IEEE Std C37.14-1999
(Revision of
IEEE Std C37.14-1992)

IEEE Standard for Low-Voltage DC Power Circuit Breakers Used in Enclosures

Sponsor

Switchgear Committee
of the
IEEE Power Engineering Society

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Abstract: This standard covers enclosed low-voltage dc power circuit breakers of the stationary or draw-out type of single- or two-pole construction with one or more rated maximum voltages of 300 V, 325 V, 800 V, 1200 V, 1600 V, or 3200 V for applications on dc systems having nominal voltages of 250 V, 275 V, 750 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 electro-mechanical or electronic trip devices. It deals with service conditions, ratings, functional components, temperature limitations and classification of insulating materials, dielectric withstand voltage requirements, test procedures, and application.
Keywords: current-limiting, general purpose, high-speed, impulse trip device, reverse-current trip device, semi-high-speed or rectifier circuit breaker.

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Introduction

(This introducton is not a part of IEEE C37.14-1999, IEEE Standard for Low-Voltage DC Power Circuit Breakers Used in Enclosures.)

IEEE Std C37.14-1979 superceded IEEE Std C37.14-1969 to properly recognize the widespread use of solid-state rectifiers in industry, particularly for the traction power systems that evolved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 groups 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.

This latest revision of IEEE Std C37.14 reestablishes the 1200 V maximum design rating and removes the 1000 V maximum design rating, while keeping the increased dielectric withstand voltages. This change recognizes the existence of installed 1200 V maximum design rated systems and also maintains a more uniform division between steps of preferred maximum design ratings. This revision also attempts to clarify 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.

Some considerations addressed in the 1992 revision and retained here are as follows.

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 C37.16-1997, 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 different from those utilized for heavy-duty systems.

The question of rectifier and feeder circuit breakers being rated identically was previously addressed in the IEEE Std C37.14-1979 appendix, but this has now been recognized and addressed in the body of the standard. Specific installation applications normally differentiate rating requirements between rectifier and feeder 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.

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 will produce given short-circuit currents and circuit stored energy at various locations regardless of the circuit breaker type applied. Thus, there is a need for only two tables: one for low-frequency impedance bonds 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 in all cases, except in allowing the maximum peak current available to flow on low inductance (close-in) faults.

Any dc circuit breaker must 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 tests “a,” “b,” “c,” and “d” of Tables 11, 11A, and 12 in the latest version of ANSI C37.16-1997. It is noted for comparison that ac low-voltage power circuit breakers are required by ANSI C37.50-1989 to be tested in four sequences for certification/conformance. Similar analysis of required testing resulted in the assignment of two sequences in the 1992 standard.

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 C37.16-1997.

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

There is presently no specific IEC LV dc circuit breaker standard. IEC 60947-2 (1995-12) covers both ac and dc breakers to 1000 VDC and 1500 VDC, but is limited to breakers of 2500 A rated current and 50 kA short-circuit breaking capacity. Circuit breakers for traction applications are not addressed. There is also an IEC 60077 (1968-01), which applies only to electrical equipment installed on motive power units.

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Contents

1. Scope 1

2. References 1

3. Definitions 2

4. Service conditions 3

5. Ratings 3

5.1 Rating information 3
5.2 Rated maximum voltage 3
5.3 Rated continuous current 3
5.4 Rated peak current 4
5.5 Rated short-time current 4
5.6 Rated short-circuit current 4
5.7 Rated-control voltage 4

6. Functional components 5

6.1 Nameplate(s) 6
6.2 Contact position indicator 6
6.3 Stored energy indicator 6
6.4 Locking 6

7. Temperature limitations and classification of insulating materials 6

7.1 Temperature limits 6
7.2 Limits of observable temperature rise 6
7.3 Classification of insulating materials 7

8. Dielectric withstand voltage requirements 7

8.1 Test values 7
8.2 Test procedures 8

9. Test requirements 8

9.1 Classification of tests 8
9.2 Schedule of design tests 9
9.3 Treatment of failures within a test sequence 19
9.4 Production tests 19

10. Application guide 21

10.1 Scope 21
10.2 General 21
10.3 Limiting transient arc voltage 24
10.4 Application limitations relating to mechanism types 25
10.5 Service conditions affecting circuit breaker applications 25
10.6 Application of general-purpose dc low-voltage power circuit breakers to motor starting and running duty 26
10.7 Repetitive duty operations and normal maintenance 26
10.8 Application of circuit breakers without enclosures 27

IEEE Standard for Low-Voltage DC Power Circuit Breakers Used in Enclosures

1. Scope

This standard covers the following types of enclosed low-voltage dc power circuit breakers:

a) Stationary or draw-out type of one- or two-pole construction;
b) Having one or more rated maximum voltages of 3200 V, 1600 V, 1200 V, 800 V, 325 V, or 300 V for applications on systems having nominal voltages of 3000 V, 1500 V, 1000 V, 750 V, 275 V, or 250 V;
c) Manually-operated or power-operated; and
d) With or without overcurrent trip devices.

NOTE—In this standard, the use of the words "circuit breaker" shall be considered to mean "enclosed low-voltage dc power circuit breaker."

2. References

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

ANSI C37.16-1997, American National Standard for Switchgear—Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors—Preferred Ratings, Related Requirements, and Application Recommendations.[1]

ANSI C37.17-1997, American National Standard for Trip Devices for AC and General Purpose DC Low-Voltage Power Circuit Breakers.

IEEE Std 1-1986, IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.[2]

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

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

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

IEEE Std C37.20.1-1993, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

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

3. Definitions

The definitions of terms contained in this standard, or in other standards referred to in this document, are not intended to embrace all legitimate meanings of these terms. They are applicable only to the subject treated in this standard.

The definitions of most terms used in this standard are found in IEEE Std C37.100-1992.[3]

3.1 circuit breaker, general purpose low-voltage dc power: 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.

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

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

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

3.3 circuit breaker, semi-high-speed low-voltage dc power: 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.

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

3.4 circuit breaker, rectifier low-voltage dc power: 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.

NOTES

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

2—For total performance at other than test circuit parameter values, consult the manufacturer.

3.5 trip device (opening release), impulse: 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 are independent of *di/dt*.

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

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 (23 °F);
b) The altitude does not exceed 2000 m (6600 ft)[4];
c) The relative humidity of the air surrounding the circuit breaker is such that there will be no condensation on the circuit breaker parts at any time; and
d) None of the conditions listed in 10.5.2 prevail.

NOTE—When properly applied in metal-enclosed power switchgear or individual enclosures, a circuit breaker will operate within the limits of ambient temperature of the air surrounding the enclosure as specified in IEEE Std C37.20.1-1993.

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 10.5.2.

5. Ratings

5.1 Rating information

The rating of low-voltage 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(s)
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 in ANSI C37.16-1997 are preferred, but are not to be considered restrictive.

5.2 Rated maximum voltage

The rated maximum voltage of a circuit breaker is the highest average dc voltage at which it is designed to perform with a recurring crest voltage no higher than that which occurs with a three-phase full-wave bridge rectifier. The circuit breakers shall be rated at one of the maximum rated voltages as specified in ANSI C37.16-1997.

5.3 Rated continuous current

The rated continuous current of a circuit breaker is the designated limit of sustained current in rms amperes that it shall require to carry continuously without exceeding the temperature limitations designated in Clause 7. The preferred continuous current ratings of the various frame sizes are listed in ANSI C37.16-1997. The rated continuous current of a circuit breaker, which is equipped with direct-acting

[4]Altitude limits are presently under review by the IEEE Switchgear Committee Common Clause Working Group.

trip devices of a smaller rating than the frame size of the circuit breaker, is determined by the rating of those devices.

5.4 Rated peak current

The rated peak current of a circuit breaker is the designated limit of nonrepetitive available (prospective) peak amperes that it shall require to close into and still be able to open and then close. This rating will apply to circuit breakers having direct-acting instantaneous trip devices active in the direction of the current flow.

5.5 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 require to carry for a period of 250 ms without impairing its ability to operate and perform all other ratings. This rating will apply both without direct-acting instantaneous trip devices and with current flow in the nonactive direction of polarized direct-acting instantaneous trip devices.

This rating also requires that the circuit breaker be able to withstand a peak current equal to at least 1.65 times the value of its rated short-time current occurring approximately 8 ms after the start of the current flow.

5.6 Rated short-circuit current

The rated short-circuit current of the circuit breakers is the designated limit of available (prospective) rms current in amperes at which they shall be required to perform their short-circuit current duty cycle of Open - 15 seconds - Close-Open (O - 15 s - CO) at rated maximum voltage and under the prescribed test conditions given in 9.2.7.

5.6.1 General-purpose dc circuit breakers

The preferred ratings are listed in Table 8 of ANSI C37.16-1997.

5.6.2 General-purpose dc circuit breakers for mining operations

The preferred ratings are listed in Table 10 of ANSI C37.16-1997.

5.6.3 Semi-high-speed dc circuit breakers

The preferred ratings are listed in Tables 11 and 11A of ANSI C37.16-1997.

5.6.4 High-speed dc circuit breakers

The preferred ratings are listed in Tables 11 and 11A of ANSI C37.16-1997.

5.6.5 Rectifier dc circuit breakers

The preferred ratings are listed in Tables 11 and 11A of ANSI C37.16-1997.

NOTE—Any applicable type circuit breaker may be utilized to meet Table 12 requirements.

5.7 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.

Rated control voltages and their ranges for low-voltage power circuit breakers are listed in Table 23 of ANSI C37.16-1997.

NOTE—Mining circuit breakers may require control voltage up to 325 V.

6. Functional components

The functional components required for manually and power-operated circuit breakers are listed in Table 1. Additional accessory devices may be available. The manufacturer should be consulted for specific information.

Table 1—Functional components

	General purpose dc circuit breakers[a]; Frame size 600–6000 A		**Rectifier or feeder Semi-high-speed and high-speed dc circuit breakers; Frame size 1200–12 000 A**
	Operating mechanism type		
Functional component	**Manual**	**Power**	
Direct-acting trip device (calibrated in accordance with ANSI C37.17-1997)	X[b]	X[b]	—
Overcurrent release (in response to forward or reverse current flow as necessary)	—	—	X[b]
Manual trip device	X	X	X
Contact position indicator—in accordance with 6.2	X	X	X
Manually-operated mechanism, trip-free with standard operating handle	X[c]	—	—
Power-operated mechanism, trip-free, with anti-pump feature and maintenance closing device	—	X	X
Shunt trip device or opening release with necessary control auxiliary switches	—	X	X
Stored energy indicator—in accordance with 6.3	X[d]	X[d]	X[d]
Locking—in accordance with 6.4	X	X	X
Nameplate(s), with markings, in accordance with 6.1	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.
[c]Manually-operated circuit breakers 3000 A and above shall be furnished with closing mechanisms that provide for only independent manual operation.
[d]Required only on closing mechanisms that provide for stored energy operation when the mechanism can be left in the charged position.

6.1 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 labeled with "high-speed," "semi-high-speed," "rectifier," "feeder," "general purpose," or "mining";
c) Frame size;
d) Rated maximum voltage;
e) Rated continuous current in rms amperes and type designation of trip devices;
f) Rated peak current;
g) Rated short-time current;
h) Rated short-circuit current;
i) Rated control voltage;
j) Year of manufacture—by date or code; and
k) Identification number.

6.2 Contact position indicator

The following colors shall be used:

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

6.3 Stored energy indicator

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.

6.4 Locking

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

7. Temperature limitations and classification of insulating materials

7.1 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.

7.2 Limits of observable temperature rise

The observable 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 2. 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 2—Limits of temperature rise

	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	125
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 connections to bus in metal-enclosed low-voltage switchgear. If connections are made to cables, recognition must be given to possible thermal limitations of the cable insulation, and appropriate measures must be taken.

7.3 Classification of insulating materials

For the purpose of establishing temperature limits, insulating materials are classified in accordance with IEEE Std 1-1986.

8. Dielectric withstand voltage requirements

8.1 Test values

Circuit breakers, when tested in accordance with Clause 9, shall be capable of withstanding, without flashover, the following 60 Hz test voltages for a period of 60 seconds. The test voltages shall be essentially sinusoidal with a crest value equal to 1.414 times the following specified values:

a) Primary circuit of a new completely assembled circuit breaker—test per Table 3.

Table 3—Voltage and insulation levels

Rated maximum dc voltage (V)	RMS Test voltage (V)	Reference dc withstand test voltage (kV)[a]
300	2200	3.1
325	2200	3.1
800	4200	5.9
1200	4800	6.8
1600	5400	7.6
3200	8800	12.4

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

NOTE—Test voltages provide for dielectric margin for open circuit or regenerative overvoltages.

b) Secondary control wiring (except items c, d, and 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 will appear in service applied across the coil.

NOTE—Impulse trip coils may be tested by capacitor discharge or by applying a voltage of appropriately 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 the previous items a, b, c, and d.
g) Electronic circuit for high-speed trip device—500 V.

NOTE—Dielectric withstand tests on electronic trip devices that use the negative bus for ground must be isolated before the 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 the previous items a through e.

8.2 Test procedures

The dielectric test procedures and the method of voltage measurements shall be in accordance with IEEE Std 4-1995.

9. Test requirements

9.1 Classification of tests

This subclause summarizes the various tests that shall be performed on low-voltage dc power circuit breakers and describes methods used in making these tests. These tests are divided into design tests and production tests.

9.1.1 Design tests

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.

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 9.2, 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 either the minimum-dimension single-unit enclosure with the smallest electrical spacings recommended by the manufacturer and with enclosure terminals exposed to the ambient air or, at the manufacturer's discretion, a single vertical section that includes the switchgear buswork. 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 within the range of 10–40 °C.

9.1.2 Production tests

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

9.2 Schedule of design tests

Design tests on the circuit breakers shall include the following, as applicable, in the order shown below. 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 ANSI C37.17-1997, when the circuit breaker is inserted into its enclosure.

Sequence 1

a) Short-time current test (9.2.3)
b) Continuous current test (9.2.4)
c) Load (low) current switching tests (9.2.8)
d) Endurance test (9.2.5)
e) AC dielectric withstand test at 60% as given in 8.1, item f

Sequence 2

a) Trip device calibration check test (9.2.1)
b) AC dielectric withstand test—values given in 8.1 (9.2.2)
c) Peak current test (9.2.6)
d) Short-circuit current test (9.2.7)
e) Trip device calibration check test (9.2.1)
f) AC dielectric withstand test at 60% as given in 8.1, item f

NOTES

1—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 obviate duplicate testing.

2—Separate breakers may be used for each sequence.

3—After short-circuit test “a” of ANSI C37.16-1997, the circuit breaker may be rebuilt or replaced with a new one.

4—Test “a” of ANSI C37.16-1997 is a test at maximum available short-circuit current with no intentional inductance, *L*, added to the dc test circuit. Test “d” of ANSI C37.16-1997 is the test at maximum inductance associated with distant faults at typical track lengths. Tests “b” and “c” of ANSI C37.16-1997 are made with intermediate values of fault current.

9.2.1 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 ANSI C37.17-1997 as well as the manufacturer’s time-current characteristic curve for the particular device.

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 seconds, 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 ensure that it will 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 ensure 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 30–60% of rated voltage. Determine that the device will 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.

9.2.2 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 in accordance with IEEE Std 4-1995. The potential shall be increased gradually from zero so as to reach the required test value in from 5 to 10 seconds and shall be held at that value for 1 minute.

The test voltages shall be essentially sinusoidal and applied with a crest 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.

9.2.2.1 Test voltages

The dielectric withstand test voltage shall be no less than the following:

a) For primary circuit of a new, completely assembled circuit breaker—see 8.1 for rated values;
b) For secondary control wiring (except the following items c, d, e, and f)—1500 V;
c) For motors—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 the rated voltage plus 1000 V;
e) For impulse trip coils—1.5 times the maximum voltage that will appear in service applied across the coil;

NOTE—Impulse trip coils may be tested by capacitor discharge or by applying a voltage of appropriately high frequency.

f) After completion of any test sequence and before servicing, the withstand test voltage shall be 60% of the values listed in the previous items a, b, c, and d;
g) Electronic circuit for high-speed trip device—500 V; and

NOTE—Dielectric withstand tests on electronic trip devices that use the negative bus for ground must be isolated before the 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 the previous items a through e.

NOTE—Tests may be conducted with dc voltage provided the dc voltage is no less than 1.414 times the ac rms listed voltage.

9.2.2.2 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 grounded, 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 grounded, 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 grounded, 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 9.2.2.1, items c and g. 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 9.2.2.1, item e.

9.2.3 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.

9.2.3.1 Condition of circuit breaker

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

9.2.3.2 Test circuit

a) The current that verifies the short-time rating shall be determined by calibrating the test circuit with the circuit breaker short-circuited or omitted.
b) 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. The circuit shall produce a current crest with a value no less than the associated short-time peak current rating of the circuit breaker in approximately 8 ms.

9.2.3.3 Test procedure

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

9.2.3.4 Performance

At the end of the test, the circuit breaker shall be in a condition suitable to continue the test sequence given in 9.2.

9.2.4 Continuous current test

The continuous current test is made to ensure 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
c) Without exceeding the allowable temperature limits specified in Table 2.

If offered as a circuit breaker component, circuit breakers shall be equipped with overcurrent trip devices 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 with no less than rated continuous current.

9.2.4.1 Duration of test

The continuous current test shall be performed 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 as indicated by three readings at 30 minute intervals. The equipment is considered to have passed the test if the temperature limits in Table 2 have not been exceeded in any of the three readings.

9.2.4.2 Method of measuring temperature of the air surrounding the enclosure (ambient)

The temperature of the air surrounding the enclosure (ambient) shall be determined by one thermometer or thermocouple placed approximately 300 mm (12 in) from the side surface of the enclosure and midway between the top and bottom of the enclosure. When thermocouples are used for measurement of ambient temperatures, the thermocouple sensing junction must be attached or embedded in a heat sink, usually consisting of a 5 × 5 × 0.63 cm (2 × 2 × 1/4 in) piece of copper.

9.2.4.3 Copper conductors for use in continuous current tests

See Table 4.

Table 4—Copper conductors for use in continuous current tests

Bus per terminal							
Circuit breaker frame size	Quantity	Size		Minimum length		Bar spacing	
A		mm	in	cm	ft	mm	in
600/800	1	6.3 × 50	1/4 × 2	120	4	—	—
1200	1	6.3 × 100	1/4 × 4	120	4	—	—
1600	2	6.3 × 75	1/4 × 3	120	4	6.3	1/4
2000	2	6.3 × 100	1/4 × 4	120	4	6.3	1/4
2500	2	6.3 × 125	1/4 × 5	120	4	6.3	1/4
3000	3	6.3 × 100	1/4 × 4	120	4	6.3	1/4
4000	4	6.3 × 100	1/4 × 4	120	4	6.3	1/4
5000	4	6.3 × 125	1/4 × 5	120	4	6.3	1/4
6000	4	6.3 × 150	1/4 × 6	120	4	6.3	1/4
8000	4	6.3 × 200	1/4 × 8	120	4	6.3	1/4
10 000 (See NOTE)	5	6.3 × 200	1/4 × 8 or channel A	120	4	6.3	1/4
12 000 (See NOTE)	6	6.3 × 200	1/4 × 8 or channel B	120	4	6.3	1/4

NOTE—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 5.

Table 5—Channel sizes

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

[a]Channel dimensions per Figure 1.

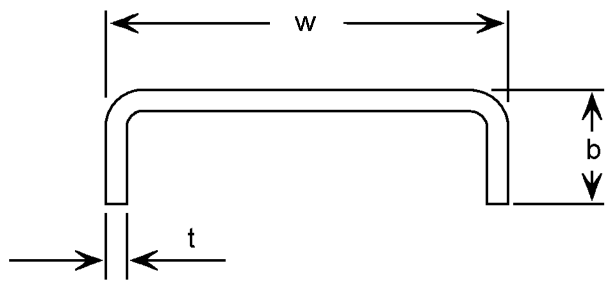

Figure 1—Channel dimensions

9.2.4.4 Method of measuring device temperature

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

Thermocouples used to measure the temperature of insulation shall be located on the current-carrying member or other metal part at a point as close as practicable to the accessible junction of the insulation and the current-carrying member or other metal part.

Thermocouples used to measure the temperature of the test enclosure terminal connections and other conducting joints shall be located approximately 1 cm (1/2 in) from the terminal or other conducting joints on the current-carrying member.

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

9.2.4.5 Performance

Circuit breakers shall be considered to have passed this test if the limits of observable temperature rise specified in Table 2 are not exceeded.

9.2.5 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 14 of ANSI C37.16-1997.

Servicing shall be permitted at the intervals given in Table 14 of ANSI C37.16-1997.

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 14 of ANSI C37.16-1997.

9.2.5.1 Frequency of operation

The frequency of operation shall be one CO operation every 2 minutes. 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 must consist of no less than 120 consecutive operations at the frequency of operation listed previously.

9.2.5.2 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 23 ANSI C37.16-1997.

9.2.5.2.1 Test circuit

The test circuit shall have an L/R (time constant) ratio between 0.02 and 0.06 seconds 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 breakers) under test for one half of the total number of electrical endurance operations listed in Table 14 of ANSI C37.16-1997, and to the positive terminal of the pole (or poles) under test for the other half of the required number of electrical endurance operations. Metallic contact between the circuit breaker frame and the enclosure shall be considered a connection. As an alternate configuration, at the manufacturer's option, the 30 A fuse may be replaced by a minimum No. 10 AWG copper wire. This configuration may be changed at any time during the test.

9.2.5.3 Mechanical endurance test

The mechanical endurance test shall be made at no load and at any one of the rated control voltages of Table 23 in ANSI C37.16-1997. A circuit breaker equipped with a high-speed electronic trip device shall be operated to trip the circuit breaker at any one of the rated control voltages in Table 23 of ANSI C37.16-1997 for 20% of the number of operations specified in Table 14 of ANSI C37.16-1997.

9.2.5.4 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 specified in 9.2.5.2.1 shall not have opened.

9.2.6 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.

9.2.6.1 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 9.2.7 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.

9.2.6.2 Test circuit

a) The current that verifies the peak current rating shall be determined by calibrating the test circuit with the circuit breaker short-circuited or omitted.
b) The test circuit shall produce a current crest with no less than the peak current rating of the circuit breaker in approximately 8 ms.

9.2.6.3 Test procedure

The circuit breaker shall be inserted in the test circuit of 9.2.6.2 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 8.1, item f.

9.2.6.4 Performance

The circuit breaker, when tested separately, shall meet the following conditions:

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 8.1, item f.

9.2.7 Short-circuit current tests

Short-circuit current tests as described in 9.2.7.1 shall be made on circuit breakers to determine their ability to close, carry, and interrupt currents within their assigned ratings. Refer to Tables 8, 9, 10, 11, 11A, and 12 of ANSI C37.16-1997.

9.2.7.1 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 tests “a” and “c” in Tables 9 through 12 of ANSI C37.16-1997 to the negative terminal of the pole (or poles in the case of two pole breakers)

under test, and for tests "b" and "d" in Tables 9 through 12, 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 minimum No. 10 AWG copper wire. This configuration may be changed at any time during the test.

d) The test circuit values for the test circuit shall be as stated in ANSI C.37.16-1997 for the following:
   1) General-purpose dc circuit breakers
   2) General-purpose dc circuit breakers for mining application
   3) Semi-high-speed dc circuit breakers
   4) High-speed dc circuit breakers
   5) Rectifier dc circuit breakers
e) The test circuit values listed in Tables 9, 10, 11, 11A, and 12 of ANSI C37.16-1997 are required for both overall guidance and as a benchmark for testing. A circuit time constant was added to Tables 11, 11a, and 12 for reference. For test purposes, resistance, *R*, may be added to either ac or dc side, but inductance, *L*, must always be added to the dc side.

9.2.7.2 General condition of circuit breaker

The circuit breaker used for the short-circuit interrupting test shall have completed the previous applicable tests required by 9.2 with the exception of 9.2.6.

9.2.7.3 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 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 12 times the rated continuous current of the circuit breaker.
   3) *Semi-high-speed and high-speed circuit breakers*. Circuit breakers shall be equipped with direct-acting instantaneous trip elements set at not more than 4 times the circuit breaker continuous current rating, or at the maximum setting below the available sustained current of the test circuit.
   4) *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 release device shall be tested so that the minimum time of short-circuit current flow shall be 250 ms.

9.2.7.4 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.

9.2.7.5 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.

9.2.7.6 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 23 of ANSI C37.16-1997.

9.2.7.7 Test procedure

The circuit breaker shall be inserted into the test circuit and tested by a duty cycle according to the applicable test "a" of Tables 9, 10, 11, 11A, and 12 of ANSI C37.16-1997. Tests "b," "c," and "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 on:

a) The same pole;
b) The other pole of a two-pole circuit breaker;
c) 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.

9.2.7.8 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, specified in item c in 9.2.7.1, shall not have opened.

9.2.8 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 9.2.5.2, but at lower values of currents than the continuous current rating to determine the current at which the circuit breaker exhibits maximum arcing time. Five opening tests shall be made at this current level.

9.2.8.1 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 c of 9.2.7.1, shall not have opened.

9.3 Treatment of failures within a test sequence

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

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

9.4 Production tests

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 assure that the device will 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.

9.4.1 Calibration

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

9.4.1.1 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

9.4.1.2 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 30–60% of rated voltage. A test shall be made to determine that the undervoltage trip device, with 85% of rated voltage applied, will 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.

9.4.1.3 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.

NOTE—A device shall withstand the upper limits of the voltage ranges as shown under the tripping functions of Table 23 of ANSI C37.16-1997.

9.4.2 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.

9.4.3 Dielectric withstand voltage test

The test shall be conducted in accordance with 9.2.2. The duration of the test may be 1 second if a voltage 20% greater than that specified in 9.2.2.1 is used.

9.4.4 No-load operation tests

9.4.4.1 Power-operated circuit breakers

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

a) Five closing and five opening, and five trip-free operations at minimum control voltage
b) Five closing, five opening, and five trip-free operations at maximum control voltage
c) Two operations to check antipumping, which shall be performed in the following manner:
    1) With the circuit breaker in the closed position, apply uninterrupted control power to the closing circuit and maintain the control switch circuit in the close position; and
    2) Trip the circuit breaker. The circuit breaker shall remain open until closing circuit power has been interrupted and then restored.
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 C37.20.1-1993 for interlocking requirements.

9.4.4.2 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 C37.20.1-1993 for interlocking requirements.

10. Application guide

10.1 Scope

This guide covers the application of power circuit breakers on low-voltage dc systems and applies to circuit breakers rated in accordance with Clause 5.

10.2 General

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 infeed 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 ensure proper fault interruption.

NOTE—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 will 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 will result in lower available peak and sustained currents due to the added resistance and inductance.

For close-in faults, the short-circuit magnitude will 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 or 8 mH/mile) and the distances between substations are approximately 1.5 km (1 mile) or greater. In these cases for remote short circuits, although the fault current magnitude may be low, the circuit energy (kW-s) that must 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 infeed 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 must be interrupted by a high-speed breaker and a semi-high-speed breaker.

Much consideration must 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 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.

10.2.1 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 5.2, 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.

10.2.2 Continuous current

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 must 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 minutes and 300% for 1 minute can be ignored when selecting the circuit breaker continuous current rating.

10.2.3 Short-circuit current

Application of circuit breakers for short-circuit protection of low-voltage 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.

10.2.3.1 Characteristics of short-circuit current

Current associated with a short-circuit in dc circuits, which 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 off-set peak value in approximately one-half cycle of the ac frequency, and successive peak values decay exponentially in approximately 10 ms to the sustained value.

10.2.3.2 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).

10.2.3.3 Systems stored energy

During interruption of short-circuit current, the circuit breaker must 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 Tables 8, 9, and 10 of ANSI C37.16-1997. No stored energy factor is listed in ANSI C37.16-1997 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.

10.2.3.4 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.

10.2.3.5 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.

10.2.3.6 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 10.2.3.4 for short-circuit current in the active direction of the polarized instantaneous trip device, and should be applied in accordance with 10.2.3.5 for short-circuit current in the nonactive 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.

10.2.3.7 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.

10.2.3.8 Short-circuit current duty cycle application

The applicable duty cycle for dc circuit breakers at maximum current, test a of Tables 9 to 12 of ANSI C37.16-1997 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 will permit the 75% dielectric test values of item h of 8.1 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.

10.3 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 $\sqrt{2}\,(4E/3 + 600)$, where E is the rated voltage of motors or generators, is an indication of the crest voltage that rotating equipment can withstand. Semiconductor power rectifiers vary in their ability to withstand voltage surges, and this ability must 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.

10.4 Application limitations relating to mechanism types

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 three classifications according to the type of closing mechanism. The operating mechanisms provide for three ways of operation in closing—power, independent-manual, and dependent-manual.

10.4.1 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.

10.4.2 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.

10.4.3 Dependent-manual operation

Circuit breakers with operating mechanisms that provide for dependent-manual operation in closing may be used in the following manners:

a) With direct-acting instantaneous trip elements set at or below 15 000 A where the available short-circuit current is limited to 50 000 A; or
b) Without direct-acting instantaneous trip elements where the available short-circuit current is limited to 15 000 A.

10.5 Service conditions affecting circuit breaker applications

10.5.1 Altitude correction

Circuit breakers, when applied at altitudes greater than 2000 m (6600 ft), should have their dielectric withstand, continuous current, and rated maximum voltage ratings multiplied by the correction factors in Table 6 to obtain values at which the application is made. The peak and short-time current ratings are not affected by altitude.

Table 6—Altitude correction factors

Altitude		Rating correction factor[a]	
m	ft	Continuous current	Voltage
2000	6600 (and below)	1.00	1.00
2600	8500	0.99	0.95
3900	13 000	0.96	0.80

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

NOTE—All values in Table 6 are currently under review by an IEEE Switchgear Committee Working Group and are given here only for reference.

10.5.2 Other service conditions

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) 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;
b) Exposure to abnormal vibration, shocks, or tilting;
c) Exposure to excessively high or low temperature;
d) Exposure to unusual transportation or storage conditions;
e) Exposure to extreme solar temperatures;
f) Unusual operating duty, frequency of operation, or difficulty of maintenance; and/or
g) Temperature of circuit breaker parts that falls below the dew point of the surrounding air, causing moisture condensation on the parts.

10.6 Application of general-purpose dc low-voltage power circuit breakers to motor starting and running duty

Table 16 in ANSI C37.16-1997 applies to general-purpose dc circuit breakers whose direct-acting trip devices are calibrated at either approximately 80–160% or 80–120% 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 16 of ANSI C37.16-1997. 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 16 of ANSI C37.16-1997.

10.7 Repetitive duty operations and normal maintenance

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 15 of ANSI C37.16-1997.

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.

10.7.1 Operating conditions

The following items, referenced in the column headings of Table 15 of ANSI C37.16-1997, 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 six months or less;
b) When closing and opening no load;
c) With rated control voltage applied;
d) Frequency of operation not to exceed 20 in 10 minutes or 30 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 15 of ANSI C37.16-1997;

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 seconds; 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.

10.8 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 A

(informative)

Technical application guide

Technical detail is provided here to guide those who apply and use traction power circuit breakers. This annex is not a part of IEEE Std C37.14-1999, IEEE Standard for Low-Voltage DC Power Circuit Breakers Used in Enclosures, but is included for information only.

Figure A1 reflects the testing required in Tables 11, 11A, and 12 of ANSI C37.16-1997. 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.

Tests "b," "c," and "d" are representative of the classic rate-of-rise curves normally associated with batteries or rotating equipment. 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.

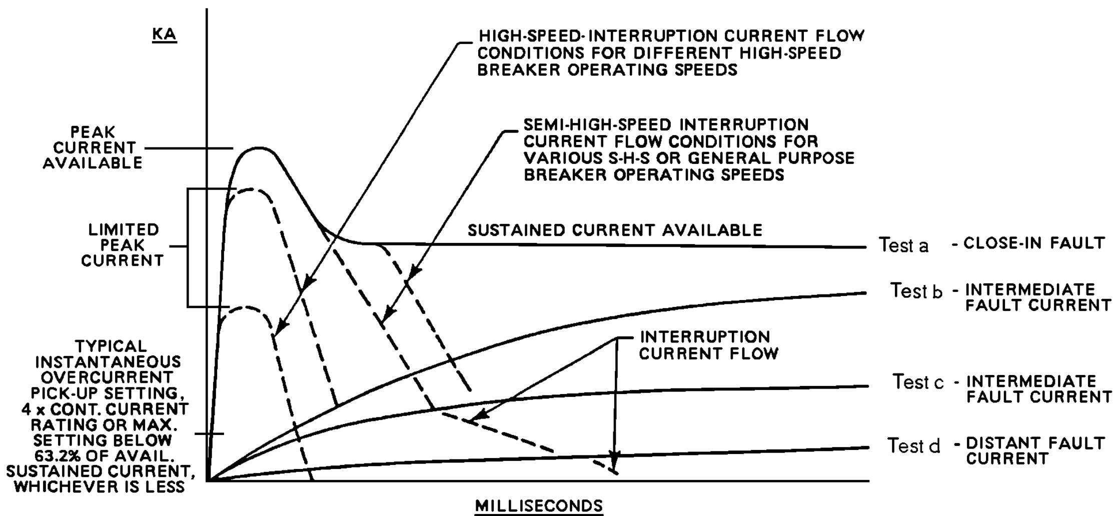

Figure A1—Representative current/circuit breaker characteristics for traction power systems

Among the many reasons for tests "b," "c," and "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 overcurrent 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 A1, 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 tests "b," "c," and "d" of Figure A1. 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 tests "b," "c," and "d," due to the low rate-of-rise of these latter test circuits. Because of the myriad combinations of dc circuit parameters, large areas overlap in the proper application of high-speed and semi-high-speed circuit breakers in various systems that are independent of the type of breaker applied, as indicated in the introduction. This enabled a consolidation of Tables 11 and 11A into new Table 11, and 12 and 12A into new Table 11A of ANSI C37.16-1997.

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 must be responsible for the breaker capabilities as tested on the particular circuits. However, the circuits selected cover the range of severities which have been identified on traction systems where test "a" represents the close-in fault condition, tests "b" and "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 or her application needs.

A new Table 12 has been introduced in ANSI C37.16-1997. It represents the so-called "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.

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 800 V 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 breakers. The light rail and heavy rail are system definitions based upon transit system characteristics. A light rail 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 rail 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, as noted in prior editions of this document, when feeder circuit breaker designs are used as rectifier circuit breakers, they will always 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 ANSI C37.16-1997, 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 ensure proper rating levels under different conditions, based on a four 2000 kW rectifier substation application, the short-circuit current rating with n–1 rectifiers would be 75% of the full feeder breaker sustained short-circuit current rating. Then, even though the short-time current would only be from one rectifier, it is listed at this same 75% level for simplicity in rating, with other non-tripping or delayed tripping circuit breakers included. This then will also provide margin for infeed contributions from multiple sources.

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 breakers in a network system, limitation of peak current by substation design, transfer trip protection, and gap 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 ensure satisfaction performance under actual conditions for any particular system.