IEEE Std C37.04-1999
(Revision of
IEEE Std C37.04-1979)

IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers

Sponsor

Switchgear Committee of the
IEEE Power Engineering Society

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IEEE-SA Standards Board

Abstract: This standard covers 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 having the preferred ratings as listed in ANSI C37.06-1997. 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, and 3000 A associated with the various maximum voltage ratings. The rating structure establishes the basis for all assigned ratings, including continuous current, dielectric withstand voltages, short-circuit current, transient recovery voltage, and capacitor switching, plus associated capabilities such as mechanical endurance, load current, and out-of-phase switching. This standard does not cover generator circuit breakers, which are covered in IEEE Std C37.013-1997.
Keywords: capacitance current switching, dielectric withstand, fast transient recovery voltage, indoor, initial, interrupting time, mechanical endurance, operating duty, outdoor, power frequency, ratings, related capabilities, short-circuit current, shortline fault, voltage distribution

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Introduction

(This introduction is not part of IEEE Std C37.04-1999, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers.)

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 1999 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 60056 Ed. 4.0b: 1987, a process that first began in 1951.

This document makes significant changes in the rating structure for circuit breakers, such as the change of the voltage range factor, K, and the standard duty cycle. With these changes, information needed to properly apply circuit breakers rated in accordance with the 1979 or 1964 editions of IEEE Std C37.04 are eliminated from this new edition. Accordingly, users must refer to the prior editions of the relevant standards (including IEEE Std C37.04-1999, ANSI C37.06, IEEE Std C37.09-1999, etc.) in order to properly select and apply circuit breakers rated in accordance with the older standards.

NOTE—These older standards are part of the IEEE archives. Contact the IEEE Standards Association for ordering information.

The changes in this standard are explained in the following clause-by-clause summary:

1. Scope—The scope was expanded to clarify the type of circuit breakers specifically covered by this standard.
2. References—A complete updated listing of references is supplied.
3. Definitions—No substantial changes.
4. Service conditions—The usual and unusual service conditions are given. Information given on how to deal with unusual service conditions has been moved to IEEE Std C37.010-1999.
5. Ratings—The rated voltage range factor, K, defined in earlier versions of IEEE Std C37.04 is commonly recognized as being equal to 1.0 for modern interrupting technologies; consequently, the rating structure has been simplified, because the use of a K factor of 1.0 has effectively eliminated K from the rating structure. The rated permissible tripping delay, Y, has been incorporated in the rated closing, latching, and short-time current carrying capability (5.8.2.3).
   - 5.1 Rated maximum voltage—No major changes.
   - 5.2 Rated power frequency—No major changes.
   - 5.3 Rated continuous current—Changes were made to Table 1 (Limits of temperature and temperature rise for various parts and materials of circuit breakers). This table has been brought into better harmony with IEC.
   - 5.4 Rated dielectric withstand capability—Changes clarify basic dielectric requirements.
   - 5.5 Rated standard operating duty (standard duty cycle)—Changed and expanded to include circuit breakers for rapid reclosing and to coordinate with IEC.
   - 5.6 Rated interrupting time—The definition was clarified and updated for modern circuit breaker performance.
   - 5.7 Contact parting time—This definition was modified to alert users of high-voltage circuit breakers that it may be necessary to add external delay to account for fault deionization times on power systems.
   - 5.8 Rated short-circuit current and related required capabilities
     - 5.8.1 Rated short-circuit current—No major changes.
     - 5.8.2 Related required capabilities—The required asymmetrical interrupting capability for three-phase faults (5.8.2.2) defines the percent dc component based on the standard time constant of 45 ms (corresponding to an X/R of 17 for 60 Hz or 14 for 50 Hz). This

replaces the “S-factor” concept used in earlier versions of IEEE Std C37.04.

The rated closing, latching, and short-time current carrying capability (5.8.2.3) incorporates the permissible tripping delay and short-time current into values that coordinate with IEC. The required reclosing capability is referenced to IEEE Std C37.010-1999.

5.9 Rated transient recovery voltage (TRV)—This subclause of the standard was expanded to provide a detailed explanation of how TRV values are calculated. The first pole-to-clear factor and transient amplitude factors have been harmonized with IEC in preparation for future harmonization of waveshapes for testing. The shortline fault surge impedance and amplitude constant were harmonized to a single value. The initial TRV was incorporated from IEEE Std C37.04i-1991.

5.10 Rated operating endurance capabilities—This subclause replaced “Required load current switching capability and life.”

5.11 Rated capacitance current switching—This subclause was not changed. Requirements for capacitance switching are currently under review by a joint IEEE/IEC working group.

5.12 Out-of-phase switching current capability—No major changes.

5.13 Shunt reactor current switching capability—References are made to IEEE Std C37.015-1993.

5.14 Rated line closing switching surge factor—No changes.

5.15 Rated control voltage—IEC definitions are incorporated.

5.16 Rated operating pressure for insulation and/or interruption (P_{re})—IEC definitions are incorporated.

5.17 Rated operating pressure for mechanical operation (P_{rm})—IEC definitions are incorporated.

6. Construction

6.1 Outdoor apparatus bushings—References have been updated.

6.2 Creepage distance—References ANSI C37.06-1997 requirements.

6.3 Mechanical loading—This subclause has been updated to reflect individual mechanical loads per IEC.

6.4 Pressurized components—Requirements for non-ceramic pressurized vessels have been added.

6.5 Pressurized systems—No major changes.

6.6 Gas and vacuum tightness—Requirements have been added that correlate to IEC.

6.7 Functional components—Basic requirements for circuit breakers have been defined.

6.8 Stored energy requirements for operating mechanisms—Basic requirements for stored energy are established based upon the time to replenish the stored energy after operation.

6.9 Operating mechanism requirements—Establishes trip-free and anti-pump requirements.

6.10 Electromagnetic compatibility (EMC)—Establishes withstand of secondary systems.

6.11 Requirements for simultaneity of poles—Establishes mechanical requirements in correlation with IEC.

7. Nameplate markings—No major changes.

Participants

This standard was developed by the High-Voltage Circuit Breaker Subcommittee of the IEEE Switchgear Committee. At the time this standard was completed, the members of this working group were as follows:

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IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers

1. Scope

This standard establishes a symmetrical current rating structure and construction requirements for all indoor and outdoor types of ac high-voltage circuit breakers rated above 1000 V. It is only applicable to three-pole circuit breakers used in three-phase systems and single-pole circuit breakers used in single-phase systems. 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 IEEE Std C37.013-1997.

2. References

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

ANSI C37.06.1-1997, 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 C37.54-1996, American National Standard for Switchgear—Indoor Alternating-Current High-Voltage Circuit Breakers Applied as Removable Elements in Metal-Enclosed Switchgear Assemblies—Conformance Test.

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.[3]

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[1]ANSI C37 standards are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://www.standards.ieee.org/).

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

[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/).

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

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

IEC 60694 Ed. 2.0b: 1996, Common specifications for high-voltage switchgear and controlgear standards.

IEEE Std 1-1986 (Reaff 1992), IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.[5]

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 693-1997, IEEE Recommended Practices for Seismic Design of Substations.

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)*.

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

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

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

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

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

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

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

IEEE Std C37.24-1986 (Reaff 1998), IEEE Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Enclosed Switchgear.

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

IEEE Std C57.19.00-1991 (Reaff 1997), IEEE Standard General Requirements and Test Procedures for Outdoor Power Apparatus Bushings.

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]

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

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

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

3. Definitions

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

4. Service conditions

4.1 Usual service conditions

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;
c) 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 in IEEE Std C37.010-1999 do not exist.

4.2 Unusual service conditions

Unusual service conditions are 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 C37.010-1999 should be followed.

5. Ratings

The rating 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 of circuit breakers, see ANSI C37.06-1997):

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 dielectric withstand capability (5.4);
f) Rated standard operating duty (standard duty cycle) (5.5);
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);
l) Rated operating pressure for insulation and/or interruption (5.16);
m) Rated operating pressure for mechanical operation (5.17);
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 these standards implies performance characteristics at least equal to those set forth in the following subclauses. 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. Alternately, for designs existing prior to the adoption of 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.

5.1 Rated maximum voltage

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 C84.1-1989 and IEEE Std 1312-1993.

5.2 Rated power frequency

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 (16 2/3 Hz, 25 Hz) should receive special consideration (see IEEE Std C37.010-1999).

5.3 Rated continuous current

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 5.3.1 and 5.3.2. For rated continuous currents, refer to the tables of preferred ratings in ANSI C37.06-1997.

5.3.1 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 indoor circuit breakers without enclosures shall have ratings based on a 40 °C ambient temperature.

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 (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 (sulfurhexaflouride)	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)

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

NOTES TO TABLE 1

1—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.

2—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.

3—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.

4—The classes of insulating materials are those given in IEC 60694 Ed. 2.0b: 1996.

5—The top oil (upper layer) temperature shall not exceed 40 °C rise or 80 °C total. The 5 °C and 90 °C values refer to the hottest spot temperature of parts in contact with oil.

6—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.

7—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."

8—When connection parts have different coatings, the permissible temperatures and temperature rises shall be those of the part having the lower value permitted in Table 1.

9—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.

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

11—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.

5.4 Rated dielectric withstand capability

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. The circuit breaker withstand capabilities are demonstrated by compliance with the applicable test requirement in IEEE Std C37.09-1999.

The rated 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 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.)

5.4.1 Dielectric withstand capability of external insulation

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

Bushings classified as outdoor apparatus bushings shall conform to the requirements of IEEE Std 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 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 dielectric withstand capability of the external insulation of ac high-voltage circuit breakers are given in ANSI C37.06-1997.

5.4.2 Rated power frequency withstand voltage

5.4.2.1 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).

5.4.2.2 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).

5.4.3 Rated lightning impulse withstand voltage

The rated lightning impulse withstand voltage is the peak value of a standard 1.2×50 μs 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 external flashover of 10% or less. As a minimum, this is demonstrated by the test requirements of IEEE Std C37.09-1999.

5.4.4 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 × 50 μs lightning impulse test voltage wave when tested under specified conditions (see IEEE Std C37.09-1999).

5.4.5 Rated chopped wave impulse withstand voltage

The rated chopped wave impulse withstand voltage is applicable to outdoor circuit breakers 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

5.4.6 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 × 2500 μs 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 shall have the probability of external flashover to ground of 10% or less. 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.

5.5 Rated standard operating duty (standard duty cycle)

The standard operating duty of a circuit breaker is

$$\text{O - t - CO - t' - CO} \tag{1}$$

where

O = Open;
CO = Close-Open;
t' = 3 min;
t = 15 s for circuit breakers not rated for rapid reclosing and
= 0.3 s for circuit breakers rated for rapid reclosing duty.

5.5.1 Minimum reclosing time

The minimum reclosing time of a circuit breaker is 0.3 s. This is the shortest permissible time in which the circuit breaker is required to reclose with rated control voltage and rated pressure. It may be necessary to add an external time delay to meet specific application requirements (see IEEE Std C37.010-1999).

5.6 Rated interrupting time

The rated interrupting time of a circuit breaker is the maximum permissible interval between the energizing of the trip circuit at rated control voltage and rated operating pressure for mechanical operation, and the interruption of the current in the main circuit in all poles. The interrupting time for a close-open operation shall not exceed the rated interrupting time by more than 1 cycle of rated power frequency for circuit breakers with interrupting times of 5 cycles or more, and 1/2 cycle for circuit breakers with interrupting times of 3 cycles or less. (Cycles are based on corresponding rated power frequency.)

5.7 Contact parting time

The arcing contact parting time shall be considered equal to the sum of 1/2 cycle (practical minimum relay time) plus the minimum opening time of the particular circuit breaker specified by the manufacturer (see IEEE Std C37.010-1999).

5.8 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 (5.8.1) to which all required short-circuit capabilities are related. All values apply to both grounded and ungrounded short-circuits on predominantly inductive three-phase circuits, with rated power frequency and phase-to-phase recovery voltage equal to the rated maximum voltage.

5.8.1 Rated short-circuit current

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 5.8.2, the highest currents that the circuit breaker shall be required to close and latch against, to carry, and to interrupt. For numerical values of rated short-circuit current, refer to the tables of preferred ratings in ANSI C37.06-1997.

5.8.2 Required related capabilities

The circuit breaker shall have the required related capabilities described in 5.8.2.1 through 5.8.2.5.

5.8.2.1 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 value of the symmetrical component.

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

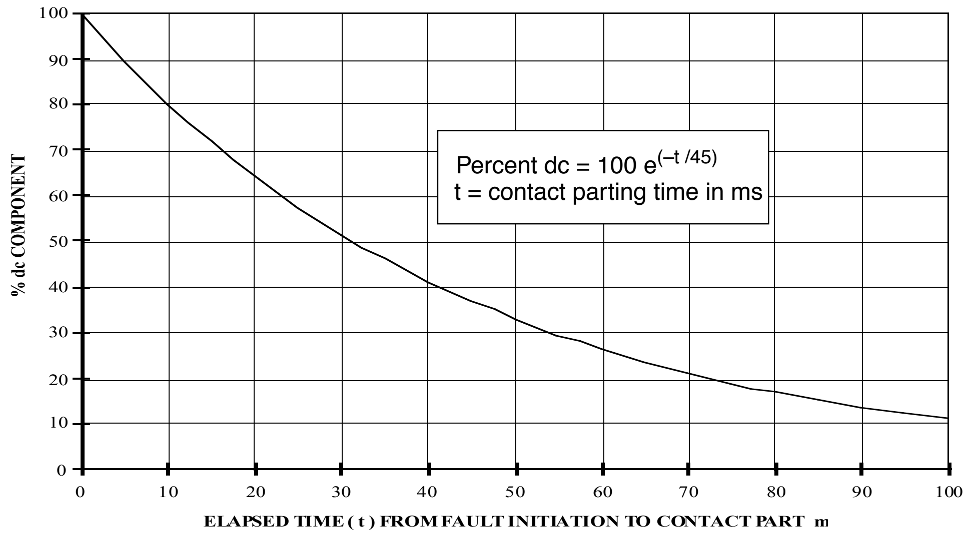

Figure 1—Percent dc component of asymmetric current as a function of contact parting time

The required asymmetrical current interrupting capability shall be determined from the rated value of the symmetrical and the direct current component of the current, expressed as a percentage of the peak value of the symmetrical current, I_{sym}, in accordance with the following formula:

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

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

5.8.2.3 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 equal to or less than 2.6 for 60 Hz power rated frequency or 2.5 for 50 Hz power rated frequency times the rated short-circuit current; and

b) Carrying a short-circuit current (short-time current), I, for a period of time as specified in 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.

5.8.2.4 Required reclosing capability

Derating factors for 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.

5.8.2.5 Service capability duty requirements

The circuit breaker shall be capable of the following interrupting performance:

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.

5.9 Rated transient recovery voltage (TRV)

At its rated maximum voltage, each circuit breaker shall be capable of interrupting three-phase grounded and ungrounded terminal faults at the rated short circuit current in any circuit in which the TRV does not exceed the rated TRV envelope (see IEEE Std C37.011-1994).

Each TRV rating is defined for a three-phase circuit breaker.

5.9.1 Rated TRV parameters

The TRV rating for a three-phase circuit breaker is defined by an envelope of required withstand capability. The parameters that define the envelope are based on the characteristic features of actual system TRVs.

5.9.1.1 Circuit breakers rated below 100 kV

For circuit breakers rated below 100 kV, the rated TRV is represented by a 1-cosine wave, as shown in Figure 2. The magnitude of this wave, E_2, for interrupting rated short circuit current, is equal to

$$E_2 = K_a \times K_f \times \frac{\sqrt{2}}{\sqrt{3}} \times V \tag{3}$$

where

K_a = transient amplitude factor = 1.54;
K_f = first pole-to-clear factor = 1.5;
V = rated maximum voltage.

Since systems below 100 kV may be operated ungrounded, a first pole-to-clear factor of 1.5 is required.

Thus,

$$E_2 = 1.88 \times V \tag{4}$$

which is the rated value of E_2 as given in ANSI C37.06-1997 and ANSI C37.06.1-1997.

The rated time to peak of the 1-cosine wave, E_2, varies with circuit breaker rated voltage, as given in ANSI C37.06-1997 and ANSI C37.06.1-1997.

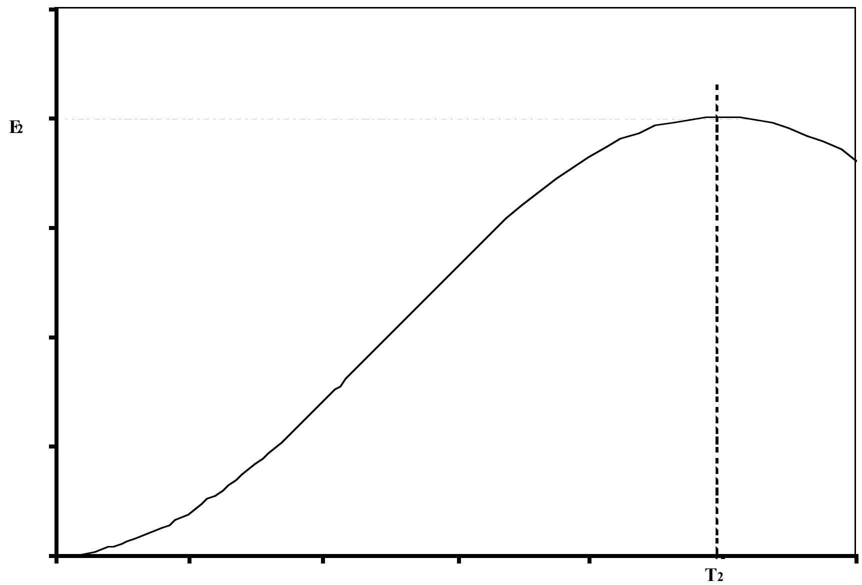

Figure 2—1-cosine TRV waveform

5.9.1.2 Circuit breakers rated 100 kV and above

For circuit breakers rated 100 kV and above, the rated TRV waveshape is defined by the higher of an exponential waveform and a 1-cosine waveform, as shown in Figure 3. The magnitude of the exponential component, E_1, is

$$E_1 = K_f \times \left(\frac{\sqrt{2}}{\sqrt{3}}\right) \times V \quad (5)$$

where

K_f = first pole-to-clear factor = 1.3;

or

E_1 = 1.06 × V.

Since most, if not all, systems operating at 100 kV and above are effectively grounded, a first pole-to-clear factor of 1.3 is required.

The rate of rise of the exponential component, R, has been established as 2 kV/μs, as shown in ANSI C37.06-1997.

The rated magnitude of the exponential cosine component, E_2, in ANSI C37.06-1997 is

$$E_2 = K_a \times K_f \times \left(\frac{\sqrt{2}}{\sqrt{3}}\right) \times V$$

$$E_2 = 1.4 \times 1.3 \times \left(\frac{\sqrt{2}}{\sqrt{3}}\right) \times V = 1.49 \times V \quad (6)$$

NOTE—A transient amplitude factor of 1.4 is used for circuit breakers rated 100 kV and above, instead of the 1.54 value used for circuit breakers rated below 100 kV.

The rated times to peak of the 1-cosine component, T_2, vary with circuit breaker rated voltage, as given in ANSI C37.06-1997.

Figure 3 shows a slight delay, T_1, in the initial build-up of the TRV wave. This delay is due to the capacitance of the circuit breaker, faulted bus, and any other connected equipment. The rated values of T_1 are shown in ANSI C37.06-1997 and ANSI C37.06.1-1997. T_1 does not apply to circuit breakers rated below 100 kV.

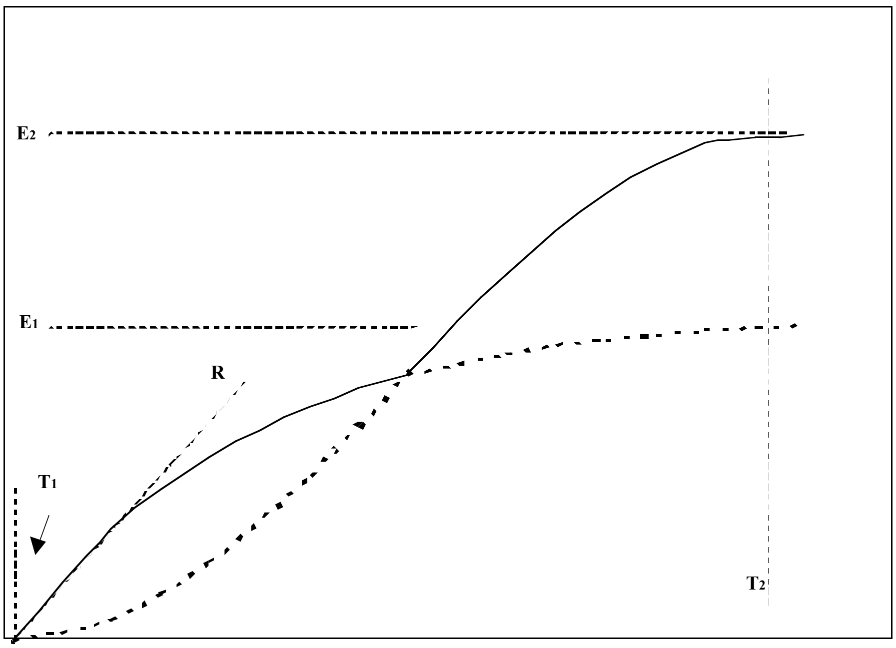

Figure 3—Exponential-cosine TRV waveform

The rated TRV parameters are summarized in Table 2 and are further described in IEEE Std C37.011-1994.

Table 2—Rated TRV parameters

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

5.9.2 Related required transient voltage withstand capabilities

5.9.2.1 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 E_2 value is higher and the T_2 time is shorter than the values corresponding to the rated short-circuit current.

The related TRV envelopes are defined by the factors shown in ANSI C37.06-1997. Figure 4 illustrates this effect for circuit breakers rated below 100 kV, and Figure 5 shows the same for circuit breakers rated 100 kV and above.

Note that as the current is decreased, E_2 is increased and T_2 is decreased. For circuit breakers rated 100 kV and above, the rate of rise, R, first increases as the current decreases; then a point is reached where a further decrease in current causes a decrease in R, until at 30% of rated current and below, the exponential-cosine wave changes to a 1-cosine wave.

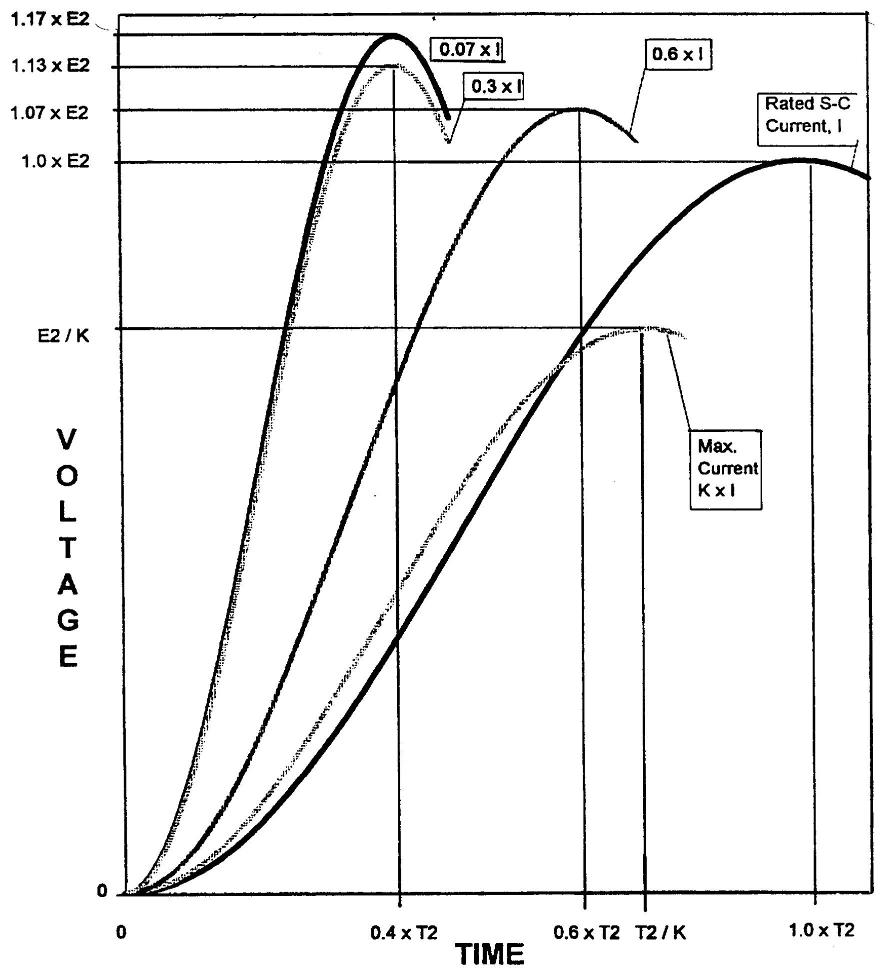

Figure 4—TRV envelopes 100 kV and below

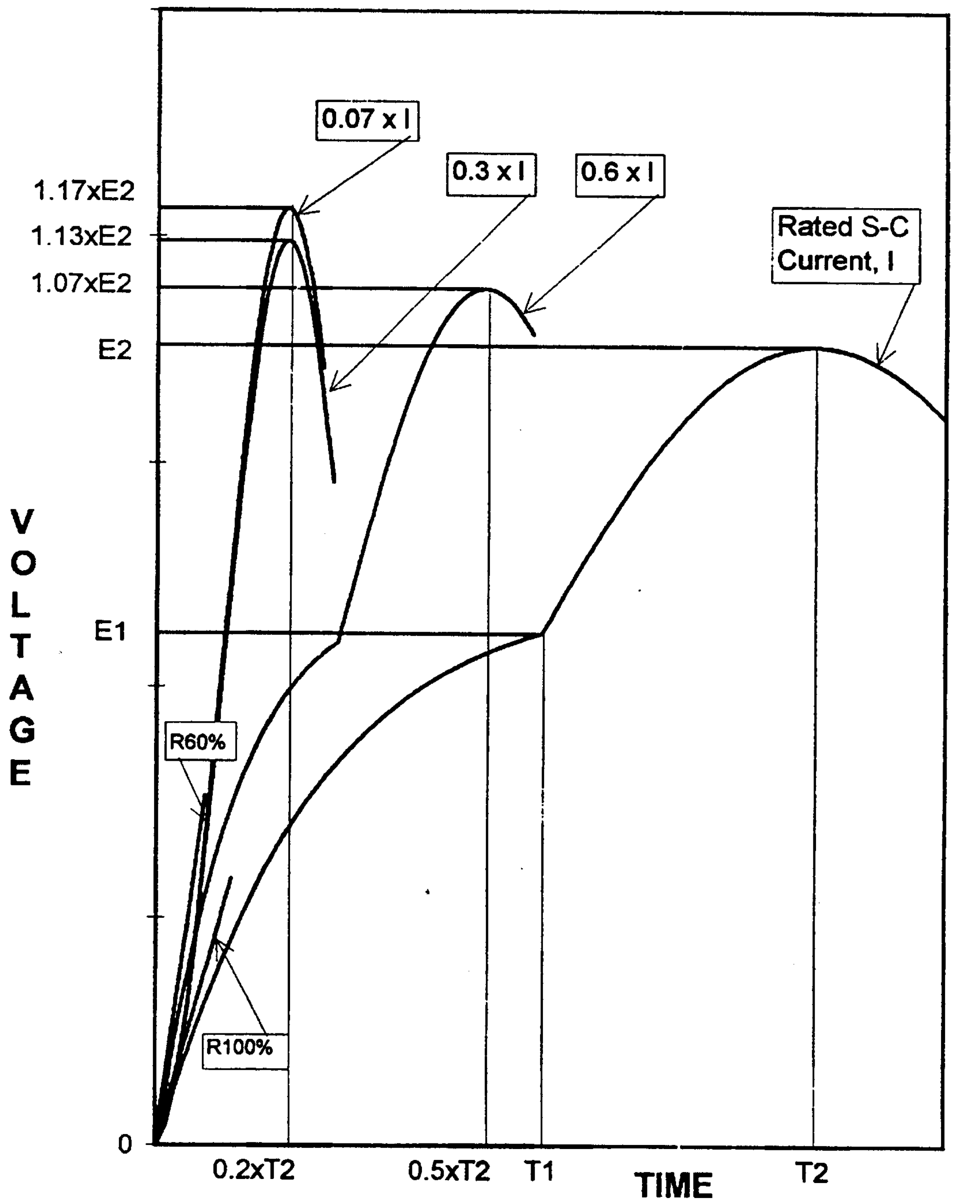

Figure 5—TRV Envelopes above 100 kV

5.9.2.2 Short line faults

Outdoor circuit breakers rated 15.5 kV and above shall be capable of interrupting single-phase, shortline faults at any distance from the circuit breaker, on a system where

a) The TRV on a terminal fault is within the rated or related TRV envelope.

b) The voltage in the first ramp of the sawtooth wave is equal to or less than that in an ideal system in which the surge impedance, *Z,* and amplitude constant, d, are 450 Ω and 1.6, respectively (see IEEE Std C37.09-1999).

c) There is a time delay of 0.5 μs for circuit breakers rated 245 kV and above, and 0.2 μs for circuit breakers rated below 245 kV.

The TRV for this shortline fault is illustrated in Figure 6. The voltage, V_{BD}, represents the source side transient which, for purposes of this illustration, is indicated as an exponential-cosine with a time delay, t_{dL}, starting at an initial voltage of V_{CDo}.

Figure 6 shows that there is a time delay of the lineside recovery voltage as a result of the capacitance of apparatus on the lineside.

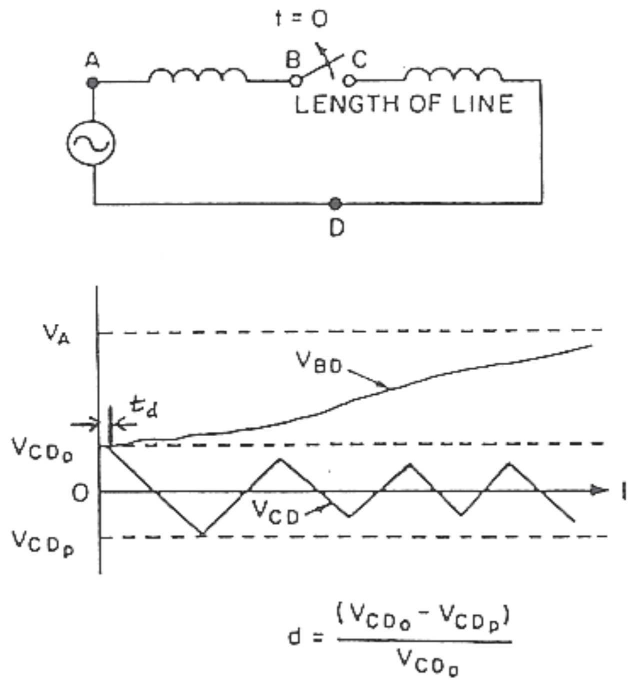

Figure 6—Shortline fault terminology

5.9.2.3 Initial TRV

Circuit breakers rated 100 kV and above, with rated short-circuit currents of 31.5 kA and above, shall have an initial TRV capability for phase-to-ground faults as defined by the envelope shown in Figure 7.

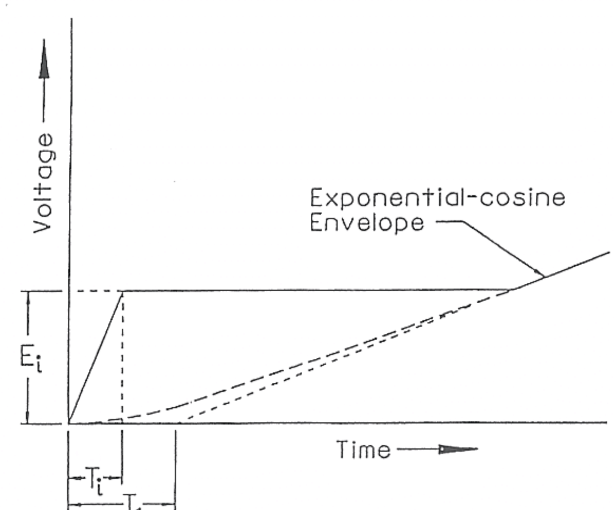

Figure 7—Initial TRV Envelope

The initial TRV envelope rises linearly from the origin to the first peak voltage, E_i, at time T_i (see Table 3). The first peak voltage and the time to the first peak voltage are determined by the fault current, bus surge impedance, bus wave velocity, and the distance from the circuit breaker to the first major discontinuity of bus surge impedance.

NOTE—As an example, the first major discontinuity of bus surge impedance may be a lumped capacitance of 1000 pF or more connected to the bus or a reduction of the bus surge impedance (i.e., the interconnection of two or more buses or lines). The apparent wave velocity is approximately 280 m/μs for outdoor substations.

The times to first peak voltage, T_i, for phase-to-ground faults are given in Table 3.

Table 3—Time to first peak of initial TRV

Rated maximum voltage (kV rms)	Time to first peak voltage (T_i μs)
123	0.3
145	0.4
170	0.5
245	0.6
362	0.8
550	1.0
800	1.1

The first peak voltage, E_i, is

$$E_i = \omega \times \sqrt{2} \times I \times Z_b \times T_i \times 10^{-6}(\text{kV}) \quad (7)$$

where

Z_b (the bus surge impedance) = 450 Ω (outdoor substations, phase-to-ground faults only);
T_i is in microseconds;
I is in kA;
$\omega = 2\pi f$ (see IEEE Std C37.09-1999).

For breakers installed in gas-insulated substations, the initial TRV can be neglected because of low bus surge impedance and small distances to the first major discontinuity.

5.10 Rated operating endurance capabilities

The rated operating endurance capabilities specified in ANSI C37.06-1997 are the types and numbers of complete closing-opening operations that the circuit breaker shall be capable of performing. The frequency of user operation shall not exceed 20 in 10 min or 30 in 1 h.

5.11 Rated capacitance current switching

NOTE—Requirements for capacitance switching are currently under review by a joint IEEE/IEC Working Group.

Capacitance current switching may comprise part or all of the operating duty of a circuit breaker, such as the charging current of an unloaded transmission line or cable or the load current of a shunt capacitor bank. Refer to ANSI C37.06-1997 for capacitance current switching preferred ratings.

The rating of a circuit breaker for capacitance current switching shall include

a) Rated overhead line switching current (outdoor circuit breakers only);
b) Rated isolated cable or isolated shunt capacitor bank switching current; and
c) Rated transient overvoltage factor.

Where applicable, the rating of a circuit breaker for capacitance current switching may include

a) Rated back-to-back cable charging and back-to-back shunt capacitor bank switching current; and
b) Required capacitance current switching endurance capability.

5.11.1 Rated overhead line switching current

The rated overhead line switching current is the highest open wire line charging current that an outdoor circuit breaker shall be capable of interrupting up to its rated maximum voltage.

5.11.2 Rated isolated cable and isolated shunt capacitor bank switching current

The rated isolated cable and isolated shunt capacitor bank switching current is the highest isolated cable charging or isolated shunt capacitor bank current that the circuit breaker shall be capable of interrupting up to its rated maximum voltage.

Cable circuits and shunt capacitor banks shall be considered to be isolated if the maximum rate of change of transient inrush current on energizing an uncharged capacitor bank does not exceed the maximum rate of change of the symmetrical current interrupting capability of the circuit breaker at the applied voltage. The limiting value of the maximum rate of change of current is

$$\frac{di}{dt} = \sqrt{2}\omega I \qquad (8)$$

where

di/dt = rate of change of transient inrush current (in amperes per second);
I = rated symmetrical short-circuit current (in amperes);
ω = $2\pi f$ = 377 for 60 Hz.

5.11.3 Rated transient overvoltage factor

The rated transient overvoltage factor shall be determined as indicated in IEEE Std C37.09-1999 and shall be as described in 5.11.3.1 and 5.11.3.2.

5.11.3.1 General purpose circuit breakers

For general purpose circuit breakers, the transient overvoltage factor shall not exceed 3.0.

5.11.3.2 Definite purpose circuit breakers for capacitor switching

For circuit breakers specially suited for capacitor switching, the transient overvoltage factor shall not exceed the following more than once in 50 random, three-phase operations:

a) 2.5 for circuit breakers rated below 100 kV; and
b) 2.0 for circuit breakers rated 100 kV and above.

5.11.4 Rated back-to-back cable charging and back-to-back shunt capacitor bank switching current

The rated back-to-back cable or back-to-back shunt capacitor bank switching current is the highest cable charging or shunt capacitor bank current that the circuit breaker shall be required to switch at any voltage up to the rated maximum voltage, when other cables or shunt capacitor banks are connected to the system in parallel with the one being switched.

5.11.5 Rated transient inrush current

The rated transient inrush current for back-to-back switching includes the components described in 5.11.5.1 and 5.11.5.2.

5.11.5.1 Rated transient inrush current peak

The rated transient inrush current peak is the highest magnitude of current that the circuit breaker shall be required to close into any voltage up to the rated maximum voltage. The inrush current peak shall be as determined by the system, unmodified by the circuit breaker.

5.11.5.2 Rated transient inrush current frequency

The rated transient inrush current frequency is the highest natural frequency present at which the circuit breaker shall be required to close against 100% of its rated back-to-back shunt capacitor bank or cable switching current.

5.11.6 Required capacitance current switching endurance capabilities

The required capacitance current switching endurance capabilities are the number of operations specified in ANSI C37.06-1997. There shall be no intentionally added inductance to ground on the disconnected side of the circuit breaker.

5.11.7 Grounding of system and shunt capacitor bank

Either or both the shunt capacitor bank and system can be grounded or ungrounded.

5.12 Out-of-phase switching current capability

Since the out-of-phase switching duty is required for only certain circuit breaker applications, it is not considered necessary to include this as a standard rating for general purpose circuit breakers.

This rating applies to circuit breakers intended to be used for switching the connection between two parts of a three-phase system during out-of-phase conditions. Out-of-phase is an abnormal circuit condition of loss or lack of synchronism between parts of an electrical system on either side of a circuit breaker. The phase angle between rotating vectors representing the voltages on either side of the circuit breaker at the instant of its operation may differ by as much as full-phase opposition.

5.12.1 Assigned out-of-phase switching current rating

The assigned out-of-phase switching current rating is the maximum out-of-phase current that the circuit breaker shall be capable of switching at a rated power frequency out-of-phase recovery voltage equal to

2 times the rated maximum voltage divided by $\sqrt{3}$ for grounded systems, and 2.5 times the rated maximum voltage divided by $\sqrt{3}$ for ungrounded systems (see IEEE Std C37.09-1999). If a circuit breaker has an assigned out-of-phase switching current rating, the preferred rating shall be 25% of the rated (symmetrical) short-circuit current expressed in kA, unless otherwise specified.

5.12.2 Interrupting time for out-of-phase switching

The interrupting time for out-of-phase switching is permitted to exceed the rated interrupting time by

a) 50% for five or more cycle circuit breakers;
b) One cycle for three or fewer cycle circuit breakers.

5.13 Shunt reactor current switching capability

This applies to circuit breakers intended for switching shunt reactors. Since shunt reactor switching is required for only certain circuit breaker applications, it is not included as a standard rating for general purpose circuit breakers.

IEEE Std C37.015-1993 can be used to evaluate the shunt reactor switching application for specific circuit breakers.

5.14 Rated line closing switching surge factor

The rated line closing switching surge factor is the rated value assigned to a circuit breaker rated 362 kV and above (rated maximum voltage), which has been specifically designed to control the line closing switching surge maximum voltage. The rating establishes that the circuit breaker is capable of controlling line closing switching surge voltages with a 98% probability of not exceeding the rated factor when switching the standard reference transmission line from the standard reference power source. Furthermore, all of the line closing switching surge factors shall remain below 1.2 times the rated line closing switching surge factor when switching the standard reference line with the standard reference source (see ANSI C37.06-1997, IEEE Std C37.09-1999, and IEEE Std C37.010-1999.)

5.15 Rated control voltage

The rated control voltage of a circuit breaker is the designated voltage as specified by Table 9 of ANSI C37.06-1997. The transient voltage in the entire control circuit, due to the interruption of the control current, shall be limited to 1500 V, peak.

5.16 Rated operating pressure for insulation and/or interruption (P_{re})

The pressure in Pascals (Pa), for insulation and/or for interruption, refers to the standard atmospheric air conditions of +20 °C and 101.3 kPa (absolute) (or density), which may be expressed in relative or absolute terms, to which the assembly is filled before being put into service or automatically replenished.

NOTE—1 Pa = 1.45×10^{-4} psia

5.16.1 Alarm pressure for insulation and/or interruption

The pressure in Pascals, for insulation and/or for interruption, refers to the standard atmospheric air conditions of +20 °C and 101.3 kPa (absolute) (or density), which may be expressed in relative or absolute terms, at which a monitoring signal may be provided to indicate that replenishment is necessary.

5.16.2 Minimum operating pressure for insulation and/or interruption

The pressure in Pascals, for insulation and/or for interruption, refers to the standard atmospheric air conditions of +20 °C and 101.3 kPa (absolute) (or density), which may be expressed in relative or absolute terms, which represents the lower limit below which the circuit breaker rated performance and capabilities are no longer available and where the circuit breaker is locked-out.

5.17 Rated operating pressure for mechanical operation (P_{rm})

The pressure in Pascals refers to the standard atmospheric air conditions of +20 °C and 101.3 kPa (absolute) (or density), which may be expressed in relative or absolute terms, to which the control device (operating mechanism) is filled before being put into service or automatically replenished.

5.17.1 Alarm pressure for mechanical operation

The pressure in Pascals refers to the standard atmospheric air conditions of +20 °C and 101.3 kPa (absolute) (or density), which may be expressed in relative or absolute terms, at which a monitoring signal may be provided to indicate that pressure replenishment for the control device (operating mechanism) is necessary.

5.17.2 Minimum operating pressure for mechanical operation

The pressure in Pascals refers to the standard atmospheric air conditions of +20 °C and 101.3 kPa (absolute) (or density), which may be expressed in relative or absolute terms, which represents the lower limit of pressure for proper operation of the control device (operating mechanism).

6. Construction

6.1 Outdoor apparatus bushings

Bushings that are classified as apparatus bushings used on oil circuit breakers shall conform to IEEE Std C57.19.00-1991 and IEEE Std C57.19.01-1991. Bushings for dead tank oil circuit breakers shall have electrical characteristics and dimensions in accordance with IEEE Std C57.19.00-1991. Bushing mountings shall be adequate to accommodate bushings having the maximum D dimension specified in IEEE Std C57.19.01-1991.

6.2 Creepage distance

Creepage distance over external insulation for outdoor circuit breakers is listed in ANSI C37.06-1997. These minimum values are for light pollution level conditions of atmospheric contamination and represent generally satisfactory service operations under these conditions. For special cases of pollution, refer to IEEE Std C37.010-1999 or to the manufacturer.

6.3 Mechanical loading

This subclause applies to outdoor circuit breakers. For indoor circuit breakers, the requirements of IEEE Std C37.20.2-1993 apply.

6.3.1 Circuit breaker

The maximum permissible mechanical loading that may be applied to a circuit breaker is as described in 6.3.1.1 through 6.3.2. All other mechanical loading is considered special, and application shall be checked with the manufacturer.

6.3.1.1 Wind loading

The circuit breaker shall be capable of withstanding a wind speed of 40 m/s. This requirement is only applicable to outdoor circuit breakers.

6.3.1.2 Ice loading

The circuit breaker shall be capable of withstanding ice loading caused by up to 20 mm of ice. This requirement is only applicable to outdoor circuit breakers.

6.3.1.3 Seismic loading

All circuit breakers shall be capable of withstanding at least 0.2 times the equipment weight applied in one horizontal direction, combined with 0.16 times the weight applied in the vertical direction at the center of gravity of the circuit breaker and support structure (see NEMA SG-4-1995). The resultant load shall be combined with the maximum normal operating load to develop the greatest stress on the anchorage.

For guidance in the application of circuit breakers, where the seismic conditions exceed those described here, refer to IEEE Std C37.010-1999 and IEEE Std 693-1997.

6.3.2 Terminal loading

The maximum permissible terminal mechanical loading that may be applied to an outdoor circuit breaker is given as static forces in Table 4 (see Figure 8). All other terminal loading in excess of these values is considered special, and application shall be checked with the manufacturer. The user shall consider all forces acting on the conductors connected to the terminals. These forces include: wind, ice, seismic, and short-circuit forces.

Table 4—Terminal mechanical loading

Rated maximum voltage	Rated continuous current	Static horizontal force		Static vertical force[a]
		Longitudinal (N)	Transverse (N)	Vertical (N)
Below 100 kV	1200 A and below Above 1200 A	500 750	400 500	500 750
123 kV to 170 kV	2000 A and below Above 2000 A	1000 1250	750 750	750 1000
245 kV	All	1250	1000	1250
362 kV to 800 kV	All	1750	1250	1250

[a]Vertical axis forces are upward and downward.

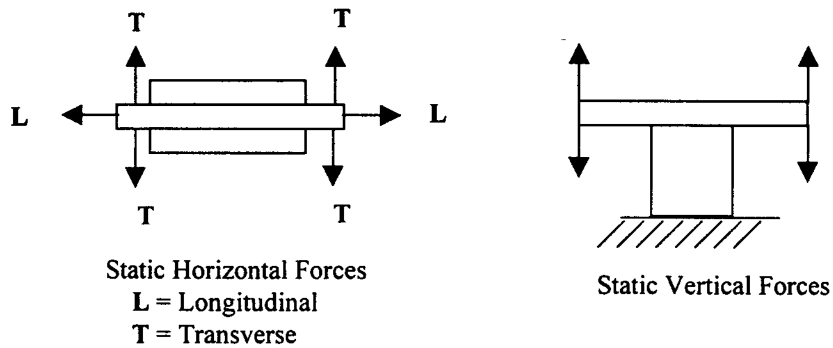

Figure 8—Direction of terminal mechanical loading forces

6.4 Pressurized components

6.4.1 Metal vessels

All metal vessels, except those having internal or external operating gas pressure not exceeding 207 kPa (absolute) (with no limitation on size), or those having an inside diameter not exceeding 152 mm (with no limitation on pressure), shall be tested in accordance with the ASME 1998 Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels, and any state and local codes that apply at the point of original installation.

6.4.2 Porcelain components

If porcelain is used in the circuit breaker, the porcelain shall satisfy the test requirements of IEEE Std C37.09-1999.

6.4.3 Non-ceramic pressurized vessels

6.4.3.1 Non-isolating pressure vessels

All non-ceramic insulating gas storage bottles, receivers, and pressure vessels that neither electrically isolate nor separate high-voltage elements of 1000 V or higher shall be designed to meet the requirements of the ASME 1998 Boiler and Pressure Vessel Code, Section X, Fiber-Reinforced Plastic Pressure Vessels, and of any state and local codes that are applicable at the point of original installation of the equipment.

6.4.3.2 Isolating pressure vessels

All pressurized vessels, insulators, and tubes consisting of non-ceramic insulating components, which electrically isolate or separate high-voltage elements of 1000 V or higher; have an internal-to-external or external-to-internal differential gas pressure exceeding 207 kPa (absolute) (15 psig); and have an inside diameter exceeding 152 mm (6 in); shall be individually tested as indicated in IEEE Std C37.09-1999.

6.5 Pressurized systems

Each gas system on a circuit breaker shall have an ASME-approved safety or relief valve set to operate to relieve pressure at a value not exceeding the maximum allowable working pressure of the system. Such valve shall be designed to prevent the pressure from rising more than 20% above the maximum allowable working pressure.

If a gas system that includes pressurized porcelains, epoxies, or other brittle materials is subjected to substantial rates-of-rise of pressure caused by exposure to abnormal events or sources of heat, additional overpressure relief set at 20% above maximum allowable working pressure shall be provided by one of the following or its equivalent:

a) Rupture diaphragm;
b) Large area relief piston;
c) Spring-clamped construction; or
d) Design for controlled rupturing.

When a pressurized metal vessel of an interconnected system of metal and porcelain elements is provided with a device qualifying under the above, this device may be used to protect the interconnected system. Any porcelain, epoxy, or other brittle materials that are pressurized shall be protected by the overpressure relief device.

NOTE—By agreement between the user and the manufacturer, the requirement for an ASME-approved safety or relief valve may be exempted for closed gas systems that have a gas volume sufficiently large so as to limit the gas pressure rise to less than 1.5 times the design pressure in the event of an uncontrolled arc for a time period limited by relay operation.

6.6 Gas and vacuum tightness

6.6.1 Closed pressure systems for gas

A closed pressure system for gas is a volume that can be replenished only periodically by manual connection to an external gas source. The tightness characteristic of a closed pressure system stated by the manufacturers shall be consistent with a minimum maintenance and inspection philosophy. The maximum leakage rate of a closed pressure system for gas shall be less than 1% per year.

6.6.2 Sealed pressure systems

A sealed pressure system is a volume for which no further gas or vacuum processing is required during the expected operating life.

6.7 Functional components

The functional components required for basic circuit breaker operation and use are listed below. Additional accessory devices may be available and the manufacturer should be consulted.

6.7.1 Contact position indicator

A reliable mechanical contact position indicator, which can easily be read by the local operator, shall be supplied. The following colors shall be used:

a) Red background with the word “closed” in contrasting letters to indicate closed contacts; and
b) Green background with the word “open” in contrasting letters to indicate open contacts.

6.7.2 Operations counter

An operations counter shall be supplied. The preferred arrangement for this device is to operate during the opening cycle of the circuit breaker operation.

6.7.3 Power-operated mechanism

The mechanism shall be trip-free and have an anti-pump feature (for definitions, see 6.9 and IEEE Std C37.100-1992).

6.7.4 Shunt release (trip) device with necessary control auxiliary switches

A shunt release coil with necessary control auxiliary switches shall be capable of tripping the circuit breaker when any voltage throughout the control voltage range is applied (see ANSI C37.06-1997).

6.7.5 Stored energy indicator

A stored energy indicator that can easily be read by the local operator shall be supplied. For stored energy systems using compressed gas, a pressure gauge shall be supplied. For stored energy systems using springs, a reliable indicator with the following colors shall be provided:

a) Yellow background with black lettering to indicate “charged” mechanism; and
b) White background with black lettering to indicate “discharged” mechanism.

6.7.6 Manual releases

Indoor circuit breaker mechanisms shall have a manual release to OPEN the circuit breaker, and a manual release to CLOSE the circuit breaker. They shall be labeled clearly so that a local operator can easily read and operate them. Manual releases for outdoor circuit breaker mechanisms, if provided, shall meet the same requirements described in 6.7.5.

Manual releases shall have the following colors:

a) Red background with the word “open” and/or “trip” in contrasting letters to indicate that the release opens the circuit breaker; and
b) Green or black background with the word “close” in contrasting letters to indicate that the release closes the circuit breaker.

6.7.7 Functional interlocking components—indoor drawout circuit breakers

All indoor drawout circuit breakers shall have the necessary drawout position (racking) and mechanism interlocks, primary and secondary disconnects, primary insulation, and control wiring to fully correlate and coordinate with IEEE Std C37.20.2-1993 requirements.

6.8 Stored energy requirements for operating mechanisms

Operating mechanism stored energy requirements depend on time to recharge after a CO (close-open) operation of the circuit breaker. Mechanism recharging requirements given in Table 5 are the maximum permissible recharging times for recharging the operating mechanism to restore rated conditions of energy storage (i.e., spring charge, pneumatic pressure, hydraulic pressure, etc.) after one CO operation starting at rated conditions. Rated control voltages shall be used in determining the recharge time.

6.9 Operating mechanism requirements

a) The circuit breaker operating mechanism(s) shall be designed so that the tripping function shall prevail over the closing function.

Table 5—Energy storage requirements of operating mechanisms

Max recharging time after CO operation	Stored energy requirements
15 s	OCO[a]
30 s	Two CO[b]
30 min	Four CO
Over 30 min	Five CO

[a]OCO = open-close-open
[b]CO = close-open

When a tripping signal (mechanical or electrical) is received while a closing operation is being executed, even if the closing signal (mechanical or electrical) is maintained, the following shall apply:

1) If the closing signal is applied simultaneously with the tripping signal (mechanical or electrical) or if the tripping signal is applied after the closing signal, the circuit breaker contacts shall be permitted to close or touch momentarily.

2) If the tripping circuit is completed through the circuit breaker auxiliary switch contact(s) (or other electronic devices), electrical tripping devices will not be energized until after the auxiliary switch contacts have closed and the circuit breaker main contacts are permitted to close or touch momentarily.

3) If the mechanical tripping signal is applied and held prior to the application of a closing signal (mechanical or electrical), the circuit breaker contacts shall not be permitted to close, even momentarily. It may be necessary for the mechanism to release energy during such an operation. However, movement of the contacts shall not reduce the open gap by more than 10%, nor shall it reduce the rated dielectric withstand capability for the contact gap, and the contacts shall come to rest in the fully open position.

b) The anti-pump function, as defined in IEEE Std C37.100-1992, shall be provided as required in IEEE Std C37.11-1997.

c) Operating mechanism components shall be capable of up to 30 CO operations per hour, as long as available mechanism energy exists, without exceeding thermal or mechanical limitations. This requirement is based on mechanical capability and does not imply stored energy capability (see Table 5).

6.10 Electromagnetic compatibility (EMC)

The secondary system shall be able to withstand transient voltage disturbances up to 1500 V without damage or malfunction. This applies to normal operation and under switching conditions, including interruption of fault currents in the main circuit. The secondary system consists of the following:

a) Control and auxiliary circuits, including circuits in control cubicles;
b) Equipment for monitoring, diagnostics, etc., that is part of the circuit breaker;
c) Circuits connected to the secondary terminals of instrument transformers.

6.11 Requirements for simultaneity of poles

When no special requirements with respect to simultaneous operation of poles is stated, the maximum difference between the instants of contacts touching during closing shall not exceed 1/4 of a cycle of rated power frequency.

When no special requirement with respect to simultaneous operation of poles is stated, the maximum difference between the instants of contacts separating during opening shall not exceed 1/6 of a cycle of rated power frequency.

Circuit breakers with an intentional delay between poles need special consideration. Circuit breakers with operations after a single-pole operation are not subject to these requirements.

7. Nameplate markings

The following minimum data, when applicable, shall appear on the nameplates of each circuit breaker.

7.1 Circuit breaker

Circuit breaker and operating mechanism nameplates may be combined.

a) Manufacturer’s name;
b) Manufacturer’s type designation;
c) Manufacturer’s serial number;
d) Year of manufacture;
e) Rated maximum voltage;
f) Rated power frequency;
g) Rated continuous current;
h) Rated full wave lightning impulse withstand voltage;
i) Rated switching-impulse withstand voltages
    1) Terminal-to-ground circuit breaker closed;
    2) Terminal-to-terminal circuit breaker open;
j) Rated operating duty cycle;
k) Rated interrupting time;
l) Rated short-circuit current;
m) Percent dc component;
n) Short time current duration;
o) Normal operating pressure;
p) Minimum operating pressure;
q) Volume of oil per tank or weight of gas per circuit breaker;
r) Weight of circuit breaker complete (with oil or gas);
s) Instruction book number;
t) Parts list number;
u) Ratings for capacitance current switching
    1) Rated overhead line charging current;
    2) Rated isolated cable and isolated shunt capacitor bank switching current;
    3) Rated back-to-back cable and isolated shunt capacitor bank switching current;
    4) Rated transient inrush current peak;
    5) Rated transient inrush current frequency;
v) Rated out-of-phase switching current.

7.2 External insulation

The rated dielectric withstand of the external insulation shall be included on the circuit breaker nameplate, except when it is a self-contained component, such as a bushing or current transformer; then it shall be included on the nameplates of the component (see IEEE Std C57.19.00-1991 for bushings).

7.3 Operating mechanism

Operating mechanism and circuit breaker nameplates may be combined.

a) Manufacturer's name;
b) Manufacturer's type designation;
c) Manufacturer's serial number;
d) Year of manufacture;
e) Closing control voltage range;
f) Tripping control voltage range;
g) Closing current;
h) Tripping current;
i) Compressor or hydraulic pump or spring charging motor control voltage range;
j) Compressor or hydraulic pump or spring charging motor current;
k) Compressor or hydraulic pump control switch closing and opening pressure (if applicable);
l) Low-pressure alarm switch closing and opening pressure (if applicable);
m) Low-pressure lockout switch closing and opening pressure (if applicable);
n) Wiring diagram number;
o) Instruction book number;
p) Parts list number.

7.4 Current transformers and linear coupler transformers

Nameplates located at respective terminal blocks are as follows:

a) Manufacturer's name;
b) Manufacturer's type designation;
c) Rated power frequency, if other than 50 Hz or 60 Hz;
d) Accuracy class;
e) Connection chart showing
   1) Full winding development;
   2) Taps;
   3) Ratio in terms of primary and secondary currents;
   4) Polarity;
   5) Pole and pocket location;
f) Instruction book number;
g) Curve sheet number;
h) Mutual reactance (for linear coupler transformers only);
i) Self-impedance (for linear coupler transformers only)
   1) Resistance;
   2) Reactance;
   3) Impedance.

7.5 Accessories

Nameplates of all accessories shall include the following:

a) Identification;
b) Pertinent operating characteristics.

7.6 Instruction and warning signs

Essential markings shall be provided to

a) Identify operating devices and positions;
b) Give pertinent instructions for operation;
c) Call attention to special precautions;
d) Call attention to environmental warnings.