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IEEE Standard for DC (3200 V and below) Power Circuit Breakers Used in Enclosures

IEEE Power and Energy Society

Sponsored by the
Switchgear Committee

IEEE
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USA

IEEE Std C37.14™-2015
(Revision of
IEEE Std C37.14-2002)

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Approved 26 March 2015

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Abstract: Enclosed dc power circuit breakers of the stationary or drawout type of one- or two-pole construction with one or more rated maximum voltages of 300 V, 325 V, 600 V, 800 V, 1000 V, 1200 V, 1600 V, or 3200 V for applications on dc systems having nominal voltages of 250 V, 275 V, 500 V, 750 V, 850 V, 1000 V, 1500 V, or 3000 V, with general-purpose, high-speed, semi-high-speed and rectifier circuit breakers; manually or power-operated; and with or without electromechanical or electronic trip devices are covered in this standard. Service conditions, ratings, functional components, temperature limitations and classification of insulating materials, dielectric withstand voltage requirements, test procedures, and application are dealt with in this standard.

Keywords: current-limiting, direct-acting trip, general purpose, high-speed, IEEE C37.14™, impulse trip device, mining duty, reverse-current trip device, semi-high-speed or rectifier circuit breaker

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When the IEEE-SA Standards Board approved this standard on 26 March 2015, it had the following membership:

Introduction

This introduction is not part of IEEE Std C37.14™-2015, IEEE Standard for DC (3200 V and below) Power Circuit Breakers Used in Enclosures.

IEEE Std C37.14-1979 superseded IEEE Std C37.14-1969, and included recognition of the widespread use of solid-state rectifiers in industry, particularly for the traction power systems that evolved in the 1970s. It was based on known applications as well as considerations for future system development, with basic ratings and tests evolving from the classic mathematical solutions available at the time.

The revision working group for IEEE Std C37.14-1992 concluded that certain major changes were necessary. One of the changes made was the replacement of the 1200 V maximum design rating, with a new 1000 V rating. Dielectric withstand test voltages were correspondingly increased.

The revision working group maintained the peak-current multiplier of 1.65 times the sustained current, even though it can be shown that a multiplier of 1.42 can be utilized for 12-pulse rectifier designs. However, since the 6-pulse rectifier designs can produce the 1.65 peak, and because of unknown future applications with additional and/or replacement circuit breakers, it was preferred to maintain the 1.65 value.

Rated peak current was maintained as a rating because depending on the transformer/rectifier-design impedance coupled with the primary short-circuit current capacity and a lower dc inductance, it may be possible to obtain a higher peak current and/or sustained current, depending on conditions. This design combination should be investigated to prevent inadvertent application of circuit breakers above their ratings.

Some considerations that were addressed in the IEEE Std C37.14-1992 revision are as follows:

a) The need for lower rated circuit breakers for light-duty transit systems, which are generally 800 V catenary surface systems, was recognized. The power requirements are approximately one-half those of a heavy-duty transit system, with the rectifier circuit breakers requiring maximum continuous current ratings of 4000 A and feeder circuit breakers with proportionately lower ratings. Tables 12 and 12A were replaced with a new Table 12 in ANSI C37.16a, which was revised to reflect a reduced base rating of 4000 kW in order to provide a lower level of design rated circuit breakers, which allows the use of designs differing from those utilized for heavy-duty systems.

b) The question of rectifier and feeder circuit breakers being rated identically was previously addressed in the IEEE C37.14-1979 appendix, but this was now recognized and addressed in the body of the standard. Specific installation applications normally differentiate rating requirements between rectifier and feeder circuit breakers in the reverse/forward-current tripping modes, as well as in the short-time/momentary rating modes. Therefore, it is important to recognize this difference in rating structures to provide for realistic design ratings and testing.

c) The designs of high-speed and semi-high-speed circuit breakers with two different rating/test tables were conceptually reviewed, and recognition of actual field application conditions forced a concept change. A given track system should produce given short-circuit currents and circuit stored-energy at various locations regardless of circuit breaker type applied. Thus, there is a need for only two tables: one for low frequency, and one for high-frequency impedance bonds. Actually, the high-speed type circuit breaker is truly current-limiting by limiting let-through current to less than the available (prospective) peak in all cases. The semi-high-speed type is "semi-current-limiting," limiting let-through current to less than the sustained current in all cases except in allowing the maximum peak current available to flow on low-inductance (close-in) faults.

IEEE Std C37.14-1999 reestablished the 1200 V maximum design rating, and removed the 1000 V maximum design rating, while keeping the increased dielectric withstand voltages. This change recognized the existence of installed 1200 V maximum design rated systems and also maintained a more uniform division between steps of preferred maximum design ratings. IEEE Std C37.14-1999 also clarified endurance design test requirements in order to eliminate confusion on the number of electrical operations required. There is a specific requirement to perform one group of no less than 120 consecutive close-open operations during electrical endurance testing.

IEEE Std C37.14-2002 again reestablished the 1000 V maximum design rating, while also retaining the 1200 V rating, in order to recognize the recent development and use of 1000 V maximum-design rated circuit breakers. Corresponding changes were made by NEMA to Table 11 and Table 11A of ANSI C37.16-2000, which established the preferred ratings for low-voltage power circuit breakers. Dielectric withstand test voltages were also relaxed for the 800 V and 1000 V maximum design ratings so as to differentiate from the 1200 V rating.

Another consideration of IEEE Std C37.14-2002 was that any dc circuit breaker shall be capable of handling all short-circuit conditions based on the speed of operation, current interrupted, and circuit energy interrupted as verified by the short-circuit test “a,” test “b,” test “c,” and test “d” of Table 11, Table 11A, and Table 12 in ANSI C37.16-2000. It was noted for comparison that ac low-voltage power circuit breakers are required by ANSI C37.50-1989 to be tested in four (4) sequences for certification/conformance. Similar analysis of required testing resulted in the assignment of two (2) sequences in IEEE Std C37.14-1992 standard.

IEEE Std C37.14-2002 acknowledged that depending on transformer/rectifier design impedance coupled with primary short-circuit current capacity and a low dc inductance, it may be possible to obtain a higher peak current and/or sustained current under certain conditions. This design combination needs to be properly investigated and applied to prevent overrating of all circuit breakers that cannot be rated higher than the rated peak and sustained currents listed in the preferred rating tables in ANSI C37.16-2000.

The working group for the present revision undertook another significant evolution of this standard. Some of the most significant considerations were as follows:

a) General-purpose dc ratings were capped at 325 V in previous editions. In recent years, many additional dc applications have risen for voltages between 325 V and 1500 V. This revision addresses these voltages, and associated requirements, which has resulted in a number of requirements throughout the document.

b) The preferred ratings, as applicable to dc power circuit breakers, have been incorporated from IEEE Std C37.16™, as IEEE Std C37.16 will be withdrawn when IEEE Std C37.13™ and IEEE Std C37.14 have been revised to incorporate the information previously included within IEEE Std C37.16. This resulted in significant restructuring of the document:

    1) A new clause has been introduced with preferred frame sizes.

    2) Preferred ratings have been introduced to “Ratings,” eliminating the references to IEEE Std C37.16. This also led to the inclusion of requirements regarding control voltages.

    3) The application specific preferred ratings and test conditions have been added as additional annexes, with one annex for general-purpose, and an additional annex for high-speed, semi-high-speed, and rectifier circuit breakers for use in traction power applications.

    4) The preferred rating table describing the preferred overcurrent performance of high-speed, semi-high-speed, and rectifier circuit breakers for use in systems with high frequency bonds had initially been removed. High or low frequency bonds is not a rating, but an application condition, and therefore it was open-ended as to which table was to be used for conformance testing. The working group considered the low frequency bonding to be the worst case application, but due to the prevalence of circuit breakers qualified in accordance to the test circuits for high frequency bonding, both the low frequency bonding tables and the high frequency bonding tables were retained, with the additional marking requirement for inclusion of the test circuit’s load circuit time constant on the nameplate.

c) Clarifications have been made with regard to required functional components. The most significant changes are:

    1) Dependent-manual operation has been removed as a preferred construction type based on working group concerns about testing (dependence of speed of operation) and because dependent-manual operation is inconsistent with general recommended safety practices.

    2) At the request of users, it is now required that for drawout circuit breakers, primary disconnect assemblies shall be located on the drawout (removable) element for inspection and maintenance purposes. This philosophy is consistent with the ac power circuit breakers described in IEEE Std C37.13.

    3) Requirements for bonding of metallic components that are intended to be grounded for operator safety conditions have been added. Consideration has been given for applications where the intended application may or may not actually be directly connected to ground.

d) Requirements have been added for flame resistance, thermal characteristics, and tracking resistance of insulating materials both in contact and not in contact with primary voltage.

e) With the increased application of solid state trip systems in dc applications, additional testing considerations were added for solid state trip systems. A new test sequence has been added for determining resistance to electromagnetic interference, and surge withstand capability.

f) Qualification of accessory devices has been added in this version, including auxiliary switches and undervoltage trip devices.

g) With consideration that many dc power circuit breakers are third party certified, and of customer requirements for product performance test data, a new clause has been added for production monitoring and product retest requirements.

This standard represents the standard practice in the United States for dc power circuit breakers. Molded-case circuit breakers are covered by other standards, but in some instances may be able to meet the requirements of this standard.

Presently, there are no IEC standards that fully apply to dc power circuit breakers. Several IEC standards apply in part to dc power circuit breakers:

a) IEC 60947-2 [B3][a] applies to industrial circuit breakers with rated voltages which do not exceed 1000 vac or 1500 vdc.

b) Circuit breakers for traction applications are addressed by two IEC standards: IEC 60077-3 [B2] (dc circuit breakers installed on motive power units), and IEC 61992-2 [B4] (dc circuit breakers installed in fixed locations).

[a] The numbers in brackets correspond to those of the bibliography in Annex A.

Contents

IEEE Standard for DC (3200 V and below) Power Circuit Breakers Used in Enclosures

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1. Overview

1.1 Scope

This standard covers the following types, preferred ratings, and testing requirements of enclosed dc power circuit breakers:

a) Stationary or drawout type of one- or two-pole functional construction

b) Having rated maximum voltages of up to 3200 V

c) Manually operated or power operated

d) With or without overcurrent trip devices

NOTE—In this standard, the use of the term "circuit breaker" is considered to mean "enclosed dc power circuit breaker."[1]

[1] Notes in text, tables, and figures of a standard are given for information only, and do not contain requirements needed to implement the standard.

1.2 Purpose

The purpose of this document is to:

a) Establish minimum functional requirements
b) Establish preferred rating structure
c) Provide preferred ratings
d) Establish testing requirements

2. Normative references

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

ASTM D229, Standard Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation.[2]

IEC 60417, Graphical Symbols for Use on Equipment.[3]

IEEE Std 1™, IEEE Recommended Practice–General Principles for Temperature Limits in the Rating of Electrical Equipment and for the Evaluation of Electrical Insulation.[4,5]

IEEE Std 4™, IEEE Standard Techniques for High Voltage Testing.

IEEE Std C37.17™, IEEE Standard for Trip Systems for Low-Voltage (1000 V and below) AC and General Purpose (1500 V and below) DC Power Circuit Breakers.

IEEE Std C37.20.1™, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

IEEE Std C37.90.1™, IEEE Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.

IEEE Std C37.90.2™, IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

UL 94, Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances.[6]

UL 746A, Standard for Polymeric Materials – Short Term Property Evaluations.

[2] ASTM publications are available from the American Society for Testing and Materials (http://www.astm.org/).
[3] IEC publications are available from the International Electrotechnical Commission (http://www.iec.ch/). IEC publications are also available in the United States from the American National Standards Institute (http://www.ansi.org/).
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3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be referenced for terms not defined in this clause.[7]

continuity bus: A bus to which the non-current carrying metal parts from individual components are connected, but is isolated from ground.

general-purpose dc power circuit breaker: A circuit breaker that, during interruption, does not limit the current peak of the available (prospective) fault current, and may not prevent the fault current from rising to its sustained value.

heavy duty: A transit application based upon a maximum of 8000 kW of source interruption capacity.

high-speed dc power circuit breaker: A circuit breaker that, during interruption, limits the current peak to a value less than the available (prospective) fault current.

impulse trip device: A trip device that is designed to operate only by the discharge of a capacitor into its release (trip) coil and is utilized on high-speed circuit breakers to produce the tripping times that become independent of *di/dt* above the pickup threshold of the device.

impulse trip system: An indirect-acting trip system that includes an impulse trip device, sensing technology, and a means of opening the circuit breaker.

instrument shunt: A particular type of resistor designed to be connected in parallel with a measuring device, such that the voltage drop across the instrument terminals is proportional to the current in the bus bar(s) it is connected to.

light duty: A transit application based upon a maximum of 4000 kW of source interruption capacity.

mining duty general-purpose dc power circuit breaker: A general-purpose dc power circuit breaker, with preferred ratings tailored to mining applications.

rectifier dc power circuit breaker: A circuit breaker that carries the normal current output of one rectifier, and during fault conditions, functions to withstand and/or interrupt abnormal current as required.

reverse-current trip device: A trip device that operates upon reversal of the direct current in the main circuit from a predetermined direction.

semi-high-speed dc power circuit breaker: A circuit breaker that, during interruption, does not limit the current peak of the available (prospective) fault current on circuits with minimal inductance, but that does limit current to a value less than the sustained current available on higher inductance circuits.

sustained short-circuit current: A long duration overcurrent resulting from a dc fault of negligible resistance between live conductors having a difference in potential under normal operating conditions.

[7] *The IEEE Standards Dictionary Online* subscription is available at http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

4. Service conditions

A circuit breaker conforming to this standard shall be suitable for operation up to and including all of its standard ratings, providing that:

a) The temperature of the air surrounding the circuit breaker is not below −5 °C,

NOTE—When properly applied in metal-enclosed switchgear or individual enclosures, a circuit breaker should operate within the limits of ambient temperature of the air surrounding the enclosure as specified in IEEE Std C37.20.1.[8]

b) The altitude does not exceed 2000 m (6600 ft),

c) The relative humidity of the air surrounding the circuit breaker is such that there shall be no condensation on the circuit breaker parts at any time, and

d) None of the conditions listed in D.9 of Annex D prevail.

Whenever the service conditions vary from those defined in this clause, consultation between the user and manufacturer is recommended. Some of the service conditions that may require additional attention are listed in D.9.

5. Frame size

5.1 General

The designated dc power circuit breaker frame sizes are preferred, but are not to be considered restrictive.

5.2 General-purpose dc power circuit breakers

The preferred frame sizes are: 600A, 800 A, 1600 A, 2000 A, 3000 A, 4000 A, 5000 A, and 6000 A.

5.3 High-speed dc power circuit breakers

The preferred frame sizes are: 1200 A, 1600 A, 2000 A, 2500 A, 4000 A, 5000 A, 6000 A, 8000 A, 10 000 A, and 12 000 A.

5.4 Rectifier dc power circuit breakers

The preferred frame sizes are: 1200 A, 1600 A, 2000 A, 2500 A, 4000 A, 5000 A, 6000 A, 8000 A, 10 000 A, and 12 000 A.

[8] Information on normative references can be found in Clause 2.

5.5 Semi-high-speed dc power circuit breakers

The preferred frame sizes are: 1200 A, 1600 A, 2000 A, 2500 A, 4000 A, 5000 A, 6000 A, 8000 A, 10 000 A, and 12 000 A.

6. Ratings

6.1 Rating information

The rating of dc power circuit breakers is a designated limit of operating characteristics based upon the service conditions of Clause 4 and shall include the following as applicable:

a) Rated maximum voltage
b) Rated continuous current
c) Rated peak current
d) Rated short-time current
e) Rated short-circuit current
f) Rated control voltage(s)

The designated ratings are preferred, but are not to be considered restrictive.

6.2 Rated maximum voltage

The rated maximum voltage of a circuit breaker is the highest average dc voltage at which it is designed to perform.

The recurring peak voltage shall be no higher than the voltage supplied by a three-phase full-wave bridge rectifier. See D.2.

The preferred maximum voltage ratings are: 300 V, 325 V, 600 V, 800 V, 1000 V, 1200 V, 1500 V, 1600 V, and 3200 V.

6.3 Rated continuous current

The rated continuous current of a circuit breaker is the designated limit of sustained current in amperes that it shall be required to carry continuously without exceeding the temperature limitations designated in Clause 8. The rated continuous current of a circuit breaker, which is equipped with direct-acting trip devices of a smaller rating than the frame size of the circuit breaker, is determined by the rating of those devices.

The preferred continuous current ratings are: 40 A, 50 A, 70 A, 90 A, 100 A, 125 A, 150 A, 175 A, 200 A, 225 A, 300 A, 350 A, 400 A, 500 A, 600 A, 800 A, 1000 A, 1200 A, 1600 A, 2000 A, 2500 A, 3000 A, 3200 A, 4000 A, 5000 A, 6000 A, 8000 A, 10 000 A, or 12 000 A.

The continuous-current-carrying capability of some circuit breaker-trip-device combinations may be higher than the trip-device current rating.

Continuous current rating of rectifier circuit breakers shall be based on the frame size, and not limited by the use of a lower rated direct-acting trip device operating on reverse current flow only.

6.4 Rated peak current

The rated peak current of a circuit breaker is the designated limit of non-repetitive available (prospective) peak current in amperes that it shall be required to close into and still be able to open. This rating shall apply to circuit breakers having direct-acting instantaneous trip devices active in the direction of the current flow. Ratings required for each circuit breaker type are shown in Table 1.

Table 1—Overcurrent ratings

Circuit breaker type	Rated peak current	Rated short-time current	Rated short-circuit current
General-purpose dc circuit breakers (see 6.6.1)	X	X	X
General-purpose dc circuit breakers for mining operations (see 6.6.2)	X	X	X
Semi-high-speed dc circuit breakers (see 6.6.3)	X	O[a,b]	X
High-speed dc circuit breakers (see 6.6.4)	O[a]	O[a,b]	X
Rectifier dc circuit breakers (see 6.6.5)	X[c,d]	X[d]	X[c]

[a] Table entries marked with an "O" indicates that the rating is optional. Some applications may require this rating, but the rating is not generally required.

[b] Short time rating applicable when current flow is in a delayed trip or non-trip direction. Impedance between source and circuit breaker to be considered when determining if rated short time peak current applies.

[c] Rated peak current and rated short-circuit current is for n-1 rectifiers.

[d] Rated peak current and rated short-time current is for its own rectifier.

6.5 Rated short-time current

The rated short-time current of a circuit breaker is the designated limit of available (prospective) sustained current in rms amperes that it shall be required to carry for a period of 250 ms without impairing its ability to operate and perform all other ratings. This rating shall apply not only to circuit breakers that do not have direct-acting instantaneous trip devices, but also to circuit breakers with current flow in the non-active direction of polarized or unidirectional direct-acting instantaneous trip devices. Ratings required for each circuit breaker type are shown in Table 1.

This rating also requires that the circuit breaker be exposed to a test circuit with a peak current equal to at least 1.65 times the value of its available (prospective) sustained current. The peak current shall occur approximately 8 ms after the start of the current flow.

6.6 Rated short-circuit current

The rated short-circuit current of the circuit breaker is the designated limit of available (prospective) sustained rms current in amperes at which they shall be required to perform their short-circuit current duty cycle (O – 15 s – CO) at rated maximum voltage. Ratings required for particular circuit breakers are shown in Table 1.

This rating also requires that the circuit breaker be exposed to a test circuit with a peak current equal to at least 1.65 times the value of its available (prospective) sustained current. The peak current shall occur approximately 8 ms after the start of the current flow.

6.6.1 General-purpose dc circuit breakers

This design circuit breaker requires a peak, a short-time current, and a short-circuit current rating.

The preferred ratings are listed in Table B.1.

6.6.2 General-purpose dc circuit breakers for mining operations

This design circuit breaker requires a peak, a short-time current, and a short-circuit current rating.

The preferred ratings are listed in Table B.3.

6.6.3 Semi-high-speed dc circuit breakers

This design circuit breaker requires a peak current and a short-circuit current rating, and may have a short-time current rating assigned.

The preferred ratings are listed in Table C.1, Table C.2, and Table C.3.

6.6.4 High-speed dc circuit breakers

This design circuit breaker requires a short-circuit current rating and may have a short-time current rating assigned.

The preferred ratings are listed in Table C.1, Table C.2, and Table C.3.

6.6.5 Rectifier dc circuit breakers

This design circuit breaker requires a short-circuit current rating for n-1 rectifiers and a short-time current rating for its own rectifier.

The preferred ratings are listed in Table C.1, Table C.2, and Table C.3.

6.7 Rated control voltage

The rated control voltage is the voltage at which the mechanism of the circuit breaker is designed to operate when measured at the control power terminals of the operating mechanism with operating current flowing.

Operating mechanisms are designed for the rated control voltages listed with operational capability throughout the indicated voltage ranges to accommodate variations in source regulation, coupled with low charge levels, as well as high charge levels maintained with floating battery chargers. The maximum voltage is the open circuit voltage measured at the control power terminals of the operating mechanism and the minimum voltage is measured with operating current flowing.

Auxiliary control relays, motors, or other auxiliary equipment that function as a part of the control for a circuit breaker shall be subject to the voltage ranges imposed by this standard, whether mounted at the device or at the remote location.

Electrically operated motors, contactors, solenoids, valves, and the like, need not carry a nameplate voltage rating that corresponds to the nominal voltage rating shown in the table as long as these components perform the intended duty cycle (usually intermittent) in the voltage range specified.

Preferred rated control voltages and their ranges for power circuit breakers are listed in Table 2.

Table 2—Preferred rated control voltage and their ranges

Rated control voltage[g] (V)	Voltage characteristic	Closing[e] and auxiliary[b] voltage[c] (V)	Opening[f] voltage[c] (V)
24 (see NOTE 2, below)	dc (see NOTE 1, below)	19–28	14–28
48 (see NOTE 2, below)	dc (see NOTE 1, below)	38–56	28–56
125	dc (see NOTE 1, below)	100–140	70–140
250	dc (see NOTE 1, below)	200–280	140–280
120	ac (60 Hz)	104–127[a,b]	104–127[a,b,d]
208	ac (60 Hz)	180–220[b]	180–220[b]
240	ac (60 Hz)	208–254[a,b]	208–254[a,b]
220	ac (50 Hz)	190–233	190–233
208Y/120	ac (60 Hz)	180Y/104–220Y/127[b]	180Y/104–220Y/127[b]

NOTE 1—It is recommended that the coils of closing, auxiliary, and opening components that are connected continually to one dc potential should be connected to the negative control bus so as to minimize electrolytic deterioration.

NOTE 2—24 vdc and 48 vdc control voltages are recommended only when both the control components and devices are located near the battery or where special effort is made to deliver adequate control voltage at the control terminals. 24 vdc closing function is not recommended.

[a] Includes supply for pump and compressor motors.

[b] Includes heater circuits.

[c] The devices utilizing standard auxiliary relays for control may not function at lower extremes of voltage ranges when relay coils are hot, as after continuous or repeated operation.

[d] Shunt trip devices used with remote mounted ground fault relaying shall operate at 50% of the nominal voltage.

[e] Closing functions include the closing power mechanism, and the means (coils, contactors, seal-in relays, etc) to actuate the power mechanisms. Auxiliary functions include all functions except closing and opening.

[f] Opening functions are those electrical functions performed intentionally to release the stored-energy mechanism allowing the device to separate its primary contacts.

[g] Mining duty circuit breakers may require control voltage up to 325 vdc.

7. Functional components

7.1 General

The functional components required for manually and power-operated circuit breakers are listed in Table 3. Additional accessory devices may be available. The manufacturer should be consulted for specific information.

Table 3—Functional components

Functional component	General-purpose dc circuit breakers[a]		Rectifier, semi-high-speed, and high-speed dc circuit breakers
	Operating mechanism type		
	Manual	Power	
a) Direct-acting trip device(s) calibrated in accordance with IEEE Std C37.17	X[b]	X[b]	–
b) Direct-acting, instantaneous over-current release (trip) in response to forward or reverse current flow as required by application	–	–	X
c) Manual operating devices – in accordance with 7.4	X	X	X
d) Contact position indicator – in accordance with 7.3	X	X	X
e) Independent, manually operated mechanism, trip-free, with attached operating handle	X[d]	–	–
f) Power-operated mechanism, trip-free, with anti-pump feature and maintenance closing device	–	X	X
g) Shunt trip device with necessary control auxiliary switches	O[c]	X	X
h) Stored-energy indicator – in accordance with 7.5	X[d]	X[d]	X[d]
i) Locking – in accordance with 7.6	X	X	X
j) Primary disconnecting devices in accordance with 7.7	X[e]	X[e]	X[e]
k) Circuit breaker bonding connection in accordance with 7.8	X	X	X
l) Secondary disconnect device(s)	X[f]	X[f]	X[f]
m) Nameplate(s), with markings, in accordance with 7.2	X	X	X

[a] General-purpose dc circuit breakers for mining applications are not covered in this table. The manufacturer should be consulted for functional components.

[b] As required by the application. Non-automatic circuit breakers do not require overcurrent protection.

[c] Table entries marked with an "O" indicates that the function is optional. Some applications may require this functionality, but the function is not generally required.

[d] Required only on closing mechanisms that provide for stored-energy operation when the mechanism can be left in the charged position.

[e] Required for drawout circuit breakers only.

[f] Required for drawout circuit breakers with external secondary connections. An alternative method (drawout and stationary circuit breakers), such as terminal blocks or an umbilical cable, may provide the method of connection to the circuit breaker, provided that it meets the requirements for secondary disconnect devices in IEEE Std C37.20.1.

7.2 Nameplate(s)

The following information shall be given on the nameplates of all circuit breakers when applicable:

a) Manufacturer‘s name and address
b) Manufacturer‘s type of circuit breaker with “high-speed,” “semi-high-speed,” “rectifier,” “general purpose,” or “mining”
c) Frame size
d) Rated maximum voltage
e) Rated continuous current and type designation of trip devices
f) Rated peak current
g) Rated short-time current
h) Rated short-circuit current
i) Load circuit time constant (“high-speed,” “semi-high-speed,” and “rectifier” only)
j) Rated control voltage
k) Year of manufacture—by date or code
l) Identification number

7.3 Contact position indicator

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

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

As an alternate to the required mechanical contact position indicator word, a symbol may also be provided in accordance with IEC 60417.

7.4 Mechanical manual open and close buttons

Reliable mechanical manual open and close buttons, which can easily be accessed by the local operator, shall be supplied for circuit breakers with stored energy mechanisms. The following colors shall be used:

a) The close button shall have a green or black background with the word “CLOSE” in contrasting letters.
b) The open button shall have a red background with the word “OPEN” in contrasting letters.

As an alternate to the required mechanical close or open function descriptive word, a symbol may also be provided in accordance with IEC 60417.

7.5 Stored-energy indicator

When stored-energy operating mechanisms are utilized, a stored-energy indicator that can easily be read by the local operator shall be supplied. A reliable indicator with the following colors shall be used:

a) Yellow background with black lettering to indicate “CHARGED” mechanism, and
b) White background with black lettering to indicate “DISCHARGED” mechanism.

As an alternate to the required stored-energy indicator word, a symbol may also be provided in accordance with IEC 60417.

7.6 Locking

Provisions shall be made for locking the circuit breaker in the open (trip-free) position.

Other locking provisions may be provided to address specific applications.

7.7 Primary disconnecting devices

Any replaceable or renewable component(s) of the primary disconnecting device assembly shall be located on the circuit breaker.

7.8 Circuit breaker bonding connection

Circuit breakers shall be provided with a bonding connection. The bonding connection shall assure effective bonding to the enclosure for all conductive circuit breaker parts that can be touched by an operator in the normal course of his duties. In addition, the bonding connection shall also be connected to any other conductive parts of the circuit breaker that are intended to be connected to the continuity bus or to ground (as applicable).

Bonding connections shall be provided for all removable elements to provide a means such that the frame and mechanism are connected to the continuity bus or to ground (as applicable) unless the primary and secondary circuits are disconnected and the removable element is moved a safe distance.

The bonding impedance shall be not greater than 0.100 ohm between circuit breaker parts and the continuity bus or to the ground bus (as applicable) when measured with a dc current of at least 30 A.

8. Temperature limitations and classification of insulating materials

8.1 Temperature limits

The temperature limits on which the rating of circuit breakers is based are determined by the characteristics of the insulating materials used and the metals that are used in current-carrying parts and springs.

8.2 Limits of observable temperature rise

The temperature rise of the various parts of the circuit breaker above the temperature of the air surrounding the circuit breaker test enclosure, when subjected to temperature tests in accordance with this standard, shall not exceed the values given in Table 4. This table applies only to a circuit breaker having all contacts silver-surfaced, silver, silver-alloy, or equivalent, and in addition, having all conducting joints, moving or fixed, including terminal connections, either:

a) Silver-surfaced and held mechanically,

b) Brazed, welded, or silver-soldered, or

c) Fixed rigid mechanical joints surfaced with suitable material other than silver.

Table 4—Limits of temperature rise and total temperature

Component	Limit of temperature rise over air surrounding enclosure (°C)	Limit of total temperature (°C)
Class 90 insulation	50	90
Class 105 insulation	65	105
Class 130 insulation	90	130
Class 155 insulation	115	155
Class 180 insulation	140	180
Class 220 insulation	180	220
Circuit breaker contacts, conducting joints, and other current carrying parts	85[b]	125[b]
Series coils with over Class 220 insulation or base	No limit	No limit
Terminal connections[a]	55	95

[a] Terminal connection temperatures are based on terminal connections exposed to ambient air (see Figure 1).

[b] No specified limit for fuse terminals, except to minimize damage to adjacent parts.

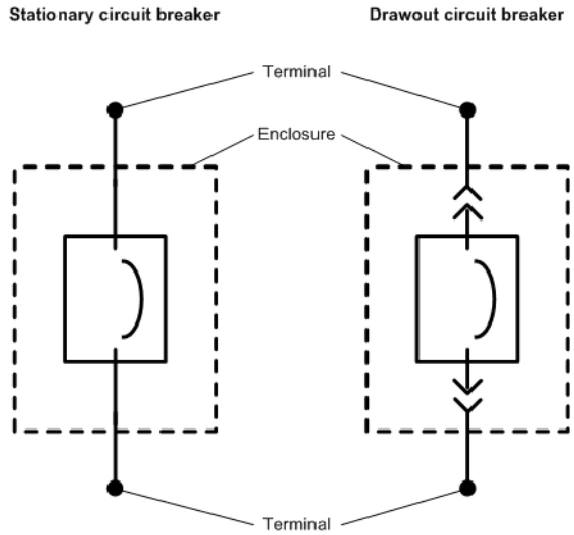

Figure 1—Circuit breaker terminals

The test enclosure is described in 10.2. Circuit breakers are not intended for operation in absence of a circuit breaker enclosure.

Terminal connections are exposed to ambient air during design sequence testing. When the circuit breaker is incorporated into switchgear, these terminals typically are enclosed within that equipment.

8.3 Classification of insulating materials

Insulating materials shall be utilized that meet the following requirements for flame and ignition resistance, thermal withstand performance, and tracking resistance.

8.3.1 Flame-resistant capabilities

The following subclauses describe the minimum flame and ignition resistance capabilities of insulating materials.

8.3.1.1 Insulating materials in contact with primary voltage parts

Insulating materials in contact with primary voltage parts shall be flame-resistant, as described in 8.3.1.1.1 or 8.3.1.1.2.

8.3.1.1.1 Sheet insulating materials

Sheet insulating materials shall not be classified as flame-resistant unless they have a minimum average ignition time of 60 s and a maximum average burning time of 500 s when tested in accordance with Method II of ASTM Std D229.

8.3.1.1.2 Molded or cast insulating materials

Molded or cast insulating materials shall not be classified as flame-resistant unless they have been rated V-0 in accordance with UL 94.

8.3.1.2 Insulating materials not in contact with primary voltage parts

Insulating materials not in contact with primary voltage parts shall be flame-resistant, as described in 8.3.1.2.1 or 8.3.1.2.2. This includes (but is not limited to) insulating materials used in items such as the contact position indicator (Table 3, item d), stored energy indicator (Table 3, item h), direct-acting trip device (Table 3, item a), manual operating device (Table 3, item c), and spring charging handle.

8.3.1.2.1 Polymeric materials

Polymeric materials that are not in contact with primary voltage parts shall have a minimum flame rating of HB in accordance with UL 746A. Polymeric materials that are closer than 0.8 mm (1/32 in) to uninsulated live primary voltage parts shall also have ignition resistance performance-level characteristics (PLCs) based on the material flame rating given in Table 5. This includes (but is not limited to) polymeric materials used in items such as the contact position indicators, stored-energy indicators, direct-acting trip device, manual trip device, and spring charging handle. Materials having values below those in Table 5 should be accepted based on successful completion of the end-product performance tests described in Clause 10.

Table 5—Required material properties

Flame rating of material	Performance Level Characteristic (PLC)			
	V-0	V-1	V-2	HB
High current arc resistance to ignition (HAI)	3	2	2	1
Hot wire ignition (HWI)	4	3	2	2
NOTE—HAI and HWI are defined in UL 746A. V-0, V-1, V-2, and HB are defined in UL 94.				

8.3.1.2.2 Non-polymeric materials

Non-polymeric materials shall be qualified to have equivalent capabilities as described in 8.3.1.2.1.

8.3.2 Thermal capabilities

The temperature limits on which circuit breaker ratings are based depend on the character of the insulating materials used.

For the purpose of establishing temperature limits, insulating materials are classified in IEEE Std 1.

8.3.3 Tracking capabilities

Insulating materials in contact with primary voltage parts shall have a comparative tracking index of PLC level 3 or lower, in accordance to UL 746A. If the material is subject to contamination by the by-products of arcing parts, it shall have a PLC level of 2 or lower.

9. Dielectric withstand voltage requirements

9.1 Test values

Circuit breakers, when tested in accordance with Clause 10, shall be capable of withstanding, without flashover, the following 60 Hz test voltages for a period of 60 s. The test voltages shall be essentially sinusoidal with a peak value equal to 1.414 times the following specified values:

a) Primary circuit of a new completely assembled circuit breaker — test voltages per Table 6.

b) Secondary control wiring [except item c), item d), and item e)] — 1500 V.

c) Motors shall be tested at their specified dielectric withstand voltage, but no less than 1000 V.

d) For undervoltage trip devices operating at a voltage above 250 V — twice rated voltage plus 1000 V.

e) Impulse trip device — 1.5 times the maximum voltage that could appear in service applied across the coil. Impulse trip coils may be tested by capacitor discharge or by applying a voltage of appropriate high frequency.

f) After interruption of a short-circuit current duty cycle and before servicing, the withstand test voltage shall be 60% of the values in item a), item b), item c), and item d).

g) Electronic circuit for high-speed trip device — 500 V. Electronic trip devices that use the negative bus for ground may be isolated before dielectric tests are performed.

h) After storage or installation in the field, a circuit breaker that has not been subjected to a short-circuit current interruption or has been serviced after interruption shall withstand 75% of the values listed in item a), item b), item c), item d), and item e).

Table 6—Voltages and insulation levels[a]

Rated maximum dc voltage (V)	rms test voltage (kV)	Reference dc withstand test voltage (kV)[b]
300	2.2	3.1
325	2.2	3.1
600	2.2	3.1
800	3.7	5.2
1000	4.6	6.5
1200	4.8	6.8
1500	5.4	7.6
1600	5.4	7.6
3200	8.8	12.4

[a] Test voltage provides for dielectric margin for open circuit or regenerative overvoltages.

[b] Tests may be conducted with dc voltage, provided that the dc voltage is no less than 1.414 times the ac rms listed voltage.

9.2 Test procedures

The dielectric test procedures and the method of voltage measurements shall be performed using the methods of IEEE Std 4.

10. Design test requirements

10.1 General

Design tests shall be made to determine the adequacy of a particular type, style, or model of a circuit breaker to meet its assigned ratings and to operate satisfactorily under the service conditions listed in Clause 4. This clause summarizes the various design tests that shall be performed on dc power circuit breakers and describes methods used in making these tests.

Design tests are made only on representative apparatus to substantiate the ratings assigned to all other apparatus of basically the same design. These tests are not intended to be used as a part of normal production. The applicable portion 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.

Additionally, manufacturers may offer accessory devices meeting the requirements described in Clause 11. Treatment of failures during any of the following test sequences described in Clause 10 or Clause 11 are addressed in Clause 12.

NOTE—These design tests should not be confused with production testing, as described in Clause 13.

10.2 Test conditions

Design tests shall be made only on representative circuit breakers to substantiate the ratings assigned to all circuit breakers of a particular design.

All tests described in 10.3, with the exception of the trip device calibration check test and the dielectric withstand voltage test, shall be made with a drawout circuit breaker in its test enclosure.

The test enclosure for a particular frame-size circuit breaker shall be the minimum-dimension enclosure with the smallest electrical spacings recommended by the manufacturer and with enclosure terminals exposed to the ambient air. The manufacturer's enclosure description shall include minimum clearance to ground, location of ventilation openings and their effective area, total enclosure dimensions, and configuration of connections to the enclosure terminals.

The conditions prevailing at the test site during tests on circuit breakers shall be those in Clause 4, except that continuous current tests and trip device calibration check tests shall be conducted at any ambient air temperature between 10 °C and 40 °C.

10.3 Schedule of design tests

Design tests on the circuit breakers shall include the following, as applicable, in the order shown in Table 7, Table 8, and Table 9. A separate design test shall be made to verify that trip devices calibrated outside the circuit breaker enclosure maintain calibration within the tolerances specified in IEEE Std C37.17 when the circuit breaker is inserted into its enclosure. For semi-high speed circuit breakers, high speed circuit breakers, and rectifier circuit breakers, consult the manufacturer for time-current characteristics and associated tolerances.

When there is a close similarity between frame-size designs or where duplicate ratings (such as short-circuit current) exist, certain tests may be combined in order to avoid duplicate testing.

Separate circuit breakers may be used for each design test sequence.

Test “a” of Annex B or Annex C is a test at maximum available short-circuit current with no intentional inductance, *L*, added to the dc test circuit. Test “b” of Annex B or test “d” of Annex C is the test at maximum inductance. Tests “b” and test “c” of Annex C are made with intermediate values of fault current and inductance.

NOTE—Test “b” in Annex B or test “d” in Annex C would emulate a fault event occurring with considerable inductance between the circuit breaker and the location of the fault. In traction power applications, this could be a fault on a track that is furthest away from the station. Test “b” and test “c” of Annex C would represent intermediate fault locations along that same length of track.

Table 7—Design sequence test 1

Test	Design Test	Circuit breaker type			
		General purpose	High-speed	Semi-high-speed	Rectifier
a)	AC dielectric withstand test (10.5) – values given in 9.1	X	X	X	X
b)	Short-time current test (10.7)	X	–	X	X
c)	Continuous current test (10.6)	X	X	X	X
d)	Load (low) current switching tests (10.11)	X	X	X	X[a]
e)	Endurance test (10.8)	X	X	X	X
f)	AC dielectric withstand test at 60% as given in item e) of 9.1	X	X	X	X

[a] If the rectifier circuit breaker is polarity sensitive, the load (low) current switching test shall be done in both directions.

Table 8—Design sequence test 2

Test	Design Test	Circuit breaker type			
		General purpose	High-speed	Semi-high-speed	Rectifier
a)	Trip device calibration check test (10.4)	X	X	X	X
b)	AC dielectric withstand test (10.5) – values given in 9.1	X	X	X	X
c)	Peak current test (10.9)	X	–	X	X
d)	Short-circuit current tests (10.10)[a]	X	X	X	X
e)	Trip device calibration check test (10.4)	X	X	X	X
f)	AC dielectric withstand test (10.5) at 60% as given in item e) of 9.1	X	X	X	X

[a] After short-circuit current test “a” of Annex B or Annex C, the circuit breaker may be rebuilt or replaced with a new one before proceeding with the subsequent short-circuit current tests. Prior to rebuilding or replacement of the test sample, the test sample shall have successfully completed trip device calibration check test (10.4), and the ac dielectric withstand test (10.5) at 60% as given in item e) of 9.1.

Table 9—Design sequence test 3

Test	Design Test	Circuit breaker type			
		General purpose	High-speed	Semi-high-speed	Rectifier
a)	Trip device calibration check test (10.4)	X	X	X	X
b)	Surge withstand test (10.12.1)	X	X	X	X
c)	Radiated electromagnetic interference test (10.12.2)	X	X	X	X
d)	Trip device calibration check test (10.4)	X	X	X	X

10.4 Trip device calibration check test

Calibration check tests shall be made as required by the test sequence to demonstrate the stability of the trip devices. For general-purpose circuit breakers, the tripping times shall be in accordance with the requirements of IEEE Std C37.17 as well as the manufacturer's time-current characteristic curve for the particular device. For semi-high speed, high speed, and rectifier circuit breakers, consult the manufacturer for time-current characteristics and associated tolerances.

Calibration check tests shall include the following, where applicable:

a) *Direct-acting trip devices*.

   1) *Long-time-delay trip elements.* The long-time-delay trip element of the direct acting trip device shall be set at the 100% long-time pickup setting and at the marked minimum time setting (band). The element shall be tested once to determine the time of operation by applying a test current equal to 300% of the 100% setting. The 300% test current shall be initiated at the test value or shall be increased from a lower value to the test value as quickly as possible, but no longer than 5 s, and shall be maintained at the test value.

   2) *Short-time-delay trip elements*. The short-time-delay trip element of the direct-acting trip device shall be set at any marked short-time-delay pickup setting and at the marked maximum time setting (band), and shall be tested once to determine the time of operation when a test current equal to 250% of that setting is applied to the trip device. The test current shall be initiated and maintained at the test value. In addition, each short-time-delay trip element shall be tested to validate that it does not trip the circuit breaker when a current less than the pickup setting (minus the allowable tolerance) is applied. This current should not be maintained for longer than 1 second.

   3) *Instantaneous trip elements*. The instantaneous trip element of the direct-acting trip device shall be set at any marked pickup setting, and shall be tested once to validate that the element operates with the allowable tolerance. Compliance with this requirement may be determined by initiating the test current at approximately 70% of the instantaneous trip setting and quickly raising the current at a uniform rate as rapidly as is consistent with an accurate determination of the trip value.

b) *Undervoltage trip device*. Check that the device trips the circuit breaker when the voltage falls within the range of 30% to 60% of rated voltage. Determine that the device shall permit the circuit breaker to be closed at 85% of rated voltage.

c) *Reverse-current trip device*. Check that the device trips the circuit breaker at its reverse-current trip setting and in the proper direction at the rated control voltage.

10.5 Dielectric withstand voltage test

Dielectric withstand tests shall be conducted on completely assembled circuit breakers including secondary control wiring at voltages, and under the following conditions. All voltages shall be measured using the methods of IEEE Std 4. The potential shall be increased gradually from zero so as to reach the required test value in 5 s to 10 s and shall be held at that value for 1 min.

The test voltages shall be essentially sinusoidal and applied with a peak value not less than 1.414 times the specified values. The frequency of the test voltage shall be 60 Hz ± 20%. If a test transformer of less than 500 VA is used, a suitable voltmeter shall be provided to measure the applied output potential directly.

10.5.1 Test voltages

The dielectric withstand test voltage shall be in accordance with 9.1.

10.5.2 Points of application of test voltage

a) With the circuit breaker in the open position, apply the test voltage to primary circuits:
   1) Between live parts, including both line and load terminals, and metal parts that are normally bonded in accordance with 7.8, and to which the control wiring has been connected, and
   2) Between line terminals and load terminals.
b) With circuit breaker in the closed position, apply the test voltage to primary circuits:
   1) Between live parts and metal parts that are normally bonded in accordance with 7.8, and to which the control wiring has been connected, and
   2) Between terminals of different poles.
c) When a circuit breaker has secondary control wiring, the secondary control wiring test voltage shall be applied between the control circuit terminals and parts that are normally bonded in accordance with 7.8, and with the circuit breaker in either the open or closed position. The terminals may be wired together with small bare wire and all intentional circuit grounds shall be disconnected. If the circuit breaker control circuit includes a motor or electronic trip device, they may be disconnected during the dielectric test on the control circuit and subsequently tested in place at the voltage specified in item c) and item f) of 9.1. If the circuit breaker control circuit includes an impulse release device that has not previously been tested, it shall be disconnected and tested in place as required by item e) of 9.1.

For the tests specified above all normally bonded metal parts shall be connected to ground (earth).

10.6 Continuous current test

The continuous current test is made to validate that circuit breakers can carry 100% of their rated continuous current under the following conditions:

a) Within a test enclosure of minimum volume,
b) With ventilation as required and documented, and
c) Without exceeding the allowable temperature limits specified in Table 4.

If offered as a component, the circuit breaker shall be equipped with an overcurrent trip device having a continuous current rating equal to the continuous current rating of the circuit breaker frame size. The overcurrent trip device shall be prevented from opening the circuit breaker. The continuous current test shall be made at no less than rated continuous current.

Table 10 —Copper conductors for use in continuous current tests[b]

Circuit breaker frame size (A)	Bus per terminal						
	Quantity	Size		Minimum Length		Bar spacing	
		in	mm	ft	m	in	mm
600/800	1	1/4 × 2	6.4 × 50.8	4	1.2	–	–
1200	1	1/4 × 4	6.4 × 102	4	1.2	–	–
1600	2	1/4 × 3	6.4 × 76.2	4	1.2	1/4	6.4
2000	2	1/4 × 4	6.4 × 102	4	1.2	1/4	6.4
2500	2	1/4 × 5	6.4 × 127	4	1.2	1/4	6.4
3000	3	1/4 × 4	6.4 × 102	4	1.2	1/4	6.4
4000	4	1/4 × 4	6.4 × 102	4	1.2	1/4	6.4
5000	4	1/4 × 5	6.4 × 127	4	1.2	1/4	6.4
6000	4	1/4 × 6	6.4 × 152	4	1.2	1/4	6.4
8000	4	1/4 × 8	6.4 × 204	4	1.2	1/4	6.4
10 000[a]	5	1/4 × 8	6.4 × 204	4	1.2	1/4	6.4
12 000[a]	6	1/4 × 8	6.4 × 204	4	1.2	1/4	6.4

[a] Two aluminum channels with legs turned outward may be used as an alternate for the 10 000 A (Channel A) and 12 000 A (Channel B) frame size. Channel sizes shall be in accordance with Table 11.

[b] Bus, bar spacing, and channel size are expressed in trade sizes (in), with approximate metric conversions.

Table 11 —Aluminum channel sizes[b]

Channel[a]	t		w		b	
	in	mm	in	mm	in	mm
A	0.31	7.9	10	250	4.62	120
B	0.50	13	10	250	4.62	120

[a] Channel dimensions per Figure 2.

[b] Bus, bar spacing, and channel size are expressed in trade sizes (in), with approximate metric conversions.

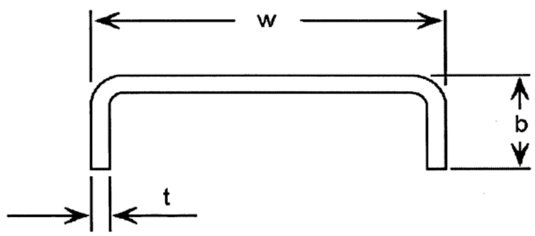

Figure 2—Channel dimensions

10.6.1 Test area conditions

Temperature tests shall be conducted in a test area that is reasonably free from drafts.

10.6.2 Measurement of ambient air temperature

The temperature of the air surrounding the enclosure (ambient) shall be determined by taking the average of the readings of three temperature-measuring devices, such as thermometers or thermocouples, placed as follows:

a) One level with the top of the structure
b) One 30 cm above the bottom of the structure
c) One midway between the two positions, position a) and position b)

All temperature-measuring devices shall be placed 30 cm (12 in) from the enclosure, not in front of ventilators, and in locations unaffected by drafts or appreciable radiation from the enclosure. When the ambient air temperature is subject to variations that might result in errors in measuring the temperature rise, the temperature-measuring devices should be immersed in a suitable liquid, such as oil in a suitable container, or reliably attached to a suitable mass of metal.

NOTE—A convenient form for such a container consists of a metal cylinder with a hole drilled partly through it. This is filled with liquid and the temperature-measuring device is placed therein. The size of the container should be at least 2.5 cm (1 in) in diameter and 5.0 cm (2 in) high.

Alternatively, thermocouples may be attached or embedded in a heat sink, usually consisting of a 5 cm × 5 cm × 0.63 cm (2 in × 2 in × 0.25 in) piece of copper.

10.6.3 Method of measuring temperature

Thermocouples shall be used to measure the temperature at the required locations on the circuit breaker.

The thermocouples, when used for measuring the temperature of insulation, shall be located on the current-carrying member or other metal part. Thermocouples used for measuring the temperature of the circuit breaker separable primary contacts shall be located approximately 13 mm (1/2 in) from the terminal or other conducting joint on the current-carrying member.

Thermocouples may be used to determine the air temperature of the areas within the circuit breaker where accessory devices are mounted as a means of establishing the required ambient temperature for separate accessory device testing.

Thermocouples shall be held in intimate contact with the conductor surface by such methods as welding, drilling, and peening or cementing.

The thermocouples on a design test shall be located in a manner so as to measure the hottest spot even though it may involve drilling holes that destroy some parts. It is recognized that thermocouples cannot be located in the actual contact point of line or point contacts without destroying the effectiveness of such line or point contacts. Measurements shall be made at junction points of insulation and conducting parts to guard against exceeding temperature limits of the insulation.

10.6.4 Duration of test

The continuous current test shall be made for such a period of time that the temperature rise of any monitored point in the circuit breaker has not changed by more than 1.0 °C over a one-hour period, with readings being taken at not greater than 30 minute intervals. The equipment is considered to have passed the test if the temperature limits in Table 4 have not been exceeded in any of the three readings.

10.6.5 Value of test current

The circuit breaker may be tested at any convenient dc voltage. Current is to be maintained at no less than the rated continuous current.

10.6.6 Conductors for use in continuous current tests

Bus bars as specified in Table 10, or Table 11 if applicable, shall be utilized for connection to the circuit breaker. If the test arrangement internal bus sizes or configurations are different from Table 10 or Table 11 (as applicable), external bus sizes or configurations equal to internal bus bars may be substituted at the option of the manufacturer. The conductors shall have a minimum external length of 1.2 m (4 ft).

10.6.7 Performance

Circuit breakers shall be considered to have passed this test if the limits of observable temperature rise specified in Table 4 are not exceeded.

10.7 Short-time current test

A short-time current test shall be made to demonstrate the rated short-time thermal withstand capability of the circuit breaker.

10.7.1 Condition of circuit breaker

The automatic trip device of the circuit breaker shall be defeated for the test.

10.7.2 Test circuit

The current that verifies the short-time rating shall be determined by calibrating the test circuit with the circuit breaker short-circuited or omitted.

The current duration shall be no less than 250 ms. The equivalent value of current for this period shall be no less than the rated short-time current. For convenience in testing, the current magnitude and current duration may be adjusted together to provide an integrated heating equivalent (I^2t) to that of the rated short time sustained current for the rated short time sustained current duration. The duration, however, shall not exceed 1.25 times the rated short time sustained current duration.

The circuit shall produce a current peak with a value no less than 1.65 times the rated short-time current approximately 8 ms after the start of current flow.

The test circuit voltage prior to the inception of current flow shall be no less than rated maximum voltage for the short time current rating being verified.

10.7.3 Test procedure

The circuit breaker shall be inserted into the test circuit and subjected to a single test while in the closed position.

10.7.4 Performance

At the end of the test, the circuit breaker shall have remained closed and be in a condition suitable to continue the test sequence given in 10.3 without repair or replacement of parts.

The circuit breaker may be serviced per item a) of D.11.2. Because current is not being interrupted, dressing of the contacts is not permitted.

10.8 Endurance tests

All endurance tests shall be performed in any order on the same circuit breaker to determine compliance with specified mechanical and electrical requirements as given in Table 12.

Servicing shall be permitted at the intervals given in Table 12.

a) Power-operated circuit breakers shall be subjected to all endurance tests.

b) Manually operated circuit breakers, which differ from the power-operated equivalent only in the means of supplying the energy to be stored, shall not be subjected to additional endurance tests.

c) Manually operated circuit breakers not having any power-operated equivalent shall be subjected to all endurance tests, except that the number of mechanical endurance operations performed shall be 50% of the number specified in Table 12.

Table 12—Endurance requirements

Circuit breaker frame size (A)	Number of make-break or close-open operations			Total
	Electrical endurance	Mechanical endurance	Between servicing[a]	
600–800	1750	9700	1750	11450
1200	500	3200	500	3700
1600	500	3200	500	3700
2000–12000	250	1100	250	1350

[a] Servicing shall consist of adjusting, cleaning, lubricating, tightening, etc. Servicing does not include replacement of parts.

10.8.1 Frequency of operation

The frequency of operation shall be one close-open (CO) operation every 2 min. At the option of the manufacturer, the frequency may be increased. During each operation, the circuit breaker shall remain closed for no less than 300 ms.

Due to the large total number of operations required, both electrical and mechanical endurance tests may be conducted in groups at the option of the manufacturer. However, during the electrical endurance testing, one group shall consist of no less than 120 consecutive operations at the frequency of operation listed previously.

10.8.2 Electrical endurance test

The electrical endurance test shall be made with no less than rated continuous current, at no less than rated maximum voltage, and at any one of the rated control voltages of Table 2.

10.8.3 Electrical endurance test circuit

The test circuit shall have an *L/R* (time constant) ratio between 0.02 s and 0.06 s with sustained current equal to no less than the continuous current rating of the circuit breaker. The load shall have negligible counter electromotive force, and for two-pole circuit breakers, shall be connected to the load side.

The open-circuit voltage of the supply circuit shall be neither less than 100% nor more than 105% of the rated maximum voltage of the circuit breaker, except that a higher voltage may be employed at the option of the manufacturer. The maximum fault current available at the circuit breaker terminals shall not exceed the rated short-circuit current of the circuit breaker.

The closed-circuit voltage, measured so as to include the circuit breaker and load, shall be no less than 80% of the rated maximum voltage for which the circuit breaker is being tested.

To detect abnormal operation during the test, such as arcing to the breaker frame, the enclosure and other normally grounded parts of circuit breakers shall be insulated from ground. A 30 A fusible element of adequate interrupting capability shall be connected between the enclosure and other normally grounded parts, and the negative terminal of the pole (or poles in the case of two-pole circuit breakers) under test for one half of the total number of electrical endurance operations listed in Table 12, and to the positive terminal of the pole (or poles) under test for the other half of the required number of electrical endurance operations. As an alternate configuration, at the manufacturer’s option, the 30 A fuse may be replaced by a No. 10 AWG copper wire. The configuration may be changed at any time during the test.

10.8.4 Mechanical endurance test

The mechanical endurance test shall be made at no load and at any one of the rated control voltages of Table 2. A circuit breaker equipped with an impulse trip device shall be operated to trip the circuit breaker at any one of the rated control voltages in Table 2 for 20% of the number of operations specified in Table 12.

10.8.5 Performance

At the conclusion of the electrical and mechanical endurance tests, the circuit breaker shall be in a condition suitable to continue the test sequence without repair or replacement of parts. The fusible element or wire specified in 10.8.3 shall not have opened.

10.9 Peak current test

The peak current test shall be made on circuit breakers to determine their ability to close on peak currents within their assigned ratings.

10.9.1 Condition of circuit breakers

When a peak current rating is assigned, the test may be made as a part of the short-circuit current test of 10.10 with the circuit adjusted to produce the required transient peak, or the test may be made on a new or rebuilt circuit breaker at the option of the manufacturer. The instantaneous trip element shall be set at its maximum setting.

10.9.2 Test circuit

The current that verifies the peak current rating shall be determined by calibrating the test circuit with the circuit breaker short-circuited or omitted.

The test circuit shall produce a peak current no less than 1.65 times the value of the rated short-time current approximately 8 ms after the start of current flow.

10.9.3 Test procedure

The circuit breaker shall be inserted in the test circuit of 10.9.2 and subjected to a single CO test. The circuit breaker shall be tripped by its direct-acting instantaneous trip element. The dielectric test shall be performed in accordance with item e) of 9.1.

10.9.4 Performance

The circuit breaker, when tested separately, shall be in the following condition:

a) *Mechanical*. It shall be substantially in the same mechanical condition as before the test; and

b) *Electrical*. It shall be capable of withstanding the dielectric test of item e) of 9.1.

10.10 Short-circuit current tests

Short-circuit current tests, as described in 10.10.1 through 10.10.8, shall be made on circuit breakers to determine their ability to close, carry, and interrupt currents within their assigned ratings. Refer to Table B.1, Table B.2, Table B.3, Table C.1, Table C.2, and Table C.3.

10.10.1 Test circuit

a) The current that verifies the short-circuit current rating shall be determined by calibrating the test circuit with the circuit breaker short-circuited or omitted.

b) The test circuit voltage prior to the inception of current flow shall be no less than rated maximum voltage for the short-circuit current rating being verified.

c) Both terminals of adjacent unused poles, and the enclosure or normally grounded frame shall be insulated from ground and connected for test “a,” or test “a” and test “c” in Table B.2, Table B.3,

Table C.1, Table C.2, and Table C.3, to the negative terminal of the pole (or poles in the case of two-pole circuit breakers) under test, and for test “b” and test “d” in Table B.2, Table B.3, Table C.1, Table C.2, and Table C.3, to the positive terminal of the pole (or poles) under test, through a 30 A fusible element of adequate interrupting capacity. As an alternate configuration, at the manufacturer’s option, the 30 A fuse may be replaced by a No. 10 AWG copper wire. The configuration may be changed at any time during the test.

d) The test circuit values for the test circuit shall be as stated in Annex B or Annex C for the following:

   1) General-purpose dc circuit breakers (Annex B)

   2) General-purpose dc circuit breakers for mining application (Annex B)

   3) Semi-high-speed dc circuit breakers (Annex C)

   4) High-speed dc circuit breakers (Annex C)

   5) Rectifier dc circuit breakers (Annex C)

e) The test circuit values listed in Table B.2, Table B.3, Table C.1, Table C.2, and Table C.3 are required for both overall guidance and as a benchmark for testing. A circuit time constant was added to Table C.1, Table C.2, and Table C.3 for reference. For test purposes, resistance, R, may be added to either the ac side or the dc side, but inductance, L, shall always be added to the dc side.

f) The test circuit shall produce a peak current no less than the peak rating of the circuit breaker in approximately 8 ms of initiation of current flow.

10.10.2 General condition of circuit breaker

The circuit breaker used for the short-circuit interrupting test shall have completed the previous applicable tests required by 10.3 with the exception of 10.9.

10.10.3 Trip device settings

The following specifies the settings of the circuit breaker direct-acting trip devices that shall exist at the time of the test:

a) Circuit breakers equipped with direct-acting instantaneous trip elements shall have the tripping elements set at the following values. The direct-acting trip devices shall have the maximum applicable coil rating.

   1) *General-purpose circuit breakers*.

      i) Circuit breakers having a continuous current rating of 2000 A and below shall have instantaneous tripping elements set to operate at maximum setting not greater than 15 times the rated continuous current of the circuit breaker.

      ii) Circuit breakers having a continuous current rating above 2000 A shall have instantaneous tripping elements set to operate at the maximum setting not greater than 12 times the rated continuous current of the circuit breaker.

   2) *Semi-high-speed and high-speed circuit breakers*. Circuit breakers equipped with direct-acting instantaneous trip elements shall be set at no greater than 4 times the circuit breaker continuous current rating, or at the maximum setting no greater than 63.2% of available short circuit sustained current, whichever is less.

   3) *Rectifier circuit breakers*. Circuit breakers should be equipped with a reverse-current tripping device set at no more than 50% of the continuous current rating.

b) Circuit breakers having only a long-time and short-time direct-acting trip element shall have the short-time tripping element set at the marked maximum pickup setting and at the maximum time delay setting.

c) Circuit breakers tripped only by a shunt trip device shall be tested so that the minimum time of short-circuit current flow shall be 250 ms.

10.10.4 Emission indicators for short-circuit current tests

An indicator consisting of three layers of cheesecloth shall be employed to detect any excessive emission of flame, hot gases, or molten particles during the short-circuit current test. The cheesecloth shall be loosely stretched on a frame at least as large as the front of the circuit breaker enclosure and shall be located 25 mm (1 in) from, and parallel to, the front door of the circuit breaker enclosure. It may be necessary to displace the cheesecloth in order to accommodate projections, such as handles.

10.10.5 Recovery voltage

The recovery voltage 8 ms after interruption shall be not less than 95% of the rated maximum voltage of the circuit breaker and shall be maintained for no less than 50 ms.

10.10.6 Short-circuit current duty cycle

Each duty cycle shall consist of an opening operation, followed by a 15-second interval, followed by a close-open operation. When an electrically operated circuit breaker is tested, it shall be operated at any one of the rated control voltages listed in Table 2.

The short-circuit duty cycle is demonstrated by the “a” tests within the short circuit test sequence. The “b” tests, “c” tests, and “d” tests are successive opening operations.

10.10.7 Test procedure

The circuit breaker shall be inserted into the calibrated test circuit and tested by one duty cycle according to the applicable test “a” of Table B.2, Table B.3, Table C.1, Table C.2, and Table C.3. Test “b,” test “c,” and test “d,” or a test to prove a short-circuit rating without a direct-acting trip device, shall be two opening operations and may be made:

a) On the same pole,

b) On the other pole of a two-pole circuit breaker,

c) On another circuit breaker, or

d) After completion of the test sequence and servicing, which includes replacement of consumable parts associated with circuit interruption, at the option of the manufacturer.

An oscillogram of the current and voltage to identify the maximum arc voltage shall be included in the measurements taken during these tests.

10.10.8 Performance

At the conclusion of this test, the circuit breaker shall be in condition to continue the applicable test sequence without repairs or replacement of parts, other than consumable parts associated with circuit interruption, and the emission indicators shall not have ignited. Scorching of the cheesecloth shall not be considered as ignition. The fusible element or wire, specified in item b) of 10.10.1, shall not have opened.

10.11 Load (low) current switching tests

Tests shall be made on all circuit breakers in a test circuit similar to the electrical endurance test requirements of 10.8.2, but at lower values of currents to determine the current at which the circuit breaker exhibits maximum arcing time (see Figure 3). Five opening tests shall be made at this current level. During each operating cycle, the circuit breaker shall be closed for a time sufficient to observe that full current is established, and then be able to open and clear the current.

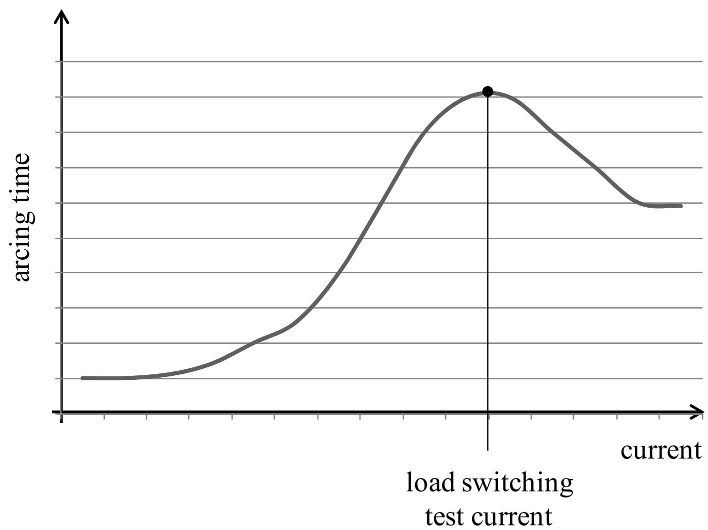

Figure 3—Load current test value

10.11.1 Performance

At the conclusion of the load (low) current switching tests, the circuit breaker shall be in a condition to continue the test sequence without repair or replacement of parts. The fusible element, specified in item b) of 10.10.1, shall not have opened.

10.12 Electromagnetic compatibility tests

The design tests specified in 10.12.1 and 10.12.2 are required to be conducted on solid state trip devices mounted on each frame size, and within its associated enclosure, as described in 10.2.

10.12.1 Surge withstand

Surge withstand capability tests, performed in accordance with IEEE Std C37.90.1.

10.12.2 Radiated electromagnetic interference

Withstand capability to radiated electromagnetic interference performed in accordance with IEEE Std C37.90.2.

11. Accessory device design tests

11.1 General

Accessory devices, as contrasted with functional components, are those devices that are not basically required for proper operation of a circuit breaker but perform a secondary or minor function as an adjunct or refinement to the primary function of the circuit breaker.

Functional components are parts of the circuit breaker required during sequential testing, as outlined in 10.3, and successful operation of those components throughout all the test sequences shall constitute sufficient proof of their design and that no further testing of them is necessary.

Available electrical accessory devices, including alarm and auxiliary switches and undervoltage trip devices, shall be operationally tested. An accessory device shall be mounted in its normal place on the circuit breaker during the applicable testing sequence when its installation or operation may affect the performance of the circuit breaker or if the circuit breaker may affect the operation of the accessory. Servicing of functional components and accessory devices by cleaning, adjusting, or repositioning the contacts shall be permitted at the intervals specified in Table 12 and in accordance with the manufacturer's established maintenance procedures.

11.2 Alarm and auxiliary switches

11.2.1 Temperature test

An alarm or auxiliary switch shall be subjected to a temperature test. With the circuit breaker and one alarm or auxiliary switch carrying not less than rated continuous current, the switch shall not attain temperatures higher than those permitted for the materials involved, in accordance with Table 4. As an alternative test procedure at the manufacturer's option, temperature tests may be conducted on alarm and auxiliary switches separately mounted in an equivalent ambient temperature determined as described in 10.6.3. When more than one alarm or auxiliary switch can be installed on a circuit breaker, the temperature test shall be performed with:

a) The maximum number of switches that can be installed.
b) Those switches that control external circuits and are normally closed when the circuit breaker is closed carrying 50% of their rated continuous current.
c) Those switches used in the internal control of a circuit breaker energized and carrying normal continuous control currents.

Rated continuous current of a switch rated only in inductive amperes is the highest rated inductive current listed.

11.2.1.1 Performance

An alarm or auxiliary switch shall meet the requirements of 10.6.4.

11.2.2 Overload test

Alarm and auxiliary switches shall be subjected to an overload test of 50 operations. The rate of operation shall be in accordance with 10.8.1. For an alarm switch, this test shall also be proof of the endurance capability of the switch. The appropriate test(s) shall be selected from Table 13.

Table 13—Overload test conditions

Type of assigned contact interrupting rating	Test conditions			
	Voltage	Current	Power factor (ac)	Type of load (dc)
None assigned	Maximum of applicable range[a]	150% continuous rating	75%–80% lagging[b]	Resistance
Noninductive	Maximum of applicable range[a]	100% assigned rating	75%–80% lagging[b]	Resistance
Inductive	Maximum of applicable range[a]	100% assigned rating	30%–35% lagging[b]	Electromagnet

[a] See Table 2.

[b] At the option of the manufacturer, the power factor may be lower.

11.2.2.1 Performance

At the conclusion of the overload test, an alarm switch shall be capable of making and breaking the test circuit without repairs or replacement of parts and shall withstand the dielectric test in item b) of 9.1.

An auxiliary switch shall be in a condition to continue with the endurance test.

11.2.3 Endurance test—auxiliary switch

An auxiliary switch that has completed the overload test shall be subjected to the number of electrical and mechanical operations specified in Table 12 and at the rate of operation given in 10.8.1. The endurance test on the auxiliary switch may be performed in conjunction with the endurance test performed on the circuit breaker. When the design of an auxiliary switch is common to more than one frame size of circuit breaker; the test may be made only in conjunction with the endurance test of the smallest frame size, at the option of the manufacturer. The appropriate test(s) shall be selected from Table 14.

Table 14—Endurance test conditions

Type of assigned contact interrupting rating	Test conditions			
	Voltage	Current	Power factor (ac)	Type of load (dc)
None assigned	Rated[a]	150% continuous rating	75%–80% lagging[b]	Resistance
Noninductive	Rated[a]	100% assigned rating	75%–80% lagging[b]	Resistance
Inductive	Rated[a]	100% assigned rating	45%–50% lagging[b]	Electromagnet

[a] See Table 2.

[b] At the option of the manufacturer, the power factor may be lower.

11.2.3.1 Performance

At the conclusion of the electrical and mechanical endurance test, the switch shall be capable of making and breaking the test circuit without repairs or replacement of parts and shall withstand the dielectric test in item b) of 9.1.

11.3 Undervoltage trip devices

11.3.1 General

The drop-out voltage range of an undervoltage trip device shall be within 30% to 60% of the voltage rating of the coil for both ac and dc applications.

An electrically reset undervoltage trip device shall pickup, or a mechanically reset undervoltage trip device shall seal in at 85% or less of the voltage rating of the coil.

11.3.2 Temperature test

With the undervoltage trip-device coil energized at the maximum voltage of the applicable range given in Table 2, the maximum temperature rise of an undervoltage trip coil shall not be higher than that permitted in Table 4 for the materials involved. As an alternate test procedure at the manufacturer's option, temperature tests may be conducted on undervoltage trip devices separately mounted in an equivalent ambient temperature determined as described in 10.6.2.

11.3.2.1 Performance

The device shall meet the requirements of 10.6.4.

11.3.3 Operation test

To determine compliance with the requirements stated in 11.3.1 tests shall be conducted as follows, starting with the circuit breaker in the tripped position.

a) Energize the undervoltage trip device to 85% of the rated voltage of the coil.

b) Close the circuit breaker.

c) Reduce the voltage to 60% of the rated voltage of the coil. The circuit breaker shall not open above this voltage.

d) Reduce voltage to 30% of the rated voltage of the coil. The circuit breaker shall open.

11.3.4 Endurance test

An undervoltage trip device shall cause the circuit breaker to trip for 10% of the electrical endurance operations and at the frequency of operation given in 10.8.1. The tests may be performed as part of the endurance test on the circuit breaker. When so tested, the number of tripping operations to be performed by the shunt trip device shall be reduced to 90%.

At the conclusion of the endurance test, the undervoltage trip device shall be capable of meeting the requirements given in 11.3.1.

11.4 Other electrical accessories

With the electrical accessory device(s) installed on the circuit breaker, the accessory device(s) shall meet the requirements for ac dielectric withstand voltage set forth in Clause 9.

11.5 Mechanical accessory devices

When accessory devices are mechanical only, such as key interlocks, mechanical interlocks, etc., which are operated relatively infrequently, normal production tests shall be the criteria for proving the operational characteristics of these devices.

12. Treatment of failures within a design test sequence

12.1 General

Should failures occur during design testing, the failures should be evaluated, and corrections should be made before retesting is done.

A design change or correction made on a circuit breaker to correct a failure in a sequence shall be evaluated for its effect on any preceding tests.

13. Production tests

13.1 General

Production tests are those tests made by the manufacturer for purposes of quality control and verification of operation, calibration, and adjustment to verify that the circuit breaker meets the design specifications and applicable standards.

All applicable production tests shall be made by the manufacturer at the factory on each circuit breaker after final assembly, except calibration, which may be performed on the individual direct-acting trip device subassembly prior to final assembly of the circuit breaker. When the latter is done, the effect of the operating time of the circuit breaker shall be recognized, and the complete assembly shall be tested to verify that the device does mechanically trip the circuit breaker.

Production tests shall include the following:

a) Calibration test.
b) Control, secondary wiring, and device check test.
c) Dielectric withstand voltage test, and
d) No-load operation test.

13.2 Calibration

Calibration tests shall include the following trip devices, where applicable.

13.2.1 Direct-acting trip devices

Direct-acting trip devices shall be subjected to the following calibration, where applicable, for conformance to published time-current-characteristic curves. Test current at any convenient voltage may be used. The following calibrations may be performed in any order deemed appropriate by the manufacturer:

a) Long-time-delay element pickup
b) Short-time-delay element pickup
c) Instantaneous element pickup
d) Time delay of long-time-delay element
e) Time delay of short-time-delay element

13.2.2 Undervoltage trip devices

Each undervoltage trip device shall be calibrated to make sure that it trips the circuit breaker when the voltage drops to a value that falls within the range of 30% to 60% of rated voltage. A test shall be made to determine that the undervoltage trip device, with 85% of rated voltage applied, shall permit the circuit breaker to be closed.

For an undervoltage trip device equipped with time delay, the time delay shall also be checked to see that it falls within the manufacturer’s specified limits and that the device resets if voltage recovers in the delay period.

13.2.3 Reverse-current trip devices

The pickup of a reverse-current trip device shall have one or more calibration marks from 5% to 50% of the continuous current rating of the circuit breaker. If control voltage is required for operation, reverse-current trip devices shall be calibrated at rated control voltage and are not required to trip when operating below 70% of rated control voltage.

A device shall withstand the upper limits of the voltage ranges as shown under the tripping functions of Table 2.

13.3 Control, secondary wiring, and devices check test

Control, secondary wiring, and devices shall be checked to make sure that all connections have been made correctly. Devices and relays, if used, shall be checked by actual operation where feasible. Those circuits for which operation is not feasible shall be checked for continuity.

13.4 Dielectric withstand voltage test

The test shall be conducted in accordance with 10.5. The duration of the test may be reduced to one second if a voltage 20% greater than that specified in 9.1 is used.

13.5 No-load operation tests

13.5.1 Power-operated circuit breakers

Power-operated circuit breakers shall be given the following no-load operation tests:

a) At minimum control voltage:
   1) Five close operations; and
   2) Five open operations.
b) At maximum control voltage:
   1) Five close operations; and
   2) Five open operations.
c) At rated control voltage:
   1) Five open operations.
   2) Five close operations.
   3) Five close-open operations with the shunt trip coil circuit electrically energized prior to giving the closing signal so that the trip coil is energized, as the circuit breaker closes, simultaneously with the closing of the auxiliary “a” contacts. During these tests, the control switch is held in the close position to demonstrate that the circuit breaker is electrically trip-free. During these tests the circuit breaker contacts are allowed to touch momentarily.
   4) Five close-open operations with the mechanical trip command applied and held prior to the application of the closing signal (mechanical or electrical). For several tests, an electric close command shall be applied and several more tests shall have a mechanical close command. During these tests the contacts shall not close, even momentarily. During these tests, the control switch is held in the close position to demonstrate that the circuit breaker is electrically trip-free.
   5) Five close-open operations with the closing signal applied electrically and held for a period of time. Following the closing command, an electrical trip signal is given. The closing signal shall be held for a sufficiently long period of time (15 s to 20 s) after the application of the trip signal. The circuit breaker shall close in response to the initial close command, shall open in response to the trip command, and shall not close again until the closing signal is first removed and then reapplied. This test is designed to demonstrate the anti-pump function.

d) If other devices, electrical or mechanical, are applicable, they shall be checked for proper functioning. Such devices shall include key interlocks, mechanical interlocks, electrical interlocks, padlocking, racking mechanism, etc. See IEEE Std C37.20.1 for interlocking requirements.

13.5.2 Manually operated circuit breakers

Manually operated circuit breakers shall be given the following no-load operational tests:

a) Five closing and five opening operations.

b) When shunt trip is used, a minimum of five openings using the shunt trip at the minimum control voltage specified for the coil.

c) Five trip-free operations.

d) If other devices, electrical or mechanical, are applicable, they shall be checked for proper functioning. Such devices shall include key interlocks, mechanical interlocks, electrical interlocks, padlocking, racking mechanism, etc. See IEEE Std C37.20.1 for interlocking requirements.

Annex A

(informative)

Bibliography

[B1] ASTM G21, Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi.

[B2] IEC 60077-3, Railway applications – Electric equipment for rolling stock – Part 3: Electrotechnical components – Rules for d.c. circuit-breakers.

[B3] IEC 60947-2, Low-voltage switchgear and controlgear – Part 2: Circuit-breakers.

[B4] IEC 61992-2, Railway applications – Fixed installations – DC switchgear – Part 2: DC circuit-breakers.

[B5] IEEE Std 693™, Recommended Practice for Seismic Design of Substations.

[B6] IEEE Std C37.81™, Guide for Seismic Qualification of Class 1E Metal-Enclosed Power Switchgear Assemblies.

[B7] NFPA 70®, National Electric Code®.[9,10]

[9] NFPA 70 is available at: http://www.nfpa.org/.

[10] NFPA, National Fire Protection Association, National Electrical Code, NFPA 70, and NEC are registered trademarks of the National Fire Protection Association.

Annex B

(normative)

Preferred ratings and test circuit parameters for general-purpose dc power circuit breakers

Table B.1—Preferred ratings and test circuit parameters for general-purpose dc power circuit breakers with or without instantaneous direct-acting trip elements

Preferred ratings						Test circuit parameters[d]	
System nominal voltage (V)	Rated maximum voltage (V)	Circuit breaker frame size (A)	Range of trip device current ratings (A)[e]	Rated peak current[a] (A)	Rated maximum short-circuit current or rated short-time current[b,c] (A)	Maximum inductance for full interrupting rating (µH)	Load circuit stored-energy factor W (kW-s)
250	300	600	40–600	41 000	25 000	160	50
		800	40–800	41 000	25 000	160	50
		1200	200–1200	83 000	50 000	80	100
		1600	200–1600	83 000	50 000	80	100
		2000	200–2000	83 000	50 000	80	100
		3000	2000–3000	124 000	75 000	50	140
		4000	4000	165 000	100 000	32	160
		5000	5000	165 000	100 000	32	160
		6000	6000	165 000	100 000	32	160
500	600	600	40–600	107 000	65 000	74	155
		800	40–800	107 000	65 000	74	155
		1200	200–1200	140 000	85 000	57	205
		1600	200–1600	140 000	85 000	57	205
		2000	200–2000	140 000	85 000	57	205
		3000	2000–3000	140 000	85 000	57	205
		4000	4000	140 000	85 000	57	205
		5000	5000	140 000	85 000	57	205
		6000	6000	140 000	85 000	57	205
750	800	600	40–600	107 000	65 000	74	155
		800	40–800	107 000	65 000	74	155
		1200	200–1200	107 000	65 000	74	155
		1600	200–1600	140 000	85 000	57	205
		2000	200–2000	140 000	85 000	57	205
		3000	2000–3000	140 000	85 000	57	205
		4000	4000	140 000	85 000	57	205
		5000	5000	140 000	85 000	57	205
		6000	6000	140 000	85 000	57	205
	1000	600	40–600	–	5000	200	2.5
		800	40–800	–	5000	200	2.5
		1200	200–1200	–	5000	200	2.5
		1600	200–1600	–	5000	200	2.5
		2000	200–2000	–	5000	200	2.5
		3000	2000–3000	–	5000	200	2.5
		4000	4000	–	5000	200	2.5
		5000	5000	–	–	–	–
		6000	6000	–	–	–	–

[a] The peak current rating is only applicable for circuit breakers for use on solid state rectifier applications.

[b] A circuit breaker with coils that have a continuous-current rating lower than those listed for the circuit breakers under a particular interrupting rating shall be given an interrupting rating corresponding to the greatest interrupting rating under which the coil rating is listed.

[c] Rated short time current is applicable only to circuit breakers without instantaneous direct-acting trip elements (short-time-delay or remote relay).

[d] If the expected inductance to the point of fault exceeds the value given, obtain the reduced interrupting rating from the formula:

$$I = 10^4 \sqrt{20W / L}$$

Where:

W is the value in column 8 in kW-s
L is the actual inductance in μH
I is in A

[e] For preferred trip-device current ratings, see 6.3. Note that the continuous-current-carrying capability of some circuit breaker-trip-device combinations may be higher than the trip-device current rating.

Table B.2—Test circuit parameters for general-purpose dc power circuit breakers

Rated maximum voltage (V)	Circuit breaker frame size (A)	Rated peak current[a] (A)	Test	Test circuit			Load circuit stored-energy factor W (kW-s)
				Current (A)	Resistance (Ω)	Inductance (µH)	
300	600–800	41 000	a	25 000	0.012	160	50
			b	9 000	0.033	1200	
	1200–2000	83 000	a	50 000	0.006	80	100
			b	13 000	0.023	1200	
	3000	124 000	a	75 000	0.004	50	140
			b	15 000	0.020	1200	
	4000	165 000	a	100 000	0.003	32	160
			b	17 000	0.018	1200	
	5000	165 000	a	100 000	0.003	32	160
			b	17 000	0.018	1200	
	6000	165 000	a	100 000	0.003	32	160
			b	17 000	0.018	1200	
600	600–800	107 000	a	65 000	0.009	74	155
	1200–2000	140 000	a	85 000	0.007	57	205
	3000	140 000	a	85 000	0.007	57	205
	4000	140 000	a	85 000	0.007	57	205
	5000	140 000	a	85 000	0.007	57	205
	6000	140 000	a	85 000	0.007	57	205
800	600–800	107 000	a	65 000	0.009	74	155
	1200–2000	140 000	a	85 000	0.007	57	205
	3000	140 000	a	85 000	0.007	57	205
	4000	140 000	a	85 000	0.007	57	205
	5000	140 000	a	85 000	0.007	57	205
	6000	140 000	a	85 000	0.007	57	205
1000	600–800	–	a	5000	0.2	200	2.5
	1200–2000	–	a	5000	0.2	200	2.5
	3000	–	a	5000	0.2	200	2.5
	4000	–	a	5000	0.2	200	2.5
	5000	–	a	5000	0.2	200	2.5
	6000	–	a	5000	0.2	200	2.5

[a] The peak current rating is only applicable for circuit breakers for use on solid-state rectifier applications.

Table B.3—Preferred ratings and test-circuit parameters for general-purpose dc power circuit breakers for mining applications[a]

System nominal voltage (V)	Rated maximum voltage (V)	Circuit breaker frame size (A)	Rated peak current[b] (A)	Rated maximum short-circuit current (A)	Test	Test circuit			Load circuit stored-energy factor W (kW-s)
						Current (A)	Resistance (Ω)	Inductance[c] (μH)	
275	325	600–2000	41 000	25 000	a	25 000	0.013	400	125
					b	9 000	0.036	3090	125
275	325	800–4000	83 000	50 000	a	50 000	0.007	200	250
					b	13 000	0.025	2950	250

[a] The above values apply to one pole of the circuit breaker.

[b] The peak current rating is only applicable for circuit breakers for use on solid state rectifier applications.

[c] If the expected inductance to the point of fault exceeds the value given, obtain the reduced interrupting rating from the formula:

$$I = 10^4 \sqrt{20W / L}$$

Where:
- W is the value in column 10 in kW-s
- L is the actual inductance in μH
- I is in A

Table B.4—Application of general-purpose dc power circuit breakers to motor starting and motor running duty[a,b]

Horsepower ratings of dc motors		Trip-device current rating (A)	Motor full-load current (A)	
120 V	240 V		Min	Max
–	7.5	40	26	35
5	10	50	32	44
7.5	15	70	45	61
10	20	90	58	78
–	–	100	64	87
–	25	125	80	109
15	30	150	96	131
20	40	175	112	152
–	–	200	128	174
25	50	225	144	196
–	60	250	160	218
30	–	300	192	261
40	75	350	224	304
–	–	400	256	348
50	100	500	320	435
60	125; 150	600	384	522
75	200	800	512	696
–	250	1000	640	870
–	300	1200	768	1044
–	350	1600	1023	1392
–	400; 500	2000	1280	1740
–	600	2500	1600	2180
–	750	3000	1920	2610
–	1000	4000	2560	3480

[a] Selection of trip-device current rating and circuit breaker frame size. The trip device rating listed is a preferred rating from 6.3. In accordance with NFPA 70 [B7][11], Article 430.110, this rating is at least 115% of the maximum motor full-load current (Column 5). With trip devices having the lowest calibration point at 80% of the trip-device rating, the requirement of Article 430.32 can be met for the minimum full-load current (Column 4). Article 430.32 requires that the trip device be set at a calibration point which does not exceed the following:

1) 140% of motor full-load current for motors with a marked service factor not less than 1.15 and for motors with a marked temperature rise not over 40 °C.

2) 130% of motor full-load current for all other motors.

Any value listed in Column 3 may also be a trip-device setting if this current can be carried continuously, and if additional adjustments allow compliance with Article 430.32.

Trip devices having a higher current rating may be used, provided that they have suitable calibration points below 80% of the trip-device rating. The circuit breaker frame size should be selected based on the applicable trip-device rating as well as the short-circuit current available. See Table B.1 for guidance.

[b] Applications to motors other than those listed. For motors with horsepower ratings not listed in this table, or for motors with other than normal speed or torque characteristics, it may be necessary to determine the full-load current by consulting with the motor manufacturer. Find the current range in column 4 and column 5 that matches the full-load current to determine the circuit breaker with the proper continuous-current rating.

[11] The numbers in brackets correspond to those of the bibliography in Annex A.

Annex C

(normative)

Preferred ratings and test circuit parameters for high-speed, semi-high-speed, and rectifier dc power circuit breakers

Table C.1—Preferred ratings and test circuit values for "heavy duty" high-speed, semi-high-speed, and rectifier dc power circuit breakers (based on transit systems with high frequency bonds)[b,c,e,f]

Circuit breaker frame size (amperes)	Test[d]	Rated maximum voltage (volts)	Semi-high-speed breaker rated peak or high-speed breaker short-circuit current (amperes)	Sustained current and semi-high-speed breaker rated short-circuit current (avg. amperes)	Rectifier or other breaker-ratings with delayed trip or in non-trip direction		Add to load circuit inductance (microhenries)	Approximate load circuit time constant (seconds)
					Rated peak current (amperes)	Rated short-circuit or short-time current (amperes)		
1200–10 000	a	300	140 000	85 000	70 000	42 500	0[a]	–
	b		–	46 200	–	–	500	0.053
	c		–	13 300	–	–	1000	0.053
	d		–	7 300	–	–	2000	0.053
1200–12 000	a	800	200 000	120 000	149 000	90 000	0[a]	–
	b		–	52 600	–	–	450	0.053
	c		–	31 200	–	–	1000	0.053
	d		–	17 900	–	–	2000	0.053
1200–8000	a	1000	158 000	96 000	119 000	72 000	0[a]	–
	b		–	50 250	–	–	500	0.053
	c		–	34 000	–	–	1000	0.053
	d		–	20 700	–	–	2000	0.053
1200–8000	a	1200	132 000	80 000	100 000	60 000	0[a]	–
	b		–	49 000	–	–	500	0.053
	c		–	35 300	–	–	1000	0.053
	d		–	22 600	–	–	2000	0.053
1200–6000	a	1600	100 000	60 000	74 000	45 000	0[a]	–
	b		–	44 300	–	–	600	0.066
	c		–	35 000	–	–	1200	0.066
	d		–	25 000	–	–	2500	0.066
1200–4000	a	3200	50 000	30 000	37 000	22 500	0[a]	–
	b		–	27 700	–	–	600	0.066
	c		–	25 600	–	–	1200	0.066
	d		–	22 300	–	–	2500	0.066

[a] No intentional inductance or resistance is to be added on the load side.

[b] Column 4, column 5, column 6, and column 7 headings delineate specific ratings for breaker types noted.

[c] The instantaneous trip element shall be set at not more than four times the circuit breaker continuous current rating or the maximum setting below 63.2% of the available sustained current (column 5).

[d] Test “a,” test “b,” test “c,” and test “d” represent simulated close-in, intermediate, and distant faults.

[e] The circuit breaker must handle all interrupting stored energy of the circuit based on the inherent speed of operation and let-through of current interrupted.

[f] For total performance at other parameters, consult the manufacturer.

Table C.2—Preferred ratings and test circuit values for "heavy duty" high-speed, semi-high-speed, and rectifier dc power circuit breakers (based on transit systems with low frequency bonds)[b,c,e,f]

Circuit breaker frame size (amperes)	Test[d]	Rated maximum voltage (volts)	Semi-high-speed breaker rated peak or high-speed breaker short-circuit current (amperes)	Sustained current and semi-high-speed breaker rated short-circuit current (avg. amperes)	Rectifier or other breaker-ratings with delayed trip or in non-trip direction		Add to load circuit inductance (microhenries)	Approximate load circuit time constant (seconds)
					Rated peak current (amperes)	Rated short-circuit or short-time current (amperes)		
1200–10 000	a	300	140 000	85 000	70 000	42 500	0[a]	–
	b		–	46 200	–	–	2000	0.21
	c		–	13 300	–	–	4000	0.21
	d		–	7 300	–	–	8000	0.21
1200–12 000	a	800	200 000	120 000	149 000	90 000	0[a]	–
	b		–	52 600	–	–	1800	0.21
	c		–	31 200	–	–	4000	0.21
	d		–	17 900	–	–	8000	0.21
1200–8000	a	1000	158 000	96 000	119 000	72 000	0[a]	–
	b		–	50 250	–	–	2000	0.21
	c		–	34 000	–	–	4000	0.21
	d		–	20 700	–	–	8000	0.21
1200–8000	a	1200	132 000	80 000	100 000	60 000	0[a]	–
	b		–	49 000	–	–	2000	0.21
	c		–	35 300	–	–	4000	0.21
	d		–	22 600	–	–	8000	0.21
1200–6000	a	1600	100 000	60 000	74 000	45 000	0[a]	–
	b		–	44 300	–	–	3250	0.34
	c		–	35 000	–	–	6400	0.34
	d		–	25 000	–	–	12 800	0.34
1200–4000	a	3200	50 000	30 000	37 000	22 500	0[a]	–
	b		–	27 700	–	–	3250	0.34
	c		–	25 600	–	–	6400	0.34
	d		–	22 300	–	–	12 800	0.34

[a] No intentional inductance or resistance is to be added on the load side.

[b] Column 4, column 5, column 6, and column 7 headings delineate specific ratings for breaker types noted.

[c] The instantaneous trip element shall be set at not more than four times the circuit breaker continuous current rating or the maximum setting below 63.2% of the available sustained current (column 5).

[d] Test “a,” test “b,” test “c,” and test “d” represent simulated close-in, intermediate, and distant faults.

[e] The circuit breaker must handle all interrupting stored energy of the circuit based on the inherent speed of operation and let-through of current interrupted.

[f] For total performance at other parameters, consult the manufacturer.

Table C.3—Preferred ratings and test circuit values for "light duty" high-speed, semi-high-speed, and rectifier dc power circuit breakers (Based on transit systems with high frequency impedance bonds)[b,c,e,f]

Circuit breaker frame size (amperes)	Test[d]	Rated maximum voltage (volts)	Semi-high-speed breaker rated peak or high-speed breaker short-circuit current (amperes)	Sustained current and semi-high-speed breaker rated short-circuit current (avg. amperes)	Rectifier or other breaker-ratings with delayed trip or in non-trip direction		Add to load circuit inductance (microhenries)	Approximate load circuit time constant (seconds)
					Rated peak current (amperes)	Rated short-circuit or short-time current (amperes)		
1200–6000	a	800	100 000	60 000	74 000	45 000	0[a]	–
	b		–	35 100	–	–	600	0.066
	c		–	24 800	–	–	1250	0.066
	d		–	15 700	–	–	2500	0.066
1200–6000	a	1200	66 000	40 000	50 000	30 000	0[a]	–
	b		–	30 700	–	–	600	0.066
	c		–	24 500	–	–	1250	0.066
	d		–	17 600	–	–	2500	0.066

[a] No intentional inductance or resistance is to be added on the load side.

[b] Column 4, column 5, column 6, and column 7 headings delineate specific ratings for breaker types noted.

[c] The instantaneous trip element shall be set at not more than four times the circuit breaker continuous current rating or the maximum setting below 63.2% of the available sustained current (column 5).

[d] Test "a," test "b," test "c," and test "d" represent simulated close-in, intermediate, and distant faults.

[e] The circuit breaker must handle all interrupting stored energy of the circuit based on the inherent speed of operation and let-through of current interrupted.

[f] For total performance at other parameters, consult the manufacturer.

Annex D

(informative)

Application guide

D.1 Overview

This guide covers the application of power circuit breakers on dc systems and applies to circuit breakers rated in accordance with Clause 6.

Other applicable codes, such as NEC, should also be consulted.

Circuit breakers should be applied within their assigned voltage(s), continuous current, short-time current, and short-circuit ratings as defined in this standard with proper consideration given to the service conditions stated in Clause 4. They should be selected to provide the protection required by the other components of the circuit. For other applications not covered by this standard, the manufacturer should be consulted.

D.2 Voltage

The voltage of the system to which circuit breakers are applied, including any variation except that caused by short-circuit current interruption, should not exceed the rated maximum voltage of the applied circuit breaker. For applications at voltages between those listed in 6.2, a circuit breaker having the next higher rated maximum voltage should be selected.

Circuit breaker dielectric ratings have been selected to provide a margin for open-circuit voltage and voltages from regeneration. Normal operational voltages are less than maximum design levels and, during short-circuit, the actual voltage is reduced to measurably less than operational. The laboratory tests are always more severe than actual field events.

D.3 Continuous current

D.3.1 General

The circuit breaker should be applied to a circuit having a maximum continuous load current no greater than the continuous current rating of the circuit breaker.

Direct-acting trip devices should be selected so as to provide the trip settings required and should have a continuous current rating equal to or greater than the maximum continuous current rating of the circuit to which they are to be applied. When overload current of 1-hour duration or more can be expected, the circuit breaker continuous current rating should be no less than the overload current expected in the circuit. When overloads repeat frequently or occur on a regular repeating cycle, the heating effects should be considered on an equivalent rms current basis.

Pickup settings of the direct-acting trip device elements are provided above the continuous current rating of these trip devices for the purpose of maintaining circuit continuity during momentary overload. However, the trip device and the circuit breaker frame combination cannot be expected to carry continuously more current than the assigned continuous current rating.

Certain dc equipment, such as semiconductor rectifiers, have specified overload current ratings. Overload current of 200% of circuit breaker continuous current rating for 5 min and 300% for 1 min can be ignored when selecting the circuit breaker continuous current rating.

D.3.2 Forced-air cooling

It is recognized that a circuit breaker may continuously carry current in excess of its continuous current rating if the circuit breaker is forced-air cooled by means such as a blower or a fan. The manufacturer of the assembly in which the circuit breaker and forced-air cooling means are to be installed should be contacted to obtain information about the increased capability. Suitable protection schemes should be utilized to assure that excessive temperatures do not result from air filters becoming clogged or from failure of the forced-air cooling means to provide sufficient cooling. Settings of direct-acting trip devices should also be reevaluated in this circumstance.

D.3.3 Lower than 40 °C ambient temperature

If the ambient temperature outside the circuit breaker enclosure is maintained at less than 40 °C, the circuit breaker may be capable of carrying current in excess of its continuous current rating. However, since the long-time performance and useful life of the circuit breaker may be affected by such an increase in continuous current, the circuit breaker manufacturer should be consulted concerning any increased capability. Settings of direct-acting trip devices should be reevaluated in this circumstance.

D.3.4 Installation location

The installation of the circuit breaker shall consider the cumulative loading and minimal enclosure size. See IEEE Std C37.20.1.

D.4 Short-circuit current

D.4.1 General

Application of circuit breakers for short-circuit protection of dc circuits should consider the characteristics of the short-circuit current, the energy stored in circuit inductance, the protection required by the system components, and the ratings of the circuit breaker with the method of tripping selected.

D.4.2 Characteristics of short-circuit current

Current associated with a short-circuit in dc circuits that include dc rotating machines, batteries or electrolytic cells, or combinations of these, rises exponentially with time until the maximum magnitude of current is reached. The current-time characteristic of short-circuit current in dc circuits where current is derived by rectification of ac energy (semiconductor power rectifiers) is similar to short-circuit current in ac circuits; that is, the current magnitude rises to a maximum offset peak value in approximately one-half cycle of the ac frequency, and successive peak values decay exponentially to the sustained value.

D.4.3 Determination of short-circuit current

The available short-circuit current, including the maximum rate-of-rise, the maximum peak value, and the sustained value, should be determined by taking into account all resistance and inductance of the dc and ac circuits, including the source, but not including the resistance or inductance of the circuit breaker under consideration. Sources of short-circuit current include not only generation and conversion equipment, but also all simultaneously connected motors, batteries, and electrolytic cells.

For rectifier circuit breakers, the short-circuit current available in the forward direction (fault on circuit breaker load terminal) is supplied solely by the rectifier of the circuit breaker. For a rare fault located between the circuit breaker and the rectifier, the available short-circuit current would be equal to that produced by the total number of rectifiers connected to the bus minus one (n-1).

D.4.4 System stored-energy

During interruption of short-circuit current, the circuit breaker should dissipate most of the energy stored in the circuit inductance. General-purpose and mining circuit breakers should be applied when the maximum energy stored in the circuit inductance is no greater than the stored-energy factor of the circuit breaker as listed in Table B.1, Table B.2, and Table B.3. No stored-energy factor is listed in Annex C for high-speed, semi-high-speed, and rectifier circuit breakers, since the arc energy interrupted is dependent upon current let-through as determined by the operational characteristics of the circuit breaker. However, stored-energy factors for the specific test circuits may be obtained from the manufacturer.

D.4.5 Instantaneous direct-acting trip devices

Circuit breakers with instantaneous direct-acting trip devices should be applied to circuits that have prospective transient offset short-circuit currents no greater than the peak current rating of the circuit breaker, and for other than high-speed circuit breakers, prospective current after transient decay no greater than the short-circuit current rating of the circuit breaker.

D.4.6 Delayed trip devices

Circuit breakers without instantaneous direct-acting trip devices should be applied to circuits that have the following:

a) Prospective transient offset short-circuit current no greater than the peak current rating of the circuit breaker

b) Prospective sustained short-circuit current averaged over 250 ms after start of short-circuit current no greater than the short-time current rating of the circuit breaker, and

c) Prospective current after transient decay no greater than the short-circuit current rating (with delayed trip) of the circuit breaker. Circuit breaker tripping should not be delayed more than 250 ms for prospective sustained short-circuit current, averaged over 250 ms, equal to the short-time current rating of the circuit breaker.

D.4.7 Polarized trip devices

In special applications such as rectifier circuit breakers, the circuit breaker may be provided with direct-acting trip devices polarized to function only on reverse current for rectifier short-circuit and may be provided with delayed trip devices to coordinate with feeder circuit breakers for feeder short circuits. Such circuit breakers should be applied in accordance with D.4.5 for short-circuit current in the active direction of the polarized instantaneous trip device, and should be applied in accordance with D.4.6 for short-circuit current in the non-active direction of the instantaneous trip device.

Reverse trip for rectifier circuit breakers need only have a fixed pickup setting not exceeding 50% of the circuit breaker frame size. A setting of 500 A is often used.

D.4.8 Maximum trip settings

General-purpose and mining circuit breakers with instantaneous trip elements and continuous current rating of 2000 A and below should be applied with a trip device set at not more than 15 times the continuous current rating of the circuit breaker. General-purpose and mining circuit breakers with instantaneous trip elements and continuous current rating greater than 2000 A should be applied with a trip device set at no more than 12 times the continuous current rating of the circuit breaker.

High-speed and semi-high-speed circuit breakers with instantaneous trip elements should be applied with a trip device set at not more than four times the continuous current rating of the circuit breaker. For applications where a higher trip setting may be required, the manufacturer should be consulted.

D.4.9 Short-circuit current duty cycle application

The applicable duty cycle for dc circuit breakers at maximum current, test “a” of Table B.2, Table B.3, Table C.1, Table C.2, and Table C.3 consists of an opening operation followed after a 15 second interval by a close-open operation (O – 15 s – CO).

When a circuit breaker has performed its short-circuit current duty cycle at or near its maximum short-circuit current or maximum circuit energy level, the circuit breaker should be removed from service and inspected, cleaned, dielectrically tested, and if necessary, otherwise maintained before being returned to service. When dielectric withstand levels have been lowered to 60% by surface deposits of interruption products, removal of these products by cleaning should permit the 75% dielectric test values of item g) of 9.1 to be met.

Most circuit breakers used on transit systems, as well as those used in other applications, are applied in conjunction with load-measuring relaying. In such cases, where the circuit breaker is not required to close in on a fault current, a manufacturer may offer a supplemental short-circuit current rating based on one or more opening operations.

D.4.10 Effect of remote protective devices

Circuit breakers not equipped with direct-acting trip elements should be applied in accordance with their assigned short-time current ratings. The remote protective devices should be set such that the total clearing time at the short-time current rating of 250 ms duration is not exceeded. Protection of the circuit breaker afforded by the remote protective device should be equivalent to that provided for the circuit breaker by a direct-acting trip device. The manufacturer should be contacted for the circuit breaker operating time characteristics.

D.5 Application of direct current instrument shunts

The instrument shunt should be sized to 1.5 times the continuous current rating of the circuit breaker. Over or under sizing the instrument shunts may affect the accuracy of the measurements.

The standard instrument shunt voltage output at the instrument terminals is typically 50 mV or 100 mV at rated current. For instrument shunts rated up to 1000 A, the rated accuracy is typically 0.33 percent. For instrument shunts rated above 1000 A, the rated accuracy is typically 0.5 percent. The shunt manufacturer should be contacted for specific output and output accuracy.

Installation location may also affect the accuracy of the instrument shunts. When installing shunts in a bus structure, they should be placed in a horizontal bus run with the leaves mounted in a vertical plane, with the shunts being so located in the bus structure as not to be immediately adjacent to right-angle turns in the bus.

In addition, they should not be mounted in immediate proximity of devices that are likely to produce heat that would raise the temperature of the shunt unevenly and they should never be mounted vertically as the upper terminal would be heated by rising air currents (resulting in a thermal gradient across the shunt). All shunt connection surfaces should be clean and the connections made tight.

For current ratings higher than 10 000 A, two lower rated instrument shunts of equal current rating may be connected in parallel. Separate leads of equal length and size (wire diameter) shall be connected between the instrument terminals of each shunt and the terminals of the measuring device.

Instrument shunts shall be installed so that they shall not be damaged by thermal expansion forces in the connecting bus bars, or short circuit forces. Where more than one bus bar is to be connected to each end of single-terminal shunts, the bars should be distributed as equally as possible on each side of the shunt terminals.

D.6 Limiting transient arc voltage

During interruption, the circuit breaker arc voltage can exceed the voltage that certain types of apparatus such as rotating machines or semiconductor rectifiers can withstand. For a particular circuit breaker design, the magnitude of overvoltage varies with the amount of inductance in the fault circuit, and this factor should be considered in any application.

The value of ($4E/3 + 600$), where E is the rated voltage in V of motors or generators, is an indication of the peak voltage that rotating equipment can withstand. Semiconductor power rectifiers vary in their ability to withstand voltage surges, and this ability should be considered for each application.

When the arc voltage characteristics of the circuit breaker are not satisfactory for a given application, voltage-limiting resistors may be used to reduce insulation or flashover problems. When resistors are used in parallel with circuit breaker contacts, another circuit breaker, preferably at opposite polarity, is required to open the circuit completely.

D.7 Application of circuit breakers for selective tripping

D.7.1 General

Where continuity of service is desired, selective tripping arrangements should be used. A selective tripping arrangement is the application of circuit breakers in series so that, of the circuit breakers carrying overcurrent, the one electrically nearest the overcurrent condition should trip to isolate this circuit condition.

D.7.2 Phase-selective tripping arrangements

When circuit breakers are applied to circuits in selective tripping arrangements, the requirements of D.7.2.1, D.7.2.2, and D.7.2.3 should be observed.

D.7.2.1 Short-circuit current ratings

Each circuit breaker should have an assigned short-circuit current rating equal to, or greater than, the available short-circuit current at the point of its application.

D.7.2.2 Time-current characteristics

The time-current characteristics of each circuit breaker, at all values of available overcurrent, should be sufficient to allow that the circuit breaker nearest the cause of the overcurrent should open to isolate this circuit condition. Those nearest the source of power should remain closed and continue to carry the remaining load current. The published time-current characteristics of a circuit breaker conforming to this standard should clearly show the minimum and maximum clearing time of the device.

It should be noted that continuity of service requires coordination of the circuit breakers with the rest of the system. For example, circuit breakers on the dc side of a rectifier should properly coordinate with relays or fuses on the ac side of the rectifier, as well as with downstream protective devices.

Some trip systems may respond to rate-of-rise, thermal memory, or other quantities which allow the device to enter pickup (begin timing) at levels below the setting in order to reduce time delays or interruption time. Such features can inhibit selective coordination unless they are properly taken into account when performing a coordination study. Manufacturers should clearly document these modifiers in published time-current characteristics.

D.7.2.3 Short-time-delay phase trip elements

Each circuit breaker, except the one farthest from the source of power, should be equipped with short-time-delay phase trip elements. The circuit breaker farthest from the source of power should normally be equipped with instantaneous trip elements if selective coordination with downstream devices is possible.

D.7.2.4 Time-current characteristics coordination

To permit the circuit breaker in any selective arrangement function to meet these requirements, the time-current characteristics of associated circuit breakers should not overlap. To accomplish this, the pickup settings and time-delay adjustments of all trip elements should be properly selected.

D.8 Application limitations relating to mechanism types

D.8.1 General

Power circuit breakers should be limited to applications that do not present a safety hazard to operating personnel standing directly in front of them. For this reason, power circuit breakers are segregated into two classifications according to the type of closing mechanism. The operating mechanisms provide for two ways of operation in closing—power and independent-manual.

D.8.2 Power operation

Circuit breakers with operating mechanisms that provide for power operation in closing may be used up to the applicable short-circuit current rating of the circuit breaker.

D.8.3 Independent-manual operation

Circuit breakers with operating mechanisms that provide for independent-manual operation in closing may be used up to the applicable short-circuit current rating of the circuit breaker.

D.9 Service conditions affecting circuit breaker applications

D.9.1 General

Certain service conditions may require unusual construction or operation, and these should be brought to the attention of those responsible for the application, manufacturing, and operation of the circuit breaker. Wherever possible, steps such as inclusion of heaters or placement in controlled-atmosphere areas should be taken at the site of the installation to nullify the deleterious effects of the following:

a) Extreme altitude,
b) Exposure to damaging fumes or vapors; excessive or abrasive dust; explosive mixture of dust or gases, steam, salt spray, excessive moisture, or dripping water; or other similar conditions,
c) Exposure to abnormal vibration, shocks, or tilting,
d) Exposure to excessively high or low temperature,
e) Exposure to unusual transportation or storage conditions,
f) Exposure to extreme solar temperatures,
g) Unusual operating duty, frequency of operation, or difficulty of maintenance, and/or
h) Temperature of circuit breaker parts that falls below the dew point of the surrounding air, causing moisture condensation on the parts.

D.9.2 Altitude correction

Circuit breakers, when applied at altitudes greater than 2000 m, should have their dielectric withstand, continuous current, and rated maximum voltage ratings multiplied by the correction factors in Table D.1 to obtain values at which the application is made. The peak and short-time current ratings are not affected by altitude.

Table D.1—Altitude correction factors

Altitude (m)	Rating correction factor[a]	
	Continuous current	Voltage
2000 (and below)	1.00	1.00
2600	0.99	0.95
3900	0.96	0.80

[a] Values for intermediate altitudes may be derived by linear interpolation.

D.9.3 Abnormal temperatures

The use of circuit breakers in an ambient temperature lower than −5 °C or higher than 40 °C shall be considered as unusual.

D.9.3.1 Abnormally cold temperatures

Temperatures below −30 °C create a harsh environment for circuit breakers. Many users in colder climates routinely experience −50 °C temperatures. The following should be considered for low ambient temperature environments:

a) Operating times may be slower than rated times (typically 1 ms to 3 ms slower than typical).

b) Humidity can cause condensation, and reduction of dielectric properties.

c) Embrittlement of plastics, composites, and metals may lead to failure during circuit breaker operation.

d) Lubricants may be required to prevent extreme sluggishness.

e) Heaters for the mechanism may be required.

D.9.3.2 Abnormally warm temperatures

Load current-carrying capabilities when ambient air temperature is greater than 40 °C, on which continuous ratings in 6.3 are based, the allowable continuous current can be calculated by the following formula:

$$I_a = I_r \left\{ \frac{\theta_{\max} - \theta_a}{\theta_r} \right\}^{1/2}$$

where

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

I_r is the rated continuous current, A, on the basis of 40 °C ambient

θ_{max} is the allowable hottest-spot total temperature

θ_a is the actual ambient temperature expected (between 40 °C and 60 °C), °C

θ_r is the 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. The exponent value of 1/2 observed in the formula has been found to be generally valid for circuit breakers applied within LV switchgear, and is therefore used in this standard.

The construction features of LV switchgear dictate the appropriate values of θ_r and θ_{max}. The major components have several different temperature limits specified in the standards or clauses of this standard as listed in Table 4.

D.9.4 Exposure to excessive dust or abrasive, magnetic, or metallic dust

If a circuit breaker is used in special areas where it comes to excessive dust containing abrasive magnetic or metallic particles the following considerations should be taken into account.

a) Totally enclosed nonventilated equipment or compartments may be necessary.

b) Where current-carrying equipment designed for ventilated operation is enclosed in a non-ventilated compartment, derating may be necessary.

c) Installation in a positive pressure room with appropriate filtration equipment may be necessary.

D.9.5 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.

D.9.6 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 circuit 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 [B1] and IEEE Std C37.81 [B6] as necessary for indoor drawout and outdoor circuit breakers. The user should specify the operational requirements, including whether functionality shall be maintained.

a) Before and after the seismic event, or

b) Before, during, and after the seismic event.

D.9.7 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.

D.9.8 Exposure to damaging fumes, vapor, steam, oil vapors, and salt air

Provision may be necessary to avoid condensation on all electrical insulation and current-carrying parts. In cases where particular exposure represents a hazard to insulation integrity and/or corrosion of metallic parts, special maintenance requirements may be necessary. Materials resistant to fungus growth may also be required. Condensation may also be mitigated with the inclusion of dehumidifying equipment and heaters in circuit breaker compartments.

When circuit breakers are anticipated of being subject to these types of conditions, installation in a positive pressure room system with appropriate filtration equipment is advisable, when possible.

D.9.9 Exposure to humid climates

When circuit breakers are installed in locations with exposure to hot and humid climates, they should be made fungus-resistant by the following modifications:

a) Heaters in quantity and sufficient rating to minimize condensation within the circuit breaker compartment should be furnished.

b) Secondary wiring that is not inherently fungus-resistant should have fungus-resistant coating applied. Secondary wiring that has fungus-resistant insulation should not require further treatment.

c) All impregnated coils should be given an external treatment with fungus-resistant coating. Encapsulated coils that are inherently fungus-resistant should not require further treatment.

d) Coatings or paints such as alkyd enamels having a fungus and rust-resistant property should be used.

e) Insulation that is not inherently fungus-resistant should have fungus-resistant coating applied. Insulation within circuit breakers that is inherently fungus-resistant should not require further treatment. Fungus-resistant coatings should not be applied where they may interfere with proper operation of the circuit breaker. In such cases, the part should be inherently fungus-resistant. These coatings should not reduce the dielectric or flame-resistant properties.

f) The fungus-resistance of materials should be determined in accordance with ASTM G21 [B1]. Materials to be classified as fungus-resistant should have a rating not greater than 1.

g) Materials that are made fungus-resistant by means of a coating should have the coating reapplied at periodic intervals.

D.10 Application of general-purpose dc power circuit breakers to motor starting and running duty

Table B.4 applies to general-purpose dc circuit breakers whose direct-acting trip devices are calibrated at either approximately 80% to 160% or 80% to 120% of their continuous current rating.

The horsepower ratings apply to all motors having full load current ratings between the minimum and maximum currents shown in Table B.4. The circuit breaker rating should be no less than 115% of the maximum full-load current of the motor. The 80% trip setting is equal to no more than 125% of the minimum full-load motor current shown in Table B.4.

D.11 Repetitive duty operations and normal maintenance

D.11.1 General

Power-operated circuit breakers, when operating under service conditions listed in Clause 4, can be expected to operate the number of times specified in Table D.2.

These numbers of operation apply to all parts of a circuit breaker that function during normal operation. They do not apply to other parts, such as direct-acting trip devices, that function only during infrequent abnormal circuit conditions.

D.11.2 Operating conditions

The following items, referenced in the column headings of Table D.2, are conditions relating to the number of required operations:

a) Servicing consists of adjusting, cleaning, lubricating, tightening, etc., as recommended by the manufacturer. When current is interrupted, dressing of contacts may be required as well. The operations listed are on the basis of servicing at intervals of one year or less.

b) When closing and opening no load.

c) With rated control voltage applied.

d) Frequency of operation not to exceed 20 operations in 10 min or 30 operations in 1 hour. Rectifiers or other auxiliary devices may further limit the frequency of operation.

e) Servicing at no greater intervals than shown in column 2 in Table D.2.

f) No functional parts should have been replaced during the listed operations.

g) The circuit breaker should be in a condition to carry its rated continuous current at rated maximum voltage and perform at least one opening operation at rated short-circuit current. After completion of this series of operations, functional part replacement and general servicing may be necessary.

h) When closing and opening current up to the continuous current rating of the circuit breaker at voltages up to the rated maximum voltage and with an *L/R* ratio between 0.02 and 0.06 s, and

i) If a fault operation occurs before the completion of the listed operations, servicing is recommended and functional part replacements may be necessary, depending on previous accumulated duty, fault magnitude, and expected future operations.

Table D.2—Application limits relating to repetitive duty and normal maintenance

Circuit breaker frame size (A)	Number of make-break or close-open operations		
	Between servicing[a]	No-load mechanical[b]	Rated continuous current switching[c]
600–800	1750	9700	1750
1200	500	3200	500
1600	500	3200	500
2000–12 000	250	1100	250

[a] See D.11.2, item a

[b] See D.11.2, item a, item b, item c, item d, item e, item f, and item g

[c] See D.11.2, item a, item b, item c, item d, item e, item f, item g, item h, and item i

D.12 Application of circuit breakers without enclosures

Application of circuit breakers without enclosures is not recommended. While it is recognized that there are existing installations of circuit breakers without enclosures, limited-access areas surrounding the circuit breakers should be established and qualified personnel in these areas should exercise extreme caution at all times.

Annex E

(informative)

Traction power technical application guide

Technical detail is provided here to guide those who apply and use traction power circuit breakers.

Circuit breakers should be applied within their assigned rated maximum voltage, continuous current, short-time current, peak current, and short-circuit current ratings as defined in this standard with proper consideration given to service conditions, stated in Clause 4, and the energy dissipation ability of the arc chute.

In the application of dc circuit breakers on transit systems, several important criteria need to be taken into account. These are system voltage, kilowatt rating and number of rectifiers in each substation, magnitude of short-circuit currents and their energy content, effect of in-feed of current from remote substations during short-circuit conditions, regeneration, and load-measuring automatic reclosing.

System voltage and limitation of a total substation to 8000 kW are normally sufficient to size the dc circuit breakers relative to continuous current ratings. Regarding short-circuit currents, system parameters may require the addition of other protective devices to help detect and initiate fault interruption.

Rectifier systems larger than 8000 kW, or with system design parameters combining low transformer impedance, high primary short-circuit current, and low dc inductance–can produce higher short-circuit currents than the circuit breakers covered by this standard can handle. Special application requirements may have to be considered such as: a) assume no fault can occur within the rectifier-dc switchgear since the negative is remote, and b) assume no fault can occur between the terminals of the feeder circuit breaker and the track since the negative is remote. These considerations can result in lower available peak and sustained currents due to the added resistance and inductance.

For close-in faults, the short-circuit magnitude can be high just from the contribution of the local substation. If the adjacent substation(s) is (are) close, then there could be sufficient in-feed contribution so that the total current interrupting duty placed upon the circuit breaker could exceed the criteria established in this standard.

Some older systems are highly inductive (5 mH/km), and the distances between substations are approximately 1.6 km or greater. In these cases for remote short-circuits, although the fault current magnitude may be low, the circuit energy (kW-s) that shall be interrupted by the circuit breaker may greatly exceed the interrupting criteria established by this standard.

For very high magnitude close-in faults, current-limiting circuit breakers may be required to limit the current contribution from the local substation and to reduce to a minimum the in-feed contribution. Note, however, that as the distance between the substation and a fault increases, a point is reached where there is sufficient system inductance, so that there is essentially no difference in current magnitude or energy that shall be interrupted by a high-speed circuit breaker and a semi-high-speed circuit breaker.

Much consideration should be given to adding relaying to heavy inductive systems. Typical relaying is transfer trip, undervoltage transfer trip, and rate-of-rise trip. Transfer trip typically has no current-sensing capability. When one circuit breaker senses a fault on a system, it trips due to its own current-sensing devices, and through the transfer trip relaying, causes the tripping of the remote circuit breaker.

In addition to carrying out the transfer trip function, undervoltage transfer trip relaying has voltage devices that sense an undervoltage condition and initiates tripping of all circuit breakers within its zone.

Rate-of-rise relaying is designed to differentiate between remote short-circuits and train starting. It is mounted in proximity to its feeder circuit breaker and requires no connection to the remote circuit breaker.

The voltage, due to regeneration coming from a stopping train, may exceed the design level of the system, but this should not be a problem since the dielectric design and test levels have been selected to take this momentary condition into account.

A load-measuring automatic reclosing system is added to dc feeder circuit breakers to prevent these circuit breakers from closing into any fault. Proper integration of this reclosing system with the fault detecting system(s) needs to be achieved to provide optimum operation.

Circuit breakers should be selected to provide the protection required by the other components of the circuit. For applications not covered by this standard, the manufacturer should be consulted.

Figure E.1 reflects the testing required in Table C.1, Table C.2, and Table C.3. Test "a" is the close-in fault simulation with no intentional inductance or resistance added to the test circuit. The current rises to a maximum peak value in approximately one-half cycle of the ac frequency and then decays to a sustained value of short-circuit current at the dc circuit breaker terminals. This sustained current is generally no more than 12 times the full-load current of the rectifier, with the peak current being no more than 1.65 times this value, occurring within 8 ms on a 60 Hz ac source. The rate-of-rise of such a close-in fault is in excess of approximately 15 A/μs, with attenuation or elimination of the peak offset possible due to substation layout design or by the use of contributing rectifier inductance with or without dc reactors.

Test "b," test "c," and test "d" are representative of the classic rate-of-rise curves normally associated with batteries, rotating equipment, and solid-state rectifiers. The rates of rise for these test circuits are low due to the increasing inductance in the circuit such as when representing the intermediate and distant fault conditions.

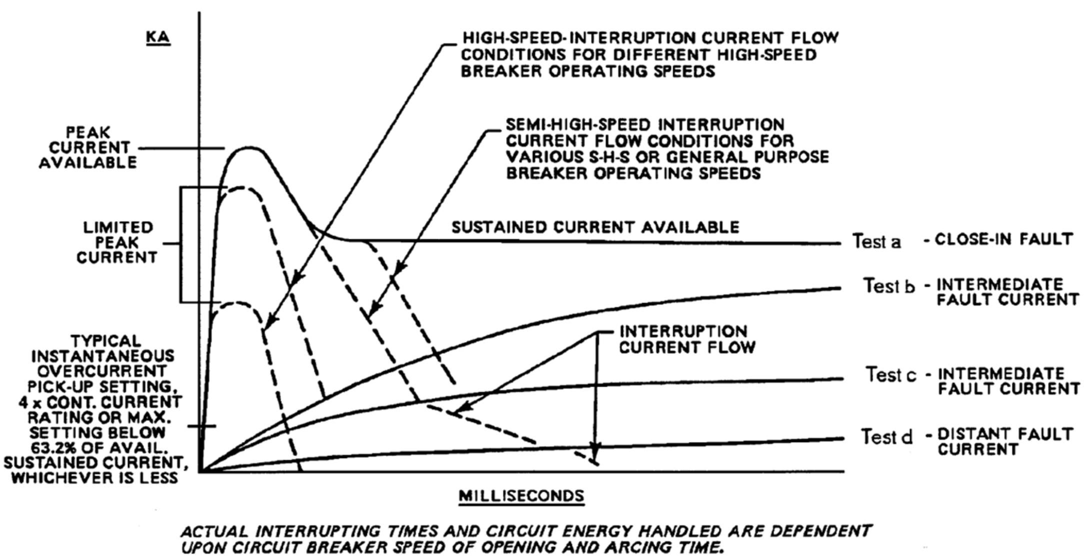

Figure E.1—Representative current/circuit breaker characteristics for traction power systems

Among the many reasons for test "b," test "c," and test "d," one major one is to prove the circuit breaker capability of handling the circuit stored-energy resulting from the inductance of the track system, with the capability of the circuit breaker dependent upon its speed of opening, arc voltage buildup, and resultant arcing time.

A circuit breaker that can respond quickly enough after the over current trip device setting level is reached can part its contacts and build arc voltage in sufficiently short time so that the peak offset, test “a” in Figure E.1, can be limited to a peak current appreciably less than the available (prospective) peak current. By the same token, a circuit breaker that responds less quickly can still be current-limiting if applied to an available (prospective) current defined by test “b,” test “c,” and test “d” of Figure E.1. The high-speed circuit breaker has been redefined as current-limiting under all four test conditions, whereas the semi-high-speed circuit breaker has been redefined as being non-current-limiting for test “a,” but current-limiting for test “b,” test “c,” and test “d,” due to the low rate-of-rise of these latter test circuits. Because of the myriad of combinations of dc circuit parameters, there are large areas of overlap in the proper application of high-speed and semi-high-speed circuit breakers when applied to various systems that, as indicated in the introduction, are independent of the type of circuit breaker applied.

The standard does not attempt to specify the degree of current-limiting for a circuit breaker, nor does it attempt to specify the level of circuit energy (kW-s) interrupted since inherent circuit breaker opening speeds are different and the manufacturer shall be responsible for the circuit breaker capabilities as tested on the particular circuits. However, the circuits selected cover the range of severities that have been identified on traction systems where test “a” represents the close-in fault condition, test “b” and test “c” intermediate fault current conditions, and test “d” the distant fault condition. It is suggested that the circuit breaker manufacturer furnish characteristic curves from which the application engineer can ascertain the suitability of the particular circuit breakers for his application needs.

Table C.3 represents the light duty system applications and, whereas 8000 kW was selected for the heavy duty transit applications, 4000 kW was selected as the maximum for these light duty transit applications. Table C.1 and Table C.2 represent the heavy duty application.

Note that a light duty circuit breaker is not the same as a “light rail” transit system, and cannot be automatically applied. Also, “heavy duty” and “heavy rail” are not necessarily equivalent. The light duty and heavy duty demarcation is based upon a traction power substation with 4000 kW rectifier capacity, resulting in a 100 kA short-circuit interrupting rating for 800V dc circuit breakers. A heavy-duty circuit breaker is applicable for traction power substations with up to 8000 kW installed rectifier capacity, and results in a 200 kA short-circuit interrupting rating for 800 V circuit breakers. The light rail and heavy rail are system definitions based upon transit system characteristics. A light rai” system is usually overhead catenary, and may be either trolley or train cars, using a lightweight rail cross-section. Right-of-way may not be dedicated. A heavy rai” system has heavier cars, heavier rails, and usually a third rail because train-running currents are too high for an overhead contact wire catenary system. Right-of-way is dedicated. The demarcation between a light rail and a heavy rail transit system is not well defined.

Additionally, when feeder circuit breaker designs are utilized as rectifier circuit breakers, they can be subject to short-circuit currents produced by less than the total number of rectifiers and, therefore, are conservatively applied. This application difference has been included in Annex C, which specifically defines the rectifier circuit breaker, assigning lower ratings since it is always subject to fault currents from one less rectifier than the total number of rectifiers (n-1) under reverse-current conditions and only from its own rectifier in the forward direction. However, to determine proper rating levels under different conditions, based on a four (4) 2000 kW rectifier substation application, the short-circuit current rating with n-1 rectifiers would be 75% of the full-feeder circuit breaker sustained short-circuit current rating. The short time rating is from one rectifier and is listed as such in Annex C.

There are many other application considerations that cannot be covered completely in a circuit breaker standard. Among these are rate-of-rise protection, load-measuring and automatic reclosing, high-resistance switchgear grounding, in-feed contribution to faulted circuit breakers in a network system, limitation of peak current by substation design, transfer trip protection, and gap circuit breaker application. The application section has been expanded to include guidance on some of these types of applications. However, due to the specialized nature of transit systems, which vary between authorities, it is always best for the authorities to specify all special requirements and discuss them with the manufacturer for the best application. Field testing is usually conducted to determine satisfactory performance under actual conditions for any particular system.

Annex F

(informative)

Production monitoring and product retest requirements

F.1 Overview

Subsequent to certification of a circuit breaker in accordance with this standard, retest intervals should be determined by elapsed time since completion of the immediately previous test schedule.

F.2 Production monitoring

Monitoring of production units should be done quarterly or at shorter intervals at the discretion of the certifying agency to verify that production tests are in accordance with the requirements given in Clause 13 and that the product conforms to the design that was certified.

F.3 Product retest requirements

Retesting should be initiated at the end of specified periods measured from time of certification. The periods are defined by the number of units built, or elapsed time intervals — whichever comes first. The test sequences to be performed at the end of each period are specified in Table 7 and Table 8, and described in the therein referenced subclauses.

When major design changes (such as contact structure) are made, a complete sequence retest should be performed. Minor design changes that affect only a specific area should be retested within the applicable sequence (for example, electrical operator change needs only an endurance test, or arc chute change needs only an interrupting test).

Table F.1—Production retest series

Frame size	Total units (#) or elapsed time (years)[a]	Test sequence	Total units (#) or elapsed time (years)[a]	Test sequence
600–800	8800 units	Design sequence test 1	17600 units	Design sequence test 2[b]
	5 years		10 years	
1600–2000	8500 units		17000 units	
	5 years		10 years	
3000	2100 units		3600 units	
	7 years		12 years	
4000–12000	830 units		1350 units	
	8 years		13 years	

[a] Whichever comes first.

[b] After completion of design sequence test 2, the series should be restarted.

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