

IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

Sponsor

**Switchgear Committee
of the
IEEE Power Engineering Society**

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Abstract: This guide covers the application of indoor and outdoor high-voltage circuit breakers rated above 1,000 V for use in commercial, industrial, and utility installations. It deals with usage under varied service conditions, temperature conditions affecting continuous current compensation, reduced dielectrics, reclosing derating as applicable, calculation of system short-circuit current, compensation at different X/R ratios, detailed calculations with application curves, out-of-phase switching, and general application.

Keywords: Ambient compensation/emergency operation, capacitor switching, high-voltage circuit breakers, indoor drawout, line closing, load current switching, outdoor, pollution level creepage distance, power frequency, rated maximum voltage, short-circuit consideration, TRV, transformer current switching,

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Introduction

(This introduction is not part of IEEE Std C37.010-1999, IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.)

This guide is a revision of IEEE Std C37.010-1979 and contains substantive changes due to the efforts of three coordinated Working Groups on revision and coordination of IEEE Std C37.04, IEEE Std C37.09, and IEEE Std C37.010.

Although much of the approach of IEEE Std C37.010-1979 has been retained, many editorial changes, significant enhancements, and some fundamental changes have been made.

Some of the major issues include

- Updating to modern interruption technologies.
- Listing of low-temperature concerns.
- Inclusion of creepage distance material from IEC 60071-2: 1976¹.
- Acknowledgment that historic voltage range factor K has been changed to 1.0 for new circuit breakers designs, which allows simplification of the rating structure and circuit breaker application. It is recognized that circuit breakers rated in accordance with older standards, having voltage range factor K differing from 1.0, are still available and will be in service for many years. If there is a K factor, it should be recorded on the circuit breaker nameplate. For circuit breakers that have a voltage range factor K differing from 1.0, the user should refer to IEEE Std C37.04-1979, IEEE Std C37.06-1987, IEEE Std C37.09-1979, IEEE Std C37.010-1979, or earlier editions of the same documents for rating, application, and testing information.
- Recommendations on applying application margins to rated interrupting time.
- Recognition that “Tripping Delay” is no longer a rating. Permissible tripping delay will be based on the short-time (closed) current rating of the circuit breaker.
- Inclusion of reclosing derating factors for air magnetic and oil circuit breakers as stated in 5.9.1.
- Handling of large dc time constants greater than 45 ms ($X/R > 17$ at 60 Hz or 14 at 50 Hz). Terminology has been converted from the total current basis to a peak current and percent dc basis. The derating methods are unchanged. However, many current interruption technologies may have limitations beyond the total current basis of 5.2 of IEEE Std C37.010-1979. Concerns exist about “expiration of interrupting window, which is the difference between the minimum and maximum arcing times,” and performance of some interrupters on a large major loop of current just after being “conditioned” by a small minor loop. Warning statements have been incorporated to consult the manufacturer for long dc time constant capabilities of the particular design being considered. The 1979 method has been retained in the guide to serve as an upper limit for long dc time constant application. It is generally agreed that if circuit breakers are applied below 80% of their short-circuit rating (equivalent of one step down on the R10 series) that dc time constants are not much of a concern to the circuit breaker.
- Addition (as an option) of a recommendation on applying resistance-capacitance “snubber circuits” for medium voltage breakers switching loaded or unloaded transformers.
- Addition of Annex B, special application circuit breakers for ac motor starting (information previously in NEMA SG-4).

Ongoing work issues include

- Working dielectric withstand. Presently, the dielectric ratings of a circuit breaker are used for dimensioning the insulation system of the breaker. A concern exists that a breaker which has done switching and fault clearing may have a reduced dielectric withstand. Users need to know what insulation withstand should be assigned to a circuit breaker for insulation coordination. In IEEE Std C37.010-1999, the working dielectric withstand is assumed to be the rated dielectric test value.
- A more comprehensive treatment on derating for long dc time constants.

¹Information on references can be found in Clause 2.

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Upon recommendation of the IEEE Switchgear Committee, the proposed American National Standard was voted on by the Standards Committee C37 on Power Switchgear and was subsequently approved as an American National Standard on 13 January 2000.

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IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

1. Scope

This application guide applies to the ac indoor and outdoor high-voltage circuit breakers rated in accordance with the methods given in IEEE Std C37.04-1999, listed in IEEE Std C37.06-1997, and tested in accordance with IEEE Std C37.09-1999. Circuit breakers rated and manufactured to meet other standards should be applied in accordance with application procedures adapted to their specific ratings or applications.

2. References

This standard shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the revision shall apply, except where more than one version of a standard is referenced.

AIEE 55-1953, Guide for Temperature Correlation in the Connection of Insulated Wire and Cables to Electronic Equipment.¹

IEC 60071-2: 1976, Insulation coordination—Part 2: Application guide.²

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.³

IEEE Std 32-1972 (Reaff 1997), IEEE Standard Requirements, Terminology, and Test Procedures for Neutral Grounding Devices.

¹AIEE Std 55-1953 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://global.ihs.com/>).

²IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

IEEE Std C57.106-1991, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

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

IEEE Std C37.04-1979 (Reaff 1988), IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.04-1999, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.06-1987, IEEE Schedule of Preferred Rating and Related Required Capabilities for AC High-Voltage Circuit Breakers Rated on Symmetrical Current Basis.

IEEE 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.

IEEE Std 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 Time.”

IEEE Std C37.09-1979 (Reaff 1988), IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

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

IEEE Std C37.010-1979 (Reaff 1988), 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 C37.012-1979 (Reaff 1988), IEEE Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

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

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

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

IEEE Std C37.81-1989 (Reaff 1992), IEEE Guide for Seismic Qualification of Class 1E Metal-Enclosed Power Switchgear Assemblies.

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

IEEE Std C57.13-1993, IEEE Standard Requirements for Instrument Transformers.

IEEE Std C57.19.00-1991, IEEE Standard General Requirements and Test Procedure for Outdoor Power Apparatus Bushings.

IEEE Std C62.2-1987 (Reaff 1994), IEEE Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems.

IEEE Std C62.22-1991, IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.

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 meaning of terms used in power switchgear.

4. General service conditions

4.1 Usual service conditions

Service conditions for circuit breakers are defined in IEEE Std C37.04-1999. These conditions specify limits in altitude and in ambient temperature and other environmental conditions.

4.1.1 Provision for system growth

Power system facilities must be expanded or modified from time to time to serve larger loads. This usually results in higher values of short-circuit current. Therefore, sufficient allowance for expected future increase in short-circuit current is advisable.

4.1.2 System design

Methods of limiting the magnitude of short-circuit currents or reducing the probability of high-current faults by system design are outside the scope of this guide. Such methods should be considered where short-circuit currents approach the maximum capability of the circuit breakers. Many station design features may depend on available circuit breaker ratings. System design should take into account the necessity for circuit breaker inspection and maintenance.

4.2 Unusual service conditions

Some unusual service conditions are listed in 4.2.1 through 4.2.14. Special installation, operation, and maintenance provisions should be considered where these conditions are encountered.

4.2.1 Abnormal temperatures

The use of apparatus in an ambient temperature lower than $-30\text{ }^{\circ}\text{C}$ or higher than $40\text{ }^{\circ}\text{C}$ shall be considered as special.

Temperatures below $-30\text{ }^{\circ}\text{C}$ create a harsh environment for circuit breakers. Many users in colder climates routinely experience $-50\text{ }^{\circ}\text{C}$ temperatures. The following should be considered for low ambient temperature environments:

- Operating times may be slower than rated times (typically 1–3 ms slower than rated).
- Wax precipitation of insulating oil “cloud point,” oil becomes extremely viscous, creating excessive drag.
- Humidity in air system freezes, sticking operating and blast valves.

- Liquefaction of sulfur hexafluoride (SF₆) may occur, necessitating derating of interrupting ratings and dielectric ratings unless heaters are utilized.
- Embrittlement of plastics, composites, and metals may lead to failure during breaker operation.
- Hydraulic or SF₆ dampers may be affected.
- Special lubricants may be required to prevent extreme sluggishness.
- Density and pressure switches may malfunction or may be out of range.
- Heaters for the mechanism may be required.

4.2.2 Applications at altitudes above 1000 m (3300 ft)

Correction factors for voltage and for continuous current to be applied to circuit breaker ratings and related required capabilities when a circuit breaker is installed and operated at altitudes above 1000 m (3300 ft) are being developed by a Common Clause Working Group. See IEEE Std 4-1995 for interim guidance.

NOTE—It is generally acceptable not to derate the continuous current capability of a circuit breaker for high altitude applications because at the higher elevations the ambient temperature is significantly lower than the normal maximum of 40 °C. In this case, the procedure outlined in 5.4.3 should be followed to determine the suitability of the circuit breaker.

Derating the breaker's dielectric capabilities is not always necessary and usually not the most economical approach. The need for derating depends on whether arresters are used on both sides of the circuit breaker (line and load) and on their protective levels. If at least a 20% margin exists between the arrester protective level and the breaker basic lightning impulse insulation level (BIL), no derating should be necessary.

4.2.3 Exposure to excessive dust or abrasive, magnetic, or metallic dust

- a) Totally enclosed nonventilated equipment or compartments may be necessary.
- b) Where current-carrying equipment designed for ventilated operation is enclosed in a nonventilated compartment, derating may be necessary.
- c) Installation in a positive pressure room with appropriate filtration equipment may be necessary.

4.2.4 Exposure to explosive mixtures of dust or gases

Standard circuit breakers are not designed for use in explosive atmospheres. For this type of service, special consideration should be given in conjunction with requirements of applicable regulatory bodies so that acceptable equipment is selected.

4.2.5 Exposure to abnormal vibration, shock, or tilting

Standard circuit breakers are designed for mounting on substantially level structures free from excessive vibration, shock, or tilting. Where any of these abnormal conditions exists, recommendations for the particular breaker's application should be obtained from the manufacturer.

Circuit breakers being applied in locations of known seismic activity should be specified with seismic withstand requirements per IEEE Std 693-1997 and IEEE Std C37.81-1989 as necessary for indoor drawout and outdoor circuit breakers. The user should specify the operational requirements, including whether functionality must be maintained

- Before and after the seismic event or
- Before, during, and after the seismic event

4.2.6 Seasonal or infrequent use

Equipment stored or de-energized for long periods should be protected against accelerated deterioration. Before energizing for service, operating performance and insulation integrity should be checked.

4.2.7 Exposure to damaging fumes, vapor, steam, oil vapors, salt air, and hot and humid climate

- a) Provision may be necessary to avoid condensation on all electrical insulation and current-carrying parts.
- b) Bushings with extra creep distance may be required.
- c) In cases where particular exposure represents a hazard to insulation integrity, special maintenance including insulator washing may be necessary.
- d) Materials resistant to fungus growth may be required.
- e) Installation in a positive pressure room system with appropriate filtration equipment may be required.
- f) Installation of heaters in mechanism cabinets and indoor switchgear may be required.

4.2.8 Exposure to excessive pollution

Creepage distance (see IEEE Std C37.100-1992) over external insulation is listed in IEEE Std C37.06-1997. These minimum values are for the normal conditions (i.e., light pollution level) of atmospheric contamination and provide generally satisfactory service operation under these conditions.

For standardization, four levels of pollution are qualitatively defined, from light pollution to very heavy pollution.

Table 1 gives, for each level of pollution, an approximate description of some typical corresponding environments. Other extreme environmental conditions exist that merit further consideration, e.g., snow and ice in heavy pollution, heavy rain, and arid areas.

For each level of pollution described in Table 1, the corresponding minimum nominal specific creepage distance, in millimeters per kilovolt (phase-to-ground) of the highest voltage for equipment is given in Table 2. This table is intended to replace Table 2 of IEC 60071-2: 1976.

Experience has shown that the criterion of “minimum nominal specific creepage distance,” which implies linearity under pollution between withstand voltage and creepage distance, applies to most insulators used on existing systems.

Some insulators specially shaped for particular kinds of pollution may not satisfy these conditions even though they perform satisfactorily in service.

4.2.9 Exposure to unusual transportation or storage conditions

Exposure to unusual transportation or storage conditions should be considered special.

4.2.10 Unusual space limitations

Unusual space limitations should be considered special.

Table 1—Environmental examples by pollution level

Pollution level	Examples of typical environments
Light	Areas without industries and with low density of houses equipped with heating plants. Areas with low density of industries or houses but subjected to frequent winds and/or rainfall. Agricultural areas. ^a Mountainous areas. All these areas shall be situated at least 10–20 km from the sea and shall not be exposed to winds directly from the sea. ^b
Medium	Areas with industries not producing particularly polluting smoke and/or with average density of houses equipped with heating plants. Areas with high density of houses and/or industries but subjected to frequent winds and/or rainfall. Areas exposed to wind from the sea but not too close to the coast (at least several kilometers distant). ^b
Heavy	Areas with high density of industries and suburbs of large cities with high density of heating plants producing pollution. Area close to the sea or in any case exposed to relatively strong winds from the sea. ^b
Very heavy	Areas generally of moderate extent, subjected to conductive dusts and to industrial smoke producing particularly thick conductive deposits. Areas generally of moderate extent, very close to the coast and exposed to sea-spray or to very strong and polluting winds from the sea. Desert areas, characterized by no rain for long periods, exposed to strong winds carrying sand and salt, and subjected to regular condensation.

^aThe use of fertilizers by spraying or the burning of crop residues can lead to a higher pollution level due to dispersal by wind.

^bDistances from seacoast depend on the topography of the coastal area and on the extreme wind conditions.

Table 2—Minimum nominal specific creepage distance by pollution level

Pollution level	Minimum nominal specific creepage distance (mm/kV line-to-ground)
Light	28
Medium	35
Heavy	44
Very heavy	54

NOTES

1—In very lightly polluted areas, nominal specific creepage distances lower than 28 mm/kV can be used depending on the service experience. A lower limit seems to be 21 mm/kV.

2—In the case of exceptional pollution severity, a nominal specific creepage distance of 54 mm/kV may not be adequate. Depending on service experience and/or on laboratory test results, a higher value of nominal specific creepage distance can be used, but in some instances the practicability of washing or greasing may have to be considered.

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

Unusual operating duty, frequent operation, and difficult maintenance should be considered special.

4.2.12 Normally open

Circuit breakers operated normally open but energized may require surge protection against lightning and switching voltage transient surges. If the circuit breakers contain grading capacitors, the manufacturer should be advised of the normal open-gap voltage stress.

Open tie breakers used under out-of-phase voltage conditions may be stressed by voltage up to 2.0 per unit across the open contacts. Such applications should be reviewed with the manufacturer.

4.2.13 Short-circuit current with asymmetry greater than 100%

Short-circuit current with asymmetry greater than 100% should be considered special.

4.2.14 Nonstandard reclosing (see IEEE Std C37.04-1999)

Nonstandard reclosing should be considered special.

4.3 Mechanical considerations for outdoor circuit breakers

4.3.1 Foundation loading

The circuit breaker should be firmly attached to a suitable foundation that supports the dead weight and any applicable dynamic loads on the circuit breaker (e.g., wind loads, terminal connection loads, seismic loads, ice loads).

4.3.2 Terminal connection loading (line pull)

Circuit breaker terminals are designed only to accept nominal mechanical loads as would be adequate to support relatively short leads. The required capabilities are listed in IEEE Std C37.04-1999. Care must be taken not to exceed these loads under any expected environmental conditions. Exceeding the mechanical load on the terminals can result in leaks, circuit breaker misoperation, or mechanical failure of the terminal. Flexible cable connections to the terminals are often most appropriate. If rigid connections are used, care must be taken to prevent thermal expansion of the rigid connection from producing excessive stress on the terminal.

5. Application considerations

In the application of circuit breakers to electrical systems, careful attention must be given to many items of technical importance to assure that a misapplication does not occur. In the usual application, the principal function of the circuit breaker is to carry load current and interrupt short-circuit current. However, it may be used for frequent load, exciting current, or capacitive current switching. In some cases, switching requirements may be the determining factor in selection rather than the requirements of short-circuit current interruption. Special attention must also be given to applications where frequent operations are essential.

In the selection of a circuit breaker, consideration must be given to the future as well as to the present needs for interrupting capacity and for current-carrying capability. These considerations include possible connected circuit changes, such as additions of supplemental cooling means for transformers or connection of multiple cable or overhead lines to the breaker, or possible future transfer of the circuit breaker from its initial position to some other location.

Various types of indoor and outdoor circuit breakers are available for use, classified by their interruption technologies. Some of these types include vacuum, oil, air magnetic, two-pressure air blast, and two-pressure and single-pressure SF₆. Each interruption technology has its own set of strengths and weaknesses and,

therefore, its own set of application considerations. The preferred ratings listed in IEEE Std C37.06-1997 may not be available in all interruption technologies, so the required ratings will limit the users' choice of interruption technologies. The choice of interruption technology may be influenced by switching frequency, special load switching (capacitor or reactor), contaminated atmosphere, environmental considerations, maintenance, ease of handling the interrupting medium, monitoring capabilities, and electrical life.

5.1 Maximum voltage for application

The operating voltage and the power-frequency recovery voltage should not exceed the rated maximum voltage because this maximum is the upper limit for continuous operation.

5.2 Voltage range factor

The voltage range factor K defined in earlier standards has been changed to 1.0 for future circuit breakers, which allows simplification of the rating structure and circuit breaker application by eliminating the voltage range factor completely. However, it is recognized that circuit breakers rated in accordance with older standards and having voltage range factor K differing from 1.0 are still available and will be in service for many years. If there is a K factor, it should be noted on the circuit breaker nameplate. For circuit breakers that have a voltage range factor K differing from 1.0, the user should refer to IEEE Std C37.04-1979, IEEE Std C37.06-1987, IEEE Std C37.09-1979, and IEEE Std C37.010-1979 (or earlier editions of the same documents) for rating, application, and testing information.

5.3 Frequency

Rated power frequencies for circuit breakers are 50 Hz and 60 Hz. Calculations used in this guide are based on 60 Hz.

Interruption of all currents on systems operating at frequencies other than rated frequency may require modification of mechanisms to change the speed of opening or may require a change in interrupting ratings of the circuit breakers.

At other frequencies, some circuit breaker types may not have a sufficiently long interruption window to interrupt successfully.

The manufacturer should be consulted for applications at frequencies differing from 50 Hz or 60 Hz.

5.4 Continuous current

Circuit breakers are designed for normal application where the sustained load current does not exceed the rated continuous current, the altitude above sea level is 1000 m (3300 ft), or less, and the ambient temperature does not exceed 40 °C. Rated continuous current of a circuit breaker should not be exceeded under normal operation except for short periods, such as when starting motors or synchronous condensers or energizing cold loads or for conditions covered by 5.4.3.

5.4.1 Normal operation

The criteria to be followed when making an application are as follows:

- a) Breakers designed for installation in an enclosure may be applied without derating.
- b) Breakers designed for use in open rooms and outdoors cannot be used in enclosures without derating or retesting to ensure that none of their temperature limits is exceeded.

- c) As far as temperature limits are concerned, any nonenclosed high-voltage circuit breaker may be used with cables having an 85 °C or lower temperature limit, provided that the temperature limit of the cable insulation is not exceeded. Indoor drawout circuit breakers are applied in accordance with IEEE Std C37.20.2-1993, and a 90 °C cable limit is recognized. Among the methods of reducing temperature at cable connections are
 - 1) Operating the breaker at a continuous current sufficiently below its rating.
 - 2) Using a section of oversize conductor or a special terminal connector ahead of the cable to reduce the temperature at the cable terminal (see AIEE 55-1953).
- d) The possible adverse effect on or by closely associated equipment operating at a higher or a lower temperature than the breaker should be examined.
- e) When a circuit breaker is properly selected for continuous current operation, it may also be used for starting such equipment as motors, synchronous condensers, and cold loads. Under this condition, the continuous current rating may be momentarily exceeded without causing damage to the circuit breaker.

5.4.2 Rated continuous current for capacitor banks

When a high-voltage circuit breaker is used in a circuit supplying static capacitors, the continuous current rating should be selected to include the effects of

- Operation at voltages below and up to 10% above the capacitor rated voltage.
- The positive tolerance in capacitance of static capacitors (−0%+15%).
- The additional heating caused by harmonic currents.
- The effect of grounded or nongrounded neutral connection of the capacitor bank.

In the absence of specific information, it will usually be conservative to use 1.25 times the nominal capacitor current at rated capacitor voltage for nongrounded neutral operation or 1.35 times the nominal current for grounded neutral operation.

5.4.3 Load current carrying capability under various conditions of ambient temperature and load

5.4.3.1 General

Circuit breakers are designed for normal application in accordance with IEEE Std C37.04-1999, where the sustained load current does not exceed the rated continuous current and the ambient temperature does not exceed 40 °C. The rated continuous current is based on the maximum permissible total temperature limitations of the various parts of the circuit breaker when it is carrying rated current at an ambient temperature of 40 °C. The total temperature of these parts under service conditions depends both on the actual load current and the actual ambient temperature. It is, therefore, possible to operate at a current higher than rated continuous current when the ambient temperature is less than 40 °C, provided that the allowable total temperature limit is not exceeded. Similarly, when the ambient temperature is greater than 40 °C, the current must be reduced to less than rated continuous current to keep total temperatures within allowable limits.

Operation at a current higher than rated continuous current will usually cause the allowable temperature limitations to be exceeded and should be avoided except in these instances:

- For short periods, such as in the starting of motors or synchronous condensers or when energizing cold loads. Generally, the time duration of this type of current increase is short enough that it does not raise temperatures significantly.
- When operating at an ambient temperature below 40 °C, as covered in 5.4.3.2.
- For short periods following operation at a current less than that permitted by the existing ambient temperature, as covered in 5.4.3.3.

The method of calculating the allowable current at an ambient temperature above 40 °C is given in 5.4.3.2. For some high ambient temperature conditions, it may not be practical to reduce current sufficiently to keep the total temperatures within their allowable limits. Forced air cooling of metal enclosed switchgear is covered in IEEE Std C37.20.2-1993 and will help in many cases. Temperature limits of associated equipment such as cables and current transformers must be considered. Effect of solar radiation must also be considered (see IEEE Std C37.24-1986). Where ambient temperature is below the minimum limit of –30 °C, special lubricants may be required, and additional heater capacity beyond that normally used should be provided in mechanism enclosures. Whenever freezing temperatures occur, precautions may be necessary to dry the air in pneumatic systems to avoid condensation and freezing.

5.4.3.2 Continuous load current capability based on actual ambient temperature

Enclosed circuit breakers are covered by IEEE Std C37.20.2-1993 for ambient compensation only. Emergency load current capability is **not** available. The continuous current that a nonenclosed circuit breaker can carry at a given ambient temperature without exceeding its total temperature limitations is given by the following formula:

$$I_a = I_r \left[\frac{\theta_{\max} - \theta_a}{\theta_r} \right]^{1/1.8}$$

where

I_a is allowable continuous load current at the actual ambient temperature θ_a (I_a is not to exceed two times I_r) (A),

I_r is rated continuous current (A),

$\theta_{\max}$ is allowable hottest-spot total temperature ($\theta_{\max} = \theta_r + 40$ °C) (°C),

θ_a is actual ambient temperature expected (between –30 °C and 60 °C) (°C),

θ_r is allowable hottest-spot temperature rise at rated current (°C).

NOTE—The temperature rise of a current-carrying part is proportional to an exponential value of the current flowing through it. Experience has shown that although the exponent may have different values, depending on breaker design and components within a breaker, it generally is in the range of 1/1.6 to 1/2.0. The exponent value of 1/1.8 represents a compromise that is suitable for this application guide.

The constructional features of a circuit breaker dictate the appropriate values of $\theta_{\max}$ and θ_r to be used in the calculation. The major components of a circuit breaker have several different temperature limitations, which are specified in standards as follows:

Circuit breaker component	IEEE standard	
	Number	Clause
Circuit breaker insulating materials, main contacts, conducting joints, etc.	C37.04-1999	5.3.2
Current transformers	C57.13-1993	4.6

The values of temperature limitations specified in these various standards are summarized in IEEE Std C37.04-1999. In order that none of these limitations be exceeded when the load current is adjusted to the value permitted by the actual ambient temperature, the values for $\theta_{\max}$ and θ_r should be determined as follows:

- a) If the actual ambient is less than 40 °C, the component with the highest specified values of allowable temperature limitations should be used for $\theta_{\max}$ and θ_r .
- b) If the actual ambient is greater than 40 °C, the component with the lowest specified values of allowable temperature limitations should be used for $\theta_{\max}$ and θ_r .

The use of these values in the calculation will result in an allowable continuous current that will not cause the temperature of any part of the circuit breaker to exceed the permissible limits.

NOTE—Although circuit breakers are designed to carry rated current continuously while exposed to an ambient temperature of 40 °C, most circuit breakers in service are subjected to a much less severe ambient temperature condition that varies with time of day and season of year. The average outdoor air temperature during any 24 h period is usually 5 °C to 10 °C lower than the maximum, and the maximum is usually less than 40 °C. This fact is one important reason for the long life that circuit breakers historically have demonstrated. Continuous operation at rated current and at an ambient temperature of 40 °C likely would result in a life somewhat shorter than usually experienced.

The user is cautioned that this guide is intended to cover situations where the circuit breaker is used at its total temperature limitations infrequently (a few occasions in the expected lifetime), for relatively short periods of time (perhaps a few days).

The manufacturer should be consulted if operation at maximum allowable temperature is required at frequent intervals or over extended periods of time.

It may not be necessary to include the extreme values of highest and lowest allowable temperature limitation, refer to IEEE Std C37.04-1999 for summary of temperature limitation for circuit breaker components.

The lowest value is for circuit breaker parts handled by the operator in the normal course of duty. The highest value generally is for external surfaces of a circuit breaker not accessible to an operator in the normal course of duty (see IEEE Std C37.04-1999). In many cases, overheating of these external parts beyond the specified allowable limitations will not impair circuit breaker performance or expected life. If these parts are neglected, a higher value of permissible continuous load current can be obtained from the calculation. In most cases, this higher value of current may safely be used. However, in some circuit breaker designs, gas-kets or other components may be located near such inaccessible external surfaces and would be damaged if overheated. The use of 80 °C rise dry-type current transformers would place a further limit on the allowable current for operation at an ambient of less than 40 °C. Evaluation of the breaker design should be made to determine whether these extreme values of temperature limitation are acceptable, and the manufacturer should be consulted.

Table 3 lists the calculated values of I_a/I_r for each specified temperature limit for the various component parts of the circuit breaker over a range of typical ambient temperatures. The allowable current in any given situation can be estimated from Table 3 or may be calculated directly from the formula given at the beginning of this subclause.

Example 1: Consider an SF₆ circuit breaker with silver-coated contacts, American National Standard bushings, and 65 °C rise current transformers. When operating at an ambient temperature of 25 °C, the current could be increased by a factor corresponding to the component with the highest temperature rise. In this case, these components are the silver-coated contacts with a maximum temperature limit of 105 °C (refer to IEEE Std C37.04-1999 Table 1); and according to Table 3, the factor of increase is 1.12 times the rated current.

When operating at an ambient temperature of 50 °C, the current must be reduced by a factor that corresponds to the component with the lowest temperature limit. In this case, the components are the bushings and the current transformers, with a temperature rise limit of 65 °C; and according to Table 3, the reduction factor is 0.91.

Example 2: Consider an oil circuit breaker with silver-to-silver contacts, American National Standard bushings, and with 55 °C rise current transformers. When the ambient temperature is 25 °C, the continuous current can be increased by a factor of 1.12. This factor of increase corresponds to the component with the highest temperature limit, which in this case are the bushings and the current transformers.

Table 3—Ratios of (I_a/I_r) for various ambient temperatures

Maximum ambient temperature (°C)	Limiting temperature of different breaker components								
	$\theta_{\max}$	50	70	80	85	90	105	110	150
	θ_r	10	30	40	45	50	65	70	110
60	—	0.54	0.68	0.72	0.75	0.81	0.82	0.89	a
50	—	0.79	0.85	0.87	0.88	0.91	0.91	0.95	a
40	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
30	1.46	1.17	1.13	1.11	1.10	1.08	1.07	1.05	b
25	1.66	1.25	1.19	1.17	1.15	1.12	1.11	1.08	b
20	1.84	1.32	1.25	1.22	1.20	1.16	1.15	1.10	b
10	2.00	1.47	1.36	1.32	1.29	1.23	1.22	1.14	b
0	2.00	1.60	1.46	1.42	1.38	1.30	1.29	1.19	b
−10	2.00	1.72	1.56	1.51	1.46	1.37	1.34	1.23	b
−20	2.00	1.84	1.66	1.60	1.54	1.43	1.41	1.28	b
−30	2.00	1.95	1.75	1.68	1.61	1.50	1.46	1.32	b

^aFor limiting current, use lowest θ_r and $\theta_{\max}$.

^bFor limiting current, use highest θ_r and $\theta_{\max}$.

If the ambient temperature was 50 °C, the reduction should be included. In case of doubt, the factor would be 0.85, corresponding to the component with the lowest temperature limit, which in this case is the top oil.

Example 3: Consider an oilless circuit breaker with silver-to-silver contacts, in air, with 55 °C rise current transformers, and with terminals connected to 85 °C insulated cable. When the ambient temperature is 25 °C, the current can be increased by a factor of 1.12, corresponding to the temperature rise limitations of 65 °C of the silver-to-silver contacts and the current transformers.

If the ambient temperature was 50 °C, the reduction factor would be 0.87 corresponding to the temperature rise limitation of 45 °C of the connected cable.

Current transformers that form part of a circuit breaker assembly or that are normally considered a part of the breaker installation will usually have heating characteristics similar to those of the circuit breaker. The continuous current permitted by the formula will not cause overheating of a current transformer connected to a ratio tap corresponding to rated current of the circuit breaker. However, if a lower ratio tap is used, the expected secondary current must be evaluated in terms of the continuous thermal-rating factor of the current transformer. The effect of the secondary current on apparatus connected to the current transformer terminals should also be considered.

5.4.3.3 Short-time load current capability

When a circuit breaker has been operating at a current level below its allowable continuous load current I_a , it is possible to increase the load current for a short time to a value greater than the allowable current without exceeding the permissible temperature limitations. The length of time that the short-time load current I_s can be carried depends on these factors:

- a) The magnitude of current I_s to be carried.
- b) The magnitude of initial current I_i carried prior to application of I_s .
- c) The thermal-time characteristics of the circuit breaker.

The time duration of the short-time current may be calculated directly or may be obtained as described by Figure 1. The time duration of the current I_s determined in one of these ways will not cause the total temperature limits of the circuit breaker to be exceeded, provided that these requirements are fulfilled:

- The circuit breaker, and in particular the main contacts, shall have been well maintained and in essentially new condition.
- The value used for the current I_i is the maximum current carried by the breaker during the 4 h period immediately preceding the application of current I_s .
- At the end of the time period, the current I_s is reduced to a value that is no greater than the current I_a .
- The value of current I_s is limited to a maximum value of two times rated continuous current I_r .

NOTE—If $\theta_s < \theta_{\max}$ the loading is an acceptable steady state. In other words, the allowable time is indefinite. This should be checked before trying to use Figure 1 or directly calculating the allowable duration of I_s .

5.4.3.3.1 Determination of allowable time for I_s , by using Figure 1

One method for determining the allowable duration of current I_s is shown in Figure 1. The values of time obtained from the figure are given in “time constant units.” The actual time is determined by multiplying the time constant units by the proper thermal time constant listed in Table 4.

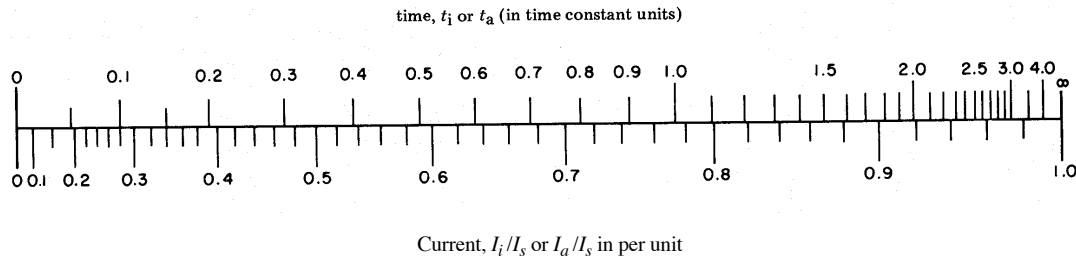
Table 4—Typical thermal time constants

Circuit breaker listed in IEEE Std C37.06-1987	Typical time constant τ (h)
Table 1	0.5
Table 2	0.5
Table 3	0.5

Example: A 1200 A oil circuit breaker with silver-to-silver contacts and American National Standard bushings is operating at 1000 A ($I_i = 1000$ A). It is desired to increase the current to 1600 A ($I_s = 1600$ A) for a short time. The maximum ambient temperature expected is 25 °C. For how long a time can the circuit breaker carry this current?

The allowable continuous current is determined according to 5.4.3.2. Since the ambient is less than 40 °C, the highest temperature rise limitation of 65 °C is used, the temperature rise limit of the bushing. From Table 3, the ratio of 1.12 is determined for the ambient temperature of 25 °C. Therefore, $I_a = 1.12 \times 1200 = 1344$ A.

The ratio (I_i/I_s) is $(1000/1600) = 0.625$. The corresponding value t_i from Figure 1 is 0.58 time constant units. The ratio (I_a/I_s) is $(1344/1600) = 0.84$. The corresponding value t_a from Figure 1 is 1.31 time constant units. The period of time for which the excess current can be carried $t_a - t_i = 1.31 - 0.58 = 0.73$ time constant units. The actual time is obtained by multiplying this value by the thermal time constant of 0.5 h taken from Table 4 (0.73×0.5 h) = 0.365 h or about 22 min. After this time, the current must be reduced to no more than 1344 A in order to prevent overheating of the bushings.



Required initial data:

Initial steady state current

Allowable continuous load current based on actual ambient temperature (from 5.4.3.2)

Desired short-time load current

I_i
 I_a
 I_s

Calculation procedure:

- 1) Determine I_i/I_s per unit initial current
- 2) From chart determine corresponding time t_i
- 3) Determine I_a/I_s per unit allowable continuous current
- 4) From chart determine corresponding time allowable t_a
- 5) Calculate $t_a - t_i =$ time (in time constant units) that breaker can carry, starting from initial continuous current of I_i with ambient temperature and permitting continuous operation at I_a .

NOTE—This procedure and the design of this chart are based on the following assumptions:

- a) At constant current, the temperature approaches its steady state value at an exponential rate. During any time interval equal to the thermal time constant of the circuit breaker, the temperature rise will be equal to 63.2% of the remaining increment of possible increase existing at the start of the period. This is represented by the “time” scale at the top of the chart.
- b) The temperature of a breaker part increases as the 1.8 power of the current increase. This is represented by the current scale at the bottom of the chart. Here, the current in per unit value is plotted to a scale representing the temperature produced by that current.

Figure 1—Current–time relationship to determine short-time load-current capability of high-voltage circuit breakers

5.4.3.3.2 Determination of allowable time for I_s by direct calculation

The allowable duration of current I_s may be calculated directly. While the chart method is quicker and simpler than hand calculation of these equations, the increasing availability of digital computers makes it desirable to provide the details of these calculations. These equations may be easily written in a computer language so that many sets of conditions may be analyzed quickly. The program also should then be immediately available for use at a future time.

These equations are used to calculate the time duration t , for a short-time load current I_s :

$$t_s = \tau \left[-1n \left\{ 1 - \frac{\theta_{\max} - Y - \theta_a}{Y[(I_s/I_i)^{1.8} - 1]} \right\} \right]$$

$$Y = (\theta_{\max} - 40^\circ\text{C}) (I_i / I_r)^{1.8}$$

where

- $\theta_{\max}$ is allowable hottest-spot total temperature from IEEE Std C37.04-1999 (°C),
- θ_a is actual ambient expected (between −30 °C and 60 °C) (°C),
- I_i is initial current carried prior to application of I_s (A) (the maximum current carried by the breaker during the 4 h period immediately preceding the application of current I_s),
- I_s is short-time load current (A),
- I_r is rated continuous current (A),
- τ is thermal time constant of the circuit breaker from Table 4 (h),
- t_s is permissible time for carrying current I_s at ambient θ_a after initial current I_i (in same units as τ).

NOTE—These equations are derived in the following manner:

Let

- θ_s = total temperature that would be reached if current I_s were applied continuously at ambient θ_a (°C)
- θ_i = total temperature due to continuous current I_i at ambient θ_a (°C)
- θ_t = total temperature at some time t after current is raised from I_i to I_s (°C)

Then

$$\theta_t = (\theta_s - \theta_i)(1 - e^{-t/\tau}) + \theta_i$$

Let $\theta_t = \theta_{\max}$; solve for t .

Then

$$t_s = -\tau \ln \left[1 - \frac{\theta_{\max} - \theta_i}{\theta_s - \theta_i} \right]$$

where

$$\theta_i = (\theta_{\max} - 40 \text{ °C})(I_i/I_r)^{1.8} + \theta_a$$

and

$$\theta_s = (\theta_{\max} - 40 \text{ °C})(I_s/I_r)^{1.8} + \theta_a$$

For the special case where the initial current is 0, the equations in this form are useful. By substitution and further manipulation, the equations given above in terms of Y are obtained; these equations are convenient to use in the more usual case where the initial current is not 0.

5.4.4 Emergency load current carrying capability

During emergency periods, operation may be required at higher load currents than permitted by the ambient compensation procedure outlined in 5.4.3. Under these conditions, all the general considerations for ambient compensation are applicable to emergency loading with additional considerations and limitations as outlined in this subclause.

The limits of total temperature for the circuit breaker will be exceeded under the specified emergency load currents, and these higher temperatures may cause a reduction in the operating life of the circuit breaker. Inspection and maintenance of the circuit breaker are required following each emergency cycle as outlined in 5.4.4.5.

5.4.4.1 Conditions for emergency load current carrying capability

- a) Emergency load current carrying capability factors can only be applied to outdoor circuit breakers, as listed in IEEE Std C37.06-1997.

These factors can be applied to circuit breakers used in gas-insulated substations until specific standards for that equipment are issued.

Circuit breakers used in metal-clad switchgear shall be coordinated with overall application limitations of the total switchgear. Load current carrying capability under various conditions of ambient temperature and load for these circuit breakers is covered in IEEE Std C37.20.2-1993.

- b) Prior to the application of the emergency load, the circuit breaker current-carrying circuit, including external connections, shall have been well maintained and be in an essentially new condition.
- c) Following the emergency period, the load current shall be limited to 95% of I_a , the rated continuous current as modified by ambient compensation according to 5.4.3, for a minimum of 2 h.
- d) During and following an emergency cycle and prior to maintenance, the circuit breaker shall be capable of one interruption at its rated short-circuit current.
- e) Circuit breakers operated at temperatures that exceed their limits of total temperature may experience a reduction in operating life. Mandatory inspection and maintenance procedures are required following this duty in accordance with 5.4.4.5 and as recommended by the manufacturer.

NOTE—The thermal capability of associated equipment, such as cables, reactors, line traps, disconnecting switches, and current transformers, also shall be suitable for emergency loading. These pieces of equipment may limit the emergency rating to less than that calculated for the circuit breaker.

5.4.4.2 Emergency load current carrying capability factors for 4 h and 8 h

Emergency load current carrying capability factors with ambient temperature at 40 °C are listed in Table 5a for each limiting temperature of various circuit breaker components.

The factors have been selected to allow operation at 15 °C above the limits of total temperature for an emergency period of 4 h, or 10 °C above for an emergency period of 8 h. The factors are expressed as the ratio of emergency load current I_e allowed at an ambient temperature of 40 °C to the rated continuous currents I_r and can be applied with the following restrictions:

- a) The circuit breaker component with the highest values of limiting temperatures, $\theta_{\max}$ and θ_r , shall be used to select the proper emergency load current carrying capability factor from Table 5a.

NOTE—Circuit breakers with contacts and conducting joints in other than oil or air may be operated at higher temperatures than listed in IEEE Std C37.04-1999, Table 1, if it can be shown that accelerated deterioration will not occur. Unless rated otherwise by the manufacturer, contacts and conducting joints in other than oil or air are assumed to have the temperature limitations of silver, silver alloy, or equivalent materials in air (65 °C hottest-spot temperature rise, 105 °C hottest-spot total temperature).

- b) The 4 h factor shall be used for a cycle of operation consisting of separate periods of not longer than 4 h each, with not more than four such occurrences before maintenance.
- c) The 8 h factor shall be used for a cycle of operation consisting of separate periods of not longer than 8 h each, with not more than two such occurrences before maintenance.

- d) Each cycle of operation is separate, and no time-current integration is permissible to increase the number of periods within a given cycle. However, any combination of separate 4 h and 8 h emergency periods may be used. However, when they total 16 h, the circuit breaker shall be inspected and maintained according to 5.4.4.5 before being subjected to additional emergency cycles.

**Table 5a—Emergency load current carrying capability factors (I_e/I_r)
(Based on an ambient temperature of 40 °C)**

Emergency period	Limiting temperature (°C) of different breaker components							
	$\theta_{\max}$	70	80	85	90	105	110	150
	θ_r	30	40	45	50	65	70	110
4 h		1.25	1.19	1.17	1.15	1.12	1.11	1.08
8 h		1.17	1.13	1.11	1.10	1.08	1.07	1.05

NOTE—For limiting current, use highest θ_r and $\theta_{\max}$.

5.4.4.3 Emergency operation at an ambient temperature other than 40 °C

When a circuit breaker is operating at an ambient temperature other than 40 °C, the emergency load current carrying capability I_{ea} can be calculated by the following equation:

$$I_{ea} = I_r \left[\left(\frac{I_a}{I_r} \right)^{1.8} + \left(\frac{I_e}{I_r} \right)^{1.8} - 1 \right]^{1/1.8}$$

where

- I_{ea} is emergency load current at actual ambient temperature (A),
- I_r is rated continuous current (A),
- I_e is emergency load current at 40 °C ambient temperature (A),
- I_a/I_r is ambient compensation factor from Table 3 or calculated according to 5.4.3.2,
- I_e/I_r is emergency load current carrying capability factor from Table 5a.

The ratio of (I_{ea}/I_r) shall not exceed the value of 2.0. Calculated values of the ratio (I_{ea}/I_r) over a range of typical ambient temperatures are shown in Table 5b for a 4 h emergency period and in Table 5c for an 8 h emergency period. If the calculation does not provide the emergency current desired, then a circuit breaker with the next higher continuous current rating should be selected.