

An American National Standard

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

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of the
IEEE Power Engineering Society**

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**Institute of Electrical and Electronics Engineers
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Change notice 1

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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.

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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 $\frac{1}{2}$ 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 AIEE¹, 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

¹AIEE (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

$$I_{1961} = \text{interrupting rating in amperes appearing in ANSI C37.6-1961}$$

$$F = \begin{array}{l} 0.915 \text{ for 3 cycle breakers} \\ 0.955 \text{ for 5 cycle breakers} \\ 1.0 \text{ for 8 cycle breakers} \end{array}$$

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 that standards 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:

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

1. Scope

This test procedure summarizes the various tests 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 $\pm 20\%$ 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 $1\frac{1}{2}$ in $\times$ 2 in $\times$ $\frac{1}{8}$ in (4 cm $\times$ 5 cm $\times$ 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 $1.2 \times 50 \mu\text{s}$, 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 $1.2 \times 50 \mu\text{s}$ 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 $1.2 \mu\text{s}$
- 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 $50 \mu\text{s}$

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

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

NOTE — Previous editions of this standard referred only to a $1.5 \times 40 \mu\text{s}$ 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 $1.2 \mu\text{s}$
- 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 $250 \mu\text{s} \pm 50 \mu\text{s}$; to the half voltage value on the tail of the wave will be $2500 \mu\text{s} \pm 1500 \mu\text{s}$. 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

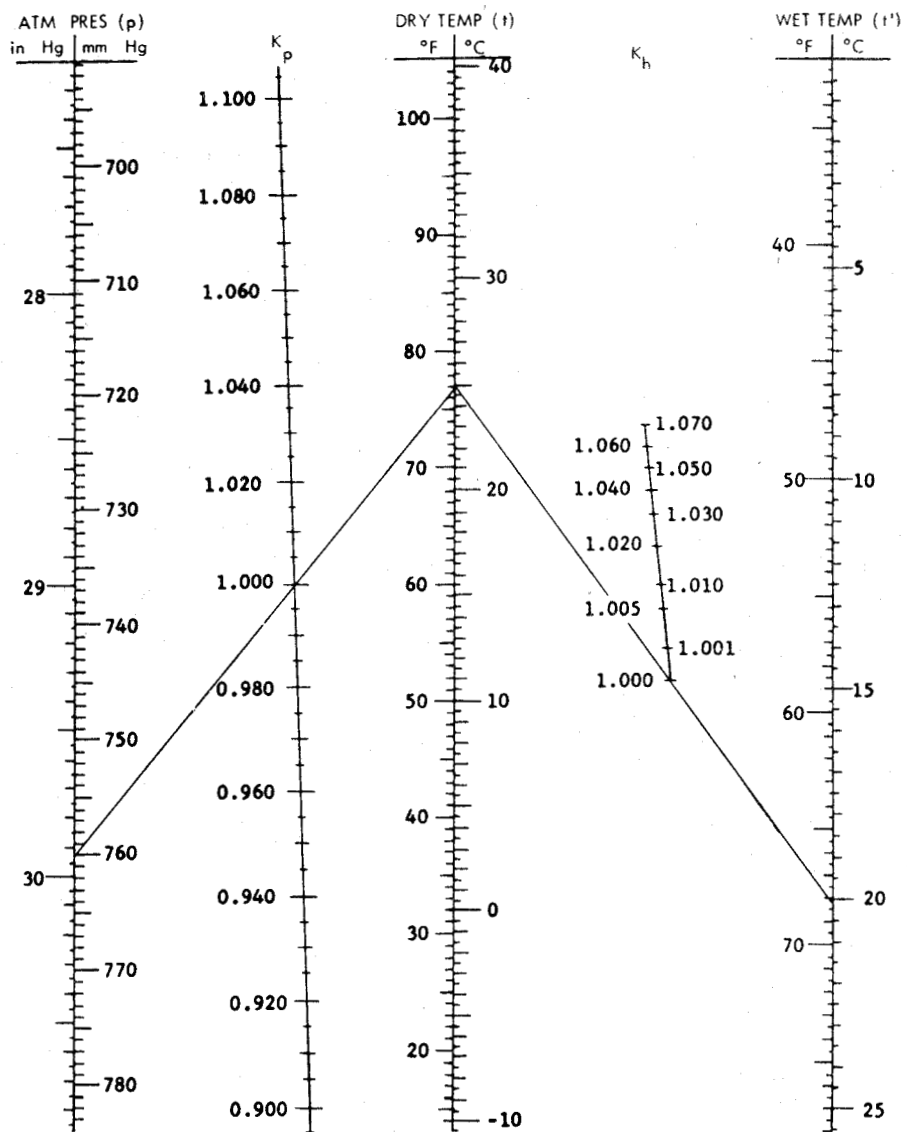
Correction factors for the atmospheric conditions surrounding the external insulation shall be made as follows:

- 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. Rohlf, 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 cycle² 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.

²On a 60 Hz basis.