

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

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Abstract: Ratings, performance requirements, and compliance test methods are provided for ac high-voltage generator circuit breakers rated on a symmetrical current basis that are installed between the generator and the transformer terminals. Guidance for applying generator circuit breakers is given. Pumped storage installations are considered a special application, and their requirements are not completely covered by this standard.

Keywords: ac high-voltage generator, application guidance, generator circuit breakers, symmetrical current-rating structure, terminals of large generators, testing procedures

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Introduction

(This introduction is not a part of IEEE Std C37.013-1997, IEEE Standard for AC High-Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis.)

This standard has been revised to clarify the meaning of rated maximum voltage as used in this standard and covers the requirements for ac high-voltage generator circuit breakers as applied directly to the outgoing terminals of generators. The rating, testing, and application requirements of these specialized circuit breakers are not adequately covered by the existing standards IEEE Std C37.04-1979, ANSI C37.06-1987, IEEE Std C37.09-1979, and IEEE Std C37.010-1979 series for ac high-voltage circuit breakers rated on a symmetrical current basis. In order to avoid the detailed integration and possible confusion by introducing the specialized requirements into the existing standards, it was determined that a separate standard was the most effective method for covering these devices.

A working group of the High-Voltage Circuit Breaker Subcommittee of the IEEE Switchgear Committee has revised this standard with input from various sources on all requirements for these specialized devices. The Working Group has developed an Application Guide, which is contained in Clause 6. of this standard. The guide is intended to assist the engineer applying a generator circuit breaker on an electric power system.

These efforts have contributed valuable standards to the industry. Further suggestions for improvement gained from the use of this standard will be welcomed.

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CLAUSE	PAGE
1. Scope	1
2. References	1
3. Definitions	2
4. Service conditions	3
4.1 Usual service conditions	3
4.2 Unusual service conditions	4
4.3 Impact on environment	4
5. Ratings and required capabilities	5
5.1 Rated maximum voltage	5
5.2 Power frequency	5
5.3 Rated continuous current	5
5.4 Rated dielectric strength	9
5.5 Rated short-circuit duty cycle	9
5.6 Rated interrupting time	10
5.7 Rated closing time	10
5.8 Short-circuit current rating	10
5.9 Transient recovery voltage (TRV) rating	13
5.10 Rated load current switching capability	14
5.11 Capacitance current switching capability	16
5.12 Out-of-phase current switching capability	16
5.13 Excitation current switching capability	17
5.14 Rated control voltage	17
5.15 Rated mechanism fluid operating pressure	18
5.16 Nameplate markings	18
6. Tests	20
6.1 General	20
6.2 Design tests	20
6.3 Production tests	40
6.4 Tests after delivery	43
7. Application guide	44
7.1 General	44
7.2 General application conditions	45
7.3 Application considerations	47
7.4 Guide to specification	68
8. Bibliography	69
Annex A (Informative) Example of the application of a generator circuit breaker	70

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

1. Scope

This standard applies to all ac high-voltage generator circuit breakers rated on a symmetrical current basis that are installed between the generator and the transformer terminals. Pumped storage installations are considered a special application, and their requirements are not completely covered by this standard.

NOTE — Since no other national or international standard on generator circuit breakers exists, this standard is used worldwide. The revision of IEEE Std C37.013-1993 takes care of this fact by adapting its content in some places to international practice.

2. References

The standard shall be used in conjunction with the following publications. When the following publications are superseded by an approved revision, the revision shall apply.

ANSI C37.06-1987 (R1994), Switchgear: AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities.¹

ASME Boiler and Pressure Vessel Code, 1995 Edition.²

IEC 60694: 1996, Common specifications for high voltage switchgear and controlgear standards.

IEEE Std 1-1986 (Reaff 1992), IEEE Standard General Principles for Temperature Limits in the Rating of Electrical Equipment and for the Evaluation of Electrical Insulation (ANSI).³

¹ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036-8002, USA.

²ASME publications are available from the American Society of Mechanical Engineers, 22 Law Drive, Fairfield, NJ 07007, USA.

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

IEEE Std 4-1995, IEEE Standard Techniques for High Voltage Testing (ANSI).

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms.

IEEE Std 119-1974, IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus (ANSI/DoD).⁴

IEEE Std C37.04-1994, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis (ANSI).

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

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

IEEE Std C37.081-1981 (Reaff 1988), IEEE Guide for Synthetic Fault Testing of AC High Voltage Circuit Breakers Rated on a Symmetrical Current Basis (ANSI).

IEEE Std C37.082-1982 (Reaff 1988), IEEE Standard Methods for the Measurement of Sound Pressure Levels of AC Power Circuit Breakers (ANSI).

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

IEEE Std C37.23-1987 (Reaff 1991), IEEE Standard for Metal-Enclosed Bus and Calculating Losses in Isolated-Phase Bus (ANSI).

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

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

NEMA MG 1-1993, Motors and Generators.⁵

NEMA SG 4-1990, Alternating Current High-Voltage Circuit Breaker.

3. Definitions

The definitions of terms contained in this standard, or in other documents referred to in this standard, are not intended to embrace all legitimate meanings of the terms. They are applicable only to the subject treated in this standard. For additional definitions, see IEEE Std C37.100-1992.

A letter symbol ^(a) indicates that at the time this standard was approved, there was no corresponding definition in IEEE Std C37.100-1992. A letter symbol ^(b) following the definition indicates that the definition in this standard differs from that appearing in IEEE Std C37.100-1992.

3.1 design tests: Those tests made to determine the adequacy of the design of a particular type, style, or model generator circuit breaker to meet its assigned ratings and to operate satisfactorily under usual service conditions or

⁴IEEE Std 119-1974 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

⁵NEMA publications are available from the National Electrical Manufacturers Association, 1300 N. 17th St., Ste. 1847, Rosslyn, VA 22209, USA.

under unusual conditions, if specified. Design tests are made only on representative circuit breakers of basically the same design, i.e., the same interrupters operating at the same contact speeds, and having at least the same dielectric strength. These tests are not intended to be used as a part of normal production. The applicable portions of these design tests may also be used to evaluate modifications of a previous design and to assure that performance has not been adversely affected. Test data from previous similar designs may be used for current designs, where appropriate.^b

3.2 excitation current switching capability (of a generator circuit breaker): The highest magnetizing current that a generator circuit breaker shall be required to switch at any voltage up to rated maximum voltage at power frequency without causing an overvoltage exceeding the levels agreed upon between the user and the manufacturer.^a

3.3 generator-source short-circuit current: The short-circuit current when the source is entirely from a generator through no transformation.^a

3.4 production tests: Those tests made to check the quality and uniformity of workmanship and materials used in the manufacturing of generator circuit breakers.^b

3.5 rated closing time (of a generator circuit breaker): The interval between energizing of the close circuit at rated control voltage and rated fluid pressure of the operating mechanism and the closing of the main circuit.^a

3.6 rated continuous current (of a generator circuit breaker): The designated limit of current in rms amperes at power frequency that a generator circuit breaker shall be required to carry continuously without exceeding any of its designated limitations.^a

3.7 rated interrupting time (of a generator circuit breaker): The maximum permissible interval between the energizing of the trip circuit at rated control voltage and rated fluid pressure of the operating mechanism and the interruption of the main circuit in all poles on an opening operation.^a

3.8 rated maximum voltage (of a generator circuit breaker): The highest rms voltage for which the circuit breaker is designed, and the upper limit for operation. The rated maximum voltage is equal to the maximum operating voltage of the generator to which the circuit breaker is applied.^b

3.9 rated mechanism fluid operating pressure (of a generator circuit breaker): The pressure at which a gas- or liquid-operated mechanism is designed to operate.^a

3.10 system-source short-circuit current: The short-circuit current when the source of the short-circuit current is from the power system through at least one transformation.^a

3.11 tests after delivery: Those tests made by the purchaser after delivery of the circuit breaker, which supplement inspection, to determine whether the circuit breaker has arrived in good condition. These tests may consist of timing tests on closing, opening, close-open no-load operations, and power frequency voltage withstand tests at 75% of the rated power frequency withstand voltage.^a

4. Service conditions

4.1 Usual service conditions

Generator circuit breakers conforming to this standard shall be suitable for operating at their standard ratings under the following usual service conditions:

- a) Ambient temperature for outdoor generator circuit breakers is not above 40 °C or below –30 °C; ambient temperature for indoor generator circuit breakers is not above 40 °C or below +5 °C.
- b) Altitude is not above 1000 m (3300 ft).
- c) For installations at nuclear power stations, static forces applied to the generator circuit breaker do not exceed the equivalent force of a 0.5 g acceleration applied horizontally at the center of gravity of the circuit breaker.

4.2 Unusual service conditions

4.2.1 Abnormal temperatures

The use of apparatus in ambient temperatures outside the limits of those specified in a) of 4.1 shall be considered as special.

4.2.2 Altitudes above 1000 m

For applications at altitudes higher than 1000 m, the basic impulse insulation level and rated continuous current shall be multiplied individually by correction factors in Table 1 to obtain appropriate values.

The rated short-circuit current, related required capabilities, and the rated interrupting time are not affected by altitude.

Table 1— Altitude correction factors

Altitude (m)	Insulation level	Rated continuous current
1000	1.00	1.00
1500	0.95	Refer to manufacturer
3000	0.80	Refer to manufacturer
NOTES: 1 — Intermediate values can be obtained by interpolation. See example in 7.2.2.2. 2 — A revision of the altitude correction factors is under consideration.		

4.2.3 Conditions affecting construction or protecting features

There are application conditions that 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 conditions are the following:

- a) Exposure to damaging fumes or vapors, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, oil spray, excessive moisture, dripping water, and other similar conditions;
- b) Exposure to abnormal vibration, shock, tilting, or seismic forces;
- c) Exposure during transportation or storage to conditions beyond temperatures listed in a) of 4.1;
- d) Unusual space limitations;
- e) Unusual operating duty, frequency of operation, and difficulty of maintenance;
- f) Condensation on dielectric surfaces, produced by the generator circuit breaker cooling medium.

4.3 Impact on environment

Generator circuit breakers conforming to this standard shall have limited impact on the environment, as follows:

- a) When operated under standard conditions, with all three poles operating simultaneously, the peak instantaneous sound pressure level of the generator circuit breaker shall be less than 140 dB (unweighted; see IEEE Std C37.082-1982)⁶;
- b) The effects of circulating currents induced by magnetic fields produced by continuous currents in the generator circuit breaker are addressed in Clause 7.

⁶Information on references can be found in Clause 2.

5. Ratings and required capabilities

The ratings and required capabilities of a generator circuit breaker are the designated limits of operating characteristics based on definite conditions and shall include the following items, where applicable:

- a) Rated maximum voltage (see 5.1);
- b) Power frequency (see 5.2);
- c) Rated continuous current (see 5.3);
- d) Rated dielectric strength (see 5.4);
- e) Rated short-circuit duty cycle (see 5.5);
- f) Rated interrupting time (see 5.6);
- g) Rated closing time (see 5.7);
- h) Rated short-circuit current (see 5.8);
- i) Transient recovery voltage (TRV) rating (see 5.9);
- j) Rated load current switching capability (see 5.10);
- k) Capacitance current switching capability (see 5.11);
- l) Out-of-phase current switching capability (see 5.12);
- m) Excitation current switching capability (see 5.13);
- n) Rated control voltage (see 5.14);
- o) Rated mechanism fluid operating pressure (see 5.15);
- p) Nameplate markings (see 5.16).

The establishment of the ratings and required capabilities and the assignment of them to a generator circuit breaker in accordance with these standards implies performance characteristics at least equal to those set forth in 5.1–5.15. The ratings and required capabilities assigned to a generator circuit breaker are based on test data in accordance with Clause 6., but other equivalent or more effective methods of testing are not precluded.

Alternatively, for designs existing prior to the adoption of this standard, the ratings and required capabilities can be based on other tests that are judged to be equally effective on the basis of the experience gained from previous design or development tests or by service performance experience.

5.1 Rated maximum voltage

The rated maximum voltage of a generator circuit breaker is the highest rms voltage for which the circuit breaker is designed and is the upper limit for operation. The rated maximum voltage is equal to the maximum operating voltage of the generator (usually equal to 1.05 times the rated voltage of the generator) to which the circuit breaker is applied.

5.2 Power frequency

The power frequency of a generator circuit breaker is the frequency at which it is designed to operate, with the frequency being 50 Hz or 60 Hz. Applications at other frequencies should receive special consideration.

5.3 Rated continuous current

The rated continuous current of a generator circuit breaker is the designated limit of current in rms amperes at power frequency, which it shall be required to carry continuously without exceeding any of the limitations designated in 5.3.1 and 5.3.2. Typical values are 6.3 kA, 8 kA, 10 kA, 12 kA, 16 kA, 20 kA, etc.

5.3.1 Conditions of continuous current rating

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

- a) Circuit breakers are used under usual service conditions defined in 4.1.
- b) Current ratings shall be based on the total temperature limits of the materials used for circuit breaker parts. A temperature rise reference is given to permit testing at reduced ambient temperature.
- c) Circuit breakers designed for installation in enclosures shall have their ratings based on the ventilation of such enclosures and on a 40 °C ambient temperature outside the enclosure [see b) in 6.2.1.1].
- d) Circuit breakers designed for operation with forced air cooling assistance shall have the ratings based on a 40 °C ambient temperature with the forced air cooling system operating.

5.3.2 Temperature limitations for continuous current ratings

5.3.2.1 Limitations on insulating materials

The temperatures of materials used to insulate main power circuit-conducting parts from phase-to-ground or from terminal-to-terminal of an open circuit breaker shall be limited to the values listed in Table 2. It is recognized that these limits are generally less than those associated with the insulating class in IEEE Std 1-1986, since such insulation may be subject to severe mechanical stress when used in a generator circuit breaker.

5.3.2.2 Limitations of main contacts

The temperatures of main contacts used in generator circuit breakers shall not exceed the values listed in Table 3. Contacts may be operated at other temperatures provided it can be shown by experience or tests acceptable to the user, that accelerated deterioration will not occur.

5.3.2.3 Limitations on conducting joints

The temperature of conducting joints in the main power circuit of a generator circuit breaker shall not exceed the values listed in Table 3. Conducting joints may be operated at other temperatures provided that experience or tests show that accelerated deterioration will not occur.

Table 2— Temperature limitations on insulating materials for continuous current ratings

Insulating class of material	Main power circuit limits, hottest spot total temperature (°C)
O	90
A	105
B	130
F	155
H	180
C	220
NOTES: 1 — See IEEE Std 1-1986 for explanation of insulating classes. 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.	

Table 3— Temperature limitations on main contacts and conducting joints for continuous current ratings

Conducting surface joint surface	Limit of hottest spot temperature rise (°C) at ambient temperature of 40 °C	Limit of hottest spot total temperature (°C)
Copper	30	70
Silver, silver alloy, or equivalent	65	105
NOTE — If an ambient temperature lower than 40 °C is specified, then the temperature rise can be higher, but the limit of the hottest spot total temperature shall not be exceeded.		

5.3.2.4 Limitations for parts subject to contact by personnel

Generator circuit breaker parts handled by the operator in the normal course of work duties shall have no greater a total temperature than 50 °C.

Generator circuit breakers having external surfaces accessible to an operator in the normal course of work duties shall have a total temperature on the surfaces no greater than 70 °C. If the bus duct connected to the generator circuit breaker is designed for a total temperature of 80 °C on the surfaces, then the circuit breaker surface temperature can be 80 °C.

Generator circuit breakers having external surfaces not accessible to an operator in the normal course of work duties shall have a total temperature on the surfaces no greater than 110 °C.

5.3.2.5 Limitations on other materials

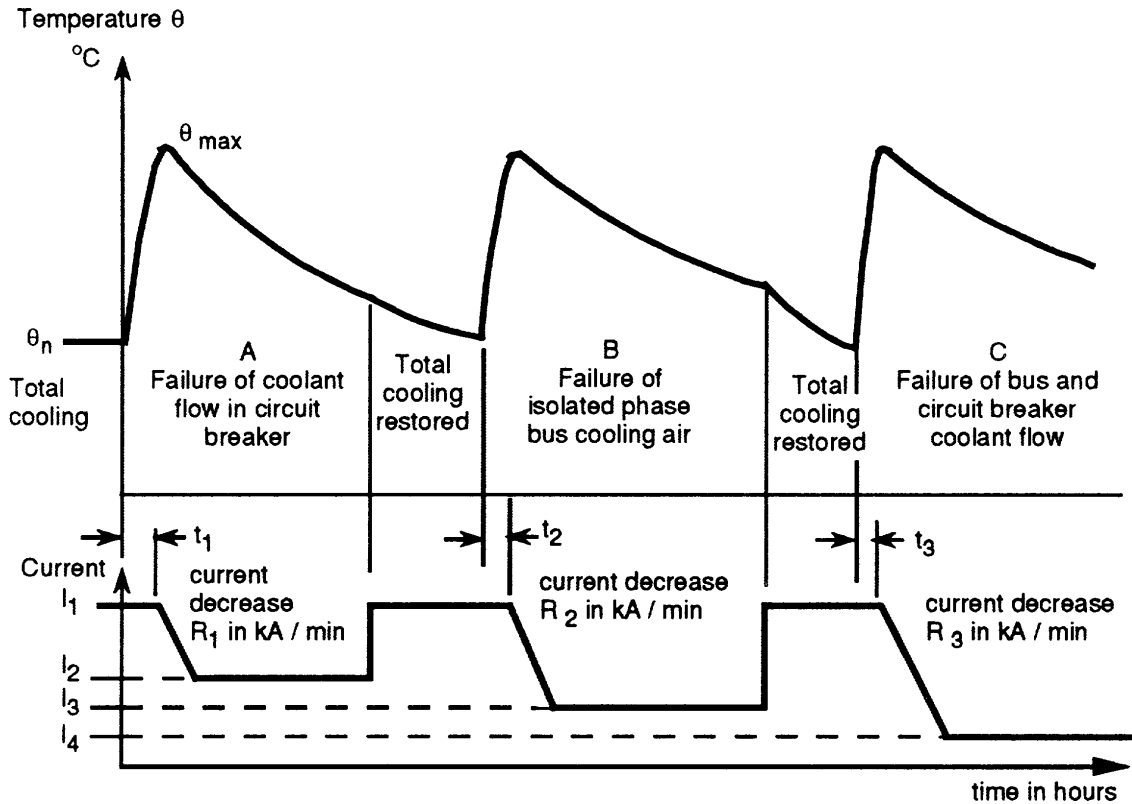
Other materials shall be chosen so that the maximum temperature to which they may be subjected shall not cause accelerated deterioration.

5.3.3 Emergency current ratings during loss of cooling

The operating considerations for generator circuit breakers require that emergency ratings are established to enable the circuit breaker to remain in service following loss of normally required auxiliary forced cooling systems. The following provisions shall be observed:

- It is possible to operate the generator circuit breaker for limited time periods with circuit breaker parts at a higher total temperature than the limits specified for the continuous current rating.
- The difference between the emergency temperature limits and the normal operating temperatures provide a definite allowable time period during which full load may be carried before the reduction in load current must be accomplished.
- The generator circuit breaker may remain in service at a reduced load current, the value of which will depend on the type of emergency condition prevailing.
- Where the circuit breaker continuous current rating is affected by several independent systems (e.g., interrupting medium, cooling medium, forced air cooling of isolated phase bus, etc.), the effect of losing each system individually and in combination should be established.
- In addition to a) through d), certain generating station designs (e.g., single generator output connected by two generator circuit breakers to two unit step-up transformers) may also require special emergency operating conditions and ratings.

Factors are illustrated in Figure 1.



- I_1 is rated current with all cooling systems in operation
 I_2 is allowable load current if failure (A) of coolant in circuit breaker occurs
 I_3 is allowable load current if failure (B) of isolated phase bus cooling air occurs
 I_4 is allowable load current if failure (C) of bus and circuit breaker coolant flow occurs
 $\theta_{\max}$ is allowable hottest spot total temperature in $^{\circ}\text{C}$
 θ_n is hottest spot total temperature at rated continuous current in $^{\circ}\text{C}$
 t_1, t_2, t_3 are allowable times without a reduction in rated continuous current and without exceeding $\theta_{\max}$

Figure 1— Effect of various cooling failures and subsequent load reductions on generator circuit breaker temperature

Figure 1 illustrates typical emergency conditions in which the loss of two cooling systems, that of the generator circuit breaker and that of the bus duct, have been studied separately and simultaneously.

The following are the parameters that are required for correct operation under each type of emergency condition and for which values must be determined by the manufacturer:

- t_1, t_2, t_3 The time available at rated current before the load must be reduced.
 R_1, R_2, R_3 The rate at which the load current must be reduced in kA/min.
 I_2, I_3, I_4 The emergency current assigned to circuit breaker for operating under each emergency condition for a specified maximum period of time.

5.4 Rated dielectric strength

The rated dielectric strength of a generator circuit breaker is its voltage withstand capability with specified magnitudes and waveshapes. In the event of loss of insulating medium pressure, the generator circuit breaker shall be able to withstand 1.5 times the following voltages:

- In the open position, the phase opposition voltage across the contacts, the phase-to-ground, and the line-to-line voltage between phases.
- In the closed position, phase-to-ground and line-to-line voltage between phases. (For applications requiring full dielectric withstand upon loss of insulating medium, agreement should be reached between the user and the manufacturer.)

5.4.1 Dielectric strength of external insulation

External insulation shall conform to the performance requirements of this standard. Requirements for the rated dielectric strength of the external insulation of generator circuit breakers are given in Table 4.

Table 4— Schedule of dielectric strength for ac generator circuit breakers and external insulation

Line	Circuit breaker rated maximum voltage kV, rms	Insulation withstand voltages	
		Power frequency 50 or 60 Hz $\pm$ 20%	Impulse $1.2 \times 50 \mu\text{s}$ wave
		1 min dry kV, rms	Full wave withstand kV, crest
	Column 1	Column 2	Column 3
1	15.8 and below	50	110
2	15.9–27.5	60	125
3	27.6–38.0	80	150

5.4.2 Rated power frequency withstand voltage (dry)

The rated power frequency withstand voltage (dry) is the voltage that a new generator circuit breaker must be capable of withstanding for 1 min (see Column 2 of Table 4 and 6.2.2).

5.4.3 Rated full wave impulse withstand voltage

The rated full wave impulse withstand voltage is the crest value of a standard $1.2 \times 50 \mu\text{s}$ impulse voltage wave that a new generator circuit breaker must be capable of withstanding (see Column 3 of Table 4 and 6.2.2).

5.4.4 Rated switching impulse withstand voltage

For generator circuit breakers, the requirements for switching impulse withstand voltage are satisfied by the power frequency withstand voltage.

5.5 Rated short-circuit duty cycle

The rated short-circuit duty cycle of a generator circuit breaker shall be two unit operations with a 30 min interval between operations (CO–30 min–CO).

5.6 Rated interrupting time

The rated interrupting time of the generator circuit breaker is the maximum permissible interval between the energizing of the trip circuit at rated control voltage and rated fluid pressure of the operating mechanism and the interruption of the main circuit in all poles on an opening operation. Typical values are approximately 60–90 ms with the actual time being dependent on the rated short-circuit current. For generator circuit breakers equipped with resistors, the interrupting time for the resistor current may be longer.

5.7 Rated closing time

The rated closing time of a generator circuit breaker is the interval between energizing of the close circuit at rated control voltage and rated fluid pressure of the operating mechanism, and the closing of the main circuit.

5.8 Short-circuit current rating

The short-circuit current rating of a generator circuit breaker is the rms symmetrical component of short-circuit current to which all required short-circuit capabilities are related. Procedures for determining the symmetrical short-circuit current duties that compare with ratings and related required capabilities are found in Clause 7.

5.8.1 Rated short-circuit current

The rated short-circuit current of a generator circuit breaker is the highest rms value of the symmetrical component of the three-phase short-circuit current. It is measured from the envelope of the current wave at the instant of primary arcing contact separation, and is the current that the generator circuit breaker shall be required to interrupt at the rated maximum voltage and rated duty cycle when the source of the short-circuit current is from the power system through at least one transformation. It establishes also, by ratios defined in 5.8.2.6, the highest current that the generator circuit breaker shall be required to close and latch against and to carry. Typical values are 63 kA, 80 kA, 100 kA, 120 kA, 160 kA, etc.

NOTE — The rare cases when the generator-source short-circuit current is higher than the system source short circuit current need special consideration.

5.8.2 Related required capabilities

The generator circuit breaker shall have the following related required capabilities, which are based on the minimum time to primary arcing contact separation including a relay time of 1/2 cycle, but may be used with any relay time.

5.8.2.1 Required symmetrical interrupting capability for three-phase faults

For three-phase faults, the required symmetrical interrupting capability of a generator circuit breaker at the instant of primary arcing contact separation for operating voltages equal to rated maximum voltage shall not exceed the rated short-circuit current for the rated duty cycle irrespective of the direct current component of the total short-circuit current.

5.8.2.2 Required asymmetrical interrupting capability for three-phase faults

The required asymmetrical system-source interrupting capability of a generator circuit breaker at rated maximum voltage and for the rated duty cycle is composed of the rms symmetrical current and the percentage dc component. The values of the dc component in percent of the peak value of the symmetrical short-circuit current are given in Figure 2 for primary arcing contact parting times in milliseconds. This figure is based on a time constant of the decay of the dc component of 133 ms, which is considered to be conservative. For time constants different than 133 ms, use the formula for calculating the dc component given in 7.3.5.3.2.

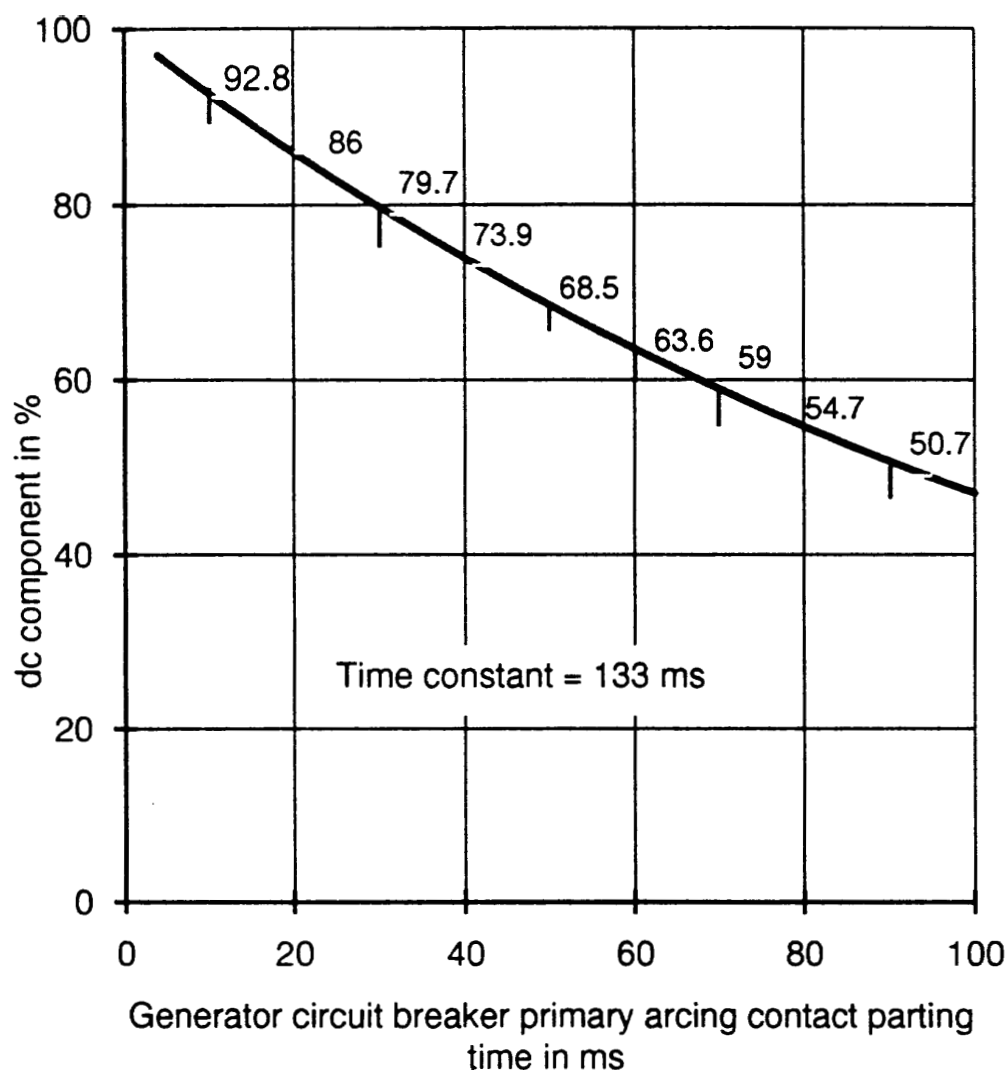


Figure 2— Asymmetrical interrupting capability: DC component in percentage of the peak value of the symmetrical three-phase system-source short-circuit current

The primary arcing contact parting time shall be considered equal to the sum of 1/2 cycle (present practical minimum tripping delay) plus the minimum opening time of the particular generator circuit breaker.

5.8.2.3 Required generator-source symmetrical interrupting capability for three-phase faults

No specific rating is assigned to cover the generator-source short-circuit current because its maximum value is usually less than the short-circuit current from the power system. If a rating is assigned, then the generator circuit breaker shall be tested for the following related capabilities. For three-phase faults, the required generator-source symmetrical interrupting capability of a generator circuit breaker is the highest value of the symmetrical component of the short-circuit current, measured from the envelope of the current wave at the instant of primary arcing contact separation that the generator circuit breaker shall be required to interrupt, at rated maximum voltage and rated duty cycle when the source of the short-circuit current is entirely from a generator through no transformations.

5.8.2.4 Required generator-source asymmetrical interrupting capability for three-phase faults

For three-phase faults, the required asymmetrical generator-source interrupting capability of a generator circuit breaker at rated maximum voltage and for the rated duty cycle is composed of the rms generator-source symmetrical current and a dc component. The value of the dc component is 110% of the peak value of the symmetrical generator-source short-circuit current for all generator circuit breaker primary arcing contact parting times. The primary arcing contact parting time shall be considered equal to the sum of 1/2 cycle plus the minimum opening time of the particular generator circuit breaker.

5.8.2.4.1 Required generator-source asymmetrical interrupting capability for maximum required degree of asymmetry

The maximum required degree of asymmetry of the current for the condition of maximum required degree for asymmetry is 130% of the peak value of symmetrical current for this condition. The symmetrical component of the short-circuit current under the condition of maximum degree of asymmetry is only 74% of the value of the required generator-source symmetrical interrupting capability.

5.8.2.5 Required interrupting capability for single-phase-to-ground faults

Generator circuit breakers are designed for use on high-impedance grounded systems where the single phase-to-ground short-circuit current will not exceed 50 A. In no case are the capabilities for single phase-to-ground faults required to exceed this value.

5.8.2.6 Required closing, latching, and carrying capabilities

The generator circuit breaker shall be capable of the following:

- a) Closing and latching any power frequency-making current (50 Hz or 60 Hz) whose maximum crest (peak making current) does not exceed 2.74 times the rated symmetrical short-circuit current or the maximum crest (peak making current) of the generator-source short-circuit current, whichever is higher. No numerical value can be given for the peak value of the generator-source peak current since it depends on the generator characteristic data (see 5.8.2.3 and A.3.2).
- b) Carrying the short-circuit current for a time of 0.25 s.

5.8.2.7 Required short-time current-carrying capability

The generator circuit breaker shall be capable of carrying for T_s equals 1 s, any short-circuit current determined from the envelope of the current wave at the time of the maximum crest, whose value does not exceed 2.74 times the rated short-circuit current, and whose rms value I determined over the complete 1 s period does not exceed the rated short-circuit current considered above.

The mathematical expression for the rms value I of a short-circuit current over the period T_s is as follows:

$$I = \sqrt{\frac{1}{T_s} \int_0^{T_s} i^2 dt} = \sqrt{\int_0^1 i^2 dt}$$

where

- i is the instantaneous current in amperes (see Clause 7. of IEEE Std C37.09-1979)
 t is the time in seconds

It is not to be inferred that the generator circuit breaker is to be capable of interrupting after the required short-time current-carrying capability duty until it has cooled down to normal heat run temperature.

5.8.3 Interrupting performance

5.8.3.1 Rated performance

A generator circuit breaker shall perform at or within its rating without producing any injurious emissions.

5.8.3.2 Service capability duty requirements

Generator circuit breakers shall be capable of the following performances under short-circuit and load current interruption conditions:

- a) One short-circuit duty cycle (CO–30 min–CO).
- b) A number of load current interruptions in which the sum of the currents interrupted does not exceed 5000% of rated continuous current of the generator circuit breaker. The number of operations used to make up the 5000% is cumulative over a period of time and is a measure of the generator circuit breaker's reliability and a guide to maintenance. Thermal limitations of parts, such as opening resistors, require that the number of opening operations comprising the 5000% shall not exceed two in 30 min or four in 4 h.

5.9 Transient recovery voltage (TRV) rating

At its rated maximum voltage, each generator circuit breaker must be capable of interrupting three-phase grounded faults at rated short-circuit current in any circuit in which the three-phase grounded circuit TRV does not exceed the rated TRV envelope.

Each TRV rating is for a three-phase generator circuit breaker. It is not required that a single phase of a generator circuit breaker interrupt a single-phase circuit that produces a circuit TRV equal to the rated TRV envelope.

However, as discussed in 6.2.3.8, the single-phase test at 1.5 times phase-to-ground 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.

5.9.1 Rated inherent TRV

The rated inherent TRV shall be defined by an oscillatory waveshape having a TRV rate, time delay, and crest voltage (E_2) as listed in Tables 5–6. The formula and method for determining the time-to-crest (T_2) are given in 7.3.6.3 and Figure 15.

Table 5— TRV parameters for system-source faults

Transformer rating MVA	T_2 in μs	Inherent TRV	
		E_2 -crest voltage	TRV rate kV/ μs
100 or less	0.62 V	1.84 V	3.5
101–200	0.54 V	1.84 V	4.0
201–400	0.48 V	1.84 V	4.5
401–600	0.43 V	1.84 V	5.0
601–1000	0.39 V	1.84 V	5.5
1001 or more	0.36 V	1.84 V	6.0
NOTES: 1 — Time delay shall be equal to or less than 1 μs . 2 — V is the rated maximum voltage in kV.			

Table 6— TRV parameters for generator-source faults

Generator rating MVA	T_2 in μs	Inherent TRV	
		E_2 -crest voltage	TRV rate kV/ μs
100 or less	1.35 V	1.84 V	1.6
101–400	1.20 V	1.84 V	1.8
401–800	1.08 V	1.84 V	2.0
801 or more	0.98 V	1.84 V	2.2
NOTES: 1 — Time delay shall be equal to or less than 0.5 μs . 2 — V is the rated maximum voltage in kV.			

5.9.2 First-pole-to-clear factor

The first-pole-to-clear factor shall be 1.5.

5.9.3 Amplitude factor

The amplitude factor shall be 1.5.

5.10 Rated load current switching capability

The operation endurance capabilities specified in Table 7 are the type and number of complete closing-opening operations that the generator circuit breaker shall be capable of performing at any voltage up to the rated maximum voltage under the following conditions:

- The generator circuit breaker shall operate with rated control voltage and rated fluid (gas or liquid) pressure in the operating mechanism.
- The frequency of operations is not to exceed two in 30 min and four in 4 h because the generator circuit breaker may be equipped with auxiliary devices, such as resistors, that have thermal limitations. When auxiliary devices such as resistors are not used, the manufacturer may provide alternate frequency of operation values.

- c) The values listed in the rating tables have been established by experience and engineering judgment. Those involving currents are derived from service capability and circuit breaker condition (see 5.8.3.2) and are not separate ratings (see 6.2.8.2.)

5.10.1 Inherent TRV

The inherent TRV for a load switching operation shall be defined by an oscillatory waveshape having a TRV rate and time delay as listed in Table 8. The formula and method for determining the time-to-crest (T_2) are given in 7.3.6.3 and Figure 15.

5.10.2 Amplitude factor

The amplitude factor shall be 1.5.

Table 7— Operation endurance capabilities for generator circuit breakers

Circuit breaker ratings	Number of operations (operation = 1 closing + opening)		
	Between servicing (see NOTE 2)	No-load mechanical (see NOTES 2–8)	Continuous current switching (see NOTES 2, 4, 5, 7, 8, and 9)
Column 1	Column 2	Column 3	Column 4
Up to 38 kV	500	1000	50
NOTES: 1 — The integrated duty on the generator circuit breaker must be within the service capability as defined in 5.8.3. See Clause 6.. 2 — Maintenance consists of cleaning, tightening, adjusting, lubricating, and dressing of contacts, etc., as recommended by the manufacturer under usual service conditions. Maintenance intervals are usually based on both an elapsed time and a number of operations, whichever occurs sooner. In determining maintenance intervals for particular applications, consideration must be given to actual conditions prevailing at the installation site. Refer to Clause 4. for service conditions and to Clause 7. for general application conditions. The number of operations specified in Column 2 are based on usual service conditions. When used as a guide for field application, they define maximum maintenance intervals. 3 — When closing and opening no-load. 4 — With rated control voltage applied (see Table 10). 5 — Frequency of operation (see 5.10). 6 — Requirements are based on specified maintenance intervals in accordance with Column 2. 7 — No functional part shall have been replaced prior to completion of the specified number of operations. 8 — After completion of the specified number of operations, the circuit breaker shall withstand 75% of its rated power frequency withstand voltage, and the resistance of the current carrying circuit from terminal to terminal measured with a current of at least 100 A flowing shall not be increase by more then the amount specified by the manufacturer compared to the value for the circuit breaker when new. Under these conditions, the circuit breaker is considered capable of carrying the rated continuous current, at power frequency, without injurious heating until maintained and of performing one interruption at rated short-circuit current or a related capability. After completion of this series of operations, functional part replacement and general maintenance may be necessary (see 6.2.8.3). 9 — If a short-circuit operation occurs before the completion of the listed operations, maintenance is recommended and possible functional part replacement may be necessary depending on previous duty, fault magnitude, and expected future operations.			

Table 8— TRV parameters for load current switching

Generator rating MVA	T_2 in μs	Inherent TRV	
		E_2 -crest voltage	TRV rate $\text{kV}/\mu\text{s}$
100 or less	1.08 V	0.92 V	1.0
101– 400	0.91 V	0.92 V	1.2
401– 800	0.77 V	0.92 V	1.4
801 or more	0.62 V	0.92 V	1.6
NOTES: 1 — Time delay shall be equal to or less than 1 μs . 2 — See 6.2.8.2 for test voltage values. 3 — V is the rated maximum voltage in kV.			

5.11 Capacitance current switching capability

This is a special case where the line or bus capacitance is separated from the generator circuit breaker through transformation. If this capability is required, the user should consult the manufacturer.

5.12 Out-of-phase current switching capability

This capability applies to a generator circuit breaker used for switching the connection between two parts of a three-phase system during out-of-phase conditions. The generator circuit breaker may be assigned an out-of-phase current switching rating when its out-of-phase current switching capability has been demonstrated by the tests specified in Clause 6. Other equivalent or more effective methods of test are not precluded.

5.12.1 Assigned out-of-phase current switching rating

The assigned out-of-phase current switching rating is the maximum out-of-phase current that the generator circuit breaker shall be capable of switching at an out-of-phase recovery voltage equal to that specified in 6.2.9.2 and under prescribed conditions.

5.12.2 Interrupting time for out-of-phase current switching

The interrupting time for out-of-phase current switching is equal to the rated interrupting time.

5.12.3 Inherent TRV for out-of-phase current switching

The inherent TRV for out-of-phase current switching shall be defined by an oscillatory waveshape having the TRV rate, time delay, and crest voltage (E_2) as listed in Table 9 (see also 7.3.9.2). The formula and method for determining the time-to-crest (T_2) are given in 7.3.6.3 and Figure 15.

Table 9— TRV parameters for out-of-phase current switching

Generator rating MVA	T_2 in μs	Inherent TRV	
		E_2 -crest voltage	TRV rate $\text{kV}/\mu\text{s}$
100 or less	0.89 V	2.6 V	3.3
101– 400	0.72 V	2.6 V	4.1
401– 800	0.63 V	2.6 V	4.7
801 or more	0.57 V	2.6 V	5.2
NOTES: 1 — Time delay shall be equal to or less than 1 μs . 2 — V is the rated maximum voltage in kV.			

5.13 Excitation current switching capability

The excitation current switching capability is the highest magnetizing current that a generator circuit breaker shall be required to switch at any voltage up to rated maximum voltage at power frequency without causing an overvoltage exceeding the levels agreed upon between the user and the manufacturer. This capability may be determined by tests in accordance with 6.2.11.

5.14 Rated control voltage

The rated control voltage of a generator circuit breaker is the designated voltage that is to be applied to the closing or tripping devices to close or open the generator circuit breaker (see Table 10). Other control voltages may be specified according to other national or international standards depending on the point of original installation.

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

NOTE — The control voltage is allowed to vary above and below its rated value within a specified range (see Table 10). The control voltage is measured at the terminals of the operating coils with the operating current flowing. The maximum voltage is measured at the control power terminals of the operating mechanism at no-load and the minimum voltage is measured with the maximum operating current flowing. Rated voltages and their permissible ranges for the control power supply of generator circuit breakers shall be as shown in Table 10.

Table 10— Rated control voltages and their ranges for generator circuit breakers

Direct current voltage ranges (see NOTES 1, 2, 3, 4, 7, 8) closing and auxiliary functions				Alternating current voltage ranges (see NOTES 1, 2, 3, 4, 7, 8)	
Rated voltage	Indoor circuit breakers	Outdoor circuit breakers	Tripping functions (all types)	Rated voltage (60 Hz)	Closing, tripping, and auxiliary functions
24 (see NOTE 5)	—	—	14–28	Single phase	
48 (see NOTE 5)	38–56	36–56	28–56	120	104–127 (see NOTE 6)
125	100–140	90–140	70–140	240	208–254 (see NOTE 6)
250	200–280	180–280	140–280	Three-phase	
				208 Y/120	180 Y/104–220 Y/127
				240	208–254
NOTES: 1 — Relays, motors, or other auxiliary equipment that function as part of the control for a device shall be subject to the voltage limits imposed by this standard, whether mounted at the device or at a remote location. 2 — Mechanism devices in some applications may be exposed to control voltages exceeding those specified here due to abnormal conditions, such as abrupt changes in line loading. Such applications require study, and the manufacturer should be consulted. Also, application of switchgear devices containing solid-state control exposed continuously to control voltages approaching the upper limits of ranges specified herein require specific attention, and the manufacturer should be consulted before application is made. 3 — Includes supply for pump or compressor motors. Note that rated voltages for motors and their operating ranges are covered in NEMA MG 1-1993. 4 — It is recommended that the coils of closing, auxiliary, and tripping devices that are connected continually to one dc potential should be connected to the negative control bus so as to minimize electrolytic deterioration. 5 — 24 V and 48 V tripping, closing, and auxiliary functions are recommended only when the device is located near the battery or where special effort is made to ensure the adequacy of conductors between battery and control terminals. 24 V closing is not recommended. 6 — Includes heater circuits. 7 — Extended voltage ranges apply to all closing and auxiliary devices when cold. Mechanisms utilizing standard auxiliary relays for control functions may not comply at lower extremes of voltage ranges when relay coils are hot, as after repeated or continuous operation. 8 — DC control voltage sources, such as those derived from rectified alternating current, may contain sufficient inherent ripple to modify the operation of control devices to the extent that they may not function over the entire specified voltage ranges.					

5.15 Rated mechanism fluid operating pressure

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

5.16 Nameplate markings

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

5.16.1 Circuit breaker

The following circuit breaker and operating mechanism nameplates may be combined:

- a) Manufacturer's name;
- b) Manufacturer's type designation;
- c) Manufacturer's serial number (limited to 15 letters or numbers);
- d) Year of manufacture;
- e) Power frequency (Hz);
- f) Rated continuous current (kA);
- g) Rated maximum voltage (kV);
- h) Rated full-wave impulse withstand voltage (kV peak);
- i) Rated short-circuit duty cycle;
- j) Rated short-circuit current (symmetrical, kA);
- k) DC component in percentage of the peak value of the rated short-circuit current;
- l) Close, latch and carry current (kA peak);
- m) Short-time current (kA for 1 s);
- n) Assigned out-of-phase switching current (kA);
- o) Rated interrupting time (ms);
- p) Rated insulating medium pressure or density at 20 °C;
- q) Forced cooling: kind, pressure, temperature, quantity (if applicable);
- r) Instruction book number;
- s) Renewal parts catalog;
- t) Weight of circuit breaker.

5.16.2 Operating mechanism

The following operating mechanism and circuit breaker nameplates may be combined:

- a) Manufacturer's name;
- b) Manufacturer's type designation;
- c) Manufacturer's serial number;
- d) Year of manufacture;
- e) Rated control voltage for closing coil;
- f) Rated control voltage for tripping coil;
- g) Rated control voltage for motors and pumps;
- h) Closing current;
- i) Tripping current;
- j) Current for motors and pumps;
- k) Rated fluid pressure or density at 20 °C;
- l) Instruction book number.

5.16.3 Accessories

Nameplates of all accessories shall include the following:

- a) Identification;
- b) Pertinent operating characteristics.

5.16.4 Modernization of circuit breakers

Revised nameplates shall be furnished when modernization is involved. IEEE Std C37.59-1996 [B5] may be consulted if desired.

5.16.5 Instruction and warning signs

Essential markings shall be provided for instruction and warning signs as follows:

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

6. Tests

6.1 General

The test procedure summarizes the various tests that are made on ac high-voltage generator circuit breakers, describes accepted methods used in making the tests, and specifies the tests that will demonstrate ratings under IEEE/ANSI standards. It does not preclude the use of other equivalent or more effective methods of demonstrating ratings. The tests are divided into the following classifications:

- a) Design tests;
- b) Production tests;
- c) Tests after delivery.

6.2 Design tests

The design tests described in this test procedure provide methods of demonstrating the ability of a generator circuit breaker to meet the assigned ratings when operating at rated maximum voltage and power frequency. The electrical and mechanical endurance tests shall be made with generator circuit breakers of the same type.

6.2.1 Rated continuous current-carrying tests

Rated continuous current-carrying tests demonstrate that the generator circuit breaker can carry its rated continuous current at its power frequency without exceeding any of the temperature limitations in 5.3.2.

6.2.1.1 Conditions of test

- a) The ambient temperature shall be between 10 °C and 40 °C inclusive, so that no correction factors need be applied.
- b) The circuit breaker shall be tested indoors under usual service conditions. Enclosed generator circuit breakers shall be tested in their enclosures.

If an isolated phase bus is used and is forced air-cooled, tests shall be conducted with the air quantity (m^3/sec) and air entrance temperature of the most unfavorable phase.

If there is no forced air-cooling of the isolated phase bus, the connections of the generator circuit breaker to the isolated phase bus shall be such that no significant amount of heat is conducted away from or conveyed to the generator circuit breaker during the tests. The temperature rise at the terminals of the generator circuit breaker live parts and at the encapsulation at a distance of 1 m from the generator circuit breaker terminals shall be measured. The difference in the two temperature rises shall not exceed 5 °C. The type and size of the connection between the generator circuit breaker and the isolated phase bus shall be recorded in the test report.

If other coolants are used (water, etc.), the coolant quantity and entrance temperature shall be adjusted to the prevailing rated service conditions.

Other apparatus incorporated in series and closely associated with the generator circuit breaker, such as current transformers, primary disconnecting contacts, buses, and the connections shall be mounted in their regular positions.

- c) Indoor or outdoor generator circuit breakers, which are normally installed in such a manner that other connected apparatus has no appreciable effect on the generator circuit breaker temperature, shall be tested with parts of the isolated phase bus of a size corresponding to the current rating of the generator circuit breaker, connected to the circuit breaker terminals by means of typical terminal connectors of corresponding current rating or by other means that shall be evaluated as equivalent for the specific application.
- d) In cases where the enclosure carries a current approximately equal to the rated continuous current, the return path during the test shall be the enclosure. The generator circuit breaker enclosure shall be made airtight when a bus duct forced air cooling system is part of the design.

6.2.1.2 Test procedure

Testing of generator circuit breakers often places special demands on the testing laboratories not only because of the high continuous current and short-circuit current ratings of the circuit breakers, but also because of their metal-enclosed design that allows them to be connected directly to metal-enclosed bus duct. In cases where the prescribed testing procedures will be difficult to meet, the test circuits and the test conditions shall take into account the practical application of the circuit breaker in the power system and also the conditions at the test laboratory. Three-phase generator circuit breakers shall be tested three-phase except in the following cases:

- a) Where there is no possibility of magnetic or thermal influence between poles or modular units, single-phase tests may be made on a single-pole or modular unit;
- b) Where there is no possibility of magnetic influence, but there may be thermal influence from other phases of the circuit breaker, tests may be made with single-phase current passed through the three poles in series;
- c) Where test stations have inadequate energy levels, single-phase tests may be made.

The continuous current-carrying capability of the generator circuit breaker is influenced by the temperature of the connected isolated phase bus. This situation must be taken into account when performing heat run tests. The temperatures of the isolated phase buses measured at a distance of 1 m from the generator circuit breaker shall be agreed upon by the user and the manufacturer, and shall be specified in the type test report.

When testing a generator circuit breaker with a forced-cooled rating, the continuous current-carrying capability shall be determined with and without the forced cooling. The temperatures in the current-carrying path shall be measured during these tests. If the forced-cooling systems of the bus duct and the generator circuit breaker use the same air, the phenomenon becomes complicated when the cooling air is lost. The temperature of the bus duct does not remain constant but will also rise, and this rise must be taken into account during testing. The limit of total temperature of the bus duct has to be agreed upon by the user and the manufacturer, and the practical application in the power system has to be taken into account as well in order to carry out realistic tests.

6.2.1.3 Duration of rated continuous current test

The test shall be made over a period of time sufficient for the temperature rise to stabilize. This condition is usually reached when the increase in temperature rise of that generator circuit breaker live part with the highest temperature limit does not exceed 1 °C in 1 h. The time for the entire test may be shortened by preheating the generator circuit breaker with a higher value of current, unless a measurement of thermal time constant is required.

6.2.1.4 Temperature measurement

Temperatures shall be measured by the following methods (see IEEE Std 119-1974):

- a) *Thermocouple*.
- b) *Thermometer*. This is the preferred method for ambient temperatures.