, Aug 1967, p 958, for a 12.5 ft air gap.

(3) *Humidity*. Refer to 1.3.4.4 of IEEE Std 4-1978 . The correction K_h for humidity may be read from Fig 2 using the ambient dry bulb temperature (*t*) and wet bulb temperature (t') at test conditions. Figure 2 is derived from the above reference and from Fig 1 of IEEE Std 271-1966, Switching Surge Testing of Extra-High-Voltage Switches.

4.6 Short-Circuit Rating

The short-circuit 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 when used on grounded and ungrounded systems. These tests are outlined in Tables 1 and 2 and described in the following sections.

Tests to demonstrate the required capabilities of the circuit breaker are made in accordance with the conditions specified in 4.6.4, under specified testing conditions in 4.6.5, and in 4.6.6.

4.6.1 Rated Short-Circuit Current

The rated short-circuit current is the highest value of the symmetrical component of the polyphase current which the circuit breaker may be required to interrupt at rated maximum voltage. The rated short circuit is demonstrated by the interruption of a symmetrical current of the rated value with a normal-frequency recovery voltage associated with the rated maximum voltage and with a circuit transient recovery voltage defined by the rated or related exponential-cosine envelope (121 kV and above) or by the rated or related one minus-cosine envelope (72.5 kV and below). This is Test Duty 4 in Tables 1 and 2.

4.6.2 Related Required Capability

For a circuit breaker to have a rated short-circuit current, it must also have the other capabilities listed in 5.10.2 of ANSI/IEEE C37.04-1979.

4.6.2.1 Symmetrical Interrupting Capability for Polyphase and Line-to-Line Faults

The required symmetrical interrupting capability varies inversely with the normal-frequency recovery voltage from a minimum value at rated maximum voltage to *K* times this value at rated maximum voltage/*K*. The lower value is the rated short-circuit current demonstrated by Test Duty 4 in Tables 1 and 2. The higher value is demonstrated by Test Duty 5 in Tables 1 and 2.

4.6.2.2 Asymmetrical Interrupting Capability for Polyphase and Line-to-Line Faults

The required asymmetrical interrupting capability varies inversely with the normal-frequency recovery voltage from a minimum value at rated maximum voltage to K times this value at rated maximum voltage/K. The value at rated maximum voltage is demonstrated by Test Duty 6 in Tables 1 and 2. The value at rated maximum voltage/K is demonstrated by Test Duty 7 in Tables 1 and 2.

4.6.2.3 Interrupting Capability for Single Phase-to-Ground Faults

The required interrupting capabilities for single phase-to-ground faults, both symmetrical and asymmetrical, usually vary with normal-frequency recovery voltage (see 5.10.2.3 of ANSI/IEEE C37.04-1979). They are demonstrated for service at rated maximum voltage by Test Duties 13 and 14 in Table 1 and for the maximum currents by Test Duties 5 and 7 in Tables 1 and 2. Single-pole tests at 0.58 times rated maximum voltage/K are not specified because in all (or practically all) cases, Test Duties 4 and 6 in Table 2, at 0.87 times rated maximum voltage and slightly lower currents, will be more severe.

4.6.2.4 Closing, Latching, Carrying, and Interrupting Capability

The required capability to close against a fault current, to latch or the equivalent, to carry the current as long as is necessary, and then to interrupt the current, specified in 5.10.2.4 of ANSI/IEEE C37.04-1979 is demonstrated by Test Duty 11 in Tables 1 and 2.

4.6.2.5 Short-Time Current-Carrying Capability

The required short-time current carrying capability of a circuit breaker is demonstrated by Test Duty 12 in Tables 1 and 2.

4.6.2.6 Reclosing Capability

Reclosing duty cycles in 5.10.2.6 of ANSI/IEEE C37.04-1979 and Fig 11 of ANSI C37.06-1979 are based on reclosing operations with intentional time delays varying from 0 to 15 s. The capability to make a reclosure with zero intentional time delay is demonstrated by Test Duties 9 and 10 of Tables 1 and 2 and with 15 s time delay by Test Duties 6-1 and 7-1 of Tables 1 and 2.

4.6.3 Interrupting Performance

When tested up to its rated short-circuit current, the interrupting performance of the circuit breaker shall be in accordance with 5.10.3 of ANSI/IEEE C37.04-1979.

4.6.3.1 Service Capability and Breaker Condition

The capability of a circuit breaker to meet its service capabilities (see 5.10.3.3 of ANSI/IEEE C37.04-1979) is demonstrated by Test Duty 7A or 8 of Tables 1 and 2.

4.6.4 Condition of Breaker Tested

The breaker shall be new and in good condition. It may be reconditioned during the testing as permitted in accordance with 4.6.4.2.

4.6.4.1 Breaker To Be Used for Test

The breaker shall be representative of the type, style, or model as required for all design tests (see 1.1).

4.6.4.2 Reconditioning of Breaker During Testing

The expendable parts of a circuit breaker may be replaced, except as specified in Notes (7) and (13) of Tables 1 and 2.

4.6.4.3 Condition of Breaker After Test

Before the final operation of Test Duties 7 and 8, specified in Tables 1 and 2, the breaker shall be in the condition specified in 5.10.3.3.2 of ANSI/IEEE C37.04-1979. The final closing-opening operation is part of the demonstration of the specified condition.

4.6.5 Testing Conditions

4.6.5.1 Power Factor

For short-circuit switching tests, the power factor of the testing circuits shall not exceed 0.15 lagging.

4.6.5.2 Frequency of Test Circuit

Tests demonstrating short-circuit capabilities shall be made preferably with rated frequency. The results of tests made with other frequencies shall be modified if necessary in accordance with 4.3.

4.6.5.3 Recovery Voltage

Both circuit transient recovery voltage and normal-frequency recovery voltage must be considered when demonstrating the rating of a circuit breaker. The determining factors are the shape of the circuit transient recovery voltage as a function of time and the magnitude and duration of the normal-frequency recovery voltage.

(1) *Normal-Frequency Recovery Voltage*. Over the testing range at which it can be obtained, the normal-frequency recovery voltage shall preferably be equal to the specified recovery voltage subject to a tolerance of – 5%. Higher voltages may be used at the manufacturer’s discretion. Indirect tests may be used to establish the interrupting capabilities of the circuit breaker. (See 4.6.6.)

During the three-phase tests demonstrating the standard duty cycle, the normal-frequency recovery voltage should be maintained on the circuit breaker for at least 6 cycles.[2] During the one-phase tests demonstrating the standard duty cycle, the specified values should be maintained for 1 cycle[2] and thereafter may be reduced as indicated in 4.6.6.2.

On all other tests, the normal-frequency recovery voltage may be removed after 1 cycle.

(2) *Transient Recovery Voltage*. The circuit transient recovery voltage (unmodified by the circuit breaker) should be such as to give the exponential-cosine or one minus-cosine envelope as applicable. The rated envelopes are required for rated symmetrical currents. For currents other than rated, the envelope shall be adjusted to prove the capabilities as stated in 5.11.4.1 of ANSI/IEEE C37.04-1979.

Asymmetrical currents should be demonstrated using test circuits capable of producing the rated envelopes unmodified by the circuit breaker when a symmetrical current is interrupted.

The actual test transient recovery voltage may differ from the circuit transient recovery voltage because of effects of the circuit breaker. This is permissible if the circuit breaker would affect the system voltages in the same manner.

In place of the above, the circuit breaker shall be considered to have passed the test if actual measured values meet the rated or related requirements.

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[2] On a 60 Hz basis.

Table 1 —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 (15)†	Phases	Voltages, Initial and Recovery, Normal-Frequency phase-to-phase V, rms (1) (2) (14)	Making Current at First Major at Peak (1) (3)		Current Interrupted at Contact Separation		Tripping Delay (Approx-imate, 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* (3)	50 to 100 (3)	$^{1}/_{2}$	Rated
2	One O and one CO	3	*V*	—	—	0.2 *I* to 0.3 *I* (10)	Less than 20 (10)	—	Rated
3	One O and one CO	3	*V*	—	—	0.4 *I* to 0.6 *I* (3)	50 to 100 (3)	$^{1}/_{2}$	Rated
4(5)(18)	O-15 s (1)-O, O-15 s(1)-CO, or CO-15 s (1)-CO	3	*V*	—	—	*I* (1) (9)	Less than 20	(4)	Rated (17)
5(5)(18)	O-15 s (1)-O, O-15 s (1)-CO, or CO-15 s (1)-CO	3	*V/K*	—	—	*KI*(1)(9)	Less than 20	(4)	Rated (17)
6-1 (7)	CO-15 s (1)-CO	3	*V*	1.6 *KI*	2.7 *KI*	*SI*(1)(3)	50 to 100 (3)	$^{1}/_{2}$	Rated (16)
6-2 (7)	C	3	*V*	1.6 *KI*	2.7 *KI*	—	—	—	Rated (16)
6-3 (7)	O-15 s (1)-O	3	*V*	—	—	*SI* (1)(3)	50 to 100 (3)	$^{1}/_{2}$(4)	Rated
7A-1 (7)	For circuit breakers 121 kV and above: CO-15 s-CO-15 min-CO-15 s-CO-1 h-CO	3	*V/K*	1.6 *KI*	2.7 *KI*	*KSI* (1)(3)	50 to 100 (3)	$^{1}/_{2}$	Rated (6) (16)
7A-2 (7)	C-15 s (1)-C-15 min-C-15 s (1)-C-1 h-C	3	*V/K*	1.6 *KI*	2.7 *KI*	—	—	—	Rated (16)
7A-3 (7)	O-15 s (1)-O-15 min-O-15 s (1)-O-1 h-O	3	*V/K*	—	—	*KSI*(1)(3)	50 to 100 (3)	$^{1}/_{2}$(4)	Rated (6)
7B-1 (7)	For all other breakers: CO-15 s-CO-1 h-CO	3	*V/K*	1.6 *KI*	2.7 *KI*	*KSI* (1)(3)	50 to 100 (3)	$^{1}/_{2}$	Rated (6) (16)

7B-2 (7)	C-15 s (1)-C-1 h-C	3	*V/K*	1.6 *KI*	2.7 *KI*	—	—	—	Rated (16)
7B-3 (7)	O-15 s (1)-O-1 h-O	3	*V/K*	—	—	*KSI* (1)(3)	50 to 100 (3)	$^{1}/_{2}$(4)	Rated (6)
8 (13)	Several O and CO operations-1 h-CO	3	*V/K*	—	—	(13)	Random	$^{1}/_{2}$	Rated (6)
9 (11)(12)	O-0 s-CO or CO-0 s-CO	3	*V*	—	—	*RSI* (1)(3)	50 to 100 (3)	$^{1}/_{2}$	Rated
10 (11)	O-0 s-CO or CO-0 s-CO	3	*V/K*	—	—	*RKSI* (1)(3)	50 to 100 (3)	$^{1}/_{2}$	Rated
11	C-*T* s-O	3	*V/K*	1.6 *KI*	2.7 *KI*	*KI*	0	*T*	Rated (16)
12	In closed position (8)	1	—	—	—	—	—	—	—
13	One O and one CO or two O	1	0.58 *V*	—	—	Smaller of 1.15 *I* or *KI*	Less than 20	(4)	Rated
14	One O and one CO or two O	1	0.58 *V*	—	—	Smaller of 1.15 *SI* or *KSI* (1)	50 to 100 (3)	$^{1}/_{2}$ (4)	Rated
15 (21)	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* (19)	Less than 20	$^{1}/_{2}$(4)	Rated (17)
16 (12) (21)	O-15 s-O or O-15 s-CO or CO-15 s-CO	1	0.58 *V/K*	—	—	0.7 *KI* to 0.8 *KI* (19)	Less than 20	$^{1}/_{2}$ (4)	Rated (17)

*See 4.5.

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

NOTES:

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.

1 — 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.

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

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

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

5 — 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.)

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

7 — 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.

8 — 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.

9 — 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.

NOTES:

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

11—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.

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

13—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.

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

15—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.

16—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.

17—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.

18—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

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

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

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

Table 2 —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 (15)**†	**Phases**	**Voltages, Initial and Recovery, Normal-Frequency Pole-Unit V, rms (1) (2) (14) (19)**	**Making Current at First Major Peak (1) (3)**		**Current Interrupted at Contact Separation**		**Tripping Delay (Approximate, 60 Hz Base) Cycles**	**Control Voltage and Operating Pressure Before First Operation**
				rms	**Peak**	**Magnitude, A, rms**	**% Asymmetry**		
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	One O and one CO	1	0.87 *V*	—	—	0.07 *II* to 0.13 *I* (3)	50 to 100 (3)	$^{1}/_{2}$	(10)
2	One O and one CO	1	0.87 *V*	—	—	0.2 *I* to 0.3 *I* (3)	Less than 20 (3)	—	(10)
3	One O and one CO	1	0.87 *V*	—	—	0.4 *I* to 0.6 *I* (3)	50 to 100 (3)	$^{1}/_{2}$	(10)
4 (5) (18)	O-15 s (1)-O, O-15, s (1)-CO, or CO-15 s (1)-CO	1	0.87 *V*	—	—	*I* (9)	Less than 20	(4)	(10) (17)
5 (5) (18)	O-1 5 s (1)-O, O-1 5, s (1)-CO, or CO-1 5 s (i)-CO	1	0.87 *V/K*	—	—	*K* (9)	Less than 20	(4)	(10) (17)
6-1 (7)	CO-15 s (1)-CO	1	0.87 *V*	1.6 *KI*	2.7 *KI*	*SI* (1) (3)	50 to 100 (3)	$^{1}/_{2}$	(10) (16)
6-2 (7)	C	1	0.58 *V*	1.5 *KI*	2.7 *KI*	—	—	—	(10) (16)
6-3 (7)	O-15 s (1)-O	1	0.87 *V*	—	—	*SI* (1) (3)	50 to 100 (3)	$^{1}/_{2}$ (4)	(10)
	For circuit breakers 121 kV and above:								
7A-1 (7)	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* (1)(3)	50 to 100 (3)	$^{1}/_{2}$(4)	(6) (10) (16)
7A-2 (7)	C-15 s (1)-C-15 min-C-15 s (1)-C-1 h-C	1	0.58 *V/K*	1.6 *KI*	2.7 *KI*	—	—	—	(10) (16)
7A-3 (7)	O-15 s (1)-O-15 min-O-15 s (1)-O-1 h-O	1	0.87 *V/K*	—	—	*KSI* (1) (3)	50 to 100 (3)	$^{1}/_{2}$ (4)	(6) (10)
	For all other breakers:								

7B-1 (7)	CO-15 S-CO-1 h-CO	1	0.87 *V/K*	1.6 *KI*	2.7 *KI*	*KSI* (1) (3)	50 to 100 (3)	$^{1}/_{2}$ (4)	(6) (10) (16)
7B-2 (7)	C-15 s (1)-C-1 h-C	1	0.58 >*V/K*	1.6 *KI*	2.7 *KI*	—	—	—	(10) (16)
7B-3 (7)	O-1 5 s (1)-O-1 h-O	1	0.87 *V/K*	—	—	*KSI* (1) (3)	50 to 100 (3)	$^{1}/_{2}$ (4)	(6)(10)
8 (13)	Several O and CO operations-1 h-CO	1	0.87 *V/K*	—	—	(13)	Random	$^{1}/_{2}$	(10)
9 (11) (12)	O-0 s-CO or CO-0 s-CO	1	0.87 *V*	—	—	*RSI* (1) (3)	50 to 100 (3)	$^{1}/_{2}$	(10)
10 (11)	O-0 s-CO or CO-0 s-CO	1	0.87 *V/K*	—	—	R*KSI* (1) (3)	50 to 100 (3)	$^{1}/_{2}$	(10)
11	C-*T* s-O	1	0.87 *V/K*	1.6 *KI*	2.7 *KI*	*KI*	0	*T*	(10) (16)
12	In closed position (8)	1	—	—	—	—	—	—	—
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	$^{1}/_{2}$ (4)	Rated (17)
16 (12) (22)	O-15 s-O or O-15 s-CO or CO-15 s-CO CO-15 s-CO	1	0.58 *V/K*	—	—	0.7 *KI* to 0.8 *KI* (20)	Less than 20	$^{1}/_{2}$ (4)	Rated (17)

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

NOTES:

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.

1— 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.

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

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

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

5— 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.)

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

7—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.

8—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.

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

10—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.)

11—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.

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

NOTES:

13—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.

14— 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.

15— 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.

16—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.

17— 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.

18—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.

19—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.

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.

4.6.5.4 Short-Line Fault Test Conditions

The short-line fault is characterized by currents approaching terminal fault values and a saw-tooth line side component of recovery voltage of high rate-of-rise. Maximum amplitude of this component is obtained for a particular test current when the bus capability is rated short-circuit current (system voltage equals V) or maximum short-circuit current (system voltage equals V/K), where V is rated maximum system voltage and K is voltage range factor. (See Tables 1, 2, 3, 4, and 5 of ANSI C37.06-1979.)

These tests are made on a single-phase basis. The bus (source) reactance limits the short-circuit current of a fault at the circuit breaker terminals to rated short circuit with a test voltage of $0.58V$, or maximum short-circuit current with a test voltage of $0.58\ V/K$. The bus-side component of transient recovery voltage is a single-phase equivalent transient recovery voltage envelope obtained by dividing the amplitude of the rated transient recovery voltage envelope by 1.5 for a test voltage of $0.58V$, and by $1.5K$ for a test voltage of $0.58V/K$. These amplitudes are obtained for a 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 bus-side component of transient recovery voltage as calculated above.

The sawtooth line-side component of recovery voltage can be described in terms of line inductance, L_L; frequency, f_L; and 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* or *MKI* be the desired test current, where *M* represents the ratio of test current to *I* or *KI*. Then the line inductance L_L is:

$$L_L = \frac{0.58V^{(MI)}}{M\omega I}[1-M] \text{ Henrys}$$

$$L_L = \frac{0.58V^{(MKI)}[1-M]}{M\omega K^2 I} \text{ Henrys}$$

The transient recovery voltage 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:

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

$$R_L = \sqrt{2}\omega MKIZ^{(MKI)} \times 10^{-6} \text{ kV}/\mu\text{s}$$

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

$$e = d(1-M)\sqrt{2}^{(MI)}(0.58V)\text{kV}$$

$$e = d(1-M)\sqrt{2}^{(MKI)}(0.58V/K)\text{ kV}$$

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

$$T_L = \frac{e}{R_L}\mu\text{s}$$

and the frequency is:

$$f_L = \frac{10^6}{2\left(\frac{e}{R_L}\right)}\text{Hz or}$$

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

$$f_L = \frac{0.866^{(MKI)}\omega MK^2IZ}{d(1-M)V} \text{ Hz}$$

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.

For single conductors (lines 242 kV and below) use a surge impedance Z of 450 Ω and an amplitude constant d of 1.8.

For bundled conductors (lines 362 kV and above) use a surge impedance Z of 360 Ω and an amplitude constant d of 1.6.

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

4.6.5.5 Control Voltage

The control voltage to be maintained in the closing and tripping circuits at the circuit breaker operating mechanism shall be as specified in Tables 1 and 2.

4.6.5.6 Operating Pressure

On breakers operated hydraulically or pneumatically, the operating pressure shall be as specified in Tables 1 and 2.

4.6.5.7 Contact Speeds During Single-Pole Tests and Unit Tests

During single-pole tests (see 4.6.6.2) and unit tests (see 4.6.6.3) the closing speed and the opening speed 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 closing and opening speeds obtained on the tests shall be approximately those obtained with the corresponding fault on a three-pole breaker.

If the short-circuit currents cause appreciable acceleration 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.

4.6.5.8 Grounding of the Breaker and Test Circuit

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

If three-phase tests are made, either the short circuit or the neutral of the supply shall be grounded, but not both.

If single-phase tests are made, a ground shall be placed on the test circuit. With multibreak breakers in which the voltage does not substantially divide equally among all breaks, this ground shall be placed at one terminal of the breaker, except as provided in 4.6.6.2.

4.6.5.9 Reversal of Test Connections

To make sure that the insulation to ground and across the pole unit is stressed in the most severe manner, circuit breakers with unsymmetrical configuration shall be tested with the short circuit applied in turn to each side of the circuit breaker. This requirement is covered by Note (5) of Tables 1 and 2.

4.6.5.10 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 less than 20% is considered to have negligible influence on the performance because it increases the total current less than 4% and the instantaneous value of the normal-frequency recovery voltage at the instant of arc extinction at the end of a large half cycle is within 2% of the crest value and at the end of a small half cycle is within 6% on 0.15 power factor circuits.

If the three-phase circuits are established simultaneously, the initial asymmetry of the most asymmetrical current can vary from 100% to 87%. This asymmetry usually decreases with time and at the time of contact separation is less than the initial value. Consequently, an asymmetry at contact parting time of at least 50% is specified to give typical asymmetrical currents which can be produced at will on testing circuits during close-open operations. It is recognized, of course, that at contact parting asymmetries of 100% may occur in some instances. However, very high asymmetries produce effects which tend to offset each other. The effect of longer intervals between zeros may be offset by a lower rate of change of current immediately before the current zero and a lower instantaneous value of the normal-frequency recovery voltage at the time of interruption.

Because of the difficulty of controlling asymmetry on close-open operations, the 50% asymmetry specified need only be met on one operation of a test duty. Note (3) of Tables 1 and 2 recognizes this and does not imply permission to use increased impedance on some operations of the test duty to make it impossible to obtain these values.

4.6.5.11 Obtaining the Most Severe Switching Conditions

To demonstrate the required interrupting capabilities, it is important that the circuit breaker perform under the most severe switching conditions. A single test demonstrating a required capability may not impose these conditions. Because the arcs are extinguished at current zeros, the arcing time may vary over a relatively wide range for a given value of current interrupted. A current with a zero occurring at a favorable time with respect to contact parting and one with a zero a few degrees earlier may subject the breaker to much different stresses. The demonstration tests should show that the breaker is capable of interrupting with the current zeros occurring in any relation to the contact parting.

When three-phase symmetrical currents are being interrupted, the current zeros occur regularly at 60 degree intervals after loops of current having the same amplitude and rate of current change as they approach zero. If the contacts part simultaneously, contact parting need be varied only over 60 degrees to cover the range. Two steps, 30 degrees apart, are usually adequate. For example, if it is possible to obtain simultaneous contact separation accurately controlled with respect to the current wave, two tests, 30 degrees apart, would demonstrate 6 current zeros at 30 degree steps after contact parting.

Obtaining correspondingly adequate demonstrations when interrupting asymmetrical currents on three-phase circuits is more difficult. The initial amounts of asymmetry depend on the part of the wave at which the circuits are closed. However, if the three phases are closed simultaneously, the initial asymmetry is at least 87% in one phase. This is sufficiently high to make it unnecessary to control the point on the wave at which the circuit is closed.

If zero decrements in both ac and dc components of the current are assumed, these asymmetries are sustained. Consequently, the amplitudes of the current loops and the rates at which the currents approach zero repeat only at intervals of one complete cycle.

Only 50% asymmetry is required when demonstrating asymmetrical interrupting capability; with nonsimultaneous closing of the circuits and any degree of asymmetry, the amplitudes of the current loops and the rates at which the currents approach zero repeat only at intervals of about one complete cycle.

To demonstrate the asymmetrical interrupting ability on three-phase tests over the entire range of arcing times requires exploring 360 degrees of possible contact parting times in suitable steps. Single-phase tests have only two zeros per cycle. Therefore, symmetrical currents require exploring 180 degrees of possible contact parting time and asymmetrical currents require exploring 360 degrees of contact parting time. However, the important test of such an exploratory series is the one which imposes the severe stresses and it is the one to be demonstrated. Usually it has the longest arcing time. If a series of tests is made in which the contact parting is moved earlier in steps over a range of 360 degrees, a shortening of the arcing time usually will happen twice in each phase. If the current is asymmetrical, one of these abrupt changes in arcing time is likely to be greater than the others. In such a case, the test just before the greater change is likely to be the most severe. It may be demonstrated by two tests: in one, contact parting occurs at a time which causes long arcing in one phase; and in another, contact parting occurs about 30 degrees earlier and results in an arcing time in this phase about a half-cycle shorter instead of about 30 degrees longer.

The contact parting times producing the long and the short arcing times may be known from previous testing or they may be found as part of the test, probably by a greater number of steps. In some cases, the contact parting time cannot be controlled with sufficient accuracy with respect to the current wave. In any case, the test should be repeated until the oscillographic records show that the long and short arcing times have been demonstrated.

The demonstration of the required capabilities under the most severe switching conditions is made preferably with the asymmetry of the currents and the relative positions of the current zeros the same for each exploratory step. Consequently, the tests for which the most severe switching conditions are specified in Note (4) of Tables 1 and 2 are those in which the asymmetry is not necessarily determined by the breaker itself and in which the time element between operations is relatively unimportant and can be extended, if necessary, for the adjustment of the timing of synchronous tripping circuits. One of the open operations in each of the operating duties specified for Test Duties 4, 5, 6, and 7 in Tables 1 and 2 should be made with the long arcing time and one with the short arcing time.

4.6.6 Methods of Demonstrating the Short-Circuit Current Rating of a Circuit Breaker

The three-phase short circuit, with either source or fault ungrounded, is usually the most severe duty on a circuit breaker and tests to demonstrate the rating are based primarily on the three-phase conditions. The test duties which completely demonstrate the performance of a circuit breaker under short-circuit conditions are listed in Table 1. If a single pole is being tested, the test duties listed in Table 2 demonstrate the performance of the corresponding three-pole circuit breaker.

Because of limitations of facilities, both in the laboratory and in the field, there are ratings of circuit breakers for which interrupting tests will not be conducted up to full rating, including TRV requirements. When circuit breakers are not tested to rating, indirect tests such as described in 4.6.6.3, Method III, Unit Tests; 4.6.6.4, Method IV, Two-Part Tests; 4.6.6.5, Method V, Pretripped Tests; 4.6.6.6, Method VI, Synthetic Tests; those described in Test Duty 11, or still other methods may also be used by the manufacturer as guides in assigning a rating to a particular circuit breaker. These are guides and require exercise of judgment as to which tests to apply and as to the interpretation of the results. They are not at this time capable of expression in standards as to their exactness. Consequently, the pattern of indirect tests which is to be conducted in any particular case is not specified. In cases where indirect test methods have been used in design tests and the circuit breaker is also tested by the three-phase direct Method I, it must be capable of performing all of the operations of Table 1.

If a circuit breaker rating has not been established by three-phase tests and a single-phase Method II is used, a single pole of the circuit breaker must be capable of performing all of the operations of Table 2. Design tests may be conducted at stresses in excess of rating. In conformance tests, field tests, or in service, the circuit breaker is not required to have the capability of passing tests or performing under stresses that exceed the applicable ratings or related required capabilities. (See ANSI/IEEE C37.04-1979 and ANSI C37.06-1979.)

In both tables, Test Duties 1, 2, and 3 demonstrate the performance of the circuit breaker switching symmetrical and asymmetrical short-circuit currents less than the maximum required. These tests may also be used as part of Test Duty 8. (See Note (13) of Tables 1 or 2.) The circuit transient recovery voltage used in the Test Duties 1, 2, and 3 should be the related capability envelope (see 5.11 of ANSI/IEEE C37.04-1979 for the appropriate test circuit breaker rating and table.

Test Duties 4 and 5 demonstrate the ability of the circuit breaker to interrupt currents equal to the required symmetrical interrupting capabilities at rated maximum voltage and at rated maximum voltage/K and may be used to demonstrate the standard duty cycle. It is permissible to make these tests with an O (open) 15 s O-duty cycle so that synchronous closing switches can be used to give symmetrical currents with most severe timing (see 4.6.5.10) and high recovery voltages.

Test Duty 6 demonstrates the performance of the circuit breaker at rated maximum voltage, closing a making current equal to the required asymmetrical interrupting capability at this voltage. Because of the inability of testing circuits to produce all the specified currents and voltages at the specified times, particularly with large values of K, it may not be possible to make Test Duty 6-1 as specified. In this case, the closing and opening capabilities are demonstrated separately by alternate Test Duties 6-2 and 6-3.

To obtain an asymmetry of 50% or more without exceeding by a large amount the required asymmetrical interrupting capability, requires, in many cases, that the ac component be less than the rated short circuit current.

Test Duty 7 demonstrates the performance of the circuit breaker at rated maximum voltage/K, and service capability (see 4.6.3.1), which is the ability of the circuit breaker to meet the total number of operations required and still be in a specified condition. The test duty required varies (7A or 7B) with the rating as indicated by Tables 1 and 2. In each case, test numbers followed by -2 or -3 constitute an alternate to the test number followed by -1. No maintenance is permitted between the operations of Test Duty 7-1 or during the performance of Test Duty 7-2 and 7-3. This test duty may be used to demonstrate the standard operating duty by holding the 15 s interval between CO (Close-Open) operations. However, if the standard operating duty is demonstrated by another test duty, the 15 s interval need not be held and becomes only a lower limit as in other test duties.

Test Duty 8 demonstrates the service capability of circuit breakers which do not have to perform Test Duty 7A. It shows the effect of several interruptions below the rated short-circuit current as specified in 5.10.3.3 of ANSI/IEEE C37.04-1979.

Test Duties 9 and 10 demonstrate high speed reclosing when the circuit breaker may be used for that service. When K is less than 1.2, the test at the higher current is adequate demonstration and Test Duty 9 is omitted. The alternate operating duty CO-0 s-CO is permitted so that tests may be made which satisfy the requirements for demonstrating a standard duty cycle.

Test Duty 11 demonstrates the ability of the circuit breaker to close against a short circuit, to remain closed until tripped, and to interrupt when tripped. Because of difficulties in sustaining the currents, either the current at contact separation may be below KI or the current may be supplied for the greater part of the carrying time from a low-voltage circuit. This circuit will then be switched off by another circuit breaker and a circuit capable of giving the specified recovery voltage connected before the test circuit breaker is opened. The time T is controlled in accordance with the provisions of 5.10.2.4 of ANSI/IEEE C37.04-1979 so as to obtain the same value of i^2t and, consequently, approximately the same heating effect, regardless of the current decrement.

Test Duty 12 demonstrates thermal capacity of the main current-carrying path through the circuit breaker. (See 7.1.6.)

Test Duties 13 and 14 are made on a circuit breaker to supplement three-phase tests and to demonstrate the ability of the circuit breaker to interrupt single phase-to-ground faults as specified in 5.10.2.3 of ANSI/IEEE C37.04-1979 , Testing by Method II. Single-Pole Tests, 4.6.6.2, do not require these tests as the Test Duties 5 and 7 in Table 2 are more severe. (See 4.6.2.3.)

Test Duties 15 and 16 demonstrate the performance of the circuit breaker during the interruption of short-line faults. When K is less than 1.2, Test Duty 16 is omitted. These tests are made on a single phase-to-ground basis with a test circuit as specified in .

Each circuit breaker will have a critical short-line fault location which produces maximum stress. The conditions specified in Test Duties 15 and 16 may not correspond to the critical values for a particular circuit breaker and are intended as a standard demonstration test. This demonstration test is not required for circuit breakers rated 72.5 kV and below.

The method or methods of testing used with a particular circuit breaker depend on circumstances such as the rating to be demonstrated, the reactive power available for testing, the circuit breaker construction, and the arcing time. The methods may be used separately or may be combined. Frequently, one method is used to supplement, enhance, or verify the results obtained by another method.

4.6.6.1 Method I, Three-Pole Tests

Method I consists of switching, by means of a three-pole breaker, a three-phase source of reactive power having a recovery voltage substantially equal to the service voltage. The currents switched are increased up to the required capabilities of the circuit breaker.

Testing a three-pole breaker to rating in accordance with all the requirements of Method I gives a complete demonstration of the three-phase performance. This method also includes single-phase interrupting tests at normal phase-to-ground voltage because interrupting capability can be influenced by interaction between phases.

To verify the rated short-circuit current of the circuit breaker by Method I, the program shown in Table 1 shall be used as applicable. It contains operating duties demonstrating all the required capabilities associated with the assigned rated short-circuit current.

4.6.6.2 Method II, Single-Pole Tests

Method II tests a single pole of a three-pole circuit breaker with single-phase power, applying to the pole the same currents and substantially the same pole-unit recovery voltages which would be impressed upon the most highly stressed pole during interruption of three-phase power by the complete three-pole breaker under corresponding conditions. The pole tested may be a part of a three-pole breaker or a single pole. To simulate three-phase grounded faults on an ungrounded system and three-phase ungrounded faults on a grounded or ungrounded system, the normal-frequency pole-unit recovery voltage shall be 87% of the corresponding three-phase voltage, usually with one terminal of the pole grounded. However, the voltage distribution among the interrupters on a multi-interrupter pole-unit is not necessarily the same for these three service conditions. For a circuit breaker rated for application only on a grounded or effectively grounded[3] system, the voltage distribution may be approximated for ungrounded faults by applying 87% across the pole with 58% on one terminal and — 29% on the other, and for grounded faults by applying 75% across the pole with one terminal grounded.

As explained in 4.9, the maximum arcing time on single-pole tests may be about 0.1 cycle longer than on the corresponding three-phase test with symmetrical currents and about 0.2 cycle longer with asymmetrical currents.

To simulate the reduction in recovery voltage on the first pole to interrupt, after the other poles have interrupted, the normal-frequency pole-unit recovery voltage on a single-pole test may be reduced to 58% of the simulated phase-to-phase voltage one cycle or more after the interruption of the current. This permits measurement of the recovery voltage during the first cycle and reduces stress on resistors which may still be in the power circuit.

Closing tests may be made at 58% of the simulated three-phase voltage because this is the voltage to which the first pole to strike is subjected.

To verify the rated short-circuit current of the circuit breaker by Method II, the program shown in Table 2 shall be used, as applicable. It contains operating duties demonstrating all the required capabilities associated with the assigned rated short-circuit current.

If there is a possibility that hot gases produced by switching may cause a flashover between poles of a completely assembled 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.

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[3] See IEEE Std 32-1972 , Terminology and Test Procedure for Neutral Grounding Devices.

4.6.6.3 Method III, Unit Tests

When the full series of short-circuit tests are not made by Method I or Method II (Tables 1 and 2) and when that part of each pole which accomplishes the interruption incorporates several relatively independent interrupting units connected in series, this method may be used to indicate the interrupting performance of the circuit breaker.

Similarly, if that part of each pole which closes the circuit incorporates several relatively independent making units in series, this method may be used to indicate the making capacity of the circuit breaker.

The value of unit tests depends on how closely the conditions imposed on the unit approximate the most severe conditions which would be imposed on the unit as a part of a three-pole breaker subjected to the simulated voltage, current, and operating duty.

4.6.6.3.1 Conditions Which Make Unit Testing Possible

(1) *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 breaker with due consideration for the effects of circuit grounding and adjacent objects, pollution of insulation, and of any distortion of voltage distribution by current magnitude, recovery transient frequency, or postarc 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 which 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.

(2) *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 4 ms and separate on opening within the same interval. 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 4 ms.

(3) *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 (2), above, 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.

(4) *Exhaust Conditions.* Ionized gases or vapors which 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 breaker as a whole by flashover, either partially or totally, through exhaust gases.

4.6.6.3.2 Determination of Voltage Distribution

The various distributions of voltage among the breaks of a multibreak circuit breaker should be determined for the types of tests to be made, the units to be working, which terminal, if any, is at ground potential, and the voltages to be applied. The types may include making and interrupting tests which are made on two or more interrupters as well as on complete poles. The range of frequencies or rates of rise and amplitudes of the transient recovery voltages, both in the test laboratory and in service, should be covered. These determinations may be made by suitable means 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 times the rated maximum voltage are compared with three single-pole tests in which the same current is interrupted by a test unit with normal-frequency and transient recovery voltages 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 normal-frequency and transient recovery voltages 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 which can be made to validate the measurements of voltage distribution. These validation tests may also qualify for demonstrating some of the test duties.

4.6.6.3.3 Factors Modifying Voltage Distribution

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

(2) *Effect of External Pollution.* External pollution can influence the voltage distribution among the units because the resistances resulting from the pollution of the various units may not be directly proportional to the corresponding impedances otherwise determining the voltage distribution.

NOTE — This influence depends upon the ratio of the surface conductance of a polluted unit or a group of units to the admittance of the voltage distributing device across the same unit or group of units; the larger this ratio, the larger the influence of pollution.

(3) *Effect of Postarc Conductivity.* Postarc conductivity may influence the voltage distribution among the units for some microseconds after current zero. The validating tests specified in 4.6.6.3.2 will detect any effect of postarc conductivity on the performance of the breaker at the current at which the comparison is made.

4.6.6.3.4 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.

1) *Interrupting Tests*
   a) *Choice of the 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 currents corresponding to the required symmetrical and asymmetrical interrupting capabilities of the circuit breaker with a recovery voltage specified in (b), below.
   b) *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.

2) *Making Tests*
   a) *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 (b), below.
   b) *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.

4.6.6.3.5 Test Duties

(1) To establish the rating of a circuit breaker by a combination of Method I or Method II and Method III, test duties may be carried out on a complete circuit breaker or one complete pole of a circuit breaker in accordance with Method I or Method II, respectively:

a) As many of the test duties specified in Table 1 or Table 2 as are applicable and can be made
b) Interrupting test duties at the maximum fraction of the required symmetrical and asymmetrical interrupting capabilities that can be made at the specified recovery voltage, if these are not included in (a), above
c) A making test duty at the maximum fraction of the required making capability that can be made at the specified initial voltage if this is not included in (a), above
d) The remaining test duty or duties specified in Table 1 or Table 2 with corresponding values of current but at the highest recovery voltage or initial voltage that can be obtained from the test plant; this may be elaborated by Method IV.

(2) On a group consisting of as many units in series as can be tested to rating by the available test facilities, unit tests may be made on the test duties not demonstrated in (1)(a), above, at the current values specified in Table 1 or Table 2 or Method I or II with the recovery and initial voltages specified for unit tests in 4.6.6.3.4.

When the full values of currents listed in Tables 1 and 2 are not obtained with the recovery and initial voltages specified for unit tests in 4.6.6.3.4, then Method IV may be utilized to elaborate the results on a single unit.

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 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 breaker and that are within the limitations of available test facilities.

4.6.6.4 Method IV, Two-Part Tests

Two-part tests can often be used to indicate the interrupting performance of a circuit breaker that has an interrupting time that varies little with the voltage of the circuit that is opening and shows no appreciable tendency to increase with current interrupted. They usually are made on the complete breaker pole, but may also be made on one or more breaker units or interrupters to obtain higher recovery voltages per break.

The voltage interrupting capability is demonstrated first by tests of the type specified in Methods I and 11, up to the maximum current available at the specified voltage. Then, at the highest available voltage that will supply the required current, the breaker is tested up to its required symmetrical interrupting capability and required asymmetrical interrupting capability for rated maximum voltage/K. Arcing time can be compared for equal currents interrupted at both voltages.

Since all circuit breakers increase their arcing time with voltage to some degree, a two-part test cannot be assumed to indicate the same interrupting time at the higher currents for both voltages. However, if the arcing time is almost the same at the currents demonstrated at the two voltages, and if the breaker shows no appreciable tendency to increase arc length with increase in current interrupted, the performance in the tests at the lower voltage may be taken as indicative of performance at rated maximum voltage.

If a circuit breaker is particularly sensitive to the initial rate-of-rise of transient recovery voltage, its performance on full voltage may be indicated by the lower voltage tests if it has the desired rate-of-rise of transient recovery voltage up to a desired fraction of the full voltage. Similarly, if a circuit breaker is particularly sensitive to the crest value of the transient recovery voltage, its performance on full voltage may be indicated by the lower voltage tests if the transient recovery voltage has the desired crest value.

Stresses associated with the release of arc energy are in some cases an important factor. It is possible to produce approximately the same arc energy as that developed in the interrupting device when interrupting rated power by increasing either the arcing time or the arc current by one of the following methods.

1) The arcing time at the lower voltage can be increased to that indicated for the higher voltage by testing with transient recovery voltages that are higher in either rate or crest magnitude, or both, than those on which the required interrupting capacity is based.
2) Lower frequencies (with less frequent zeros) may be used to increase the arcing time.
3) The current can be increased above the required interrupting capabilities to compensate for the shorter arcing time.
4) The voltage distribution among series breaks may be distorted by the addition of shunting impedance. Since all breaks carry the same current, one break has impressed on it almost the entire recovery voltage.
5) Longer arcing times at reduced voltages can be achieved by obtaining the most severe conditions (see 4.5.5.10) on highly asymmetrical currents.

The increases which should be obtained in time or current vary for different designs of interrupting devices and must be determined by laboratory tests and calculations.

4.6.6.5 Method V, Pretripped Tests

Pretripping 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 breaker before the inception of the short circuit, so that the contacts of the 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. The tests should be controlled to produce maximum arcing time and duty on the breaker (see 4.6.5.11).

Pretripped tests may be supplemented by Test Duty 11 of Table 1 or 2 to demonstrate the ability of the circuit breaker’s contacts to withstand the maximum short-circuit current for the full time which the circuit breaker is required to operate under normal conditions.

4.6.6.6 Method VI, 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 breaker about the time of interruption. Thus, the breaker has the duty of carrying the high short-circuit current of the low-voltage source up to the time of arc 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.

(1) The arc voltage should be relatively low and should cause little distortion of the current wave. It is larger with respect to the voltage of the current source than it is with respect to the voltage of the circuit being represented. Consequently, 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 distortion is appreciable, the interrupted current assigned to the test should be the product of the value measured in the usual way at contact parting and a factor which compensates for the distortion.

(2) The transient recovery voltage should appear across the terminals of a pole unit in the same manner as the transient recovery voltage in the tests made in accordance with Methods I and II.

a) It should appear at the instant of arc extinction.
b) The circuit transient recovery voltage should increase at least as rapidly and to at least as high a value as the circuit transient recovery voltage being simulated.
c) The parameters of the high-voltage sources should be such that the effect of postarc conductivity on the transient recovery voltage is no greater than that in the circuit being simulated; or failing this, the characteristics of the transient recovery voltage should be judged on the basis of the actual voltage appearing across the breaker contacts instead of the circuit transient recovery voltage.

(3) The arcing time should be controlled so that it covers the range of arcing time which will occur when the breaker actually interrupts the power being simulated.

4.6.7 Suggested Short-Circuit Performance Data Form

Test data is preferably presented in a form with an accompanying tabulation of pertinent data similar to that shown in Table 3.

4.7 Rated Transient Recovery Voltage

The ability to withstand rated transient recovery voltages, as specified in Tables 1, 2, 3, 4, and 5 of ANSI C37.06-1979 for rated symmetrical current, is demonstrated during the short-circuit switching tests (see Tables 1 and 2).

4.8 Rated Standard Operating Duty (Standard Duty Cycle)

The standard duty cycle is demonstrated by Test Duties 4, 5, 6-1, or 7-1, or as described in Note (7) of Table 1 or Table 2.

Because it may be difficult to obtain specified values of making current, asymmetry, and interrupting current in the same operation and because it is desirable to demonstrate open operations as well as close-open operations, it is suggested that the listed alternate operating duties be used in some test duties.

4.9 Rated Interrupting Time

The interrupting time of a circuit breaker is demonstrated for many different current and operating voltages by the test duties in Tables 1 and 2. Interrupting times of tests, when expressed in cycles, shall be in cycles of the rated frequency.

The interrupting times shall meet the requirements of the rating in 5.7 of ANSI/IEEE C37.04-1979. On single-phase tests, a small plus tolerance is permitted because single-phase testing at 87% of the three-phase phase-to-phase voltage is not exactly the equivalent of a three-phase test. Because the current zeros occur less frequently than in a three-phase test and the 87% of voltage is impressed only on the first pole to interrupt and only until the other two poles interrupt, the arcing time obtained on single-pole tests may exceed the arcing time obtained on the three-phase test. During a three-phase test with symmetrical currents, after the contact gap or time has been reached at which the arc will be extinguished, a current zero will occur in one of the phases within 60 degrees. The arc in this phase will be extinguished and the arcs in the other two phases will be extinguished 90 degrees later, a total of not over 150 degrees after the time at which arc extinction is certain to occur. During a single-phase test made in accordance with 4.6.5.11, the next current zero may occur 180 degrees later. Consequently, on a single-phase test with symmetrical currents, the maximum arcing time may be about 0.1 cycles longer than can be obtained on the three-phase test being simulated.

On three-phase asymmetrical tests, the six current zeros do not occur at 60 degree intervals; on single-phase tests, the six current zeros may be nearly one cycle apart. In demonstrating the most severe conditions by an asymmetrical single-phase test, the arcing time may be about 0.2 cycles longer than can be obtained on a three-phase test being simulated by a single-phase test.

Table 3 —Suggested Short-Circuit Performance Data Form

Test Duty Number	Operating Duty	Method of Demonstrating	Unit Tested	Phases	Normal-Frequency Voltage			Transient Recovery Voltage		Making Current rms or Peak A	Interrupted Current			Time			Notes	Test Identification
					Initial	Recovery												
					rms, kV	Pole-Unit rms, kV	Percent of Specified	Circuit or Modified Circuit TRV	Actual TRV		ac Component rms kA	Total rms kA	% Asymmetry	Arcing Cycles	Interrupting Cycles	Reclosing Cycles		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Column 1, Test Duty: This shall be in accordance with Table 1 or Table 2.

Column 2, Operating Duty: This shall be in accordance with Table 1 or Table 2 for the Test Duty, but if the Test Duty is not demonstrated by Method I or Method II, more than one operating duty may be performed and more than one line, or group of lines, may be required for recording the test results.

Column 3, Method of Demonstrating: This is intended to assist in the analysis of the test data by designating, by the numbers used in 4.6.6, the method or methods which were used in demonstrating the Test Duty.

Column 4, Unit Tested: This is a three-pole breaker, single-pole breaker, or a part of a breaker.

Column 5, Phases: This column identifies the phases for which data in other columns apply. A fourth line may be used for line-to-line voltages on three-phase tests.

Column 6, Initial Normal-Frequency Voltage: For three-phase tests, the line-to-line voltage should be given.

Column 7, Normal-Frequency Pole-Unit Recovery Voltage: See 7.2.

Column 8, Percent of Specified Recovery Voltage: For three-phase tests, this value is the ratio of · 100 · the average of the three-phase values in Column 7 to the corresponding value in Column 4 of Table 1. For single-phase tests, this value is 100 times the ratio of the value in Column 7 to the corresponding value in Column 3 of Table 2, modified in the case of unit tests to correspond to the maximum value to be applied across the test unit in accordance with 4.6.6.3.4(1)(b).

Column 9, Circuit Transient Recovery Voltage or Modified Circuit Transient Recovery Voltage: See 5.11 of C37.04-1979 and 4.6.5.3.2 of this standard. This is the measured value of TRV of the circuit without the breaker connected.

Column 10, Actual Transient Recovery Voltage: See 4.6.5.3.2. This is the measured value of TRV of the circuit following interruption by the test circuit breaker.
In both Column 9 and Column 10, list measured values of E_2 and T_2, and if the TRV has an exponential-cosine waveshape, list measured values of E_1.

Column 11, Making Current: This may be tabulated as either rms A or peak A as discussed in 7.1.5. State which units are used.

Column 12, ac Component of Interrupted Current: This is measured at the instant of the contact separation. (See 7.1.3.)

Column 13, Total rms Value of Interrupted Current: This is measured at the instant of contact separation. (See 7.1.4.)

Column 14, Assymmetry of Interrupted Current: This is measured in accordance with 7.1.4.

Column 15, Arcing Time: See ANSI/IEEE C37.100-1972.

Column 16, Interrupting Time: See ANSI/IEEE C37.100-1972.

Column 17, Reclosing Time: See ANSI/IEEE C37.100-1972.

Column 18, Notes: For example, this would include control voltage other than rated, operating pressure other than rated, observations of performance, etc.

Column 19, Test Identification.

Table 3 —Suggested Short-Circuit Performance Data Form

Date__________

	References
Apparatus Tested	
Manufacturer	
Interrupters	
Type of circuit breaker	
Number of poles	
Actuating device	
Opening time with rated short-circuit current	ANSI/IEEE C37.100-1972
Opening speed in region of arc	
Closing speed in region of arc	
Rating	
Rated maximum voltage	ANSI/IEEE C37.04-1979 , 5.1
Voltage range factor, *K*	ANSI/IEEE C37.04-1979 , 5.2
Rated frequency	ANSI/IEEE C37.04-1979 , 5.3
Rated short-circuit current	ANSI/IEEE C37.04-1979 , 5.10.1
Rated interrupting time	ANSI/IEEE C37.04-1979 , 5.7
Rated control voltage	ANSI/IEEE C37.04-1979 , 5.18
Rated fluid operating pressure	ANSI/IEEE C37.04-1979 , 5.19
Rated reclosing time	ANSI/IEEE C37.04-1979 , 5.9
Required Capabilities	
Voltage range	
Maximum voltage	
$1/K \cdot$ maximum voltage	
Making current	ANSI/IEEE C37.04-1979 , 5.10.2.4(1)
Required symmetrical interrupting capability	ANSI/IEEE C37.04-1979 , 5.10.2.1
At rated maximum voltage	
Three phase	
Single phase	
At $1/K \cdot$ maximum voltage	
Three phase	
Single phase	
Required asymmetrical interrupting capability	ANSI/IEEE C37.04-1979 , 5.10.2.2
At rated maximum voltage	
Three phase	

Single phase	
At $1/K \cdot$ maximum voltage	
Three phase	
Single phase	
Short-time current-carrying capability on C-Y	ANSI/IEEE C37.04-1979 , 5.10.2.5
Amperes	
Time	
Short-time current-carrying capability on C-Y sec-O test duty	ANSI/IEEE C37.04-1979 , 5.10.2.4
Amperes	
Time	
Test Circuit	
Frequency	
Power factors for range or for specific circuits	ANSI/IEEE C37.09-1979 , 4.6.5.1
Transient recovery voltages for the various circuits	ANSI/IEEE C37.100-1972

4.10 Rated Permissible Tripping Delay

The rated permissible tripping delay and the ability of the breaker to make an interruption immediately thereafter is demonstrated by Test Duty 11. The tripping delay for other test duties is preferably about 0.5 cycles to simulate tripping with high-speed relays. (See 4.6.6 for greater detail.)

4.11 Rated Reclosing Time

The rated reclosing time is demonstrated by Test Duties 9 and 10 of Tables 1 and 2. Reclosing times of tests, when expressed in cycles, shall be in cycles of the rated frequency.

4.12 Load Current Switching Tests

Load current switching tests are made to determine the ability of a breaker to switch all currents under other than short-circuit conditions.

Load current switching tests shall be made under the following conditions.

1) If three-phase tests are made, they shall be made with normal-frequency initial and recovery voltages at least equal to the rated maximum voltage of the breaker. If single-phase tests are made, they shall be made with normal-frequency initial and recovery voltages at least equal to 87% of the rated maximum voltage, except in the case of breakers intended for grounded neutral service only, or where otherwise specified.
2) 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 breakers intended for grounded neutral service only, or where otherwise specified.
3) The normally grounded parts of the circuit breaker shall be grounded.
4) 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 breaker and part with the source connected to the other.

5) Tests shall be made with the breaker contacts parting at various positions on the current wave to assure satisfactory operation under all switching conditions within its rating. Steps of 30 degrees will usually be small enough for testing. (See 4.6.5.11.)
6) The tests shall be made at rated frequency with a tolerance of ± 20%.

4.12.1 Required Load Current Switching Capability

Tests are made to determine the ability of the breaker to switch load currents such as may be encountered in normal service.

All types of breakers shall interrupt currents up to rated continuous current with a normal-frequency line-to-line recovery voltage not less than rated maximum voltage. Three opening tests with random tripping time with respect to the current wave shall be made with a power factor of 0.8 lagging or less. Tests are to be made at rated continuous current and at any current below rated continuous current at which the breaker exhibits a maximum arcing time if that current is not demonstrated by other required tests. A demonstration of the interruption of power-load currents with leading power factors or with lagging power factors greater than 0.8 is not required because these currents are considered easier to interrupt.

When resistance is added to control power factor, it shall be connected in series with the reactor.

Breakers designed to meet this standard are expected to be capable of performing the load-switching operations shown in Column 4 of Table 9 of ANSI C37.06-1979 in a circuit having a power factor of 0.8 lagging to 0.8 leading. They are also expected to be able to close circuits having making currents 600% of rated continuous current for the number of times shown in Column 6 of Table 9 of ANSI C37.06-1979.

Design tests to demonstrate these capabilities are not specified because if a circuit breaker has successfully met the service capability requirements for short-circuit conditions in accordance with 4.6.3.1 or 4.6.4.3, it will be assumed that it is capable of meeting these load switching capabilities.

4.13 Rated Capacitor Switching Current

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 4 and 5.

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.

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.

4.13.1 Demonstration of Conformance with Rated Transient Overvoltage Factor

4.13.1.1 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 crest 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 crest 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.

Table 4 —Three-Pole Capacitance Current Switching Tests

	Test Duty (See 4.13.11)	Test Voltage phase-to-phase (1)*	Percent of Rated Capacitance Switching Current	Number and Type of Operations (3, 8, 11)	Interrupter Pressure	Circuit Grounding
1A	Isolated capacitor bank or cable switching	$V\frac{2}{1+A}$	30	24 O	Rated	(6)
1B	Isolated capacitor bank or cable switching	$V\frac{2}{1+A}$	100 (4)	24 C-O	Rated (5)	(6)
2A	Back-to-back capacitor bank or cable switching	$V\frac{2}{1+A}$	30	24 O	Rated	(6)
2B	Back-to-back capacitor bank or cable switching	$V\frac{2}{1+A}$	100 (2, 4, 10)	24 C-O	Rated (5)	(6)
3A	Open wire line charging current switching	$V\frac{2}{1+A}$	30 (10)	24 O-C (9)	Rated	(7)
3B	Open wire line charging current switching	$V\frac{2}{1+A}$	100 (4, 10)	24 C-O	Rated (5)	(7)

NOTES:

V =Rated maximum voltage (see 5.1 of ANSI/IEEE C37.04-1979).

A =Voltage regulation factor (see 4.13.4.1).

1)Test circuit voltage with test breaker open but with bus capacitor bank connected for back-to-back tests in Test Duty 2 (see 4.13.4.1).

2)Rated transient inrush current on closing.

3)Type of operations:

At 30% of ratings: Open (see Note (9) for Test Duty 3A)

At 100% of ratings: Close-Open allow sufficient time before tripping for closing transient currents to decay

4)For breakers with nonsymmetrical insulation paths, reverse terminal connections for half of 100% operations (see 4.13.9).

5)Interrupter pressure shall be minimum for three operations (see 4.13.6).

6)Grounding: source neutral grounded; capacitor bank neutral grounded for breakers rated 121 kV and above (see 4.13.8).

7)Grounding: source neutral grounded; neutral of one-half of the capacitive load ungrounded, neutral of one-half of the capacitive load grounded (see 4.13.8). The recovery voltage across the first phase to interrupt should be 2.4 times $E_{\max}$, (phase).

8)The operations specified shall include the following:

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

b)Six interruptions with contact separation at the point on the current wave, plus or minus 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.

c)Six interruptions with contact separation at the point on the current wave, plus or minus 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.

d)During these tests, the performance specified in performance on capacitance current switching for definite purpose circuit breakers (see 5.13.4.1 of ANSI/IEEE C37.04-1979) 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 (see 5.13.4.2 of ANSI/IEEE C37.04-1979) the performance will be considered to have been met if there are no operations with overvoltages greater than the allowable limit.

9)For breakers rated for instantaneous reclosing, these operations are to be made with a duty of Open-O s-Close to demonstrate the 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 breaker under test (see 5.9 of ANSI/IEEE C37.04-1979).

10)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.

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

*Numbers in parentheses correspond to those in the explanatory NOTES.

Table 5 —Single-Pole Capacitance Current Switching Tests

	Test Duty (See 4.13.11)	Test Voltage (1, 2)[*]	Percent of Rated Capacitance Switching Current	Number and Type of Operations (4, 7, 11)	Interrupter Pressure	Circuit Grounding
1A	Isolated capacitor bank or cable switching	$0.58BV\frac{2}{1+A_1}$	30	24 O	Rated	(8)
1B	Isolated capacitor bank or cable switching	$0.58BV\frac{2}{1+A_1}$	100 (5)	24 C-O	Rated (6)	(8)
2A	Back-to-back capacitor bank or cable switching	$0.58BV\frac{2}{1+A_1}$	30	24 O	Rated	(8)
2B	Back-to-back capacitor bank or cable switching	$0.58BV\frac{2}{1+A_1}$	100 (3, 5, 10)	24 C-O	Rated (6)	(8)
3A	Open wire line charging current switching	$0.58BV\frac{2}{1+A_1}$	30 (10)	24 O-C (9)	Rated	(8)
3B	Open wire line charging current switching	$0.58BV\frac{2}{1+A_1}$	100 (5, 10)	24 C-O	Rated (6)	(8)

NOTES:

V =Rated maximum voltage (see 5.1 of ANSI/IEEE C37.04-1979).

A_i =Voltage regulation factor (see 4.13.4.2).

B =Voltage multiplying factor (see 4.13.4.2).

1)Test circuit voltage with test breaker open but with bus bank connected for back-to-back tests in Test Duty 2 (see 4.13.4.2).

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

B =1.5 for breakers rated 72.5 kV and below

B =1.0 for breakers rated 121 kV and above

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

3)Rated transient inrush current on closing.

4)Type of operations:

At 30% of ratings: OPEN (see Note (9) for Test Duty 3A).

At 100% of ratings: CLOSE-OPEN allow sufficient time before tripping for closing transient currents to decay.

5)For breakers with nonsymmetrical current path, reverse terminal connections for half of 100% operations (see 4.13.9).

6)Interrupter pressure shall be minimum for 3 operations (see 4.13.6).

7)The operations specified shall include the following:

a)Two interruptions, each with contact separation at 30° intervals over the current loop: 0, 30, 60, 90, 120, 150°.

b)Six interruptions with contact separation at the point on the current wave, plus or minus 7.5°, which as determined above resulted in the shortest capacitance current arcing time, not including reignition or restrike.

c)Six interruptions with contact separation at the point on the current wave, plus or minus 7.5°, which as determined above resulted in the longest capacitance current arcing time, not including reignition or restrike.

d)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 (see 5.13.4.1 of ANSI/IEEE C37.04-1979) 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 (see 5.13.4.2 of ANSI/IEEE C37.04-1979) 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 crest value of the average of the open and closed circuit test voltage.

8)Circuit grounding: Test circuit may be grounded (see 4.13.8).

9)For breakers rated for instantaneous reclosing, these operations are to be made with a duty of OPEN-0 s-CLOSE to demonstrate the 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 breaker under test (see 5.9 of ANSI/IEEE C37.04-1979).

10)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.

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

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*Numbers in parentheses correspond to those in the explanatory NOTES.

4.13.1.2 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. It 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.

4.13.1.2.1 General-Purpose Circuit Breakers

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

(2) 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.

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

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

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.

(b) *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

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

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.

4.13.1.2.2 Definite Purpose Circuit Breakers

(1) 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.

(2) 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.

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

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

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 Fig 13.

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

(b) *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

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

and that restrike shall not follow a current pause greater than $^1/_3$ cycle.

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.

4.13.2 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 4.13.2.2.

4.13.2.1 Circuit Breaker To Be Used for Test

The circuit breaker shall be representative of the type or model as required for all design tests. (See 1.1.)

4.13.2.2 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 Table 1 and Table 2. If this is done, an explanatory note shall be included in the test report.

4.13.2.3 Condition of Circuit Breaker After Test

Following the test operations listed for Test Duties 1, 2, and 3 in Tables 1 and 2, the circuit breaker shall be in the condition specified in 5.10.3.3 of ANSI/IEEE C37.04-1979. 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.

4.13.3 Testing Conditions

4.13.3.1 Power Factor

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

4.13.3.2 Frequency of Test Circuit

Tests demonstrating capacitance current switching capabilities of circuit breakers are to be made at the rated 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.

4.13.3.3 Recovery Voltage

In the switching of capacitance currents, because of the charge which 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 which can reach a peak value approximately between $2E_{\max}$ and $3E_{\max}$ (phase) at a time $^1/_2$ cycle after current interruption. The actual value which 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 which a circuit breaker may have to switch, the approximate maximum peak recovery voltage which 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 ($C_1 = 2C_o$)	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 $2E_{max}$ (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.

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 voltagechange, when the capacitive load is switched is equal to:

$$\text{Percent voltage change} = \frac{\text{kvar}_o}{\text{kVA}_o - \text{kvar}_o} \times 100\%$$

where

kVA_o = symmetrical three-phase short circuit kVA at the point of the capacitive load
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 4.13.4 which 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.

4.13.4 Test Voltage

4.13.4.1 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 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 which occurs in a system which is operating at rated maximum voltage and which has negligible voltage change when the capacitive load is removed, it may be necessary to have an open circuit test voltage which is less than rated maximum voltage depending on regulation of the laboratory circuit.

The open circuit test voltage E_o is determined as follows:

$E_c = A\,(E_o)$

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
$I_c =$ rms capacitance current

The nominal recovery voltage across the circuit breaker $^1/_2$ cycle after current interruption will be proportional to the crest value of:

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

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:

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

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

4.13.4.2 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 4.13.3.3, 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 4.13.4.1.

For grounded shunt capacitor bank or cable charging current switching tests on a three-phase basis, $B = 1$.

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 ($C_1 = 2C_o$), $B = 1.2$.

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

$$E_{O1} = 0.58V\left(\frac{2}{1+A}\right)B$$

where

$$A_1 = \frac{I_{sc}}{I_{sc} - I_c}$$

and

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

NOTE — The methods described in 4.13.4.1 and 4.13.4.2 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.

4.13.5 Control Voltage and Mechanism Operating Pressure

Rated values of control voltage and mechanism operating pressure shall be maintained for the closing and tripping circuits.

4.13.6 Interrupter Pressure

Circuit breakers which depend on external energy or pressure to drive an interrupting gas or fluid and which have a minimum permissible pressure specified, shall be capable of performing at minimum permissible pressure as specified in Tables 4 and 5.

4.13.7 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.

4.13.8 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 in 5.13.8 of ANSI/IEEE C37.04-1979 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.

4.13.9 Reversal of Test Connections

On circuit breakers which 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 Tables 4 and 5.

4.13.10 Obtaining the Most Severe Switching Conditions

In capacitance current switching operations where 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 a small amount of capacitance to the source side of the test circuit breaker to reduce the natural frequency, and thereby the rate-of-change of the voltage regulation occurring at interruption. Another method is the use of series capacitance to increase the apparent short circuit kVA of the source.

4.13.11 Methods of Demonstrating Capacitance Switching Rating

Tests which 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 4 and single-phase tests are listed in Table 5. 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 4 or 5. 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 4 and Table 5 to provide equivalent test results.

In Table 4 and Table 5, Test Duty 1 demonstrates the performance of the circuit breaker switching the current associated with its isolated cable and isolated shunt capacitor bank 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.

4.13.11.1 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 4.

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.

4.13.11.2 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 5.

4.13.11.3 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 which operate in a relatively independent manner in capacitance current switching operations. See 4.6.6.3.1 for a discussion of conditions which 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 5 shall be followed. The test voltage for such tests should be determined as given in Table 5 for the portion of the total voltage represented by the number of interrupter units or breaks tested.

4.13.11.4 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 which 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 4.6.6.6.

4.13.12 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:

1) Circuit breaker and test identification
    - Circuit breaker identification
    - The value of pole unit or interrupter shunting resistance (other than resistance normally applied only for interrupter voltage grading)
    - Method of test
        - Three-pole
        - Single-pole
        - Unit interrupter
    - Test duty
        - Isolated shunt capacitor bank or cable
        - Back-to-back shunt capacitor bank or cable

        - Open wire line charging
2) Test results
    - Capacitance current switched
    - Test circuit voltage
        - Open circuit
        - Closed circuit
    - Interrupting time, through primary arcing contacts
    - Interrupting time, through secondary arcing contacts
    - Number of tests
    - Number of tests with restrikes and whether single or multiple
    - Time from interruption of the normal frequency load current to the first restrike
    - Transient overvoltage factor
    - Inrush current characteristics in back-to-back shunt capacitor bank switching tests
        - Inherent peak inrush current
        - Natural frequency
    - Maintenance on test circuit breaker for each duty (see 4.13.2.2)

4.14 Rated Line Closing Switching Surge Factor

The ability of a circuit breaker design to meet its line closing switching surge factor rating may 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 6.3. Rated factors are found in Table 8 of ANSI C37.06-1979.

4.14.1 Standard Reference Power System

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

4.14.1.1 Standard Reference Power Source

The standard reference power source is a three-phase **Y**-connected voltage source with neutral grounded and with each of the three-phase voltages in series with an inductive reactance which 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 ($X_1 = X_2 = X_0$).

4.14.1.2 Standard Reference Transmission Line

The standard reference transmission line is a perfectly transposed three-phase transmission line with balanced parameters as listed in Table 8 of ANSI C37.06-1979. These values have been selected to make the lines typical of anticipated service conditions.

4.14.2 Standard Conditions of Simulation

4.14.2.1 Simulation of Power Source

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

4.14.2.2 Simulation of Transmission Line

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

4.14.2.3 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.

4.14.2.4 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 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.

4.14.3 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.

4.15 Out-of-Phase Switching Current Tests

The tests specified in this section 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 6 and are described in the following sections.

The test requirements demonstrate out-of-phase switching capability for the majority of out-of-phase switching conditions. However, the tests do not ensure capability under all conditions when interruption occurs at full phase opposition of 180°. Even on an effectively grounded system, the first two phases to clear may experience an overvoltage of 2.5 times the normal phase-to-ground voltage (instead of 2.0 times) until the last phase clears. Attention is called to suggested preventive measures described in ANSI/IEEE C37.010-1979.

4.15.1 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 single-phase if the conditions for tests on single-pole units in accordance with 4.6.5.7 are fulfilled. If these conditions are not fulfilled, three-phase tests should be made. Unit tests may be made provided the conditions of 4.6.6.3 are satisfied.

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

1) The value of the out-of-phase switching current
2) The value of the out-of-phase recovery voltage
3) The value of the peak, time to crest, and wave shape of the transient recovery voltage

4.15.2 Conditions of Severity for Out-of-Phase Switching Current Tests

The out-of-phase switching current tests shall be carried out under the conditions of severity specified in 4.15.3 through 4.15.10.

4.15.3 Arrangement of Circuit Breaker for Tests

The circuit breaker subjected to out-of-phase switching current tests shall be a complete assembly with its own operating mechanism and shall truly represent its own type 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.

Table 6 —Test Duties to Demonstrate the Assigned Out-of-Phase Switching Rating of ac High-Voltage Circuit Breakers (Testing a Single Pole of a Three-Pole Breaker on a Single-Phase Circuit)

Test Duty [See (5) and (6)]*	Operating Duty [See (4)]	Phases	Voltages E [See (1)] Normal Frequency Initial and Recovery (See 4.6) (V, rms)	Transient Recovery Voltage [(1 – cos) wave shape]		Current Interrupted at Contact Separation	
				Crest Voltage	Time to Crest [See (2)]	Magnitude [See (1)] (A, rms)	% Asymmetry
1	two open	1	1.16 V	2.04 V	$2T_2$	0.05 I to 0.10 I	random
2	one open and one close-open [See (7)]	1	1.16 V	2.04 V	$2T_2$	0.25 I	[See (3)]
2a	close-open [See (7)]	1	0.87 V	1.53 V	$2T_2$	0.25 I	[See (3)]

NOTES:

1 — V is the rated maximum voltage (see 5.1 of ANSI/IEEE C37.04-1979). I is the rated short-circuit current (rated out-of-phase switching current = 0.25 I).

2 — The time to crest T_2 is listed in ANSI C37.06-1979, Tables 2, 3, 4, or 5 for the circuit breaker under test.

3 — The value of the dc component shall be not more than 20% for one test and not less than 50% for the other test. (This is expressed as a percent of the crest value of the ac component and does not apply to 5 and 8 cycle breakers.) Selection of open or close-open duty for the two conditions is left to the discretion of the manufacturer.

4 — The instant of contact separation shall be chosen so as to produce the most severe switching conditions as determined by design tests. See 4.6.5.11.

5 — No reconditioning of the circuit breaker is permissible in the course of the four tests. However, where additional tests become necessary, reconditioning of the circuit breaker in accordance with 4.15.5 is permitted and only a repeat of the particular test duty is then required.

6 — Circuit breakers equipped with opening resistors should receive special attention, and the tests should demonstrate that resistor current will be interrupted within 8 cycles for 2 and 3 cycle breakers, and proportionally longer for 5 and 8 cycle breakers to avoid resistor damage. If the user has an unusual application where the system may produce less than 5% of the circuit-breaker short-circuit current rating, he should consult the manufacturer for appropriate lower symmetrical tests to produce the most unfavorable conditions.

7 — Test Duty 2a may be substituted for the close-open portion of the Test Duty 2 for those breakers that may have thermal or voltage limitations on resistors used for line closing switching surge control. (Subject to agreement between user and manufacturer.)

*Numbers in parentheses correspond to those of the explanatory NOTES below.

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

1) Speed of closing and opening
2) Arc-extinguishing medium
3) Power and strength of operating mechanism
4) Rigidity of the structure

4.15.4 Behavior of Circuit Breaker During Tests

When performing any test duty up to its assigned out-of-phase switching current rating, the behavior of the circuit breaker shall comply with the following conditions.

1) An oil circuit breaker shall perform at or within its rating without emitting flame and without emitting oil except for minimum quantities through vent openings.
2) Oilless circuit breakers, including compressed-air circuit breakers or air-blast circuit breakers and magnetic air circuit breakers, shall perform at or within their respective ratings without emitting injurious flame.

4.15.5 Condition of Circuit Breaker After Tests

After performing the test specified in 4.15.9, the mechanical parts, insulators, opening resistors, closing resistors, and interrupters of the circuit breaker shall be substantially in the same mechanical condition as before the tests.The circuit breaker shall be capable of withstanding rated maximum voltage in the open position and of carrying rated continuous current without injurious heating at any operating voltage up to rated maximum voltage. The circuit breaker shall be capable of a close-open operation at its required interrupting capabilities and at its operating voltage after an interval of at least 1 h, but the interrupting time may be exceeded by as much as 1 cycle.

The circuit breaker may be inspected between test duties. The circuit breaker may be restored to its initial condition by maintenance work subject to the circumstances indicated in 4.15.10 as follows:

1) Repair or replacement of any expendable parts of the breaker
2) Renewal or reconditioning of the oil or of any other extinguishing medium, and addition of any quantity of the medium necessary to restore its normal level
3) Removal of deposits from the insulators caused by decomposition of the extinguishing medium

4.15.6 Test Voltage

For single-phase tests called for in Test Duties 1 and 2 of Table 1, both the applied voltage E (as shown in Figs 1 through 3) and the normal frequency recovery test voltage shall be equal, as nearly as possible, to 2.0 times the rated maximum voltage V divided by $\sqrt{3}$ (for effectively grounded neutral, see the following note). The inherent TRV (transient recovery voltage) of the test circuit shall have a 1 – cos wave shape with a peak value of 1.25 times the value of the crest of the normal frequency recovery voltage and a time to crest no greater than 2 times the time T_2 as listed in Tables 2, 3, 4, or 5 of ANSI C37.06-1979 for the circuit breaker under test. (See the Notes to Table 6.)

For the alternate single-phase close-open test called for in Test Duty 2a of Table 6, the applied voltage shall, as nearly as possible, be equal to 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 ANSI/IEEE C37.010-1979.)

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

NOTE — An ungrounded neutral is considered unusual for US applications, and circuit breakers intended for this application should meet a test voltage of 2.5 times the rated maximum voltage V divided by $\sqrt{3}$. Many circuit breakers that would meet the requirement for an effectively grounded neutral would not meet this requirement. The user should specify whether his application has an effectively grounded or ungrounded neutral when referring to this standard. Note that in this context, effectively grounded refers to system neutrals on both sides of the circuit breaker under consideration.

4.15.7 Test Frequency

Tests shall be carried out at the rated frequency ±20%.

4.15.8 Test Circuit

(1) The power factor of the test circuit shall not exceed 0.15 lagging.

(2) 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 Fig 3).

If it is not feasible to use this circuit in the testing station, it is permissible to use either of the circuits shown in Figs 4 and 5 at the option of the manufacturer.

1) 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 4.1 5.6 (see Fig 4).
2) Tests with one terminal of the circuit breaker grounded may be used (see Fig 5).

4.15.9 Test Duties

The Test Duties to be made are shown in Table 6. 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 breaker, provided the conditions of Note (4) of Table 6 have been established.

4.15.10 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:

1) Switching current in each phase
2) Voltage across each phase
3) Instant of energizing trip coil
4) Travel of moving contacts, if practicable
5) Current in closing coil
6) Timing wave
7) Gas pressure before test
8) Voltage of the supply circuit
9) Interrupting time
10) Resistor current in each phase (when applicable)

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

4.16 Rated Shunt Reactor Current Switching

See 5.16 of ANSI/IEEE C37.04-1979.

4.17 Rated Excitation Current Switching

See 5.17 of ANSI/IEEE C37.04-1979.

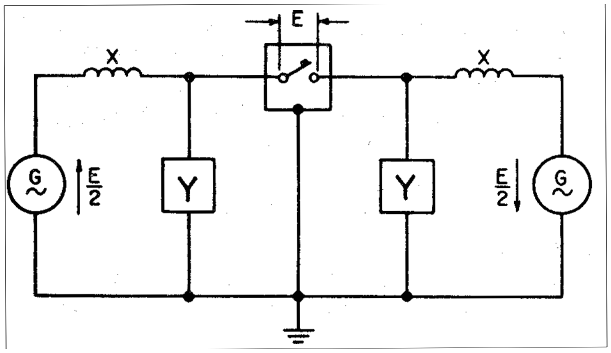

Figure 3 —Dual Voltage Testing, 180°

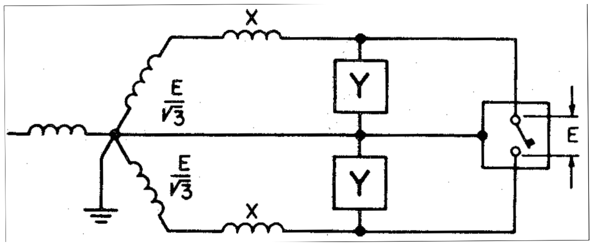

Figure 4 —Dual Voltage Testing, 120°

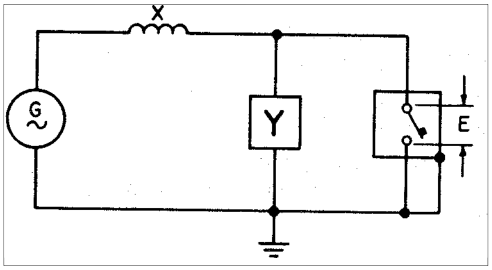

Figure 5 —Single Voltage Testing with One Side Grounded

4.18 Mechanical Life

No-load mechanical operation tests are made on a complete power circuit breaker to ensure its satisfactory operation in normal service without excessive maintenance.All mechanical operation tests shall be made at rated control voltage or air pressure, or both, except as noted below, without repair or replacement of any major part and with the number of operations between servicing at least equal to the number shown in Column 2 of Table 8 of ANSI C37.06-1979. Mechanical operation tests may be made with any interval between operations which does not overheat bearings, momentary-rated coils, valves, rectifiers, or other auxiliary devices. A mechanical operation test shall consist of a number of close operations followed by opening operations shown in Column 3 of Table 8 of ANSI C37.06-1979.

To demonstrate that an outdoor breaker can operate with an ambient of –30°C, a few of these tests should be made on it after the breaker has come to a steady temperature in that ambient. However, if testing facilities do not permit this demonstration (as is usually the case), the performance of important components of the breaker may be demonstrated in this ambient temperature.

During these tests, the electrical operating mechanism and its appurtenances shall make 20 successive closing-opening operations at 20 s intervals and 100% of normal control voltage without overheating to a point which would injure the coil insulation or change the resistance characteristics sufficiently to adversely affect the circuit breaker performance. For stored energy mechanisms, the operations shall be performed at 30 s intervals as long as available energy permits and then at the rate inherent in the storage system until 20 operations have been completed.

During these tests, a few operations shall be made at both the upper and lower limits (see Table 10 of ANSI C37.06-1979) of the range for the rated control voltage.

During these tests, it shall be demonstrated that the transient voltage produced in the control circuit associated with the circuit breaker itself does not exceed 1500 V crest when the control circuit is interrupted.

To verify that the circuit breaker is in a condition meeting the requirements specified in 5.10.3.3.2 of ANSI/IEEE C37.04-1979, after completion of the no-load mechanical operations test, the breaker shall be inspected visually and the travel records taken before and after the tests shall be substantially the same.

4.19 Rated Control Voltage Current (Nominal Control Voltage)

Operation at rated control voltage, and at the minimum voltage corresponding to it, is demonstrated during mechanical operation tests (see 4.18) and the short-circuit switching tests (see Tables 1 and 2).

4.20 Rated Fluid Operating Pressure

Operation at rated fluid operating pressure and over its range is demonstrated during the mechanical operation tests (see 4.18) and during the short-circuit switching tests (see Tables 1 and 2).

4.21 Design Tests on Porcelain Components

A representative of each design of porcelain insulators, porcelain housings, or porcelain tubes having an internal or external gas pressure exceeding 1.0546 $\mathrm{Kg/cm^2g}$ (with no limitation on size) shall withstand for 5 min 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 which 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.

In addition to the above tests when pressurized porcelain elements with end flanges having an internal or external gas pressure exceeding 1.0546 $\mathrm{Kg/cm^2g}$ (with no limitation on size), are subjected 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 5 min a total stress equivalent to the end plate loading from maximum allowable working pressure plus three times the maximum rated cantilever stress.

The maximum rated cantilever stress shall be based on the load on the porcelain element resulting from:

1) The combination of the short circuit forces internally of the circuit breaker plus rated line pull withstand and 90 mi/h wind velocity withstand
2) 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.

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 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 (see 1.3).

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

1) Current and linear coupler transformer tests (see 5.2)
2) Bushing tests (see 5.3)
3) Gas receiver tests (see 5.4)
4) Pressure tests (see 5.5)
5) Nameplate check (see 5.6)
6) Leakage tests (see 5.7)
7) Resistors, heaters, and coils check tests (see 5.8)
8) Control and secondary wiring check tests (see 5.9)
9) Clearance and mechanical adjustment check tests (see 5.10)
10) Mechanical operation tests (see 5.11)
11) Timing tests (see 5.12)
12) Stored energy system tests (see 5.13)
13) Conductivity of current path test (see 5.14)
14) Low-frequency withstand voltage tests on major insulation components (see 5.15)
15) Low-frequency withstand voltage tests on control and secondary wiring (see 5.16)

5.2 Current and Linear Coupler Transformer Tests

All current transformers used in high-voltage circuit breakers shall be designed in accordance with the ANSI/IEEE standards for transformers (C57) series. Current and linear coupler transformers shall receive the following tests where applicable:

1) Each transformer shall be checked for presence of correct nameplate, terminal, and polarity markings.
2) Each transformer shall be checked electrically to ensure proper direction of winding to give the correct polarity.
3) 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.
    a) Relaying transformers shall receive ratio or mutual reactance tests to ensure proper turn ratios. Multiratio 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.
    b) 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.
4) After installation in the circuit breaker, each transformer shall be given a 1 min low-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 Bushing Tests

High-voltage circuit breaker bushings shall be tested in accordance with ANSI/IEEE Std 21-1976.

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 1.0546 kg/cm^{2}g (with no limitation on size) or those having an inside diameter not exceeding 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 which apply at the point of original installation.[4]

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 1.0546 kg/cm^{2}g (with no limitation on size) shall individually withstand for 5 min 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 which 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 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 5 min.

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 which can be subjected to this pressure in service.

5.6 Nameplate Check

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

5.7 Leakage Tests

(1) Oil circuit breaker tanks shall be given leakage tests to ensure against oil leakage at joints or welds. At the manufacturer’s option, leakage tests may be made by any of the following accepted methods:

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[4] Requirements for Fiberglass-Reinforced Plastic-Pressurized Vessels, Supplement 3.14 to NEMA Standards Publication SG 4-1975, ac High-Voltage Circuit Breakers, was published Nov 1977. Copies are available from National Electrical Manufacturers Association, 2101 L Street NW, Suite 300, Washington DC 20037.

a) Compressed air tests
b) Oil or water pressure tests
c) Penetrating liquid without pressure

(2) Systems containing gas under pressure shall be placed under normal operating pressure and the supply of additional gas cut-off by removal of compressor power or by closing a valve to a common supply. The leakage must not cause a decrease in pressure with time which exceeds a rate specified by the manufacturer.

5.8 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.

5.9 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.

5.10 Clearance and Mechanical Adjustment Check Tests

Close the breaker or independently operating unit of the breaker by means of the maintenance operating device and check 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 breaker or independently operating unit of the breaker with power and repeat the checks in the preceding paragraph.

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

5.11 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 its rated control voltage in ANSI C37.06-1979, and 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:

1) At minimum control voltage and maximum pressure:
   a) Five close operations
   b) Five open operations
2) At maximum control voltage and maximum pressure:
   a) Five close operations
   b) Five open operations

3) At rated control voltage and rated pressure:
    a) Five close-open operations with the shunt trip coil energized simultaneously with the closing of the main circuit through the breaker. During these tests, the control switch is held in the close position to demonstrate that the breaker is electrically trip-free. See 2.2 of ANSI C37.11-1979, Requirements for Electrical Control for ac High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis for a Total Current Basis.

For indoor circuit breakers rated 15.5 kV and over and for all outdoor circuit breaker ratings, the mechanical operating tests shall also include the following:

At rated control voltage and pressure,

i) Five close operations
ii) Five open operations
iii) Five reclosing operations (if breaker is intended for reclosing service)

Check to make certain that the closing operation will be completed after momentary contact of the closing control switch. See 2.1 of ANSI C37.11-1979.

The breaker shall also be tripped by slowly moving the shunt trip armature manually in the direction of tripping.

Check to make certain that all interlocks function as intended.

Check to make certain that all shock absorbing devices function as intended.

5.12 Timing Tests

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

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

1) An oscillograph with suitable travel indicators connected to an appropriate point or points of the breaker linkage or contacts
2) 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
3) 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 breaker within the speed range selected during development of this type of breaker. After a breaker has been in service, these tests may be used to determine whether it is still operating correctly.

Opening times shall be obtained for all breakers for which the product of times rated maximum voltage times rated short-circuit current equals 900 MVA or higher.

Travel-time curves shall be obtained for all outdoor breakers with an interrupting time of 3 cycles or less.

5.13 Stored Energy System Tests

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

1) The pressure switches shall be set and tested for operation at the correct pressures.
2) 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.
3) 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.
4) Starting at normal pressure and without replenishing the gas in the reservoir, a pneumatically or pneumo-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.

The energy stored by a motor in the closing spring or springs of a spring-driven circuit breaker operating mechanism shall be replaced by the motor within 10 s after being used during a close operation when rated control voltage is maintained at the motor terminals.

5.14 Electrical Resistance of Current Path Test

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

5.15 Low-Frequency Withstand Voltage Tests on Major Insulation Components

Low-frequency withstand voltage tests for 1 min shall be made either on completely assembled breakers at the voltages and conditions specified in 4.5.1 or on major insulation components such as bushings, insulation braces, and operating rods.

5.16 Low-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 low-frequency withstand test of 2500 V for 1 min. See also 5.2 (4). All other control wiring shall receive a low-frequency withstand test of 1500 V for 1 min.

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 Method of Conducting Conformance Tests for Impulse Withstand Voltage

When impulse voltage tests are required for conformance tests, circuit breakers shall be capable of passing a 1.2 · 50 μs full wave impulse voltage test series with values as specified by the purchaser in accordance with the following:

1) A virtual front time, based on the rated full wave impulse voltage, equal to or greater than 1.2 μs
2) A crest voltage not exceeding the rated full wave impulse withstand voltages
3) A time to the 50% value of the crest voltage not exceeding 50 μs

Circuit breakers shall be in new condition and properly adjusted.

6.2 Method of Conducting Conformance Tests for Switching Impulse Withstand Voltage

Conformance tests are to be made in accordance with 4.5.5 with the following exceptions:

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

6.3 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 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 2 out of 48 tests; or 3 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, represents non-conformance.

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 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.

7. Standard Methods for Determining the Values of a Sinusoidal Current Wave and a Normal-Frequency Recovery Voltage

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

1) The rms (root-mean-square) or effective value, measured from the envelope of an asymmetrical sinusoidal wave at a time such as the time of the maximum crest of the time of contact parting
2) The rms value of a short-circuit current over several cycles
3) The rms value of a normal-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

Root-mean-square 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 which 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.

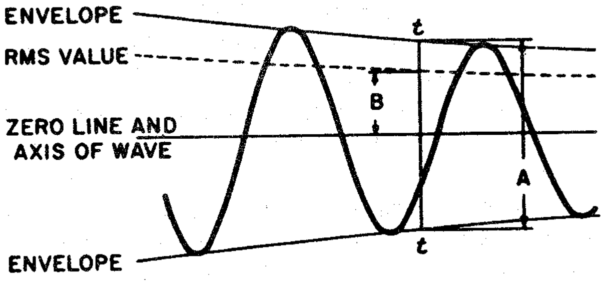
When a current is specified as an rms value over a time of several cycles, the integration may be based on the instantaneous values of current over this time or, more easily, the rms current may be determined by the method in 7.1.6.

7.1.2 Classification of Current Wave

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

7.1.3 Root-Mean-Square 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 at the given instant, and divide by 2.828. See Fig 6.



t = instant for which measurement is made
A = peak-to-peak value of wave
B = rms value = $\frac{A}{2.828}$

Figure 6 —Measurement of the rms Value of a Symmetrical Wave

7.1.4 Root-Mean-Square 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 component and a direct 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. See Fig 7.

7.1.4.1 Alternating Component

The alternating component has a peak-to-peak value equal to the distance between the envelopes and has an axis midway between the envelopes.

$$\text{Peak value alternating component} = \frac{\text{Major ordinate} + \text{Minor ordinate}}{2}$$

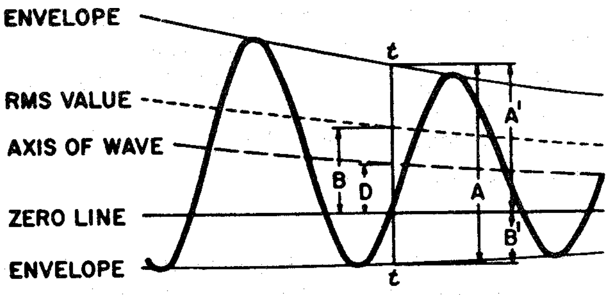
7.1.4.2 Direct Component

The direct component has an amplitude to the displacement of the axis of the alternating component.

$$\frac{\text{Major ordinate} - \text{Minor ordinate}}{2}$$

7.1.4.3 Calculation of the rms Value of an Asymmetrical Sinusoidal Wave

See Fig 7 for the method of calculation. The direct use of the formula in Fig 7 involves a considerable amount of calculation to determine the components and to combine them, but it may be used to develop tables, charts, and scales by which the effective values are easily and quickly obtained.



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
$= \sqrt{\left(\text{rms value of alternating component}\right)^2 + \left(\text{direct component}\right)^2}$
$= \sqrt{\left(\frac{A}{2.828}\right)^2 + D^2}$

Figure 7 —Measurement of the rms Value of an Asymmetrical Wave

7.1.4.4 Chart for Determining rms Value

A chart which gives the rms value of the asymmetrical wave in terms of the peak-to-peak and maximum values is shown in Fig 8. These two values are read on an oscillogram. The point, whose abscissa is the maximum value of the wave and whose ordinate is the peak-to-peak value, indicates the rms value of the asymmetrical wave. The point whose ordinate is the peak-to-peak value and which is on the line having a slope of 2, indicates on the scale the rms value of the alternating component. These values are multiplied by the scale of the oscillogram.

7.1.4.5 Scale for Determining rms Value

A transparent scale which can be laid over an asymmetrical sine wave and used for reading the rms value directly can be made by tracing Fig 9. The scale is placed over the wave with its axis *XX′* parallel to the zero line of the wave and with the upper and lower edges of the scale passing through the intersections of the envelope of the wave and the line *tt′* marking the instant for which the rms value is to be obtained. The intersection of *tt′* and the zero axis of the wave indicates on the scale the rms value of the asymmetrical wave. The intersection of *tt′* and *XX′* indicates on the scale the rms value of the ac component of the wave. The scale gives the rms value in inches. These rms values are multiplied by the scale of the oscillogram to obtain current values.

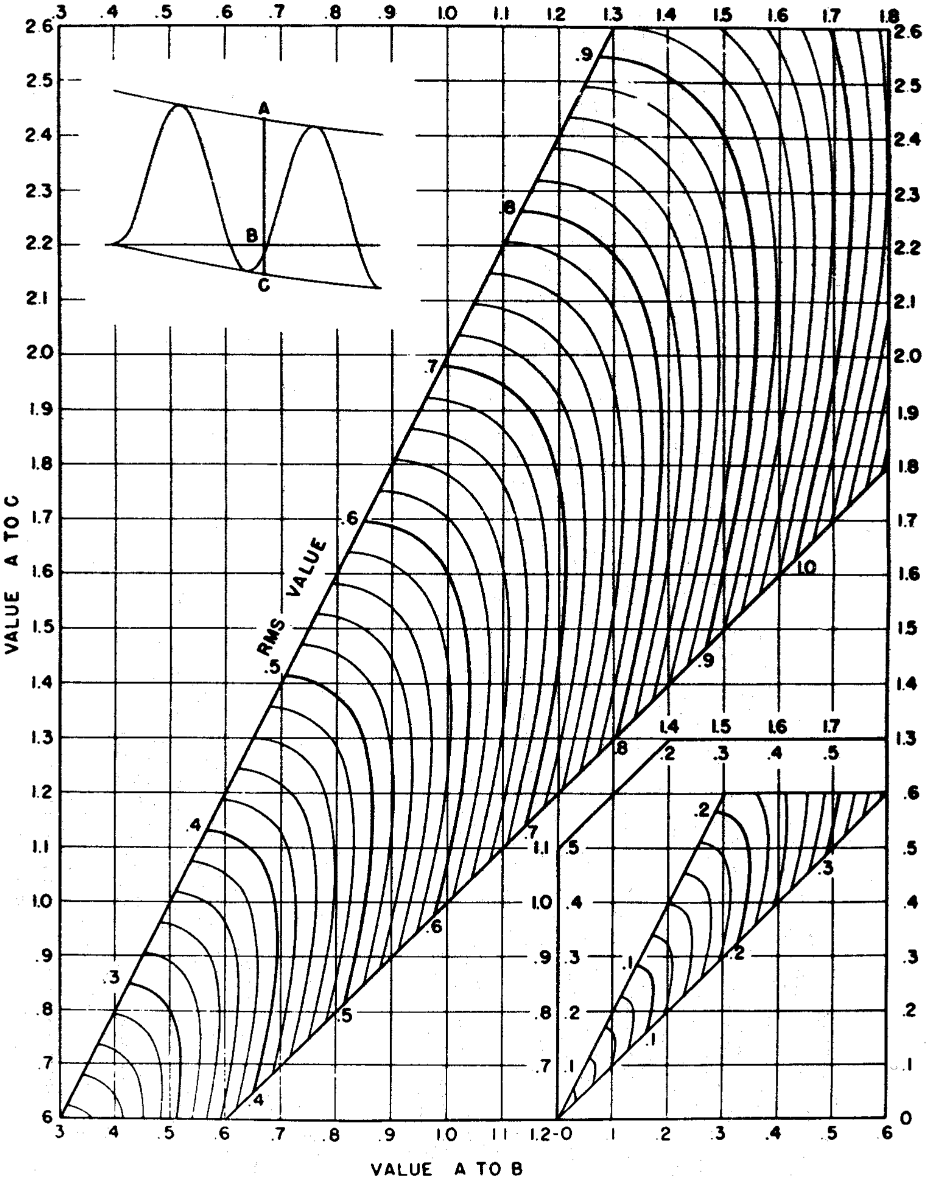
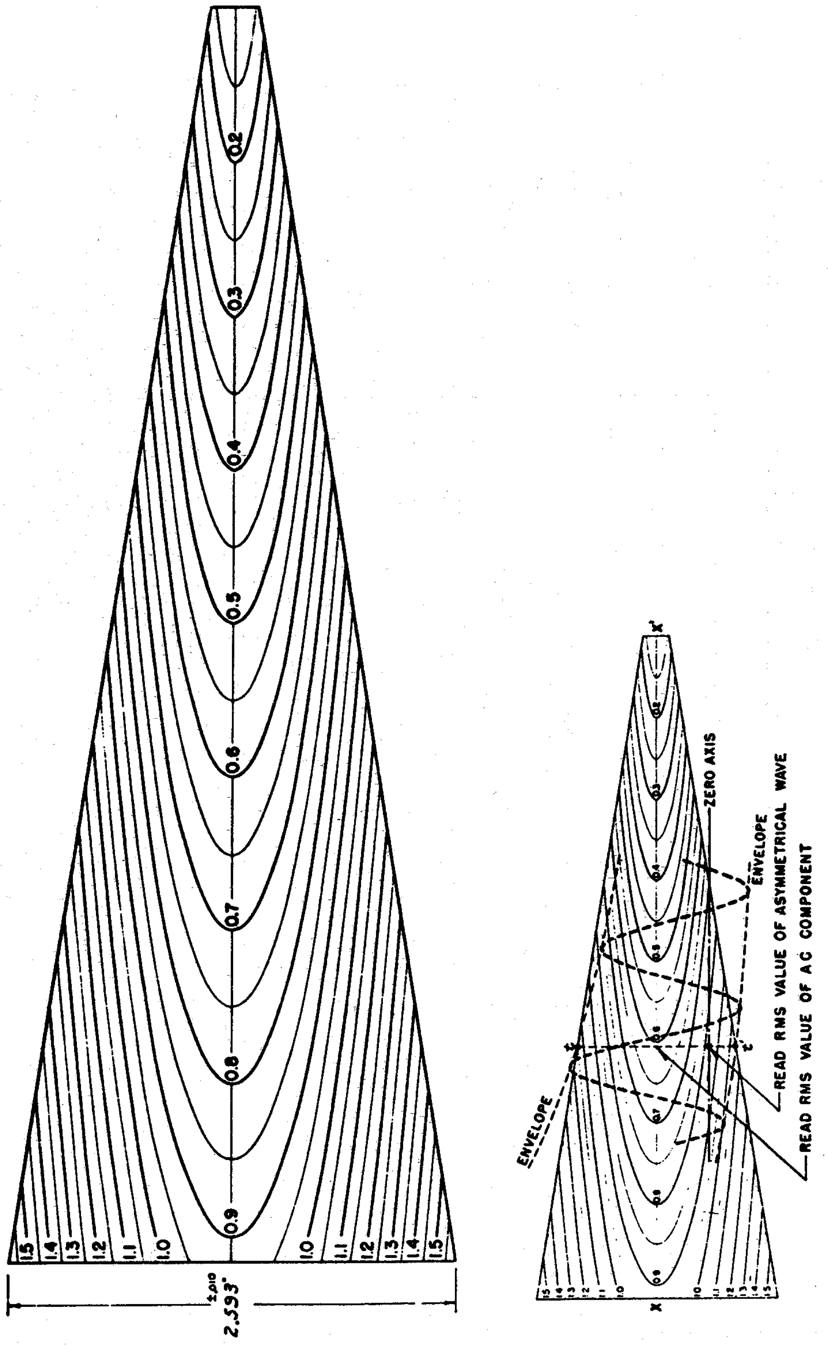


Figure 8 —Chart for Determining the rms Value of an Asymmetrical Sine Wave

7.1.4.6 Root-Mean-Square Value of a Current of Less than One Cycle Duration

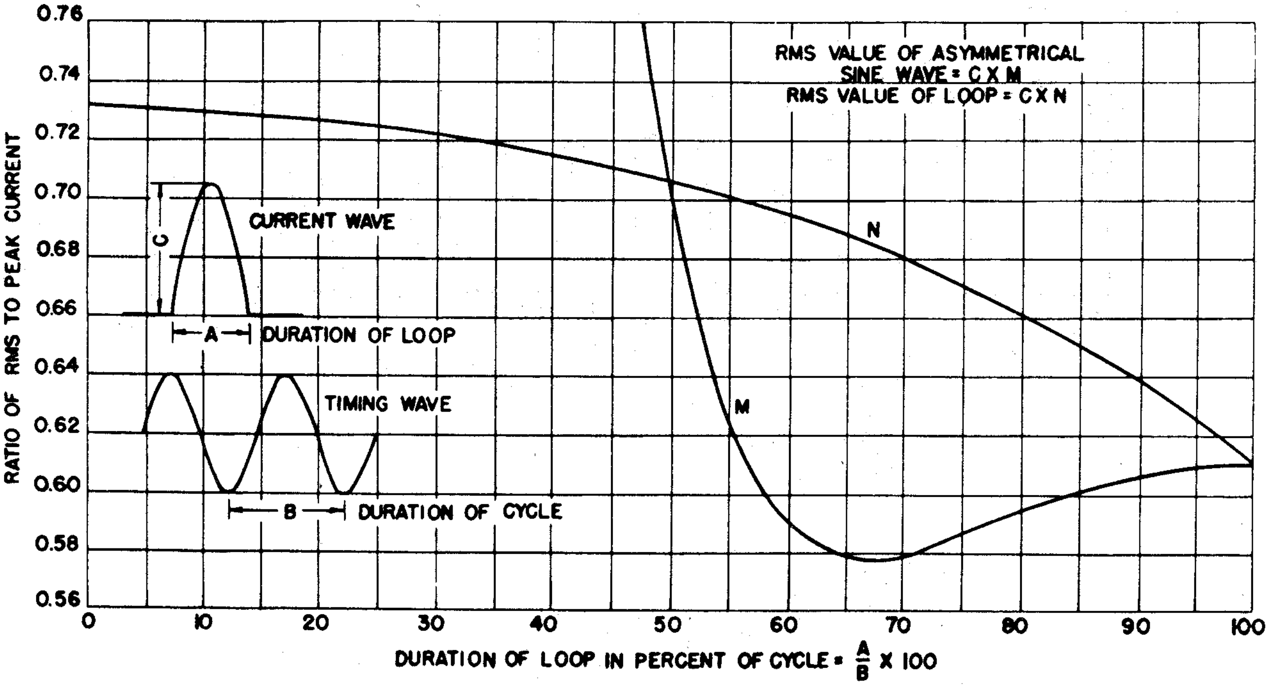
A current may flow for less than one cycle and make it impossible to determine the envelope of the current wave by inspection of the oscillogram. However, if the oscillogram indicates that the current was part of the large loop of a wave that was at least 20% asymmetrical, the crest value may be divided by 1.69 to give the rms value as discussed in 7.1.5. If the current is not distorted by arc voltage, the rms value of the sine wave integrated over a complete cycle may be determined from the amplitude of the single loop, its duration, and the curve *M* of Fig 10. In some cases, the rms value of the current, for the fraction of a cycle for which the current actually flowed, may be desired in analyzing test data, even though this value is not referred to in any rating. The value may be determined from the amplitude of the single loop, its duration, and curve *N* of Fig 10.



NOTES: Use of the scale: The line *t'* on the oscillogram marks the instant for which the measurement is to be made and determines three points where it intersects the two envelopes and the zero line of the wave. The transparent scale (or the oscillogram) is then moved with the axis *XX'* of the scale parallel to the zero axis of the sine wave until the two points on the envelope at *tt'* coincide with the upper and lower edges of the scale.

The third point, the intersection of *tt'* and the zero axis of the wave, indicates on the scale the rms value of the total wave. The intersection of *tt'* and *XX'* indicates on the scale the rms value of the ac component. These values are in inches and are multiplied by the scale of the oscillogram to give the current values.

Figure 9 —Scale for Measuring the rms Value of an Asymmetrical Sine Wave at a Particular Instant



NOTE: Curves are based on the assumption of zero decrement in both components.

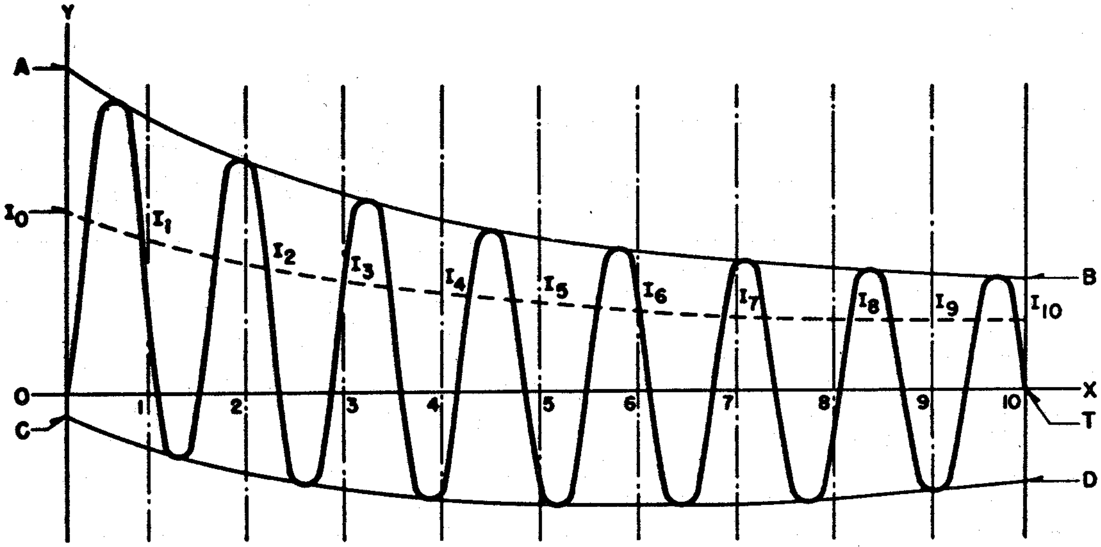
Figure 10 —Curve for Determining the rms Value of an Asymmetrical Sine Wave Having a Single Loop

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 crest, or as the instantaneous value of the current at the crest. 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 varies with asymmetry, as follows.

% Asymmetry	Peak Value	rms Value	Peak Value to rms Value
100	2.83	1.732	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

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 making capability.



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 11 —Determination of the Equivalent rms Value of a Short-Time Current

7.1.6 Measurement of the rms Value of a Current During a Short Circuit of Several Cycles Duration

The oscillogram shown in Fig 11 represents a record of a current which has passed through a circuit breaker during a short circuit of several cycles duration. Times are indicated as abscissae on the axis *OX* and the current values as ordinates on the axis *OY*. The origin *O* of the coordinates represents the beginning of the short circuit and *OT* its duration.

The rms value of the current during the time interval of *O* to *T* of such a wave is given by the following formula:

$$I_{\text{rms}} = \sqrt{\frac{1}{T}\int_0^T i^2 dt}$$