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(Revision of ANSI/IEEE C37.04-1964)
(Includes Supplement ANSI/IEEE C37.04c-1985)

An American National Standard

IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

Sponsor
Switchgear Committee
of the
IEEE Power Engineering Society

Secretariat

Institute of Electrical and Electronics Engineers
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American National Standard

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Foreword

(This Foreword is not a part of ANSI/IEEE C37.04-1979, American National Standard, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.)

The development of standards for the rating, testing, and manufacture of high-voltage circuit breakers began almost simultaneously with the application of the first circuit breakers in early power supply systems.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

where

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

American National Standards Institute
1430 Broadway
New York, NY 10018

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

C. L. Wagner, *Chair*
J. P. Lucas, *Secretary*
J. E. Beehler *(Executive Vice-Chairman of High-Voltage Switchgear Standards)*
W. E. Laubach *(Executive Vice-Chairman of Low-Voltage Switchgear Standards)*
W. R. Wilson *(Executive Vice-Chairman of IEC Activities)*

Organization Represented	Name of Representative
Association of Iron and Steel Engineers	J. M. Tillman
Electric Light & Power Group	J. E. Beehler H. G. Darron H. G. Frus K. D. Hendrix F. R. Solis K. G. Adgate (Alt) R. L. Capra (Alt) R. L. Lindsey (Alt) E. E. Ramm (Alt)
Institute of Electrical and Electronics Engineers	M. J. Maier H. H. Fahnoe R. E. Friedrich G. W. Walsh H. F. White M. J. Beachy (Alt) C. A. Mathews (Alt) R. A. McMaster (Alt) D. C. Musgrave (Alt)
National Electrical Manufacturers Association	A. P. Colaiaco R. W. Dunham D. G. Portman G. A. Wilson W. R. Wilson
Testing Laboratory Group	E. J. Huber R. A. Naysmith R. W. Seelbach (Alt)
Tennessee Valley Authority	R. C. St. Clair
U.S. Department of the Army	R. H. Bruck
U.S. Department of the Interior, Bureau of Reclamation	E. M. Tomsic
U.S. Department of the Navy, Naval Facilities Engineering Command	D. M. Hannemann

The personnel of the C37 Subcommittee on High Voltage Circuit Breakers which reviewed and approved this document were as follows:

F. G. Schaufelberger, *Chair*
J. J. Fayed, *Secretary*

J. E. Beehler
D. O. Craghead
M. A. Durso
C. J. Dvorak
R. E. Friedrich
R. D. Hambrick

D. R. Kanitz	G. N. Lester	D. L. Swindler
W. E. Laubach	F. W. Smith	W. R. Wilson

The basic source documents used in this consolidated document were prepared by various Working Groups of the Power Circuit Breaker Subcommittee of the IEEE Switchgear Committee. The personnel of the subcommittee at the time of consolidation were as follows:

G. N. Lester, *Chair*

H. W. Anderl	R. D. Hambrick	A. B. Rishworth
J. E. Beehler	G. R. Hanks	W. N. Rothenbuhler
D. M. Benenson	W. C. Huening, Jr	F. G. Schaufelberger
L. E. Brothers	P. L. Kolarik	H. N. Schneider
R. G. Colclaser	S. R. Lambert	E. F. Solorzano
J. C. Coon	D. M. Larson	C. J. Truax
C. F. Cromer	W. E. Laubach	E. F. Veverka
C. R. Cusick	M. J. Maier	C. L. Wagner
A. Dupont	J. A. Maneatis	D. R. Webster
C. J. Dvorak	R. A. McMaster	A. C. Wert
J. D. Finley	G. J. Meinders	G. A. Wilson, Jr
R. E. Friedrich	G. L. Nuss, Jr	W. R. Wilson
T. F. Garrity	I. E. Olivier	B. F. Wirtz
W. F. Giles	G. O. Perkins	C. E. Zanzie
K. I. Gray	J. G. Reckleff	
G. P. Guaglione	H. K. Reid	

The Working Group of this subcommittee responsible for the editorial consolidation work on this standard consisted of:

N. E. Reed	W. N. Rothenbuhler	F. G. Schaufelberger

When the IEEE Standards Board approved this standard on September 4, 1975, it had the following membership:

An American National Standard

IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

Supplement C37.04c-1985 is indicated by revision bars in the margin.

1. Scope

This standard applies to all indoor and outdoor types of ac high-voltage circuit breakers rated above 1000 V and rated on a symmetrical current basis.

2. Purpose

The purpose of this standard is to establish a rating structure for ac high-voltage circuit breakers rated on a symmetrical current basis.

3. Definitions

The terms and conditions applicable to this standard and to the related standards for ac high-voltage circuit breakers shall be in accordance with ANSI C37.100-1972, Definitions for Power Switchgear. These definitions are not intended to embrace all possible meanings of the terms. They are intended for the sole purpose of establishing those meanings of terms used in power switchgear. ANSI/IEEE Std 100-1977, Dictionary of Electrical and Electronics Terms, should be referred to for other meanings that the terms properly may have when used in connection with other subjects.

4. Service Conditions

4.1 Usual Service Conditions

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

1) Where the temperature of the ambient is not above 40°C or below –30°C
2) Where the altitude is not above 3300 ft (1000 m)

4.2 Unusual Service Conditions

4.2.1 *Abnormal Temperatures.*

The use of apparatus in cooling media having a temperature lower than –30°C or higher than 40°C shall be considered as special.

4.2.2 *Altitudes Above 3300 ft (1000 m).*

For applications at altitudes higher than 3300 ft (1000 m), rated dielectric strength and rated maximum voltage shall be multiplied by an altitude correction factor for voltage, and the rated continuous current shall be multiplied by an altitude correction factor for continuous current to obtain values at which applications may be made. These correction factors are shown in Table 1. (Rated short-circuit current, rated voltage range factor, and rated interrupting time are not corrected for altitude.)

4.2.3 *Conditions Affecting Construction or Protecting Features.*

There are further unusual conditions which, where they exist, should receive special consideration. Such conditions should be brought to the attention of those responsible for the application, manufacture, and operation of the equipment. Apparatus for use in such cases may require special construction or protection. Among such unusual conditions are:

4.2.3.1

Exposure to damaging fumes or vapors, excessive or abrasive duct, explosive mixtures of dust or gases, steam, salt spray excessive moisture, dripping water, and other similar conditions.

Table 1— Altitude Correction Factors (ACF)

Altitude (ft)	Altitude (m)	ACF for Voltage†*	ACF for Continuous Current†
3300	1000	1.00	1.00
5000	1500	0.95	0.99
10,000	3000	0.80	0.96

**NOTE:* Interpolated values shall be used in determining correction factors for intermediate altitudes.

†**NOTE:** For some types of circuit breakers (for example, those with sealed interrupters), it may not be necessary to apply the ACF for voltage to rated maximum voltage. The manufacturer should be consulted.

4.2.3.2

Exposure to abnormal vibration, shocks, or tilting.

4.2.3.3

Exposure to excessively high or low temperatures.

4.2.3.4

Exposure to unusual transportation or storage conditions.

4.2.3.5

Unusual space limitations.

4.2.3.6

Unusual operating duty, frequency of operation, and difficulty of maintenance.

4.2.3.7

Short-circuit current with asymmetry greater than 100 percent.

5. Ratings

The rating of a circuit breaker is a designated limit of operating characteristics based upon definite conditions and shall include the following items, where applicable:

1) Rated maximum voltage (see 5.1)
2) Rated voltage range factor *K* (see 5.2)
3) Rated frequency (see 5.3)
4) Rated continuous current (see 5.4)
5) Rated dielectric strength (see 5.5)
6) Rated standard operating duty (standard duty cycle) (see 5.6)
7) Rated interrupting time (see 5.7)
8) Rated permissible tripping delay *Y* (see 5.8)
9) Rated reclosing time (see 5.9)
10) Rated short-circuit current (see 5.10.1)
11) Rated transient recovery voltage (see 5.11)
12) Required load current switching capability and life (see 5.12)
13) Rated capacitance current switching (see 5.13)
14) Rated line closing switching surge factor (see 5.14)
15) Rated out-of-phase switching current (see 5.15)
16) Rated shunt reactor current switching (see 5.16)
17) Rated excitation current switching (see 5.17)
18) Rated control voltage (see 5.18)
19) Rated fluid operating pressure (see 5.19)

For standard ratings of circuit breakers, see ANSI C37.06-1979, Schedules of Preferred Ratings and Related Required Capabilities for AC High-Voltage Circuit Breakers.

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 sections. The ratings assigned to a circuit breaker are based on test data in accordance with ANSI/IEEE C37.09-1979, Test Procedure for AC High-Voltage Circuit Breakers; but other equivalent or more effective methods of test are not precluded.

Alternatively, for designs existing prior to the adoption of these standards, the rating can be based on other tests which are judged to be equally effective on the basis of the experience gained from previous design or development tests, or by service performance experience.

5.1 Rated Maximum Voltage.

The rated maximum voltage of a circuit breaker is the highest rms (root-mean-square) voltage, above nominal system voltage, for which the circuit breaker is designed, and is the upper limit for operation. Nominal system voltage refers to the general voltage class and rated maximum voltage is the same as maximum design voltage rating referred to in ANSI C84.1-1977, Voltage Ratings for Electric Power Systems and Equipment (60 Hz), and ANSI C92.2-1974, Preferred Voltage Ratings for Alternating-Current Electrical Systems and Equipment Operating at Voltages Above 230 Kilovolts Nominal.

5.2 Rated Voltage Range Factor *K*.

The rated voltage range factor K is the ratio of rated maximum voltage to the lower limit of the range of operating voltage in which the required symmetrical and asymmetrical interrupting capabilities vary in inverse proportion to operating voltage. For numerical values of K, refer to the tables of preferred ratings in ANSI C37.06-1979.

5.3 Rated Frequency.

The rated frequency of a circuit breaker is the frequency at which it is designed to operate. Standard frequency is 60 Hz. Applications at other frequencies should receive special consideration.

5.4 Rated Continuous Current.

The rated continuous current of a circuit breaker is the designated limit of current in rms amperes at rated frequency which it shall be required to carry continuously without exceeding any of the limitations designated in 5.4.1 and 5.4.2. For rated continuous currents, refer to the tables of preferred ratings in ANSI C37.06-1979.

5.4.1 *Conditions of Continuous Current Rating.*

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

1) Breakers are used under the usual service conditions defined in 4.1.
2) Current ratings shall be based on the total temperature limits of the materials used for breaker parts. A temperature rise reference is given to permit testing at reduced ambient.
3) Breakers designed for installation in enclosures shall have their ratings based on the ventilation of such enclosures and a 40°C ambient temperature outside the enclosure.
4) Outdoor breakers and indoor breakers without enclosures shall have ratings based on a 40°C ambient temperature.

5.4.2 *Temperature Limitations*.

5.4.2.1 *Limitations on Insulating Material.*

The temperature 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 breaker shall be limited to the values listed in columns B and C in Table 2. It is recognized that these limits are generally less than those associated with the insulating class in IEEE Std 1-1969, General Principles for Temperature Limits in the Rating of Electric Equipment, since such insulation may be subject to severe mechanical as well as dielectric stress when used in high-voltage circuit breakers.

Where outdoor apparatus bushings within the scope of ANSI/IEEE Std 21-1976, General Requirements and Test Procedures for Outdoor Apparatus Bushings, and ANSI/IEEE Std 24-1977, Standard Electrical, Dimensional, and Related Requirements for Outdoor Apparatus Bushings, are used, the temperature limits in Table 3 do not apply to the bushings.

5.4.2.2 ***Limitations on Main Contacts.***

The temperature of the main contacts used in circuit breakers shall not exceed the values listed in Table 3.

Contacts in other than oil or air may be operated at other temperatures providing it can be shown, by experience or tests acceptable to the user, that accelerated deterioration will not occur. (Future consideration will be given to standardized values.)

Table 2— Temperature Limitations on Insulating Material

Class of Material	Insulating Class Limits	Main Power Circuit Limits	
	Column A Hottest Spot Total Temperature(°C)	Column B Hottest Spot Temperature Rise(°C)	Column C Hottest Spot Total Temperature(°C)
O	90	40	80
A	105	55	95
B	130	80	120
F	155	105	145
H	180	130	170
C	220	180	220
Oil (see Note 4)	90	50	90

NOTES:
1 — Temperatures of materials used to insulate other than from phase to ground or from terminal to terminal of an open breaker shall be limited to the hottest spot temperatures listed in Column A. Multiturn coils constitute an example.

2 — If gaseous insulating material is used as conforming to one of the above classes, the manufacturer shall establish that it will not cause accelerated deterioration of other parts.

3 — The total temperature of main power circuit conducting parts in contact with insulation shall be limited at the points of contact to the total temperature limit of the insulating material (see Column C).

4 — The top oil (upper layer) temperature shall not exceed 40°C rise or 80°C total. The 50°C and 90°C values refer to the hottest spot temperature of parts where they contact the oil.

Table 3— Temperature Limitations on Main Contacts

Contact Surfaces	Limit of Hottest Spot Temperature Rise (°C)	Limit of Hottest Spot Total Temperature (°C)
Copper Silver, Silver alloy, or Equivalent	30 50 (in oil) 65 (in air)	70 90 (in oil) 105 (in air)

Table 4— Temperature Limitations on Conducting Joints

Conducting Joint Surfaces	Limit of Hottest Spot Temperature Rise (°C)	Limit of Hottest Spot Total Temperature (°C)
Copper Silver, Silver Alloy, or Equivalent	30 50 (in oil) 65 (in oil)	70 90 (in oil) 105 (in air)

5.4.2.3 *Limitations on Conducting Joints*

5.4.2.3.1 *Conducting Joints Other than Terminals for Insulated Cable Connection.*

The temperature of conducting joints in the main power circuit of a circuit breaker shall not exceed the values listed in Table 4.

Conducting joints in other than oil or air may be operated at other temperatures providing it can be shown, by experience or tests acceptable to the user, that accelerated deterioration will not occur. (Future consideration will be given to standardized values.)

5.4.2.3.2 *Terminals for Connection to Insulated Cable.*

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 85°C maximum insulated cable, rated for the full continuous current rating of the circuit breaker.

5.4.2.4 *Limitations for Parts Subject to Contact by Personnel.*

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

Circuit breakers having external surfaces not accessible to an operator in the normal course of his duties shall have no higher total temperature on the surfaces than 110°C.

5.4.2.5 *Limitations on Other Materials.*

Other materials shall be chosen so that the maximum temperatures to which they may be subjected shall not cause accelerated deterioration.

5.5 Rated Dielectric Strength.

The rated dielectric strength of a circuit breaker is its voltage withstand capability with specified magnitudes and waveshapes of test voltage applied under specified test conditions. The circuit breaker shall withstand these various test voltages without flashover or puncture of any of its parts except as stated in this standard and in ANSI/IEEE C37.09-1979.

The rated dielectric strength of a circuit breaker shall include:

1) Dry and wet (where applicable) low-frequency withstand voltage
2) Dry impulse withstand voltage
3) Dry chopped wave impulse withstand voltage (where applicable)
4) 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.

5.5.1 *Dielectric Strength of External Insulation.*

External insulation shall conform to the performance requirements of this standard except as noted below.

Bushings classified as outdoor apparatus bushings shall conform to the requirements of ANSI/IEEE Std 21-1977 and ANSI/IEEE Std 24-1977. Other bushings shall conform to the performance requirements of this standard. Wet dielectric tests on bushings may be substituted for wet dielectric tests on circuit breakers using ANSI/IEEE Std 21-1977 bushings 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 low-frequency and impulse tests.

Requirements for the rated dielectric strength of the external insulation of outdoor ac high voltage circuit breakers are given in Table 6 of ANSI C37.06-1979.

5.5.2 *Rated Low-Frequency Withstand Voltage*

5.5.2.1 *Dry.*

The rated low-frequency withstand voltage (dry) is the test voltage which a new circuit breaker must be capable of withstanding for one minute without flashover or puncture when tested under specified conditions. See Tables 1, 2, and 6 of ANSI C37.06-1979 for required voltages. See also 4.5 of ANSI/IEEE C37.09-1979.

5.5.2.2 *Wet.*

The rated low-frequency voltage (wet) is the voltage which a new outdoor circuit breaker or external components thereof, such as supporting insulating structures, shall be capable of withstanding for 10 s without flashover or puncture when tested under specified conditions. The bushing wet withstand values as indicated in ANSI/IEEE Std 24-1977 will be acceptable as the wet withstand values of the breaker.

5.5.2.3 *Frequency and Wave Shape of Low-Frequency Test Voltage.*

The frequency of the low-frequency test voltage shall be within ±20 percent of the rated frequency of the apparatus tested. A sine wave shape is recommended. The test shall be made with alternating voltage having a crest value equal to $\sqrt{2}$ times the specified test voltage.

5.5.3 *Rated Full Wave Impulse Withstand Voltage.*

The rated full wave impulse withstand voltage is the crest value of a standard 1.2×50 impulse voltage wave which a new circuit breaker must be capable of withstanding without flashover or puncture when tested under specified conditions. See ANSI C37.06-1979 and ANSI/IEEE C37.09-1979.

5.5.4 *Impulse Test Voltage for Interrupter and Resistors.*

Outdoor circuit breakers having a rated maximum voltage of 121 kV and above, having isolating gaps in series with interrupting gaps or additional gaps in the resistor or capacitor circuits, shall be capable of being subjected, without damage, to a standard 1.2×50 impulse test voltage wave having a crest value of 75 percent of the rated full wave impulse withstand voltage of the circuit breaker applied across a pole unit to the series connected interrupting gaps only, with all isolating gaps and all gaps in the resistor and capacitor circuits closed. See ANSI C37.06-1979 and ANSI/IEEE C37.09-1979.

It is recognized that for circuit breakers utilizing low-ohmic resistors, the above wave shape is unattainable with practical facilities. In this case, the voltage is defined as an open-circuit voltage equal to 75 percent of the rated full wave impulse withstand voltage of the circuit breaker applied through a series resistance not exceeding 500 Ω, and with the minimum practical series inductance in the impulse generator.

5.5.5 *Rated Chopped Wave Impulse Withstand Voltage.*

For outdoor power circuit breakers having a rated maximum voltage of 15.5 kV and above, the rated chopped wave impulse withstand voltage is the crest value of a standard impulse voltage higher than the rated full wave impulse withstand voltage which a new circuit breaker must 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 4-1978, Standard Techniques for High Voltage Testing.

The rated chopped wave impulse withstand test voltages shall consist of two values:

1) 129 percent of rated full wave impulse withstand voltage chopped at a minimum time of 2 μs
2) 115 percent of rated full wave impulse withstand voltage chopped at a minimum time of 3 μs

Values shall be as given in columns 6 and 7 of Table 6 of ANSI C37.06-1979. See 4.5.4 of ANSI/IEEE C37.09-1979.

5.5.6 *Rated Switching-Impulse Withstand Voltage.*

For outdoor power circuit breakers having a rated maximum voltage of 362 kV and above, the rated switching-impulse withstand voltage is the crest value of the standard 250 × 2500 μs switching-impulse voltage wave which a new circuit breaker must be capable of withstanding without puncture or damage when tested both wet and dry under specified conditions. It demonstrates 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.

Unidirectional switching-impulse voltages of both positive and negative polarities shall be applied to each open circuit breaker terminal with the opposite terminal and adjacent phases grounded, and to each pole of the closed circuit breaker with the adjacent phases grounded.

At the rated switching-impulse withstand voltage, the closed circuit breaker shall have the probability of external flashover to ground of 10 percent or less. Table 6 of ANSI C37.06-1979 lists the required values of rated switching-impulse withstand voltage for the circuit breaker open and closed positions.

5.5.7 *Condition of Circuit Breaker to be Tested.*

The breaker shall be in good condition, and tests shall be applied before the breaker is put into commercial service, unless otherwise specified. High-voltage tests to determine whether specifications are fulfilled are admissible on new breakers only.

5.5.8 *Where High-Voltage Tests Are to be Made.*

Unless otherwise agreed upon, high-voltage tests shall be made at the factory.

5.5.9 *Temperature at Which High-Voltage Tests Are to be Made.*

High-voltage tests shall be made at the temperature assumed under normal operation or at the temperature attained under the conditions of commercial testing.

5.5.10 *Points of Application of Test Voltage*

5.5.10.1 *Tests*

Test 1—Terminals to Ground. With the circuit breaker closed, apply the test voltage simultaneously to all terminals.

Test 2—Across Open Contacts. With the circuit breaker open, apply the test voltage simultaneously to the terminals on one side of the breaker with the other terminals grounded.

Test 3—Between Phases. With the circuit breaker closed, apply the test voltage to the terminals of one phase with the terminals of the other phases grounded. On 3- or 4-pole breakers, the voltage shall be applied to the interior phase or phases. This test is not required on single-pole breakers, nor when the phase-to-phase spacing is greater than the spacing between the terminals of one pole.

5.5.10.2 *Grounding.*

In all tests, normal grounded metal parts shall be connected to the grounded side of the test circuit.

5.5.10.3 *Insulation Taping or Special Insulation.*

When the dielectric strength of a circuit breaker is dependent upon taping of the leads or the use of special insulation, such taping of special insulation may be used when the factory test is made.

5.5.11 *Measurement of Test Voltage.*

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

5.5.12 *Creepage Distance.*

Creepage distance over external insulation is listed in Table 6 of ANSI C37.06-1979. These minimum values are for the normal conditions of atmospheric contamination and represent generally satisfactory service operation under these conditions.

NOTE — Precise definitions of normal conditions cannot be given since the performance of an envelope of insulation for protection from atmospheric conditions will depend not only on the deposition of solid matter, but also on the nature of the deposit and the prevalence of fog and conditions on high humidity. Experience in the area of the installation is the best guide, but in the case of localized industrial contamination, for example, chemical fumes, cement dust, etc, such considerations and exposure at the installation itself must be considered. In the case of soluble deposits such as salt, consideration should also be given to the probability of rainfall to act as a washing agent. For heavy contamination, it is the general practice to use increased leakage distances, but it should be realized that frequently satisfactory results may also require consideration of the shape of the envelope of insulation to obtain the required protection from the atmospheric conditions. Special cases of pollution should be referred to the manufacturer.

5.6 Rated Standard Operating Duty (Standard Duty Cycle).

The standard operating duty of a circuit breaker shall be two unit operations with 15 s interval between operations (CO – 15 s – CO).

5.7 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 the interruption of the main circuit in all poles on an opening operation, when interrupting a current within the required interrupting capabilities and equal to 25 percent or more of the required asymmetrical interrupting capability at rated maximum voltage. At duties below 25 percent of the required asymmetrical interrupting capability at rated maximum voltage, the circuit shall be interrupted, but the time required for interruption may be greater than the rated interrupting time by as much as 50 percent for 5 and 8 cycle breakers and 1 cycle for breakers of 3 cycles and less. For breakers equipped with resistors, the interrupting time of the resistor current may be longer. The interrupting time for a close-open operation at a specified duty shall not exceed the rated interrupting time by more than 1 cycle for 5 and 8 cycle breakers and $^1/_2$ cycle for breakers of 3 cycles and less. When time is expressed in cycles, it shall be on a 60 Hz basis.

5.8 Rated Permissible Tripping Delay *Y*.

The rated permissible tripping delay of a circuit breaker is *Y* seconds and is the maximum value of time for which the circuit breaker is required to carry *K* times rated short-circuit current after closing on this current and before interrupting. For values, see ANSI C37.06-1979.

5.8.1 *Permissible Tripping Delay T.*

Tripping of the circuit breaker may be delayed beyond the rated permissible tripping delay at lower values of current in accordance with the following formula:

$$T = Y\left[\frac{K\ \text{(rated short-circuit current)}}{\text{short-circuit current through breaker}}\right]^2$$

The aggregate tripping delay on all operations within any 30 minute period must not exceed the time obtained from the above formula.

The short-circuit current through the breaker equals the rms of the current over the delay period *T* and is expressed by:

$$I = \sqrt{\frac{1}{T}\int_0^T i^2 \mathrm{d}\,t}$$

where

i =	instantaneous rms current in amperes
t =	time in seconds

To find the permissible tripping delay *T*, combine the above two equations, giving:

$$\sqrt{\frac{1}{Y}\int_0^T i^2 \mathrm{d}\,t} = K\ \text{(rated short-circuit current), or}$$

$$\int_0^T i^2 \mathrm{d}\,t = Y\ [K\ \text{(rated short-circuit current)}]^2$$

Determine the envelope of the short-circuit current through the breaker, against time, and obtain the rms values from 7.1.6 of ANSI/IEEE C37.09-1979.

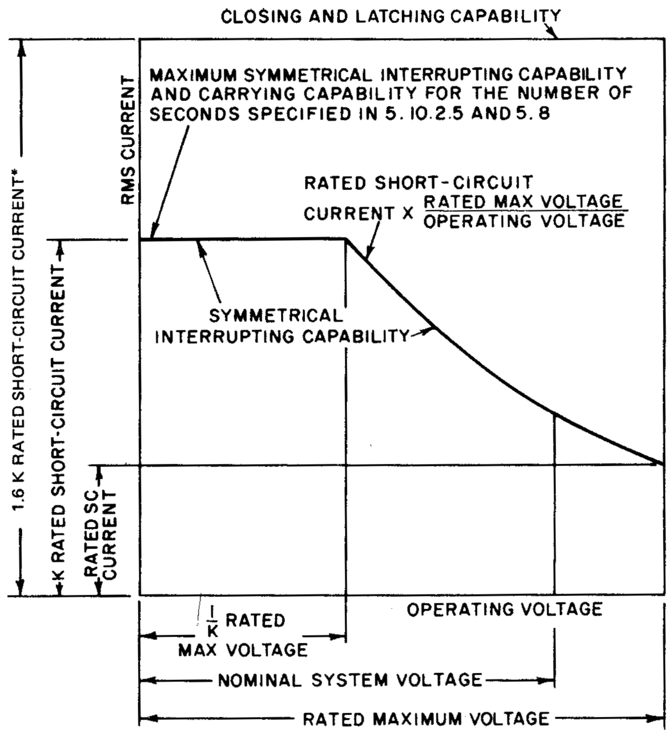
Square the latter values and obtain the corresponding curve. Integrate this ($i^2\,dt$) for various values of delay periods *T*. (See ANSI/IEEE C37.09-1979.) The value of *T* for which the integral equals *Y* times *K* times rated short-circuit current squared is the permissible tripping delay.

5.9 Rated Reclosing Time.

The rated reclosing time of a circuit breaker is the shortest reclosing time which the breaker is required to meet with rated control voltage and rated fluid operating pressure applied. See ANSI C37.06-1979.

5.10 Short-Circuit Rating.

The short-circuit rating of a circuit breaker is established by the symmetrical component of short-circuit current in rms amperes, designated rated short-circuit current, to which all required short-circuit capabilities are related. All values apply to both grounded and ungrounded short circuits on predominantly inductive or resistive 3-phase circuits with a normal frequency phase-to-phase recovery voltage equal to the operating voltage.



*Or 2.7*K* times rated short-circuit current if current is measured in peak amperes.
NOTE: *K* equals voltage range factor. (For preferred standard values see ANSI C37.06-1979.)

Figure 1— Relation of Symmetrical Interrupting Capability, Closing Capability, Latching Capability, and Carrying Capability to Rated Short-Circuit Current

5.10.1 *Rated Short-Circuit Current.*

The rated short-circuit current of a circuit breaker is the highest value of the symmetrical component of the polyphase or phase-to-phase short-circuit current in rms amperes measured from the envelope of the current wave at the instant of primary arcing contact separation which 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 5.10.2, the highest currents which the 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 C37.06-1979.

The relationship of rated short-circuit current to the other required capabilities is illustrated graphically in Figs 1 and 2.

5.10.2 *Related Required Capabilities.*

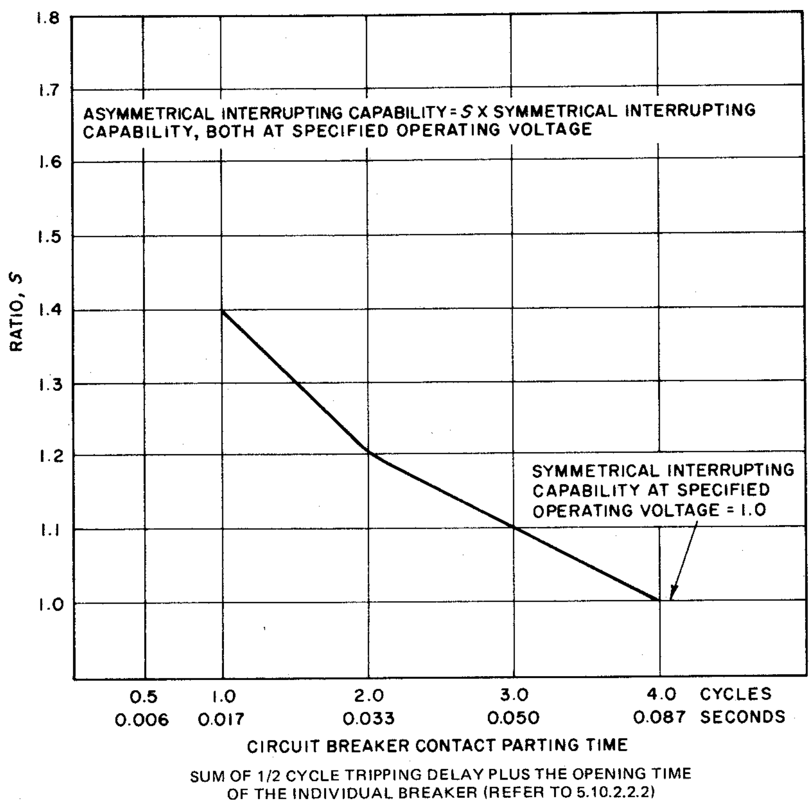
The circuit breaker shall have the following related required capabilities which are based on a relay time of one-half cycle, but may be used with any permissible tripping delay.

5.10.2.1 *Required Symmetrical Interrupting Capability for Polyphase and Phase-to-Phase Faults.*

For polyphase and phase-to-phase faults, the required symmetrical interrupting capability of a circuit breaker is the highest value of the symmetrical component of the short-circuit current in rms amperes at the instant of primary arcing contact separation which the circuit breaker shall be required to interrupt at a specified operating voltage on the standard operating duty and irrespective of the direct current component of the total short-circuit current. The numerical value at an operating voltage between 1/*K* times rated maximum voltage and rated maximum voltage shall be determined by the following formula:

$$\begin{array}{c}\text{required}\\\text{symmetrical}\\\text{interrupting}\\\text{capability}\end{array} = \begin{array}{c}\text{rated}\\\text{short-}\\\text{circuit}\\\text{current}\end{array} = \left(\frac{\text{rated maximum voltage}}{\text{operating voltage}}\right)$$

In no case shall the required symmetrical interrupting capability exceed *K* times short-circuit current.



NOTE: For relation of symmetrical interrupting capability at specified operating voltage to rated short-circuit current, see Fig 1.

Figure 2— Ratio of Circuit Breaker Asymmetrical to Symmetrical Interrupting Capabilities

5.10.2.2 *Required Asymmetrical Interrupting Capability for Polyphase and Phase-to-Phase Faults.*

For polyphase and phase-to-phase faults, the required asymmetrical interrupting capability of a circuit breaker is the highest value of the total short-circuit current rms amperes at the instant of primary arcing contact separation which the breaker shall be required to interrupt at a specified operating voltage and on the standard operating duty. The numerical value shall be equal to the product of a ratio *S*, specified below and illustrated in Fig 2, times the required symmetrical interrupting capability of the breaker determined for the operating voltage. The values of *S* shall be 1.4, 1.3, 1.2, 1.1, or 1.0 for breakers having primary arcing contact parting times of 1, 1.5, 2, 3, 4, or more cycles, respectively. The values of *S* for primary arcing contact parting times between those given above shall be determined by linear interpolation. The primary arcing contact parting time shall be considered equal to the sum of one-half cycle (present practical minimum tripping delay) plus the lesser of:

1) The actual opening time of the particular breaker, or
2) 1.0, 1.5, 2.5, or 3.5 cycles for breakers having a rated interrupting time of 2, 3, 5, or 8 cycles, respectively.

NOTE — Any combination of symmetrical and direct current components is permissible, provided that the following conditions are met at the instant of primary arcing contact separation:

1) The symmetrical component does not exceed the required symmetrical interrupting capability
2) The degree of asymmetry does not exceed 100 percent
3) The total short-circuit current does not exceed the required asymmetrical interrupting capability

5.10.2.3 *Required Interrupting Capability for Single Line-to-Ground Faults.*

For single line-to-ground faults, the required symmetrical interrupting capability and the required asymmetrical interrupting capability of a circuit breaker shall be 1.15 times the corresponding values specified in 5.10.2.1 and 5.10.2.2 for polyphase and phase-to-phase faults. In no case are the capabilities for single line-to-ground faults required to exceed *K* times the symmetrical interrupting capability (that is, *K* times rated short-circuit current) and *K* times asymmetrical interrupting capability, respectively, determined at rated maximum voltage.

5.10.2.4 *Required Closing-Latching-Carrying-Interrupting Capabilities.*

The circuit breaker shall be capable of performing the following duties in immediate succession:

1) Closing and, immediately thereafter, latching any normal-frequency making current which does not exceed 1.6*K* times the rated short-circuit or whose maximum crest (peak making current) does not exceed 2.7*K* times the rated short-circuit current.
2) Carrying a short-circuit current *I* for any time up to the permissible tripping delay determined in accordance with 5.8.
3) Interrupting any short-circuit current which, at the instant of primary arcing contact separation, has a symmetrical value not exceeding the required asymmetrical interrupting capability.

5.10.2.5 *Required Short-Time Current Carrying Capability.*

The circuit breaker shall be capable of carrying, for T_s = 3 s, any short-circuit current whose rms value, determined from the envelope of the current wave at the time of the maximum crest, does not exceed 1.6*K* times rated short-circuit current, or whose maximum crest value does not exceed 2.7*K* times the rated short-circuit current, and whose rms value *I* determined over the complete three-second period, does not exceed *K* times rated short-circuit current. The mathematical expression for the rms value *I* of a short-circuit current over the period T_s is:

$$I = \sqrt{\frac{1}{T}\int_0^T i^2 dt} \qquad I = \sqrt{\frac{1}{3}\int_0^3 i^2 dt}$$

where

i = instantaneous rms current in amperes (see 7.1 of ANSI/IEEE C37.09-1979).
t = time in seconds

It is not to be inferred that the circuit breaker is to be capable of interrupting after the above duty until it has cooled down to normal heat run temperature. A breaker is required, however, to carry this value of short-circuit current for a certain maximum time *Y* and thereafter interrupt this current. This is covered in 5.8. For values, see ANSI C37.06-1979.

5.10.2.6 *Required Reclosing Capability.*

Interrupting rating factors for reclosing duty cycles other than the standard operating duty shall be determined on the basis of the required symmetrical interrupting capability at operating voltage and shall be applied to the required symmetrical and asymmetrical interrupting capabilities. Interrupting capability factors for reclosing service apply to all ac high-voltage circuit breakers as shown in ANSI C37.06-1979 which are:

1) Rated 72.5 kV and above, regardless of continuous current rating.
2) Rated below 72.5 kV and having continuous current ratings above 1200 A and below. Breakers with continuous current ratings above 1200 A are not intended for reclosing service applications. When such applications arise, the manufacturer should be consulted for capability factors.

Whenever a circuit breaker is applied on a duty cycle having either more operations or a shorter time interval between operations or a shorter time interval between operations than the standard CO + 15 s + CO duty cycle, its rated short circuit current and related required capabilities shall be modified by the reclosing capability factor *R*, to enable the circuit breaker to meet its standard of interrupting performance as defined in 5.10.3.3.

Modifications of rated interrupting capability are required for duty cycles with these characteristics:

1) For each operation in excess of 2
2) In addition, for each reclosure which is made in a period of time less than 15 s down to an instantaneous reclosure. Interpolation shall be used to determine the value of the capability factor for reclosing times between 0 and 15 s. Fifteen seconds means any period 15 s or longer. Zero seconds means any instantaneous reclosure with no intentional delay.

The reclosing capability factor *R* is determined as follows: $R = 100 - D$ (percent) and

$$D = d_1(n-2) + d_1\frac{(15-t_1)}{15} + d_1\frac{(15-t_2)}{15} + \dots$$

where

D = total reduction factor in percent
d_1 = calculating factor for D in percent of breaker symmetrical interrupting capability at operating voltage, from Fig 2 of ANSI C37.06-1979
n = total number of openings
t_1 = first time interval less than 15 s
t_2 = second time interval less than 15 s
t_3 = ….

The modified symmetrical interrupting capability of the circuit breaker with this duty cycle is then (rated symmetrical short-circuit current) × (*R*).

Other related required capabilities may be determined by multiplying this value by the factors established in 5.10.2.2, 5.10.2.3, and 5.10.2.4.

Interrupting capability factors determined in this manner are subject to these conditions:

1) A duty cycle shall not contain more than five opening operations.

2) All operations within a 15 min period are considered part of the same duty cycle.
3) A period of 15 min between opening operations is considered sufficient to initiate a new duty cycle.
4) A charge transforming operator (CTO) operation may be substituted for a CO operation provided that the aggregate time for carrying current does not exceed the time given in 5.8.1.
5) For circuit breakers rated 121 kV and above having opening resistors, or closing resistors, or both, repetitive operations may be limited by the resistor thermal capability as stated in 5.20.1.

5.10.3 *Interrupting Performance*

5.10.3.1 *Oil Circuit Breaker.*

An oil circuit breaker shall perform at or within its rating without emitting flame, and without emitting oil except for minimum quantities through vent openings.

5.10.3.2 *Oilless Circuit Breaker.*

Oilless circuit breakers, including compressed air circuit breakers, shall perform at or within their respective ratings without emitting injurious flame.

5.10.3.3 *Service Capability and Breaker Condition*

5.10.3.3.1 *Service Capability Duty Requirements.*

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

1) Between 85 and 100 percent of its required asymmetrical interrupting capability at its operating voltage. For breakers 121 kV and above, two standard duty cycles separated by at least 15 m[1](CO + 15 s + CO + 15 min + CO + 15 s + CO).
   For all breakers, one standard duty cycle (CO + 15 s + CO).
2) Between its rated continuous current and 85 percent of its required asymmetrical interrupting capability at its operating voltage.
   A number of operations in which the sum of the currents interrupted does not exceed 400 percent of the required asymmetrical interrupting capability of the breaker at its operating voltage.
   NOTE — The number of operations used to make up the 400 percent is cumulative over a period of time and is a measure of the circuit breaker reliability and a guide to maintenance. Thermal limitations of parts, such as resistors in interrupting elements, blow-out coils, etc, require that the number of opening operations making up the 400 percent shall not exceed 5 in 1 h or 7 in 2 h for breakers rated 121 kV and above, and 10 in 1 h or 14 in 2 h for all other breakers. Applications requiring more frequent operations per hour should be referred to the manufacturer for consideration.
3) Any reclosing service duty cycle within the limits of the rating factors for reclosing service as defined in 5.10.2.6 in which the sum of the currents interrupted does not exceed 400 percent of the required asymmetrical interrupting capability at its operating voltage.
4) For circuit breakers rated 121 kV and above having opening resistors, or closing resistors, or both, repetitive operations may be limited by the resistor thermal capability as stated in 5.20.1.

5.10.3.3.2 *Breaker Condition.*

After performance in accordance with any one of the three duty requirements listed above, the breaker shall be in the following condition:

[1]An estimate time for transient conditions in the circuit breaker to have subsided sufficiently to restore the interrupting capability to its rated value for the second standard duty cycle is 15 min. This time can be reduced at lower interrupting duties in accordance with rating factors for reclosing service included in 5.10.2.6.

1) The breaker shall be in substantially the same mechanical condition as before the performance of the required duty cycles.
2) The breaker shall be capable of withstanding rated maximum voltage in the open position and of carrying rated continuous current without injurious heating or any operating voltage up to rated maximum voltage. The resistance of the current carrying circuit from terminal to terminal, measured with a current of at least 100 A flowing, shall be less than 200 percent of the maximum value given by the manufacturer for the circuit breaker when new. The breaker shall also be capable of a CO operation at its required interrupting capabilities and at its operating voltage after an interval of at least 1 h, but the interrupting time may be exceeded by as much as 1 cycle. It is recognized that after completion of the required duty cycles, the circuit breaker should be inspected and maintained, if necessary.

5.11 Rated Transient Recovery Voltage.

At its rated maximum voltage, each circuit breaker must be capable of interrupting 3-phase ungrounded terminal faults at rated short-circuit current in any circuit in which the 3-phase ungrounded circuit transient recovery voltage does not exceed the rated transient recovery voltage envelope.

Each transient recovery voltage rating is for a 3-phase circuit breaker. It is not required that a single phase of a circuit breaker interrupt a single-phase circuit which produces a circuit transient recovery voltage equal to the rated transient recovery voltage envelope.

However, as covered in 4.6.6 of ANSI/IEEE C37.09-1979, the single-phase test at 1.5 times leg voltage is given as one of the basic approaches to demonstrating the rating in a design test. It is an optional design test, not a rating requirement.

5.11.1 *Rated 1 Cosine Envelope.*

For circuit breakers rated 72.5 kV and below, the rated transient recovery voltage shall be defined as the envelope formed by the 1-cosine curve obtained by using the rated values of E_2 and T_2 from ANSI C37.06-1979 and shall apply for the rated value of rated short-circuit current I shown in Tables 2, 3, and 4 of that standard.

NOTE — See 5.11.4.1 under related required transient voltage withstand capabilities for values of interrupting current less than rated.

5.11.2 *Rated Exponential-Cosine Envelope.*

For breakers rated 121 kV and above, the rated transient recovery voltage shall be defined as the envelope formed by the exponential-cosine curve obtained by using the rated value of E_1, R, T_1, E_2, and T_2 from ANSI C37.06-1979 and shall apply for values of rated short-circuit current I as shown in Table 5 of that standard.

NOTE — The above rated values define the rated ex-cos envelope graphically and mathematically except for the very small portion between the origin and the joining to the large exponential curve. This portion can be ignored for application purposes. For more rigorous definition of the rated ex-cos envelope, the following formula for the complex exponential starting at zero can be used:

$$e = E_1\left[1 - \varepsilon^{-\alpha t}\left(\text{Cosh } \beta t + \frac{\alpha}{\beta} \sinh \beta t\right)\right]$$

where

$$\alpha = \frac{1}{2ZC}$$

$$\beta = \sqrt{\alpha^2 - \frac{1}{LC}}$$

$$Z = \frac{R10^6}{\sqrt{2}\omega I} \ \Omega$$

where

R and I =values from Table 5 of ANSI C37.06-1979

$\omega = 2\pi f$

$$C = \frac{T_1 10^{-6}}{Z} \ \text{F}$$

where T_1, is a value from Table 5 of ANSI C37.06-1979 and Z is from above.

NOTE — See 5.11.4.1 under related required transient voltage withstand capabilities for values of interrupting current less than rated.

5.11.3 *Rated Transient Recovery Voltage Rate*.

The rated transient recovery voltage rate is the initial rate, ignoring the effect of lumped bus side capacitance, at which the recovery voltage rises across the terminals of the first pole to interrupt a 3-phase, ungrounded, load side terminal fault on a line breaker under the conditions of 5.11.1 and 5.11.2. The rate is a close approximation of the maximum d*e*/d*t* in the rated envelope but is slightly higher because the bus side capacitance is ignored.

NOTE — For circuit breakers 72.5 kV and below (1-cosine envelope) the rated trnasient recovery voltage rate is zero.

5.11.4 *Related Required Transient Voltage Withstand Capabilities*

5.11.4.1 *3-Phase Ungrounded Faults with Values of Fault Current Other than Rated.*

The circuit breaker shall be capable of withstanding a transient recovery voltage envelope greater than rated when interrupting fault currents less than rated. The related transient recovery voltage envelopes are defined by the factors shown in Table 7 of ANSI C37.06-1979.

Circuit breakers with a rated voltage range factor K greater than 1, may interrupt fault currents greater than rated when used at voltages less than rated. See 5.10.2.1.

In these cases, the circuit breaker transient recovery capability shall be obtained by reducing the applicable rated parameters E_1, E_2, and T_2 by the ratio of the lower system voltage to the rated maximum voltage of the circuit breaker. The parameters R and T_1 remain the same.

5.11.4.2 *Short Line and Other Line Faults.*

The circuit breaker shall be capable of interrupting single-phase line faults at any distance from the circuit breaker, on a system in which:

(1) The transient recovery voltage on a terminal fault is within the rated or related transient recovery voltage envelope.

(2) The voltage in the first ramp of the saw-tooth wave is equal to or less than that in an ideal system in which the surge impedance *Z* an amplitude constant *d* (see 4.6.5.4 of ANSI/IEEE C37.09-1979) are as follows:

242 kv and below		(single conductor line)
Z	450	
d	1.8	

362 kV and above		(bundled conductors)
Z	360	
d	1.6	

The above voltage ramp shall be measured at a point on the line that would yield 70 percent of rated short-circuit current if the bus were capable of supplying 100 percent rated short-circuit current at rated transient recovery voltage.

The amplitude constant *d* is the ratio of the peak of the sawtooth component which will appear across the circuit breaker terminal at the instant of interruption. See Fig 3.

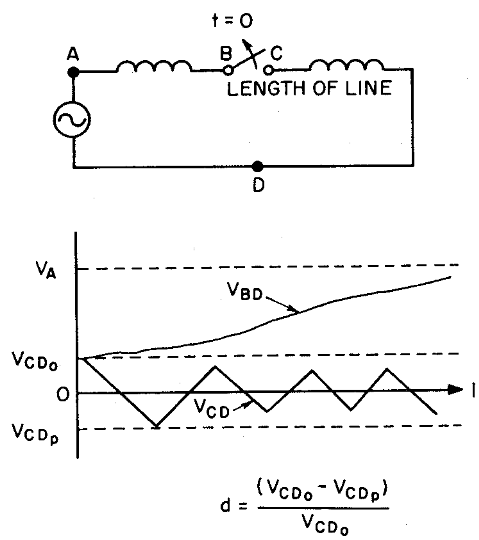


Figure 3— Short-Line Fault Terminology

The voltage V_{BD} represents the source side transient which, for purposes of this illustration, is indicated as an exponential-cosine with time delay, starting at an initial voltage of V_{CDo}.

The line side component is a sawtooth wave with peak magnitude, as seen by the circuit breaker, of ($V_{CDo} - V_{CDp}$) represented by the distance between the two dashed lines. The theoretical maximum of this value is $2V_{CDo}$, or in other words, the theoretical maximum amplitude constant is 2. This rating is expressed in terms of a voltage ramp in an ideal system because the surge impedance and amplitude constant of a line may vary along its length and with time. However, experience to date with actual lines indicates that damping effects due to the ground return path, line resistance including high-frequency skin effect and transient resistance and other factors, all of which are not fully understood at this time, reduce the amplitude constant to the values of 1.8 and 1.6 as indicated above.

Also, the above mentioned factors act in such a manner that actual conditions are less severe than indicated by the formulas of 4.6.5.4 of ANSI/IEEE C37.09-1979 as the faults are moved closer to the circuit breaker.

In addition, there is a time delay in the sawtooth line side recovery voltage as a result of the capacitances of apparatus on the line side. Although the existence of this delay should be recognized in tests, there is not sufficient information to assign values at this time.

5.12 Required Load Current Switching Capability and Life (Repetitive Operation).

The required load current switching capability and life specified in Table 9 of ANSI C37.06-1979 is the type and number of complete closing-opening operations which the circuit breaker shall be capable of performing at any voltage up to the rated maximum voltage under the following conditions:

1) With rated control voltage or operating gas or oil pressure applied.
2) The frequency of operation is not to exceed 20 in 10 min or 30 in 1. h, except that circuit breakers with auxiliary devices such as resistors, rectifiers, etc, may have further limitations on their frequency of operation. In switching load current, all breakers shall at least be able to meet the requirements of the note to 5.10.3.3.1(2).
3) The values in ANSI C37.06-1979 have been established by experience and engineering judgment and those involving currents are derived from service capability and breaker condition (see 5.10.3.3) and are not separate ratings. Refer also to 4.12.1 of ANSI/IEEE C37.09-1979.

5.13 Rated Capacitance Current Switching.

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. A circuit breaker may be modified or especially designed for such duty. For numerical values of capacitance current switching ratings, refer to Tables 1A, 2A, 3A, 4A, and 5A of ANSI C37.06-1979.

The rating of a circuit breaker for capacitance current switching shall include, where applicable:

1) Rated open wire line charging switching current
2) Rated isolated cable charging and isolated shunt capacitor bank switch current
3) Rated back-to-back cable charging and back-to-back shunt capacitor bank switching current
4) Rated transient overvoltage factor
5) Rated transient inrush current
6) Rated interrupting time
7) Required capacitance current switching life
8) Grounding of system and capacitor bank

5.13.1 *Rated Open Wire Line Charging Switching Current.*

The rated open wire line charging switching current is the highest open wire line charging current which the circuit breaker shall be required to switch at any voltage up to rated maximum voltage.

5.13.2 *Rated Isolated Cable Charging and Isolated Shunt Capacitor Bank Switching Current*.

The rated isolated cable charging and isolated capacitor bank switching current is the highest isolated cable charging or isolated shunt capacitor bank current which the circuit breaker shall be required to switch at any voltage up to rated maximum voltage.

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

$$\frac{\mathrm{d}i}{\mathrm{d}t} = \sqrt{2}\omega\left[\frac{\text{rated max voltage}}{\text{operating voltage}}\right]I = 533\left[\frac{\text{rated max voltage}}{\text{operating voltage}}\right]I$$

where:

$\frac{\mathrm{d}i}{\mathrm{d}t}$ = rate of change of transient inrush current, ampere per second

I = rated short-circuit current, ampere
ω = $2\pi f$ = 377 for 60 Hz system

The ratio of rated maximum voltage per operating voltage shall not exceed.the voltage range factor K.

5.13.3 *Rated Back-to-Back Cable Charging Current and Back-to-Back Shunt Capacitor Bank Switching Current.*

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

Cable circuits and shunt capacitor banks shall be considered switched back-to-back if the highest rate of change of inrush current on closing exceeds that specified as the maximum for which the cable or shunt capacitor bank can be considered isolated (see 5.13.2).

NOTE — Under the above criteria, two cable circuits of any length or two capacitor banks of any size operating from the same bus without a large reactor between them require breakers with back-to-back switching capability.

5.13.4 *Rated Transient Overvoltage Factor*.

The rated transient overvoltage factor shall be as follows:

5.13.4.1 *Definite Purpose Circuit Breakers*.

For circuit breakers specifically designed for capacitance switching, the transient overvoltage factor shall not exceed the following more than once in 50 random 3-phase operations:

1) 2.5 for circuit breakers rated 72.5 kV and below
2) 2.0 for circuit breakers rated 121 kV and above

5.13.4.2 *General Purpose Circuit Breaker.*

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

5.13.5 *Rated Transient Inrush Current*.

The rated transient current includes the following components:

5.13.5.1 *Rated Transient Inrush Current Crest.*

The rated transient inrush current crest is the highest magnitude which the circuit breaker shall be required to close at any voltage up to rated maximum voltage, and shall be as determined by the system and unmodified by the breaker.

5.13.5.2 *Rated Transient Inrush Current Frequency*.

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

5.13.6 *Rated Capacitance Current Switching Interrupting Time*.

See 5.7.

5.13.7 *Required Capacitance Current Switching Life (Repetitive Operation)*.

See 5.12. The number of operations specified in columns 4 and 5 of Table 9 of ANSI C37.06-1979 shall be no inductances to ground on the disconnected side of the breaker.)

5.13.8 *Grounding of System and Shunt Capacitor Bank*

1) 72.5 kV and below: Shunt capacitor banks may either be grounded or ungrounded. (With ungrounded shunt capacitor banks there shall be no inductances to ground on the disconnected side of the breaker.)
2) 121 kV and above: Both shunt capacitor banks and systems shall be grounded. If the neutral of the system, the capacitor bank, or both are ungrounded, the manufacturer should be consulted for circuit breaker application.

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 designates that the circuit breaker is capable of controlling line closing switching surge voltages so that the probability of not exceeding the rated factor is 98 percent or higher when switching the standard reference transmission line from the standard reference power source. Furthermore, all of the line closing switching surge factors must remain below 1.2 times the rated line closing switching surge factor when switching the standard reference line with the standard reference source. (See 4.14 of ANSI/IEEE C37.09-1979 and ANSI/IEEE C37.010-1979, Application Guide for AC High Voltage Circuit Breakers Rated on a Symmetrical Current Basis.)

5.15 Rated Out-of-Phase Switching Current.

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.

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.

A circuit breaker may be assigned an out-of-phase switching current rating when its out-of-phase switching capability has been demonstrated by the tests specified in ANSI/IEEE C37.09-1979. However, other equivalent or more effective methods of test are not precluded.

5.15.1 *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 an out-of-phase recovery voltage equal to that specified in 4.15.6 of ANSI/IEEE C37.09-1979 and under prescribed conditions. If a circuit breaker has an assigned out-of-phase switching current rating, this shall be 25 percent of the rated (symmetrical) short circuit current expressed in kiloamperes, unless otherwise specified.

5.15.2 *Interrupting Time for Out-of-Phase Switching*.

The interrupting time for out-of-phase switching is permitted to exceed the rated interrupting time by 50 percent for 5 and 8 cycle circuit breakers, and by 1 cycle for 2 and 3 cycle circuit breakers.

5.16 Rated Shunt Reactor Current Switching.

Because of the specialized nature of shunt reactor installations at the present time, and the absence of comprehensive standards covering the physical construction of shunt reactors, no ratings are given at the present time.

5.17 Rated Excitation Current Switching.

Rated excitation current switching is under study in the IEEE Switchgear Committee.

5.18 Rated Control Voltage (Nominal Control Voltage).

The rated control voltage of a circuit breaker is the designated voltage which is to be applied to the closing or tripping devices to close or open the circuit breaker. (See ANSI C37.06-1979.)

The transient voltage in the entire control circuit, due to the interruption of the control current, shall be limited to 1500 volts crest.

NOTE — The control voltage may be allowed to vary, above or below the rated control voltage, within a specified range. The control voltage is measured at the terminals of the operating coils with the operating current flowing.

5.19 Rated Fluid Operating Pressure.

The rated fluid operating pressure of a circuit breaker is the pressure at which a gas or liquid operated mechanism is designed to operate. This pressure is allowed to vary above and below its rated value within a specified range.

5.20 Required Capability of Resistors for Circuit Breakers Rated 121 kV and Above.

Circuit breakers may have resistors that are inserted in the main current path during opening operations, or closing operations, or both, for the general purposes of voltage division over serially connected contact gaps, recovery voltage modification, or line closing surge control. These respective functions may be performed by separate, or by the same resistor elements.

5.20.1 *Required Thermal Capability*.

The required thermal capability of opening and closing resistors for circuit breakers rated 121 kV and above shall be based upon the operation of the circuit breaker to make and interpret a 3-phase grounded short circuit on an effectively grounded source (0.58 times rated maximum voltage) through the following operation sequence: CO-0 s-CO-15 s-CO-15 s-CO-1 h-CO-30 min-CO-30 min-CO, when applied at rated maximum voltage.

5.20.2 *Required Dielectric Capability*.

The required dielectric capability of opening resistors shall be based upon the operation of the circuit breaker to interrupt 3-phase ungrounded short circuits at rated maximum voltage, in which 0.87 times rated maximum voltage can appear for up to 0.4 cycles across the first phase to interrupt.

The required dielectric capability of closing resistors shall be based upon the operation of the circuit breaker to close on 3-phase ungrounded short circuits at rated maximum voltage, in which rated maximum voltage can appear across the resistor of the second and third phases to be shunted out, from the time the first phase resistor is shunted out until the second phase resistor is shunted out.

The resistors will meet their dielectric requirements before, during, or immediately after the duty cycle specified in 5.20.1.

6. Construction

6.1 Outdoor Apparatus Bushings.

Bushings that are classified as apparatus bushings shall conform to ANSI/IEEE Std 21-1977 and ANSI/IEEE Std 24-1977. Bushings for dead tank oil circuit breakers shall have electrical characteristics and dimensions in accordance with ANSI/IEEE Std 21-1977. Bushing mountings shall be adequate to accommodate bushings having the maximum D dimensions specified in ANSI/IEEE Std 24-1977.

6.2 Terminal Connection Mechanical Loading.

The maximum permissible mechanical loading which may be applied to a circuit breaker terminal connection of either the stud or flat pad type shall be as shown below and the listed values shall include loads from wind, ice, earthquake, or short-circuit currents as well as connected dead weight:

(1) For circuit breakers rated 72.5 kV and below:

100 lb for 1200 A ratings
150 lb for 2000 A and above ratings

The above forces are to be applied in any direction.

(2) For circuit breakers rated 121 kV through 242 kV: When the rated short circuit current does not exceed 50 kA, the resultant of the following forces imposed upon it simultaneously:

(a) A wind load of 90 mi/h or an earthquake shock of 0.2 G (static) imposed upon the exposed structure supporting the terminal connection, whichever is the more severe

(b) A line pull of 300 lb in line with an axis drawn through the phase terminals plus 150 lb at right angles to an axis drawn through the phase terminals or any vector sum of these two forces

When the rated short circuit current exceeds 50 kA but does not exceed 63 kA, the loading shall be the resultant of the forces (a) and (b) above, except the line pull loads shall be 300 lb and 240 lb respectively, rather than 300 lb and 150 lb.

When the rated short circuit current exceeds 63 kA but does not exceed 80 kA, the loading shall be the result of the forces (a) and (b) above, except the line pull loads shall be 300 lb and 400 lb respectively, rather than 150 lb.

(c) Additional loading imposed by the interruption of rated short circuit current or the magnetic forces resulting within the length of the circuit breaker from an adjacent phase unit of the circuit breaker. Such loading may occur simultaneously with (a) and (b) above.

(3) For circuit breakers rated 362 kV and above: [Work in progress — not yet standardized.]

6.3 Pressurized Components.

6.3.1 *Metal Components.*

All metal gas storage bottles, receivers, and pressure vessels shall be designed to meet the requirements of the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels[2] and any state and local codes which apply at the point of original installation.[3]

6.3.2 Porcelain Components.

All pressurized porcelain housings, porcelain insulators, or porcelain tubes which have an internal or external gas gage pressure exceeding 15 lbs/in^2 (with no limitation on size) shall be individually tested in accordance with 5.4.2 and 5.4.3 of ANSI/IEEE C37.09-1979.

6.3.3 *Identification Markings.*

Each component covered by this standard shall have a marking (not readily removable) to show that it has been subjected to the production test procedures although this marking may not be visible after final assembly.

6.4 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 a valve shall be designed to prevent the pressure from rising more than 20 percent above the maximum allowable working pressure, except when the overpressure is caused by exposure to abnormal events; for example, fire or other sources of heat.

When a gas system which includes pressurized porcelains may be subjected to substantial rates-of-rise of pressure caused by exposure to abnormal events or sources of heat, additional overpressure relief set at 20 percent above the maximum allowable working pressure shall be provided by one of the following, or its equivalent:

1) Rupture diaphragm
2) Large area relief piston
3) Spring clamped construction

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 that is pressurized shall be protected by the overpressure relief device.

7. Nameplate Markings

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

7.1 Circuit Breaker

NOTE — Circuit breaker and operating mechanism nameplates may be combined.

[2]Copies are available from the American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.
[3]Requirements for Fiberglass-Reinforced-Plastic Pressurized Vessels are published in NEMA Standards Publication SG 4-1975, AC High-Voltage Circuit Breakers. Copies are available from the National Electrical Manufacturers Association, 2021 L Street, N.W., Washington, DC 20037.

1) Manufacturer's name
2) Manufacturer's type designation
3) Manufacturer's serial number
4) Year of manufacture
5) Rated frequency
6) Rated continuous current
7) Rated maximum voltage (kV)
8) Rated voltage range factor *K*
9) Rated full wave impulse withstand voltage (kV)
10) Rated switching-impulse withstand voltage
    a) Terminal to ground — circuit breaker closed
    b) Terminal to terminal — circuit breaker open
11) Rated line closing switching surge factor
12) Rated short-circuit current
13) Rated interrupting time
14) Normal operating pressure
15) Minimum operating pressure
16) Gallons of oil per tank or weight of gas per breaker
17) Weight of circuit breaker complete (with oil or gas)
18) Instruction book number
19) Parts list number
20) Ratings for capacitance current switching
    a) Rated transient overvoltage factor
    b) Rated open-wire line charging current
    c) Rated isolated shunt capacitor bank current
    d) Rated back-to-back shunt capacitor bank current
    e) Rated transient inrush current peak
    f) Rated transient inrush current frequency
21) Assigned out-of-phase switching current rating

7.2 External Insulation.

The rated dielectric strength 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, and then it shall be included on the nameplates of the component (refer to 6.3 of ANSI/IEEE Std 21-1977 for bushings).

NOTE — Work is in progress on requirements for current transformers for ac high-voltage circuit breakers rated on a symmetrical current basis.

7.3 Operating Mechanism

NOTE — Operating mechanism and circuit breaker nameplates may be combined.

1) Manufacturer's name
2) Manufacturer's type designation
3) Manufacturer's serial number
4) Year of manufacture
5) Closing control voltage range
6) Tripping control voltage range
7) Closing current
8) Tripping current
9) Compressor control switch closing and opening pressures
10) Low pressure alarm switch closing and opening pressures
11) Low pressure lockout switch closing and opening pressures
12) Wiring diagram number
13) Instruction book number
14) Parts list number

7.4 Current Transformers and Linear Coupler Transformers (Nameplates Located at

Respective Terminal Blocks)

1) Manufacturer's name
2) Manufacturer's type designation
3) Rated frequency, if other than 60 cycles
4) American National Standard accuracy class
5) Connection chart showing:
   a) Full winding developing
   b) Taps
   c) Ratio in terms of primary and secondary currents
   d) Polarity
   e) Pole and pocket location
6) Instruction book number
7) Curve sheet number
8) Mutual reactance (for linear coupler transformers only)
9) Self impedance (for linear coupler transformers only):
   a) Resistance
   b) Reactance
   c) Impedance

7.5 Accessories.

Nameplates of all accessories shall include:

1) Identification
2) Pertinent operating characteristics

7.6 Modernization of Circuit Breakers.

Revised nameplates shall be furnished when modernizations are involved.

7.7 Instruction and Warning Signs.

Essential markings shall be provided to:

1) Identify operating devices and positions
2) Give pertinent instructions for operation
3) Call attention to special precautions