

IEEE Standard for Ratings and Requirements for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V

IEEE Power and Energy Society

Sponsored by the
Switchgear Committee



IEEE
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USA

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(Revision of
IEEE Std C37.04-1999)

IEEE Standard for Ratings and Requirements for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V

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Switchgear Committee
of the
IEEE Power and Energy Society

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Abstract: The rating structure for all high-voltage circuit breakers, which include all voltage ratings above 1000 V ac and comprise both indoor and outdoor types, is covered in this standard. Preferred ratings are also provided. Typical circuit breakers covered by these standards have maximum voltage ratings ranging from 4.76 kV through 800 kV, and continuous current ratings of 600 A, 1200 A, 2000 A, 3000 A, and 4000 A associated with the various maximum voltage ratings. The rating structure establishes the basis for all assigned ratings, including continuous current, insulation capability (formerly dielectric withstand voltages), short-circuit current, transient recovery voltage, and capacitor switching, plus associated capabilities such as mechanical endurance, load current, and out-of-phase switching. Generator circuit breakers are covered by IEC/IEEE Std 62271-37-013.

Keywords: capacitive current switching, IEEE C37.04™, indoor, insulation capability, interrupting time, mechanical endurance, outdoor, operating duty, power frequency, ratings, related capabilities, short-circuit current, short-line fault, transient recovery voltage

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Introduction

This introduction is not part of IEEE Std C37.04-2018, IEEE Standard for Ratings and Requirements for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V.

In 1964, consolidated standards for circuit breakers rated on a symmetrical current basis were published to take the place of standards established on the total current basis of rating. This revision was undertaken to update the standard to reflect today's circuit breaker technology and application on modern power systems. The revision also continues harmonization with IEC 62271-100, a process that first began in 1951.

This revision includes the changes introduced into capacitive switching ratings and harmonization of TRV requirements of amendments 1 and 2 to IEEE Std C37.04-1999, IEEE Std C37.04a™-2003, and IEEE Std C37.04b™-2008 as well as all corrigenda and errata. The major change in this edition of IEEE Std C37.04 is the incorporation of the preferred ratings values from IEEE Std C37.06™-2009 [B24] into this document. With the approval of this edition of IEEE Std C37.04™-1999 [B23], IEEE Standards Association Standards Board action will withdraw IEEE Std C37.06-2009.

This revision does not make major changes to requirements that have been in practice. Revisions have been made to incorporate information that was offered to IEEE by the NEMA SG4 (High-Voltage Circuit Breakers) technical committee. With some exceptions, this new material has been incorporated essentially as received from NEMA. The areas covered by the NEMA material include new definitions related to pressure systems and noise, new requirements for flat terminals, ground terminals, additional requirements for various operating mechanisms, enclosures, wiring, noise, X-radiation for vacuum interrupters, current transformers (and their connections) (including free-standing current transformers), undervoltage trip devices, and specialized applications.

The reader is reminded that these requirements do not apply retroactively. Circuit breakers designed, tested, and manufactured to earlier versions of the standards must be applied in accordance with the versions of the standards that were in effect when the specific circuit breaker was manufactured.

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IEEE Standard for Ratings and Requirements ~~Rating Structure~~ for AC High-Voltage Circuit Breakers with Rated Maximum Voltage Above 1000 V

1. Scope

This standard applies to ~~establishes a symmetrical current rating structure and construction requirements for all indoor and outdoor types of~~ ac high-voltage circuit breakers with rated nominal voltage above 1000 V. It establishes a rating structure, preferred ratings, construction and functional component requirements.

This standard encompasses the following:

- ~~is only applicable to~~ Three pole circuit breakers used in three-phase systems ~~and~~
- Single pole circuit breakers used in single-phase systems
- Attachments for these circuit breakers, such as bushings, current transformers, interlocks, shunt trips, etc., and auxiliary equipment sold with the circuit breakers such as closing relays and structural steel supports.

This standard does not cover circuit breakers used at frequencies other than 50 Hz or 60 Hz, or generator circuit breakers that are covered in IEC/IEEE Std 62271-37 ~~C37.013~~ [B14] ~~1997~~.

2. Normative references

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

~~This standard shall be used in conjunction with the following publications. When a standard is superseded by an approved revision, the revision shall apply.~~

ANSI C37. ~~85 06-1997~~, American National Standard for Switchgear — Alternating-Current AC High-Voltage Power Vacuum Interrupters—Safety Requirements for X-Radiation Limits.¹ ~~Circuit Breakers Rated on a Symmetrical Current Basis Preferred Ratings and Related Required Capabilities.~~¹

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

~~ANSI C84.1-1989, American National Standard for Voltage Ratings for Electric Power Systems and Equipment (60 Hz).~~²

ASME ~~1998~~ Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels. ²³

ASME ~~1998~~ Boiler and Pressure Vessel Code, Section X, Fiber-Reinforced Plastic Pressure Vessels.

ASTM D2472, Standard Specification for Sulfur Hexafluoride.³

ASTM D3487, Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus.

IEC 60529, Degrees of Protection Provided by Enclosures (IP Code).⁴

¹ ANSI publications are available from the American National Standard Institute (<http://www.ansi.org>).

² ASME publications are available from the American Society of Mechanical Engineers (<http://www.asme.org/>).

³ ASTM publications are available from the American Society for Testing and Materials (<http://www.astm.org/>).

⁴ IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch/>) and the American National Standards Institute (<http://www.ansi.org>).

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

[IEC 62271-100:2008, High-voltage switchgear and controlgear – Part 100: Alternating-current circuit breakers.](#)

[IEC 62271-100:2008/AMD1:2012, Amendment 1 – High-voltage switchgear and controlgear – Part 100: Alternating-current circuit breakers.](#)

[IEC 62271-100:2008/AMD2:2017, Amendment 2 – High-voltage switchgear and controlgear – Part 100: Alternating-current circuit breakers.](#)

[IEC/TS 62271-304, High-voltage switchgear and controlgear – Part 304: Design classes for indoor enclosed switchgear and controlgear for rated voltages above 1 kV up to and including 52 kV to be used in severe climatic conditions.](#)

~~IEC 60056 Ed. 4.0b: 1987, High voltage alternating current circuit breakers.⁴~~

IEEE Std 1TM ~~1986 (Reaff 1992)~~, IEEE [Recommended Practice – Standard](#) General Principles for Temperature Limits in the Rating of [Electrical](#) ~~Electric~~ Equipment and for the Evaluation of Electrical Insulation.^{5,6}

[IEEE Std 4TM, IEEE Standard for High-Voltage Testing Techniques.](#)

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

~~IEEE Std 1312 1993, IEEE Standard Preferred Voltage Ratings for Alternating Current Electrical Systems and Equipment Operating at Voltages Above 230 kV Nominal (formerly C92.2).~~

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⁴ ~~IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH 1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.~~

IEEE Std C37.09TM-1999, IEEE Standard Test [Procedures](#) ~~Procedure~~ for AC High-Voltage Circuit Breakers [with Rated Maximum Voltage Above 1000 V](#). ~~on a Symmetrical Current Basis.~~

IEEE Std C37.010TM-1999, IEEE Application Guide for AC High-Voltage Circuit Breakers [> 1000 Vac](#) Rated on a Symmetrical Current Basis.

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

IEEE Std C37. [017TM](#) ~~013-1997~~, IEEE Standard for [Bushings for AC](#) High-Voltage [\[over 1000 V \(ac\)\]](#) ~~Generator~~ Circuit Breakers [and Gas-Insulated Switchgear](#) ~~Rated on a Symmetrical Current Basis.~~

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

IEEE Std C37.11TM-1997, IEEE Standard Requirements for Electrical Control for [AC](#) High-Voltage [\(>1000 V\)](#) Circuit Breakers ~~Rated on a Symmetrical Current Basis.~~

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

IEEE Std C37. [20.3TM](#) ~~24-1986 (Reaff 1998)~~, IEEE [Standard](#) ~~Guide~~ for [Metal-Enclosed Interrupter Switchgear \(1 kV–38 kV\)](#). ~~Evaluating the Effect of Solar Radiation on Outdoor Metal-Enclosed Switchgear.~~

IEEE Std C37. [20.10TM](#) ~~100-1992~~, IEEE Standard Definitions for [AC \(52 kV and below\) and DC \(3.2 kV and below\)](#) ~~Power~~ Switchgear [Assemblies](#).

IEEE Std [C37.100.1-2007TM](#) ~~C57.19.00-1991 (Reaff 1997)~~, IEEE Standard [of Common](#) ~~General~~ Requirements ~~and Test Procedures~~ for [High-Voltage Out-door](#) Power [Switchgear Rated Above 1000 V](#). ~~Apparatus Bushings.~~

[IEEE Std C37.100.5TM, IEEE Standard for Definitions of High-Voltage Circuit Breakers Above 1000 Vac and 3200 Vdc, and Reclosers and Other Distribution Equipment from 1000 Vac to 38 000 Vac.](#)

[IEEE Std C57.13TM, IEEE Standard Requirements for Instrument Transformers.](#)

[IEEE Std C57.106TM, IEEE Guide for Acceptance and Maintenance of Insulating Mineral Oil in Electrical Equipment.](#)

[ISO 7000, Graphical symbols for use on equipment—Registered symbols.](#)⁷

[NEMA CC 1, Electric Power Connection for Substations.](#)⁸

[NEMA 107, Methods of Measurement of Radio Influence Voltage \(RIV\) of High-Voltage Apparatus.](#)

~~IEEE Std C57.19.01-1991 (Reaff 1997), IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.~~

~~NEMA SG 4 1995, Alternating Current High Voltage Circuit Breakers.~~⁶

3. Definitions, acronyms, and abbreviations

3.1 Definitions

[For the purposes of this document, the following terms and definitions apply. The IEEE Standards Online Dictionary should be referenced for terms not defined in this clause.](#)⁹

The terms and definitions applicable to this standard and to the related standards for ac high-voltage circuit breakers shall be in accordance with IEEE Std C37.20.10 and IEEE Std C37.100.5-1992. These definitions are not intended to embrace all possible meanings of the terms. They are intended solely to establish the meanings of terms used in power switchgear.

air system (for pneumatic operating mechanism): An assembly of parts and devices that provide compressed air for the operation of a circuit breaker or circuit breaker operating mechanism.

amplitude factor (of transient recovery voltage): The ratio of the highest peak of the transient recovery voltage to the peak value of the normal-frequency recovery voltage.

⁷ ISO publications are available from the International Organization for Standardization (<http://www.iso.org/>) and the American National Standards Institute (<http://www.ansi.org/>).

⁸ NEMA publications are available from the National Electrical Manufacturers Association (<http://www.nema.org/>).

⁹ IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

⁶ ~~NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (global.ihs.com/).~~

NOTE—In tests made under one condition to simulate duty under another, as in single-phase tests made to simulate duty on three-phase ungrounded faults, the amplitude factor is expressed in terms of the duty being simulated.¹⁰

cable charging current: Current delivered to charge the parasitic capacitance surrounding an unloaded cable.

cable system: A system in which the supply side of the circuit breaker is connected with 100 m or more of cables or the equivalent capacitance.

circuit breaker class C0: Circuit breaker with unspecified probability of restrike when switching capacitive current under rated conditions. *Syn:* **class C0**.

circuit breaker class C1: Circuit breaker with low probability of restrike when switching capacitive current under rated conditions. *Syn:* **class C1**.

circuit breaker class C2: Circuit breaker with very low probability of restrike when switching capacitive current under rated conditions. *Syn:* **class C2**.

circuit breaker class M1: Circuit breaker with normal mechanical endurance. *Syn:* **class M1**.

circuit breaker class M2: Frequently operated circuit breaker for special service requirements and designed so as to require only limited maintenance. *Syn:* **class M2**.

circuit breaker class S1: Circuit breaker with rated maximum voltage less than 100 kV intended to be used in a cable system. *Syn:* **class S1**.

circuit breaker class S2: Circuit breaker with rated maximum voltage less than 100 kV intended to be used in a line system. *Syn:* **class S2**.

close and latch: The capability of a switching device to close (allow current flow), and immediately thereafter, latch (remain closed), and conduct a specified current through the device under specified conditions.

contact position indicator: A device that is located at or near the operating mechanism to indicate whether the main contacts are in the closed or open position.

¹⁰ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

dc component (of a total current): A unidirectional (dc) component which constitutes the asymmetry of the total current. The unidirectional component can be of either polarity, but will not change polarity, and will decrease at some predetermined rate.

definite-purpose circuit breaker: A circuit breaker that has been designed, tested, and rated in accordance with general-purpose circuit breaker requirements of applicable standards and that has been designed, tested, and rated in accordance with the requirements of one or more specific performance requirements.

hydraulic system (for hydraulically operated mechanisms): An assembly of parts and devices that provides for the control of hydraulic energy for the operation of a circuit breaker or circuit breaker operating mechanism.

impulse withstand voltage: The crest value of an impulse that, under specified conditions, can be applied without causing a disruptive discharge.

initial transient recovery voltage (ITRV): A component of the transient recovery voltage that appears in the very short time immediately after current interruption. The ITRV is a result of traveling waves on the conductors adjacent to the circuit-switching device.

line-closing switching-surge maximum voltage: The maximum transient peak voltage to ground measured on a transmission line during a switching surge that results from energizing that line.

line system: A system in which the supply side of the circuit breaker is connected to overhead lines with less than 100 m of cables.

NOTE—Because the terms ‘line system’ and ‘cable system’ within this standard are only used for the selection of a class S1 or class S2 circuit breaker, a line system may be classified as a cable system regardless of the physical length of cables if the required TRV capabilities is within the capabilities of a class S1 circuit breaker.

noise (continuous): The sound level above ambient produced by vibrations, fans, and blowers.

noise (impulse): The sound level above ambient produced by a closing, opening, or combination of closing and opening operations.

noise (intermittent): The sound level above ambient produced by periodic operation (occurring one or more times per week) of such devices as compressors, hydraulic pumps, compressor unloader exhausts, air regulator valves, and air drains.

operating mechanism (of a switching device): The part of the mechanism that actuates all the main circuit contacts of the switching device either directly or by the use of pole-unit mechanisms.

pressure switch (alarm): A switch that operates on given values, or on a given rate of change to send an alarm signal when the pressure that is being monitored has reached the set point.

pressure switch (lockout): A switch that prevents the electrical operation of a circuit breaker if the operating pressure is below a predetermined value.

reclosing time (of a circuit breaker): The interval between the time when the actuating quantity of the release (trip) circuit reaches the operating value (the breaker being in the closed position) and the reestablishment of the circuit on the primary arcing contacts on the reclosing stroke.

shunt release (trip): A release energized by a source of voltage.

stroke (of a circuit breaker): The distance covered by the moving contacts between the fully closed and fully opened (at rest) positions.

symmetrical component (ac component) (of a total current): That portion of the total current that constitutes the symmetry.

total (asymmetrical) current: The combination of the symmetrical component and the dc component of the current.

transient recovery voltage (TRV): The voltage transient that occurs across the terminals of a pole of a switching device upon interruption of the current.

NOTE—TRV is the difference between transient voltages to ground occurring on the terminals. The term transient recovery voltage is usually designated as TRV, and may refer to inherent TRV, modified inherent TRV, or actual TRV as defined elsewhere. In a multipole switching device, the term is usually applied to the voltage across the first pole to interrupt. For switching devices having several interrupting units in series, the term may be applied to the voltage across units or groups of units.

3.2 Acronyms and abbreviations

<u>ASME</u>	<u>American Society of Mechanical Engineers</u>
<u>AWG</u>	<u>American wire gauge</u>
<u>BC</u>	<u>rated capacitor bank breaking current</u>
<u>CC</u>	<u>rated cable charging capacitive breaking current</u>
<u>C_n</u>	<u>total time of exposure at a specified sound level</u>
<u>d</u>	<u>peak factor, used in short-line fault TRV calculations</u>
<u>f</u>	<u>frequency (Hz)</u>
<u>f_{bb}</u>	<u>back-to-back capacitor inrush making current frequency</u>
<u>f_i</u>	<u>multiplying factor used in calculation of u_i</u>
<u>f_r</u>	<u>rated power frequency</u>
<u>GIS</u>	<u>gas-insulated substation (syn: gas-insulated switchgear)</u>
<u>I_r</u>	<u>rated continuous (normal) current</u>
<u>I_{sc}</u>	<u>rated short-circuit current</u>
<u>I_t</u>	<u>total current</u>
<u>I_{test}</u>	<u>actual achieved current during a type test</u>
<u>ITRV</u>	<u>initial transient recovery voltage</u>
<u>k_{af}</u>	<u>amplitude factor, used in calculating TRV parameters</u>
<u>K_{pp}</u>	<u>first-pole-to-clear factor</u>
<u>LC</u>	<u>rated line charging capacitive breaking current</u>
<u>OP</u>	<u>out-of-phase (switching conditions)</u>
<u>OP1</u>	<u>first test duty for out-of-phase switching conditions type test</u>
<u>OP₂</u>	<u>second test duty for out-of-phase switching conditions type test</u>

<u>PD</u>	<u>partial discharge</u>
<u>pu</u>	<u>per unit</u>
<u>RRRV</u>	<u>rate of rise of recovery voltage</u>
<u>s</u>	<u>RRRV factor, used in short-line fault TRV calculations</u>
<u>SLF</u>	<u>short-line fault</u>
<u>t'</u>	<u>time to reach u', used in describing TRV envelope</u>
<u>t_1</u>	<u>time to reach u_1, used in describing TRV envelope</u>
<u>T10</u>	<u>terminal fault test duty at 10% of I_{SC} (rms)</u>
<u>T100a</u>	<u>terminal fault test duty at 100% of I_t (asymmetrical value, rms)</u>
<u>T100s</u>	<u>terminal fault test duty at 100% of I_{SC} (symmetrical value, rms)</u>
<u>t_2</u>	<u>time to reach u_c, used in describing TRV in four parameter envelope</u>
<u>t_3</u>	<u>time to reach u_c, used in describing TRV in two parameter envelope</u>
<u>T30</u>	<u>terminal fault test duty at 30% of I_{SC} (rms) T60 terminal fault test duty at 60% of I_{SC} (rms)</u>
<u>t_d</u>	<u>time delay of the start of the delay line used in describing TRV envelope</u>
<u>t_{dL}</u>	<u>line side time delay, used in short-line fault TRV calculations</u>
<u>t_i</u>	<u>time to u_i of ITRV</u>
<u>Ti, Tn</u>	<u>total time of exposure permitted at a specified sound level</u>
<u>TLF</u>	<u>transformer limited fault</u>
<u>t_{min}</u>	<u>minimum mechanical reclose time</u>
<u>t_r</u>	<u>reclosing time</u>
<u>t'_r</u>	<u>second reclosing time</u>
<u>TRV</u>	<u>transient recovery voltage</u>
<u>u'</u>	<u>reference voltage of delay line used in describing TRV envelope</u>

u_1	first reference voltage used in describing TRV envelope
U_{BD}	source side TRV, used in short-line fault TRV calculations
u_c	second reference voltage used in describing TRV envelope
U_{CD}	line side TRV, used in short-line fault TRV calculations
U_{CD0}	initial line side TRV, used in short-line fault TRV calculations
U_{CDp}	peak line side TRV, used in short-line fault TRV calculations
U_d	test level for rated power-frequency withstand voltage for GIS u_i reference voltage of ITRV
U_n	line-to-neutral voltage
U_p	test level for lightning impulse withstand voltage for GIS
U_r	rated maximum voltage (see also V)
U_s	test level for phase-to-ground switching impulse withstand voltage for GIS
V	rated maximum voltage (see also U_r)
Y	permissible tripping delay
Z	surge impedance
Z_b	bus surge impedance
ω	angular frequency (rad/s) corresponding to the frequency f

4. Service conditions

4.1 Usual service conditions

4.1.1 Indoor circuit breakers

[The normal service conditions for indoor switchgear are as follows:](#)

- a) [The ambient air temperature does not exceed 40 °C and its average value, measured over a period of 24 h does not exceed 35 °C.](#)

- b) The ambient air temperature does not drop below -5°C .
- c) There is no influence from solar radiation.
- d) The altitude does not exceed 1000 m above sea level.
- e) The ambient air is not polluted by dust, smoke, corrosive and/or flammable gases, vapors or salt and would be considered as having a site pollution severity class (SPS) “very light” according to Table C.1.
- f) The conditions of humidity are as follows:
 - 1) The average value of the relative humidity, measured over a period of 24 h, does not exceed 95%.
 - 2) The average value of the water vapor pressure, over a period of 24 h, does not exceed 2.2 kPa.
 - 3) The average value of the relative humidity, over a period of one month, does not exceed 90%.
 - 4) The average value of the water vapor pressure, over a period of one month, does not exceed 1.8 kPa.

NOTE 1—Condensation can be expected where sudden temperature changes occur in periods of high humidity.

NOTE 2—High humidity may also be due to ground level rainwater or for underground applications, from incoming cable raceways connected to switchgear.

- g) Vibration due to causes external to the switchgear or earth tremors do not exceed vibrations caused by operation of the switchgear itself.

~~Circuit breakers conforming to this standard shall be suitable for operating at their standard ratings~~

- ~~a) Where the temperature of the ambient is not above 40°C or below -30°C ;~~
- ~~b) Where the altitude is not above 1000 m;~~
- ~~e) Where the effect of solar radiation is not significant (the principles stated in IEEE Std C37.24-1986 may be used for guidance);~~

- d) ~~Where the seismic conditions do not exceed those defined in 6.3.1.3; and~~
- e) ~~Where unusual conditions as listed~~

4.1.2 Outdoor circuit breakers

The normal service conditions for outdoor switchgear are as follows:

- a) The ambient air temperature does not exceed 40 °C and its average value, measured over a period of 24 h, does not exceed 35 °C.
- b) The ambient air temperature does not drop below –30 °C.
- c) Solar radiation does not exceed a level of 1044 W/m². During periods above this intensity, the effects of solar radiation may be significant.

NOTE—Details on evaluating the effects of solar radiation are in IEEE Std C37.24 [B29].

- d) The altitude does not exceed 1000 m above sea level.
- e) The ambient air may be polluted by dust, smoke, corrosive gas vapors, or salt. The pollution does not exceed the site pollution severity class (SPS) “light” according to Table C.1.
- f) Ice coating does not exceed 20 mm.
- g) The wind speed does not exceed 40 m/s (144 km/h) (90 mi/h).
- h) Condensation or precipitations may occur.
- i) Vibration due to causes external to the switchgear or earth tremors do not exceed vibrations caused by operation of switchgear itself.

4.2 Unusual service conditions

4.2.1 General

When high voltage switchgear is expected to be used under conditions that are different from the normal service conditions given in 4.1, the user's requirements should refer to the information in 4.2.2 through 4.2.7. Unusual service conditions are also discussed listed in IEEE Std C37.010-1999. Such conditions should be brought to the attention of those responsible for the application, manufacture, and operation of the equipment, and the guidelines for application given in IEEE Std C37.010 should be followed. Any requirements outside of the usual conditions or those conditions mentioned in IEEE Std C37.010 shall be specified by the end user-1999-should be followed.

NOTE—Appropriate action should also be taken to ensure proper operation of other components (e.g., relays, control power transformers) under such conditions.

4.2.2 Altitude

For installations at an altitude higher than 1000 m, refer to IEEE Std C37.010.

4.2.3 Exposure to pollution

For outdoor applications, ambient air that may be polluted by dust, smoke, corrosive gas, vapors, or salt at a level that exceeds "light" pollution level as defined by Annex C is considered to be a special condition.

For indoor applications, ambient air that may be polluted by dust, smoke, corrosive gas, vapors, or salt at a level that exceeds severity class (SPS) "very light" as defined by Table C.1 should be classified as "light," "medium," "heavy," or "very heavy" as defined by Annex C.

NOTE—More information about exposure to pollution can be found in Annex C.

For indoor applications up to and including 52 kV, IEC/TS 62271-304 applies.

4.2.4 Temperature and humidity

For installation in a location where the ambient temperature can be outside the normal service condition range stated in 4.1.1 and 4.1.2, the ranges of minimum and maximum temperature to be specified should be as follows:

- a) –50 °C to +40 °C for extremely cold climates
- b) –40 °C to +40 °C for very cold climates
- c) –30 °C to +40 °C for cold climates (for indoor circuit breakers, normal for outdoor)
- d) –15 °C to +40 °C for moderate climates (for indoor circuit breakers)
- e) –5 °C and +55 °C for very hot climates
- f) –15 °C and +55 °C for hot and dry desert regions

NOTE—IEC has adopted a minimum temperature of –25 °C for normal outdoor service conditions and uses the IEEE normal service range of –30 °C to +40 °C as a special condition for cold climates.

4.2.5 Exposure to abnormal vibration, shock, or tilting

Standard switchgear is designed for mounting on substantially level structures free from excessive vibration, shock, or tilting. Where any of these standard conditions may not exist, the requirements for the particular application should be specified by the user.

For installations where earthquakes are likely to occur, the severity level according to a relevant standard or specification should be specified by the user.

NOTE—Relevant standards for seismic evaluation include: IEEE Std 693 [B21], IEEE Std C37.81 [B31], IEC 62271-300 [B17], IEC 62271-207 [B13], and IEC 62271-210 [B19].

Other unusual forms of vibration such as close proximity to mine blasting or mobile applications should be identified.

4.2.6 Wind speed

If the wind speed is expected to be in excess of the normal service wind speed, the requirements for the particular application should be specified by the user.

NOTE—Refer to IEEE Std C37.30.2 [B32] for additional information on wind loading and wind speed charts.

4.2.7 Other parameters

Any other unusual, or special environmental, operational, or other conditions prevailing at the location where switchgear is to be placed in service should be identified by the user.

NOTE—For other special environmental conditions, the user is referred to IEEE Std C37.010.

5. Descriptions of ratings and capabilities

5.1 General

The rating and capability of a circuit breaker is a designated limit of operating characteristics that is based upon usual service conditions as specified in 4.1. ~~The rating of a circuit breaker shall include the following parameters (for values of~~ Preferred ratings are given in Clause 6. ~~of circuit breakers, see ANSI C37.06-1997):~~

The rating of a circuit breaker shall include the following parameters (as applicable):

- a) Rated maximum voltage
- b) Rated insulation capability
- a) For operation (5.17);
- b) Out-of-phase switching current (5.12), rated maximum voltage (5.1);
- c) Rated power frequency ~~(5.2);~~
- d) Rated continuous current ~~(5.3);~~
- e) Rated short-circuit current
- e) ~~Rated dielectric withstand capability (5.4);~~

- f) [Rated capacitive current switching](#)
- g) [Rated out of phase switching current](#)
- h) Rated standard operating duty (standard duty cycle) ~~(5.5);~~
- i) [Rated control voltage](#)
- ~~g) Rated interrupting time (5.6);~~
- ~~h) Rated short-circuit current (5.8);~~
- ~~i) Rated transient recovery voltage (TRV) (5.9);~~
- ~~j) Rated capacitance current switching (5.11)~~
- ~~(NOTE—Definite purpose is an optional rating.);~~
- ~~k) Rated control voltage (5.15);~~
- j) Rated operating pressure for insulation and/or interruption ~~(5.16);~~
- k) Rated operating pressure for mechanical operation ~~(5.17);~~
- l) [Rated operating endurance capabilities](#)
- m) [Rated interrupting time](#)
- ~~n) Out-of-phase switching current capability (5.12) (out-of-phase switching current is an optional rating that may be assigned where applicable).~~

The establishment of a rating and the assignment of it to a circuit breaker in accordance with [this standard](#) ~~these standards~~ implies performance characteristics at least equal to those set forth in the [applicable following](#) ~~subclauses of Clause 5~~. Compliance with these ratings is demonstrated by testing performed in accordance with IEEE Std C37.09-1999 ~~and, where applicable, by ANSI C37.54.1996~~; however, other equivalent or more effective methods of testing are not precluded. [Alternatively](#) ~~Alternately~~, for designs existing prior to the adoption of [this standard](#) ~~these standards~~, the rating can be based on other tests that are judged to be equally effective on the basis of the experience gained from previous design or development tests or by service performance experience.

~~NOTE—~~It shall be recognized that proper maintenance is required to ensure these ratings throughout the life of the circuit breaker.

5.2 Rated maximum voltage (V) or (Ur)

The rated maximum voltage of a circuit breaker is the highest rms phase-to-phase voltage for which the circuit breaker is designed, and is the upper limit for operation. Rated maximum voltage has the same meaning as maximum system voltage rating referred to in ANSI C84.1 ~~[B3]-1989 and IEEE Std 1312-1993.~~

Preferred ratings are given in Clause 6.

5.3 Rated insulation ~~dielectric withstand~~ capability

The rated insulation ~~The rated dielectric withstand~~ capability of a circuit breaker is its voltage withstand capability with specified magnitudes and waveshapes of voltage applied under specified conditions. Preferred ratings are given in Clause 6 ~~The circuit breaker withstand capabilities are demonstrated by compliance with the applicable test requirement in IEEE Std C37.09-1999.~~

The rated insulation ~~dielectric withstand~~ capability of a circuit breaker shall include the following:

- a) Dry power frequency withstand voltage for indoor circuit breakers;
- b) Dry and wet (where applicable) power frequency withstand voltages for outdoor circuit breakers;
- c) Dry lightning impulse withstand voltage;
- d) Dry chopped wave impulse withstand voltage (where applicable); ~~and~~
- e) Dry and wet switching impulse withstand voltage (where applicable)

In addition, the insulation of the interrupters and associated resistors or capacitors (or both) shunting the primary arcing contacts of a circuit breaker shall not be damaged when impulse voltages of specified values are applied across the interrupters and the associated shunting devices, while the primary arcing contacts are open. ~~(See IEEE Std 4-1978.)~~

5.3.1 Insulation ~~Dielectric withstand~~ capability of external insulation

External insulation shall conform to the performance requirements of this standard, except as follows: ~~noted in the following paragraph.~~

- Bushings ~~classified as outdoor apparatus bushings~~ shall conform to the requirements of IEEE Std C37.017, ~~C57.19.00-1991 and IEEE Std C57.19.01-1991. Other bushings shall conform to the performance requirements of this standard.~~
- Wet dielectric tests on bushings may not be substituted for wet dielectric tests on bushings installed on a circuit breaker, ~~because a wet dielectric test on such a breaker affords no additional information on adequacy of the design of the interior of the circuit breaker beyond what is revealed by the dry power frequency and impulse tests.~~

Requirements for the rated insulation ~~dielectric withstand~~ capability of the external insulation of ac high-voltage circuit breakers are given in 6.2 ~~ANSI C37.06-1997~~.

5.3.2 Rated power frequency withstand voltage

5.3.2.1 Dry withstand voltage

The rated power frequency dry withstand voltage is the rms voltage that a circuit breaker in new condition shall be capable of withstanding for 1 min when tested under specified conditions (see IEEE Std C37.09-~~1999~~).

5.3.2.2 Wet withstand voltage

The rated power frequency wet voltage withstand is the rms voltage that an outdoor circuit breaker or external components (such as supporting insulating structures) in new condition shall be capable of withstanding for 10 s when tested under specified conditions (see IEEE Std C37.09-~~1999~~).

5.3.3 Rated lightning impulse withstand voltage

The rated lightning impulse withstand voltage is the peak value of a standard $1.2 \mu\text{s} \times 50 \mu\text{s}$ impulse voltage wave, as defined in IEEE Std 4-~~1978~~, that a circuit breaker in a new condition shall be capable of withstanding when tested under specified conditions (see IEEE Std C37.09-~~1999~~).

NOTE—The rated values of lightning impulse voltages for circuit breakers have the probability of [flashover to ground](#) ~~external flashover~~ of 10% or less. As a minimum, this is demonstrated by the test requirements of IEEE Std C37.09-~~1999~~.

5.3.4 Lightning impulse test voltage for interrupter and resistors

~~Outdoor~~—Circuit breakers having a rated maximum voltage of 15.5 kV and above, having isolating gaps in series with interrupting gaps, or additional gaps in the resistor or capacitor circuits, shall be capable of withstanding a standard $1.2\text{ }\mu\text{s} \times 50\text{ }\mu\text{s}$ lightning impulse test voltage wave when tested under specified conditions (see IEEE Std C37.09-~~1999~~).

5.3.5 Rated chopped wave impulse withstand voltage

The rated chopped wave impulse withstand voltage is applicable to [line-connected](#) ~~outdoor~~ circuit breakers [as shown in Table 6.](#) ~~of 15.5 kV and above.~~ The rated chopped wave impulse withstand voltage is the peak value of a standard lightning impulse voltage higher than the rated full wave impulse withstand voltage that a circuit breaker in new condition shall be capable of withstanding for a specified time, from the start of the wave at virtual time zero until flashover of a rod gap or coordinating gap occurs, when tested under specified conditions [\(see IEEE Std C37.09\). Chopped wave impulse withstand is not a required rating for class S1 circuit breakers.](#)

5.3.6 Rated switching-impulse withstand voltage

The rated switching-impulse withstand voltage is applicable to ~~outdoor~~-circuit breakers having a rated maximum voltage of 362 kV and above. The rated switching-impulse withstand voltage is the peak value of the standard $250\text{ }\mu\text{s} \times 2500\text{ }\mu\text{s}$ switching-impulse voltage wave that a new circuit breaker shall be capable of withstanding without puncture or damage under both wet and dry conditions. This rating recognizes the circuit breaker's ability to withstand those transient overvoltages associated with and created by the switching of open, loaded, or faulted lines and equipment.

Switching-impulse voltage surges can take many forms—unidirectional, oscillatory, or both simultaneously. At the rated switching-impulse withstand voltage, the circuit breaker ~~has~~ ~~shall have~~ the probability of external flashover to ground of 10% or less. [Clause 6](#) ~~ANSI C37.06-1997~~ lists the required values of rated switching-impulse withstand voltages for the circuit breaker open and closed positions, and it also lists the required dielectric test values for circuit breakers supplied in gas-insulated substations.

5.4 Rated power-frequency (f_r)

The rated power frequency of a circuit breaker is the frequency at which it is designed to operate. Standard frequencies are 50 Hz and 60 Hz. Applications at other frequencies (*e.g.*, 16 2/3 Hz ~~or~~ 25 Hz) should receive special consideration (see IEEE Std C37.010-~~1999~~).

5.5 Rated continuous (normal) current (I_r)

The rated continuous current of a circuit breaker is the established limit of current in rms amperes at rated power frequency that it shall be required to carry continuously without exceeding any of the limitations designated in [5.5.1](#) ~~5.3.1~~ and [5.5.2](#) ~~5.3.2~~. For rated continuous currents, refer to the tables of preferred ratings in [Clause 6](#) ~~ANSI C37.06-1997~~.

5.5.1 Conditions of continuous current rating

The conditions on which continuous current ratings are based are as follows:

- a) Circuit breakers are used under the usual service conditions defined in 4.1.
- b) Current ratings shall be based on the total temperature limits of the materials used for circuit breaker parts. A temperature rise reference is given to permit testing at reduced ambient.
- c) Circuit breakers designed for installation in enclosures shall meet these ratings when in their proper enclosure and based on a 40 °C ambient temperature outside the enclosure.
- d) Outdoor circuit breakers and class S1 circuit breakers not intended for use in enclosures shall be rated based on a 40 °C ambient temperature.

A circuit breaker is considered to be capable of being loaded above its continuous current rating as limited by IEEE Std C37.010 depending upon circuit breaker pre-loading, duration of the load, ambient temperature and the value of the thermal time constant determined from circuit breaker continuous current design tests.

5.5.2 Temperature limits on insulating materials, connections and surfaces

Table 1 provides limitations on the maximum permitted total temperature (with rise above normal ambient condition of 40 °C provided for convenience) for circuit breakers.

~~5.3.2 Temperature limitations~~

~~See IEEE Std 1-1986.~~

~~5.3.2.1 Limitations on insulating material~~

~~The temperatures of materials used to insulate the main power circuit conducting parts from phase-to-ground, from phase to phase, or from terminal to terminal of an open circuit breaker shall be limited to the values listed in Table 1.~~

~~Where outdoor apparatus bushings within the scope of IEEE Std C57.19.00-1991 and IEEE Std C57.19.01-1991 are used, the temperature limits in Table 1 do not apply to the bushings.~~

**Table 1—Limits of temperature and temperature rise ~~for various parts~~
and materials of circuit breakers^a**

Nature of the part and material ^{a, b, c}		Total temperature (°C)	Temperature rise above ambient (°C)
1. Material used as insulation and metal parts in contact with insulation of these classes ^d	O	90	50
	A	105	65
	B	130	90
	F	155	115
	H	180	140
	C	220	180
	Oil ^e	90	50
2. Contacts ^f	Bare copper and bare-copper alloy		
	— in reactive gases(RG) ^g	75	35
	— in non-reactive gases(NRG) ^g	105	65
	— in oil	80	40
	Silver-coated or nickel-coated ^h		
	— in reactive gases(RG) ^g	105	65
	— in non-reactive gases(NRG) ^g	105	65
	— in oil	90	50
	Tin-coated ^h		
	— in reactive gases(RG) ^g	90	50
	— in non-reactive gases(NRG) ^g	90	50
	— in oil	90	50
3. Connections, bolted or the equivalent ⁱ	Bare-copper, bare-copper alloy, bare aluminum or bare-aluminum alloy		
	— in reactive gases(RG) ^g	90	50
	— in non-reactive gases(NRG) ^g	115	75
	— in oil	100	60
	Silver-coated or nickel-coated		
	— in reactive gases(RG) ^g	115	75
	— in non-reactive gases(NRG) ^g	115	75
	— in oil	100	60
	Tin-coated		
	— in reactive gases(RG) ^g	105	65
	— in non-reactive gases(NRG) ^g	105	65
	— in oil	100	60
4. All other contacts or connections made of bare metals or coated with other materials		Footnote ^j	Footnote ^j
5. Terminals for the connection to external conductors by screws or bolts ^k	Bare-conductor	90	50
	Silver-coated, nickel-coated, tin-coated	105	65
	Other coatings	Footnote ^j	Footnote ^j
6. Metal parts acting as springs		Footnote ^l	Footnote ^l
7. Accessible surfaces	External surfaces handled by the operator in the normal course of his or her duties	50	10
	External surfaces accessible by the operator in the normal course of his or her duties	70	30
	External surfaces not accessible to an operator in the normal course of his or her duties	110	70

(New)

Nature of the part and material (NOTES 1, 2, 3)		Total temperature (°C)	Temperature rise at ambient (40°C)
1. Material used as insulation and metal parts in contact with insulation of these classes (NOTE 4)	O	90	50
	A	105	65
	B	130	90
	F	155	115
	H	180	140
	C	220	180
	Oil (NOTE 5)	90	50
2. Contacts (NOTE 6)	Bare copper and bare-copper alloy		
	— in air	75	35
	— in SF ₆ (sulfurhexafluoride)	105	65
	— in oil	80	40
	Silver-coated or nickel-coated (NOTE 7)		
	— in air	105	65
	— in SF ₆	105	65
	— in oil	90	50
	Tin-coated (NOTE 7)		
	— in air	105	65
	— in SF ₆	105	65
	— in oil	90	50
3. Connections, bolted or the equivalent (NOTE 8)	Bare-copper, bare-copper alloy, bare aluminum or bare-aluminum alloy		
	— in air	90	50
	— in SF ₆	115	75
	— in oil	100	60
	Silver-coated or nickel-coated		
	— in air	115	75
	— in SF ₆	115	75
	— in oil	100	60
	Tin-coated		
	— in air	105	65
	— in SF ₆	105	65
	— in oil	100	60
4. All other contacts or connections made of bare metals or coated with other materials		(NOTE 9)	(NOTE 9)
5. Terminals for the connection to external conductors by screws or bolts (NOTE 10)	Bare-copper and bare-copper alloy	90	50
	Silver-coated, nickel-coated, tin-coated	105	65
	Other coatings	(NOTE 9)	(NOTE 9)
6. Metal parts acting as springs		(NOTE 11)	(NOTE 11)

(Deleted)

^aNumbers in parentheses correspond to those in the explanatory NOTES.

NOTES TO Table 1—Limits of temperature and temperature rise

(continued)

- ^a According to its function, the same part may belong to several categories as listed Table 1. In this case, the permissible maximum values of total temperature and temperature rise to be considered are the lowest among the relevant categories.
- ^b For sealed interrupters, the values of total temperature and temperature-rise limits are not applicable for parts inside the sealed interrupter. The remaining parts shall not exceed the values of temperature and temperature rise given in Table 1.
- ^c The temperatures of conductors between contacts and connections are not covered in Table 1, as long as the temperature at the point of contact between conductors and insulation does not exceed the limits established for the insulating material.
- ^d The classes of insulating materials are those given in [IEEE Std 1 IEC 60694 Ed. 2.0b: 1996](#).
- ^e The top oil (upper layer) temperature shall not exceed 40 °C rise or 80 °C total. The [50](#) 5°C and 90 °C values refer to the hottest spot temperature of parts in contact with oil.
- ^f When contact parts have different coatings, the permissible temperatures and temperature rises shall be those of the part having the lower value permitted in Table 1.
- ^g [NRG, \(-Non-Reactive Gases\), for the purposes of this standard, are considered as not accelerating ageing of contacts by corrosion or oxidation due to their chemical characteristics and demonstrated operational records.](#)

[— Recognized NRG are SF6, N2, CO2, and CF4. They can be used pure or as a mixture of various NRG.](#)

[— RG, \(Reactive Gases\), for the purposes of this standard, are reactive gases that can accelerate ageing of contacts either by corrosion phenomena \(presence of humidity\) or by oxidation phenomena \(mostly due to ambient air medium like oxygen\). Gases classified as RG are ambient air, “dry” air, any gas not classified as NRG and any mixture that includes an RG.](#)

NOTE—Some gases considered as RG in the classification above may be re-classified as NRG, taking advantage of service experience or demonstration justifying the change of classification.

— For description of these corrosion and oxidation phenomena, refer to IEC 60943 [B16].

— Due to the absence of corrosion and oxidation, a harmonization of the limits of temperature for different contact and connection parts in the case of gas insulated switchgear appears appropriate. The permissible temperature limits for bare copper and bare copper alloy parts can be equalized to the values for silver coated or nickel-coated parts in the case of NRG atmospheres.

— In the particular case of tin-coated parts, due to fretting corrosion effects (refer to IEC 60943 [B16]) an increase of the permissible temperatures is not applicable, even under the oxygen-free conditions of SF₆. Therefore, the initial values for tin-coated parts are retained.

^h The quality of the coated contacts shall be such that a layer of coating material remains at the contact area

a) After making and breaking tests (if any).

b) After short-time withstand current tests.

c) After the mechanical endurance test; according to the relevant specifications for each piece of equipment. Otherwise, the contacts shall be regarded as “bare.”

ⁱ Where the connection parts have different coatings, the permissible temperature rise shall be as follows: those of the part having the lower value permitted in Table 1.

— For factory-controlled inaccessible connections (e.g., not subject to servicing in the field) and with both sides having copper as the base metal, those of the surface material having the highest value permitted in item 3 of Table 1.

— For all other connections, those of the surface material having the lowest value permitted in item 3 of Table 1.

j When materials other than those given in Table 1 are used, their properties shall be considered in order to determine the maximum permissible temperature rises.

k The values of temperature and temperature rise are valid even if the conductor to the terminals is bare.

l The temperature shall not reach a value where the temper of the material is impaired.

~~12—For indoor circuit breakers used on switchgear assemblies, the temperature limits given in IEEE Std C37.20.2-1993 shall not be exceeded.~~

~~5.3.2.2 Limitations on main contacts~~

~~The temperature of the main contacts used in circuit breakers shall not exceed the values listed in Table 1.~~

~~5.3.2.3 Limitations on connections~~

~~a)—The temperature of connections in the main power circuit of a circuit breaker shall not exceed the values listed in Table 1.~~

~~b)—Terminals of circuit breakers designed for direct cable connection shall not exceed 45° C rise or 85° C hottest spot total temperature when connected to an 85° C maximum insulated cable, rated for the full continuous current rating of the circuit breaker.~~

~~c)—Connections of indoor circuit breakers to switchgear assemblies shall conform only to the thermal requirements given in IEEE Std C37.20.2-1993.~~

~~5.3.2.4 Limitations for parts subject to contact by personnel~~

~~Circuit breaker parts handled by the operator in the normal course of duty shall have no higher total temperature than 50° C. Circuit breakers having external surfaces accessible to an operator in the normal course of duty shall have no higher total temperature on the surfaces than 70° C.~~

~~5.3.2.5 Limitations on materials~~

~~Materials shall be chosen so that the maximum temperatures to which they may be subjected shall not cause accelerated deterioration over the life of the circuit breaker.~~

5.6 Rated short-circuit current and related required capabilities

The short-circuit current rating of a circuit breaker is the symmetrical component of short-circuit current in rms amperes ([see](#) 5. [68.1](#)) to which all required short-circuit capabilities are [referenced related](#). All values apply to both grounded and ungrounded short-circuits on predominantly inductive three-phase [loads of low power factor circuits](#), with rated power frequency and phase-to-phase recovery voltage equal to the rated maximum voltage.

5.6.1 Rated short-circuit current (I_{sc})

The rated short-circuit current of a circuit breaker is the highest value of the symmetrical component of the three-phase, short-circuit current in rms amperes measured from the envelope of the current wave at the instant of primary arcing contact separation that the circuit breaker shall be required to interrupt at rated maximum voltage and on the standard operating duty. It also establishes, by fixed ratios as defined in 5. [68.2.3](#), the highest currents that the circuit breaker shall be required to close and latch against, to carry, and to interrupt. [Preferred](#) ~~For numerical~~ values of rated short-circuit current [follow](#), ~~refer to~~ the [R10 series](#), [see](#) tables ~~of preferred ratings~~ in [Clause 6 ANSI C37.06-1997](#).

5.6.2 Required related capabilities

The circuit breaker shall have the required related capabilities described in 5. [68.2.1](#) through 5. [68.2.65](#).

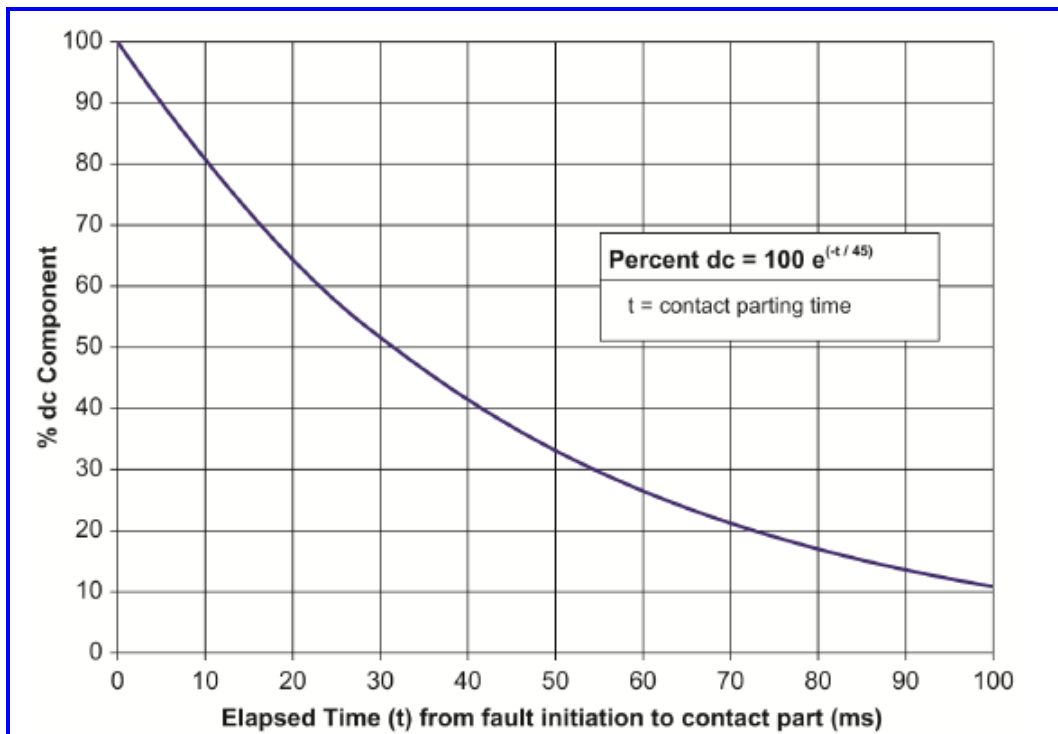
5.6.2.1 Required symmetrical interrupting capability for three-phase faults

For three-phase faults, the required symmetrical interrupting capability of a circuit breaker is the value of the symmetrical component of the short-circuit current in rms amperes at the instant of arcing contact separation that the circuit breaker shall be required to interrupt at a specified operating voltage, on the standard operating duty cycle, and with a direct current component of less than 20% of the current [peak](#) value of the symmetrical component.

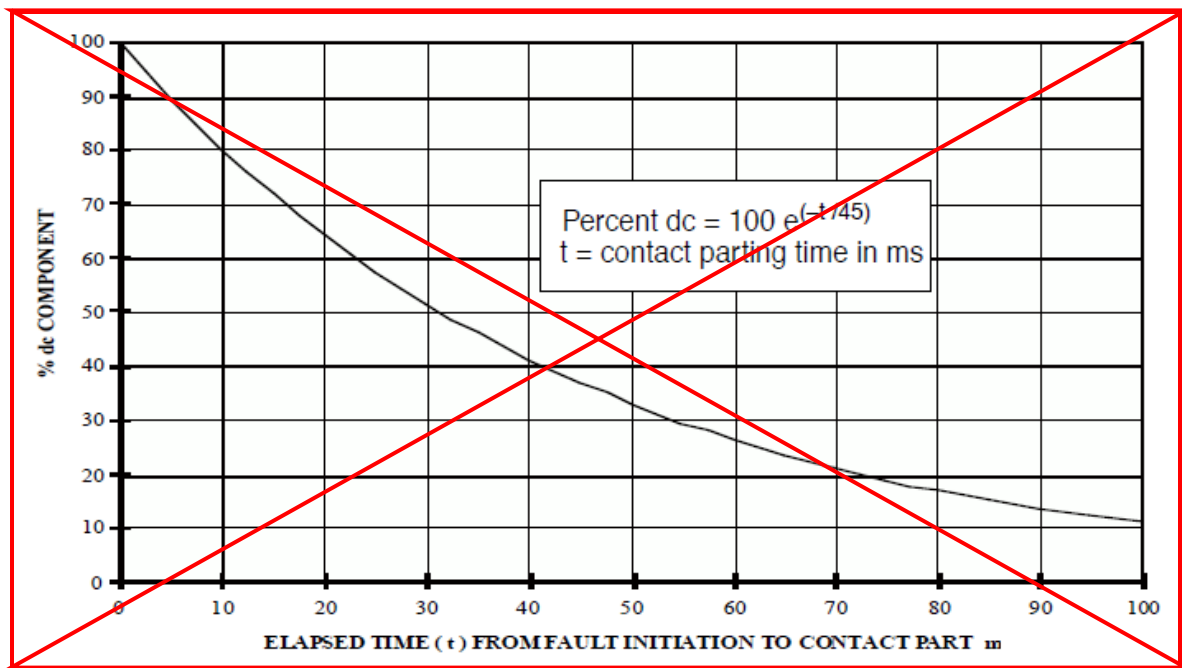
5.6.2.2 Required asymmetrical interrupting capability for three-phase faults

The required asymmetrical current interrupting capability of a circuit breaker is the value of the total rms short-circuit current (I_t) at the instant of the arcing contact separation that the circuit breaker shall be required to interrupt at a specified operating voltage and on the standard operating duty cycle.

The required percent value of the dc component is based on a standard time constant of 45 ms (corresponding to X/R values of 17 and 14 for 60 Hz and 50 Hz, respectively) and an assumed [release delay, or](#) relay time of 1/2 cycle, as illustrated in Figure 1. The elapsed time shown in Figure 1 [is the contact parting time and](#) is equal to the sum of 1/2 cycle of relay time (on the basis of the applicable rated power frequency) plus the [minimum](#) ~~contact~~ opening time of the circuit breaker.



[\(New\)](#)



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Figure 1—Percent dc component of asymmetric current as a function of contact parting time

The required asymmetrical current interrupting capability shall be determined from the rated value of the symmetrical [current](#) and the direct current component of the current, expressed as a percentage of the peak value of the symmetrical current, $I_{sc}I_{sym}$, in accordance with [Equation \(1\)](#) ~~the following formula:~~

$$I_t = I_{sc} \sqrt{1 + 2 \times \left(\frac{\%dc}{100} \right)^2} \quad (1)$$

~~NOTE—~~For time constants greater than 45 ms, see IEEE Std C37.09-1999 and IEEE Std C37.010-1999.

[The peak current and duration of the last half wave prior to interruption during asymmetrical testing shall be recorded. This will be used for checking asymmetrical capability for specific applications where the time constant and/or relay time are different from the standard values of 45 ms time constant and 0.5 cycle \(8.33 ms at 60 Hz\) or \(10 ms at 50 Hz\) relay time.](#)

5.6.2.3 Rated closing, latching, and short-time current carrying capability

The circuit breaker shall be capable of the following:

- a) Closing and latching any power frequency making current whose maximum peak (peak making current) is:
 - 1) Equal to or less than 2.6 ~~times the for 60 Hz power~~ rated ~~short circuit current frequency or 2.5 for 60 50Hz power rated frequency~~ and having time constants less than or equal to 45 ms times the rated short circuit current; and
 - 2) Equal to or less than 2.5 times the rated short circuit current for 50 Hz power rated frequency and having time constants less than or equal to 45 ms
 - 3) Equal to or less than 2.7 times the rated short circuit current for all time constants greater than 45 ms up to 133 ms
- b) Carrying a short-circuit current (short-time current), I_{sc} , for a period of time as specified in Clause 6 ANSI C37.06-1997 under the list of preferred ratings. These time durations establish the maximum permissible tripping time delay, Y, for each circuit breaker group.

5.6.2.4 Required reclosing capability

~~Derating~~ Factors for reducing the rated interrupting capacity for reclosing duty cycles other than the standard operating duty can be determined, when required, using the method contained in IEEE Std C37.010-~~1999~~.

5.6.2.5 Service capability duty requirements

The circuit breaker shall be capable of ~~the following~~ interrupting a number of terminal faults where the sum of the symmetrical test currents is equivalent to the service capability duty of at least performance:

- a) $8 \times$ the rated short-circuit breaking current (I_{sc}), for circuit breakers rated below 72.5 kV
- b) $6 \times I_{sc}$ for circuit breakers rated 72.5 kV and above

- ~~a) Between 85% and 100% of its required asymmetrical interrupting capability at its operating voltage, three standard duty cycles (O 15 s CO 3 min CO or O 0.3 s CO 3 min CO for circuit breakers intended for rapid reclosing);~~
- ~~b) Between its rated continuous current and 85% of its required asymmetrical interrupting capability, a number of operations in which the sum of the currents is a minimum of 800% of the required asymmetrical interrupting capability of the circuit breakers at its operating voltage.~~

5.6.2.6 Electrical endurance capability

The electrical endurance of a circuit breaker is the capability to repeatedly switch currents significantly less than the rated short circuit current, I_{SC} . Experience has shown that for modern circuit breaker designs, basic electrical endurance capability is covered by meeting the required service capability of 5.6.2.5. Where extended electrical endurance is required, Table F.1 provides the requirements for class E2 circuit breakers intended for auto-reclosing duty (normally class S2, rated 72.5 kV and lower). An example of such extended duty is a class S2 circuit breaker intended for auto-reclosing that may be exposed to a significant number of low-level faults on connected overhead lines. This category is intended for qualifying circuit breakers for extended electrical duty beyond the requirements of a) and b) in 5.6.2.1. While the E2 exceeds the accumulative current requirements of a) and b), it does not replace the requirements of a) and b) in 5.6.2.1, which are a portion of the required type tests. Circuit breakers not requiring electrical endurance capability class E2 are classified class E1, termed basic electrical endurance.

NOTE—The requirements for basic electrical endurance (class E1) and class E2 for circuit breakers without auto-reclosing duty as defined in IEC 62271-100 are different than those described in this clause. Meeting the requirements of IEC 62271-100 can, but will not necessarily, meet the requirements for basic electrical endurance defined in this clause.

5.6.2.6.1 Circuit breakers rated below 72.5kV

The sum of the currents is a minimum of 8 times the rated short circuit current of the circuit breakers.

Each T100s and T100a operation shall be included as $1 \times I_{SC}$ in the accumulation. The degradation of the interrupter for each breaking test is considered to be a power function of the current. The power function is the ratio of the test current I_{test} to I_{SC} , raised to the power of 1.8. The contribution of each current interruption to the service capability shall be determined as follows:

- If I_{test} is less than I_{SC} , the contribution is $[(I_{test}) / (I_{SC})]^{1.8} \times I_{SC}$.
- If I_{test} is equal to or greater than I_{SC} , the contribution is I_{SC} .

Each T60 operation, performed at $0.6 \times I_{SC}$, shall be included in the accumulation as $0.4 \times I_{SC}$, but no more than (5) T60 tests may be included in the accumulation.

Contributions of breaking test currents less than $0.6 \times I_{SC}$ shall not be included in the accumulation.

At a minimum, one T100s or T100a shall be included in the I_{SC} test accumulation.

5.6.2.6.2 Circuit breakers rated 72.5kV and higher

The service capability is demonstrated by performing terminal fault test duties T60 and T100s and/or T100a on the same pole in the case of single-phase tests or the same circuit breaker in the case of three-phase tests. Alternatively, it is possible to perform T100s with six interruptions at 100% rated short-circuit current in order to have an accumulation of 6 times rated symmetrical interrupting capability.

At a minimum, one T100s or T100a shall be included in the I_{SC} test accumulation.

5.7 Transient recovery voltage (TRV)

5.7.1 General

The TRV related to the rated short-circuit interrupting current in accordance with 0 is the reference voltage that constitutes the limit of the prospective TRV of circuits, which the circuit breaker shall be capable of withstanding under fault conditions. Each TRV rating is defined for a three-phase circuit breaker. Refer to the tables of preferred ratings for prospective TRV in Clause 6.

See Annex B for more detailed information on TRV and application considerations.

5.7.2 Summary of rated TRV parameters

5.7.2.1 Table of rated TRV parameters

Table 2 summarizes rated TRV parameters. The parameters in Column 1 are illustrated in Figure 2 and Figure 3. The derivation of these values is further described in IEEE Std C37.011 [B26].

Table 2—Rated TRV parameters

TRV parameter	Rated voltages and system conditions			
	100 kV and above $k_{pp} = 1.3$	100 kV and above $k_{pp} = 1.5$	Below 100 kV line systems $k_{pp} = 1.5$ (class S2)	Below 100 kV cable systems $k_{pp} = 1.5$ (class S1)
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
	Four-parameter (Figure 2)	Four-parameter (Figure 2)	Two-parameter (Figure 3)	Two-parameter (Figure 3)
k_{af}	1.4	1.4	1.54	1.4
u_1	$0.796 \times U_r$	$0.919 \times U_r$	—	—
t_1	$u_1/RRRV$	$u_1/RRRV$	—	—
u_1/t_1	2 kV/us	2 kV/us	—	—
u_c	$1.49 \times U_r$	$1.72 \times U_r$	$1.88 \times U_r$	$1.715 \times U_r$
t_2 or t_3	$t_2 = 4 t_1$	$t_2 = 4 t_1$	t_3^a	t_3^b
t_d	2 μ s	2 μ s	$t_d = 0.05 t_3$	$t_d = 0.15 t_3$
u'	$u_1/2$	$u_1/2$	$u_c/3$	$u_c/3$
t'	$t_d + u'/RRRV$	$t_d + u'/RRRV$	$t_d + u'/RRRV$	$t_d + u'/RRRV$

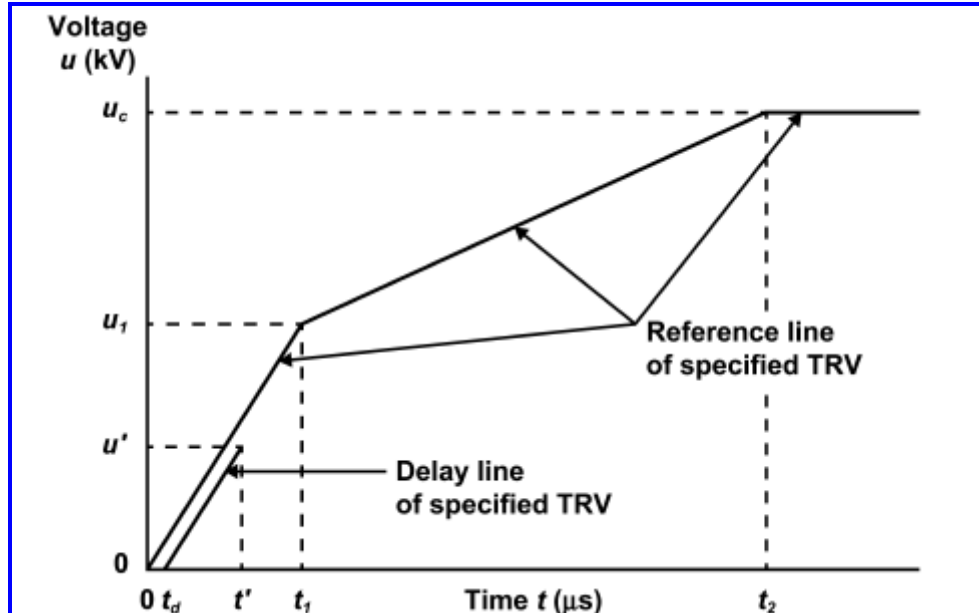
(New)

Breaker rating	Envelope	E_2	T_2	R	E_1	T_1
Below 100 kV	1-cos Figure 2	$1.88 \times V$	See ANSI C37.06-1997	NA	NA	NA
100 kV and above	Exp-cos Figure 3	$1.49 \times V$	See ANSI C37.06-1997	See ANSI C37.06-1997	$1.06 \times V$	See ANSI C37.06-1997

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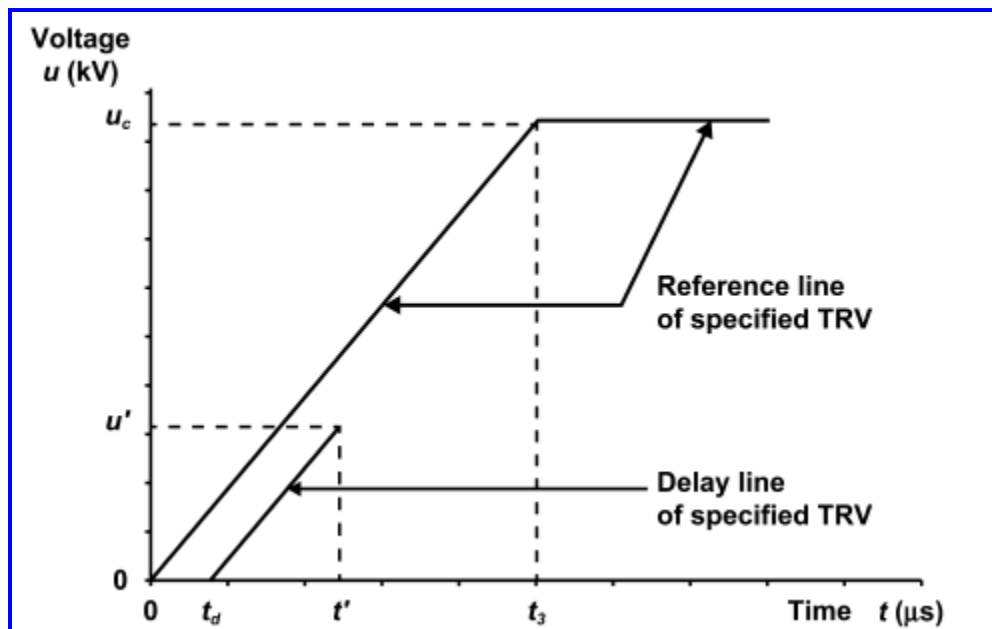
^a For line systems, time t_3 for terminal fault and short-line fault is equal to $4.65 \times (U_r)^{0.7}$ with t_3 in microseconds and U_r in kilovolts. The equation is derived from the values given in Table 6 of IEEE Std C37.06-2009 [B24] for rated voltages 15.5 kV, 25.8 kV, 48.3 kV, and 72.5 kV.

^b For cable systems, the values of t_3 are those found in Table 10.



(New)

Figure 2—Four-parameter TRV envelope



(New)

Figure 3—Two-parameter TRV envelope

5.7.2.2 Standard values of TRV related to the rated short-circuit interrupting current

Standard values of required TRV capabilities for three-pole circuit breakers of rated voltages below 100 kV make use of two parameters.

Standard values of required TRV capabilities for three-pole circuit breakers of rated voltages 100 kV and above make use of four parameters.

The TRV tables also indicate values of rate of rise, taken as u_c/t_3 and u_1/t_1 , in the two-parameter and in the four-parameter cases, respectively, which together with TRV peak values u_c may be used for purposes of specification of TRV.

The values given in the tables are prospective values. They apply to circuit breakers for general transmission and distribution in three-phase systems having service frequencies of 50 Hz or 60 Hz and consisting of transformers, overhead lines, and short lengths of cable.

In the case of single-phase systems or where circuit breakers are for use in an installation having more severe conditions, the values may be different, particularly for the following cases:

- a) Circuit breakers adjacent to generator circuits
- b) Circuit breakers directly connected to transformers without appreciable additional capacitance between the circuit breaker and the transformer, which provides approximately 50% or more of the rated short-circuit interrupting current of the circuit breaker
- c) Circuit breakers in substations with series reactors
- d) Circuit breakers used for series compensated lines
- e) Circuit breakers in substations with capacitor banks

The TRV corresponding to the rated short-circuit interrupting current when a terminal fault occurs is used for testing at short-circuit interrupting currents equal to the rated value. However, for testing at short-circuit interrupting currents less than 100% of the rated values, other values of TRV are specified (see 5.7.2.3.1). Further additional requirements apply to circuit breakers rated at 15.5 kV and above and having rated short-circuit interrupting currents exceeding 12.5 kA, which may be connected to overhead lines and may be subjected to short-line fault conditions (see 5.7.2.3.3).

5.7.2.3 Related required transient voltage withstand capabilities

5.7.2.3.1 Fault currents other than rated

The circuit breaker shall be capable of interrupting short-circuit currents that are less than the rated short-circuit current. This requires withstanding a TRV envelope where the $u_c E_2$ -value is higher and the t_2 or t_3 time is shorter resulting in a faster RRRV than the values corresponding to the rated short-circuit current.

The related TRV envelopes are defined by the use of multiplier factors shown in Table 3 times the rated values and the resulting values are shown in Table 9, Table 10, Table 13, Table 14, Table 17, Table 18, Table 19, or Table 20 as appropriate. That is, the related required peak voltage at a lower short-circuit current is a multiplier times the two-and four-parameter values specified at the rated short-circuit current. The related required time to reach the peak voltage is a multiplier times the two-and four-parameter values specified at the rated short-circuit current. Note that as the current is decreased, the multipliers have the effect of increasing the peak TRV value and of increasing the RRRV ~~ANSI C37.06-1997~~.

Table 3 shows the family of amplitude factors and rates-of-rise or t_3 values for the various test duties.

The effect of these multipliers on the TRVs at the various specified fractional values of the rated short-circuit current are illustrated as families of TRV envelopes as shown in the following four figures:

- Figure 4 illustrates a family of TRVs ~~this effect for circuit breakers rated below 100 kV, and Figure 5 shows the same~~ for circuit breakers rated 100 kV and above.