



1015™

IEEE Recommended Practice for

**Applying Low
Voltage Circuit
Breakers Used in
Industrial and
Commercial Power
Systems**

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IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems

Sponsor

**Power Systems Protection Committee
of the
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Abstract: Information is provided for selecting the proper circuit breaker for a particular application. This recommended practice helps the application engineer specify the type of circuit breaker, ratings, trip functions, accessories, acceptance tests, and maintenance requirements. It also discusses circuit breakers for special applications, e.g., instantaneous only and switches. In addition, it provides information for applying circuit breakers at different locations in the power system, and for protecting specific components. Guidelines are also given for coordinating combinations of line-side and load-side devices.

Keywords: circuit breakers, circuit breaker evaluation, insulated case, insulated-case circuit breakers, low-voltage circuit breaker, low-voltage power circuit breaker, low-voltage protection, low-voltage protection device, molded case, molded-case circuit breaker, overcurrent protection, power circuit breaker, rating, testing

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Introduction

This introduction is not part of IEEE Std 1015-2006, IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems.

This introduction provides an engineer a comprehensive reference source to aid in deciding what type of low-voltage circuit breaker to use for a particular application, and how to apply the circuit breaker. This recommended practice includes a comparison between the standards of low-voltage power circuit breakers and molded-case circuit breakers so that an engineer can make better, more informed choices. Pertinent tables have been extracted from other standards to provide the basis for the selection and application guidelines. In addition, specific application examples are provided.

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This recommended practice is dedicated in memory of Shaun Slattery. The Working Group especially acknowledges his contributions to the original development of this recommended practice and his valuable insight into the material contained within this revision.

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IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems

Chapter 1 Overview

1.1 Scope

This recommended practice provides information for selecting the proper circuit breaker for a particular application. This recommended practice helps the application engineer specify the type of circuit breaker, ratings, trip functions, accessories, acceptance tests, and maintenance requirements. It also discusses circuit breakers for special applications, e.g., instantaneous only and switches. In addition, it provides information for applying circuit breakers at different locations in the power system and for protecting specific components. Guidelines are given for coordinating combinations of line-side and load-side devices. Acceptance testing and maintenance guidelines are provided so that reliable operation can be verified and maintained.

This recommended practice does not cover the selection and application of circuit breakers such as marine circuit breakers and definite purpose circuit breakers.

1.2 Two classifications of breakers

There are two main classifications of low-voltage circuit breakers: molded-case circuit breakers and low-voltage power circuit breakers. Within the molded-case circuit breaker classification, there is another type of circuit breaker called the insulated-case circuit breaker. The construction and characteristics of these three types will be discussed. Throughout the balance of this recommended practice, these devices will be referred to as follows:

- MCCB: molded-case circuit breaker
- ICCB: insulated-case circuit breaker
- LVPCB: low-voltage power circuit breaker

Each one of these circuit breakers has different design characteristics and, in many cases, different application requirements.

This recommended practice compares the different types of circuit breakers so that the power systems engineer can decide which one is best suited for a particular application. In addition, it discusses ratings, such as overload, short-time, and interrupting capabilities. Protection requirements depend on the circuit breaker location in the power system as well as the type of equipment that is being protected. Examples for different types of equipment and circuit locations are discussed in this recommended practice.

MCCBs are tested and rated in accordance with UL 489-2002.¹ Their current-carrying parts, mechanisms, and trip devices are completely contained within a molded case of insulating material. The cover and base of smaller MCCBs are designed so that the MCCBs cannot be opened for maintenance purposes. The main contacts of MCCBs cannot be removed; however, some MCCBs are available with field-installable accessories. MCCBs are available in stationary or plug-in construction with circuit-breaker enclosures that can be flush or surface mounted. They are available in a large number of continuous-current and interrupting ratings. The smaller continuous-current ratings are equipped with thermal-magnetic or magnetic only trip units. Larger sizes are also available with thermal-magnetic or electronic (static) trip devices.

ICCBs are also tested and rated in accordance with UL 489-2002. As with MCCBs, ICCB current-carrying parts, mechanisms, and trip units are contained within a molded case of insulating material. The case is designed so that it can be opened for inspection of contacts and arc chutes and for limited maintenance. Most manufacturers offer designs that permit replacement of accessories, and some designs permit replacement of the main contacts. ICCBs are available in both stationary and drawout construction. They are generally characterized by a stored energy mechanism, larger frame sizes, and higher short-time withstand ratings than MCCBs. Electronic trip units are standard.

LVPCBs are tested and rated according to the following standards:

- ANSI C37.16-2000
- ANSI C37.17-1997
- ANSI C37.50-1989 (R2000)
- IEEE Std C37.13TM-1990
- UL 1558-1999

LVPCBs are generally characterized by physically large frame sizes, drawout construction, and the highest short-time withstand ratings of all the types of low-voltage circuit breakers. When the circuit breaker is removed from its enclosure, the current-carrying parts and operating parts are accessible for inspection, maintenance, and replacement purposes. Electromechanical trip units were used in the circuit breakers prior to the early 1970s. However, electronic trip units are used in new LVPCBs and are available as upgrades for older units.

1.3 Description of a molded-case circuit breaker

Figure 1-1 is a cutaway view of a typical MCCB. Letters are used to indicate the various elements of the circuit breaker, with a description listed in the legend. This typical circuit

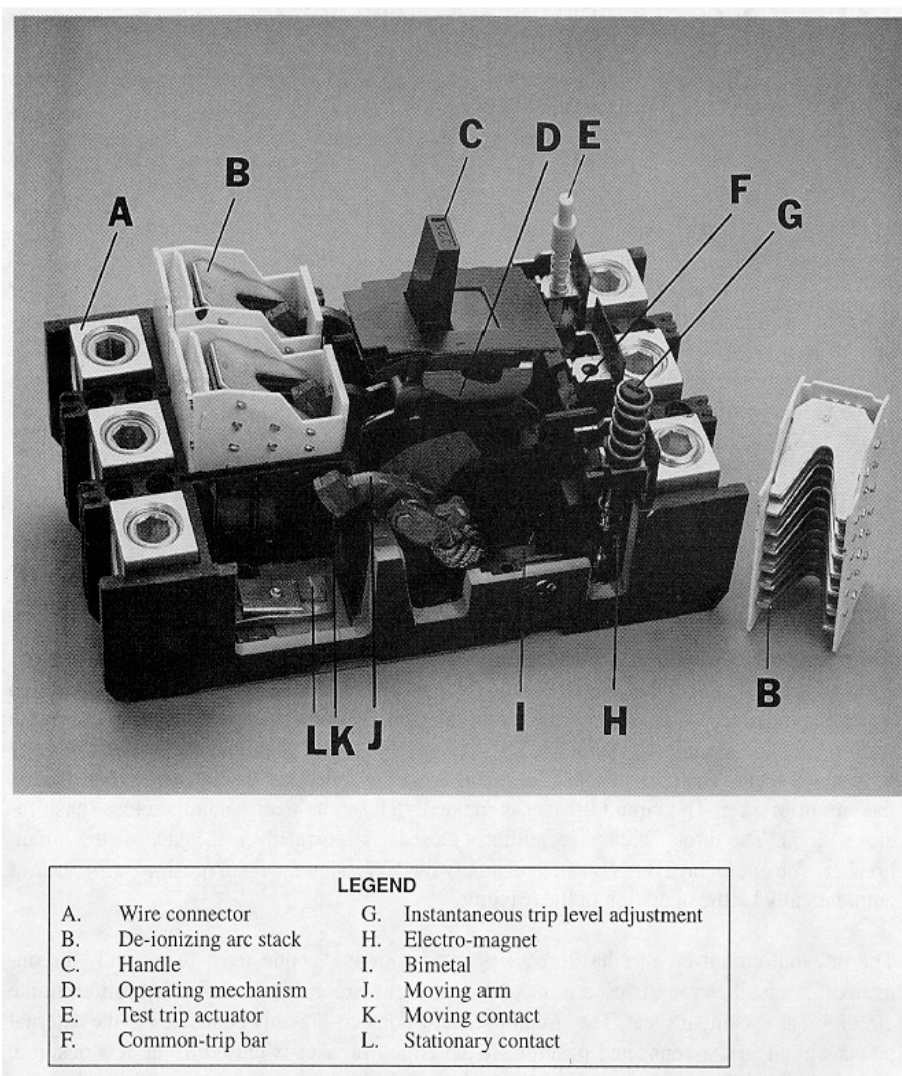
¹Information on references can be found in 1.7.

breaker operates using an over-center toggle, quick-make-quick-break mechanism. This mechanism is operated manually to the ON (closed) and OFF (open) positions using the handle. The quick-make-quick-break action ensures that the speed at which the breaker contacts are open or closed is independent of the speed at which the handle is moved. This toggle mechanism is also trip-free, which means that the circuit breaker cannot be prevented from tripping by holding or locking the handle in the ON position. When the circuit breaker trips open automatically, the handle will assume either an intermediate position between ON and OFF or the OFF position. If the handle moves to the intermediate position, it must be manually moved slightly past the OFF position to reset the mechanism. Instructions for resetting a particular circuit breaker after it trips should be marked on the circuit breaker and/or indicated on the equipment where the circuit breaker is installed.

1.4 Description of a low-voltage power circuit breaker

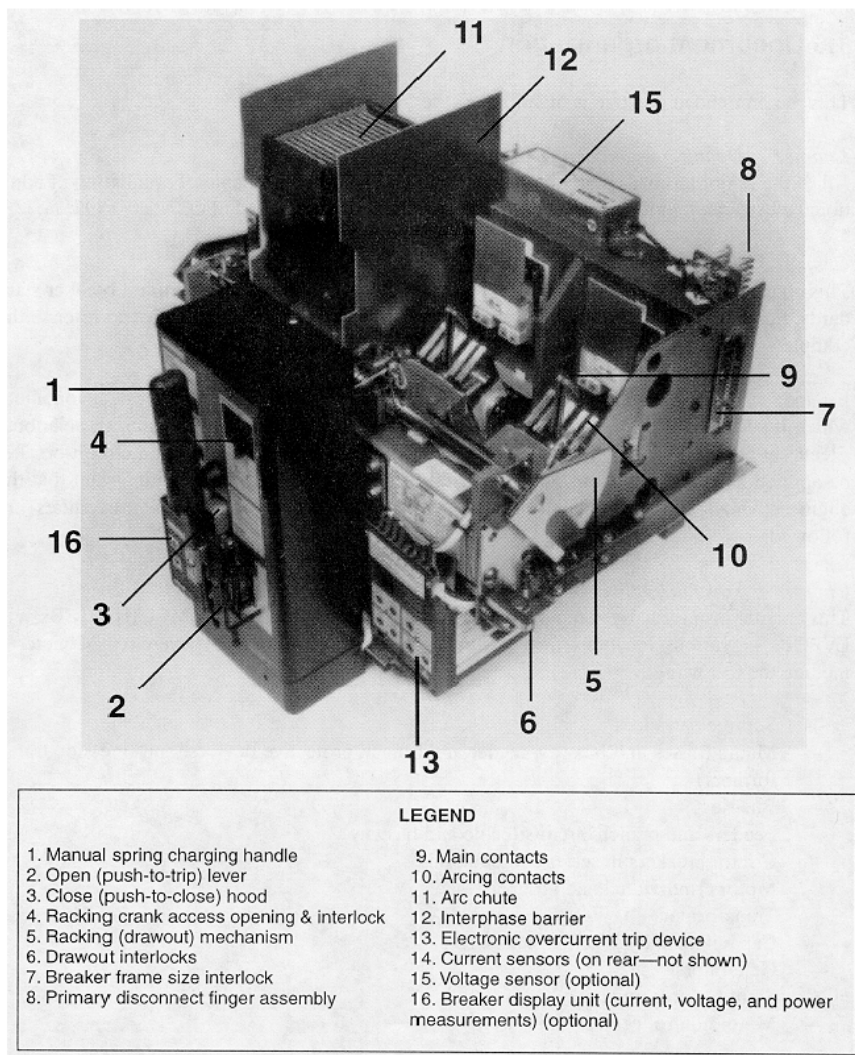
Figure 1-2 is a view of a partially disassembled, manually operated, drawout LVPCB. The open construction permits access to the circuit-breaker parts for maintenance and parts replacement. Numbers are used to indicate the various elements of the circuit breaker. A description of each element is listed in the legend. The following description of the operation of the circuit breaker starts with the open position. The circuit breaker condition “open” is indicated on the face of the circuit breaker. To close the circuit breaker, a spring mechanism must be charged. The springs are charged by pulling down and releasing the manual spring charging handle. The spring condition “charged” is indicated on the face of the circuit breaker. The circuit breaker is manually closed by depressing the close (push-to-close) hood. The circuit breaker condition “closed” is indicated on the face of the circuit breaker. The circuit breaker is opened manually by depressing the open (push-to-trip) lever or automatically by the operation of the trip unit.

The drawout circuit breaker has three separate positions: “CONNECT,” “TEST,” and “DISCONNECT.” A racking crank is used to move the drawout circuit breaker to each position in the circuit breaker compartment. The circuit breaker's contacts are only connected to the external power circuit in the connected position. If the circuit breaker is closed in the TEST position, there is no effect to the external power circuit. Interlocking prevents moving a closed circuit breaker between these positions or closing it in other than the CONNECT or TEST position. Further interlocking prevents inserting circuit breakers of the wrong frame size into a compartment. Primary disconnects and optional secondary disconnects automatically complete the power circuit in the CONNECT position and control circuits in the CONNECT and TEST positions, respectively.



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Figure 1-1—Cutaway view of a typical MCCB



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**Figure 1-2—Low-voltage ac power circuit braker-drawout type
(shown partially disassembled to show internal features)**

1.5 Document organization

This recommended practice is organized in the following manner:

Chapter 2: Definitions, acronyms, and abbreviations

All of the major terms used in this recommended practice are defined in this chapter. For a listing of additional electrical definitions, refer to *The Authoritative Dictionary of IEEE Standards Terms* [B1]² and IEEE Std C37.100TM-1992.

Chapter 3: Rating and testing

This chapter summarizes the application requirements of recognized low-voltage circuit breaker standards. For more details on a particular application, the engineer is encouraged to refer to the complete standard for amplification and a more complete discussion.

By understanding the differences in standards, an engineer can make a better decision about which type of breaker should be used for a particular application. In addition, Section 110.3(B) from the National Electrical Code[®] (NEC[®]) (NFPA 70-2005) requires that a circuit breaker be applied according to the information listed in the standards. Thus, it is important that the engineer know and understand the standards so that proper application procedures are followed.

Chapter 4: Specific applications

This chapter provides a systematic procedure for selecting and applying MCCBs, ICCBs, and LVPCBs at various locations in a power system. The applications covered in Chapter 4 are as follows:

- Service entrances
- Mains (buses and busway, feeder and branch protective devices, and line-side transformers)
- Bus ties
- Feeders and branch circuits (cable and busway)
- Circuit breakers in series combinations
- Motors (individual and grouped)
- Transformers
- Capacitors and capacitor banks
- Generators
- Switchboards and panelboards
- Motor control centers and starters

²The numbers in brackets correspond to those of the Bibliography in 1.8.

Chapter 5: Selective coordination of low-voltage circuit breakers with other protective devices

This chapter explains how to coordinate different combinations of devices and provides typical settings. Conflicting objectives normally occur between protection and selective coordination. The objective of protection is to minimize the damage by removing the overload or short circuit as quickly as possible. However, the objective of selective coordination is to disconnect a minimum amount of equipment from the power system. Coordination is obtained by selecting the appropriate type of circuit breaker, trip characteristics, and trip settings so that only the circuit breaker closest to the overload or short-circuit condition clears the problem.

To obtain selective coordination over the entire range of available short-circuit current, delayed operation of the line-side circuit breaker is necessary to allow the load-side circuit breaker to clear a fault. The additional time delay of the line-side device can increase the extent of the damage to circuit components. However, it is often necessary to make a compromise in protection to obtain coordination, within the limits of the National Electric Code (NFPA 70-2005) and ANSI protection requirements. Coordination between devices is often sacrificed when continuity of service and/or equipment damage and associated cost are not critical.

Chapter 6: Fused and special-purpose circuit breakers

This chapter discusses application of the following special-purpose circuit breakers:

- Instantaneous trip only
- Mine duty
- Current limiting
- Molded-case switch
- Integrally fused
- Circuit breaker and ground fault circuit interrupters
- Arc-fault circuit interrupters
- Supplementary protectors

Chapter 7: Acceptance and maintenance requirements.

This chapter is divided into the following two time periods:

- Acceptance testing that should be performed *before* placing a circuit breaker into service
- Maintenance guidelines that should be followed *after* a circuit breaker is placed into service

Acceptance testing and maintenance are required to ensure that the circuit breaker will perform satisfactorily to the full extent of the manufacturer's ratings. In addition, proper maintenance is required for continued, reliable operation. Also discussed briefly are testing and maintenance for insulated case circuit breakers, molded-case switches, and ground fault circuit interrupters. Annex 7A and Annex 7B provide sample data record sheets for recording circuit breaker test information and results.

A circuit breaker may be damaged during shipment, or defective components may be present; therefore, acceptance testing should be performed prior to placing it in service. Acceptance testing of circuit breakers is the initial testing on a breaker before it is placed into service to verify that the circuit breaker will perform properly. This chapter provides instructions for performing and documenting test results. Some acceptance test criteria discussed are insulation resistance, electrical operations at selected settings, mechanical operation, and auxiliary functions. Acceptance test data sheets are provided.

Maintenance procedures are important to power system reliability and safety. Proper maintenance will improve confidence that the circuit breakers will operate properly when called on to interrupt an overload or fault condition. The operating performance of a circuit breaker may deteriorate with time due to contamination by pollutants in the atmosphere, excessive use, or lack of operation for a prolonged duration. Welding in the main contact may occur during a short circuit if the contacts are in a deteriorated condition due to excessive use. In addition, the performance characteristics of other components in the breaker, such as contact pressure springs, may be degraded for some other reason such as overheating. This chapter discusses proper maintenance procedures and schedules that should be followed to maintain reliable operation.

1.6 Summary

This recommended practice identifies the differences between the two classifications of low-voltage circuit breakers and provides information for selecting the best one for a particular situation. In addition, this recommended practice gives information for applying circuit breakers at different locations in the power system and for protecting specific components. Guidelines are also given for coordinating combinations of line-side and load-side devices. Acceptance testing and maintenance guidelines are given so that reliable operation can be verified and maintained.

1.7 Normative references

The following referenced documents are indispensable for the application of this recommended practice. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI C37.16-2000, American National Standard Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors-Preferred Ratings, Related Requirements, and Application Recommendations.³

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

³ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

ANSI C37.50-1989 (R2000), American National Standard for Switchgear-Low-Voltage AC Power Circuit Breakers Used in Enclosures-Test Procedures.

IEEE Std C37.13-1990 (R1995), IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.^{4, 5}

IEEE Std C37.100-1992, (R2001) IEEE Standard Definitions for Power Switchgear.

NFPA 70-2005, National Electrical Code[®] (NEC[®]).⁶

UL 489-2002, Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures.⁷

UL 1558-1999, Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

1.8 Bibliography

[B1] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition. New York: Institute of Electrical and Electronics Engineers, Inc.

[B2] IEEE Std 141[™]-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*[™]).

[B3] IEEE Std 242[™]-2001, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (*IEEE Buff Book*[™]).

⁴ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

⁵The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

⁶ NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

⁷UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

Chapter 2

Definitions, acronyms, and abbreviations

2.1 Definitions

For the purposes of this document, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B1]¹ should be referenced for terms not defined in this clause.

2.1.1 adjustable: (as applied to circuit breakers) A qualifying term indicating that the circuit breaker can be set to trip at various values of current, time, or both, within a predetermined range. [adapted from the National Electrical Code® (NEC®) (NFPA 70-2005)]²

2.1.2 alarm switch: An auxiliary switch that actuates a signaling device upon the automatic opening of the circuit breaker with which it is associated.

2.1.3 auxiliary switch: A switch that is mechanically operated by the main switching device for signaling, interlocking, or other purposes.

NOTE—Auxiliary switch contacts are classified as a, b, aa, bb, LC, etc., for the purpose of specifying definite contact positions with respect to the main device.³

2.1.4 available short-circuit current: (at a given point in a circuit) The maximum current that the power system can deliver through a given circuit to any negligible-impedance short circuit applied at the given point, or at any other point that will cause the highest current to flow through the given point. *See also:* **prospective fault current.**

2.1.5 circuit breaker: A device designed to open and close a circuit by nonautomatic means, and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating. [adapted from the NEC] *Syn:* **low-voltage circuit breaker.**

2.1.6 continuous load: A load where the maximum current is expected to continue for 3 hours or more. [adapted from the NEC]

2.1.7 coordination: The selection and/or setting of protective devices to provide protection of system components and to provide selectivity when a short circuit or other abnormality occurs.

2.1.8 current-limiting circuit breaker: A circuit breaker that does not use a fusible element and that when operating within its current-limiting range limits the let-through I^2t

¹The numbers in brackets correspond to those of the bibliography in 2.4.

²Information on references can be found in 2.3.

³Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

to a value less than the I^2t of a 1/2 cycle wave of the symmetrical prospective current. (adapted from UL 489-2002) *See also:* **current-limiting overcurrent protective device**.

2.1.9 current-limiting overcurrent protective device: A device that, when interrupting currents in its current-limiting range, reduces the current flowing in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device were replaced with a solid conductor having comparable impedance. (adapted from the NEC) *See also:* **current-limiting circuit breaker**.

2.1.10 drawout-mounted circuit breaker: An assembly of a circuit breaker together with a supporting structure so constructed that the breaker is supported and can be moved between the main circuit connected and the disconnected positions without unbolting connections or mounting supports. The stationary portion of the drawout assembly includes self-supporting primary circuit terminals and may include an interlocking means that permits movement of the breaker between the main circuit connected and the disconnected positions only when the breaker contacts are in the open position. (adapted from UL 489-2002)

2.1.11 dynamic impedance: The arc impedance introduced into a circuit by the opening of the circuit-breaker contacts during current interruption. (adapted from NEMA AB 1-1993)

2.1.12 electrical operator: A controlling device that is used to open, close, and reset a circuit breaker. (adapted from UL 489-2002)

NOTE—The term *motor operator* is sometimes used when the operating device is a motor.

2.1.13 electronic trip unit: A self-contained portion of a circuit breaker that senses the condition of the circuit breaker electronically and that actuates the mechanism that opens the circuit breaker contacts automatically.

NOTE—Where the term *electronic trip unit* is used in this book, the alternate terms *solid state trip unit* and *static trip unit* are commonly used in literature.

2.1.14 frame: As applied to circuit breakers, that portion of an interchangeable trip unit circuit breaker remaining when the interchangeable trip unit is removed. (adapted from UL 489-2002)

2.1.15 frame size: A term applied to a group of circuit breakers of similar physical configuration. Frame size is expressed in amperes and corresponds to the largest ampere rating available in the group. The same frame size designation may be applied to more than one group of circuit breakers. (adapted from UL 489-2002)

2.1.16 ground-fault delay: An intentional time delay in the tripping of a circuit breaker when a ground fault occurs. (adapted from NEMA AB 1-1993)

2.1.17 ground-fault pickup: The nominal value of the ground fault current at which the ground fault delay function is initiated. (adapted from UL 489-2002)

2.1.18 ground-fault protection of equipment: A system intended to provide protection of equipment from damaging line-to-ground fault currents by operating to cause a disconnecting means to open all ungrounded conductors of the faulted circuit. This protection is provided at current levels less than those required to protect conductors from damage through the operation of a supply circuit overcurrent device. (adapted from the NEC)

2.1.19 I^2t : An expression related to the energy available as a result of current flow, meaningful only for adiabatic conditions. With respect to circuit breakers, the expression refers to the I^2t between the initiation of fault current and the clearing of the circuit. The defining equation is $I^2t = \int I^2(t) dt$ over the stated period, in units of amperes-squared seconds. (adapted from UL 489-2002)

2.1.20 instantaneous pickup: The nominal value of current at which an adjustable circuit breaker is set to trip instantaneously. (adapted from UL 489-2002)

2.1.21 instantaneous trip: (as applied to circuit breakers) A qualifying term indicating that no delay is purposely introduced in the tripping action of the circuit breaker. (adapted from the NEC)

2.1.22 instantaneous-trip-only circuit breaker: A circuit breaker intended to provide short-circuit protection only. Although acting instantaneously under short-circuit conditions, instantaneous trip breakers shall be permitted to include a transient damping action to ride through initial motor transients. (adapted from UL 489-2002)

2.1.23 insulated-case circuit breaker (ICCB): A circuit breaker that is assembled as an integral unit in a supporting and enclosing housing of insulating material and with a stored energy mechanism.

2.1.24 integrally-fused circuit breaker: A circuit breaker in which coordinated fuses are connected in series with the release (trip) elements of the circuit breaker and are mounted within the housing of the circuit breaker. (adapted from NEMA AB 1-1993)

2.1.25 interrupting rating: The highest current at rated voltage that a device is intended to interrupt under standard test conditions. (adapted from the NEC)

2.1.26 inverse time: (as applied to circuit breakers) A qualifying term indicating that there is purposely introduced a delay in the tripping action of the circuit breaker, which delay decreases as the magnitude of the current increases. (adapted from the NEC)

2.1.27 I_p : *See:* peak current.

2.1.28 long-time delay: An intentional time delay in the overload tripping of an adjustable circuit breakers inverse time characteristic. (adapted from UL 489-2002)

2.1.29 long-time pickup: The current at which the long-time delay function is initiated. (adapted from UL 489-2002)

2.1.30 low-voltage power circuit breaker (LVPCB): A mechanical switching device, capable of making, carrying, and breaking currents under normal circuit conditions and making and carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short circuit. Rated 1000 V ac or below, or 300 V dc and below, but not including molded-case circuit breakers. (adapted from IEEE Std C37.100™-1992)

2.1.31 molded-case circuit breaker (MCCB): A circuit breaker that is assembled as an integral unit in a supporting and enclosing housing of insulating material. (adapted from UL 489-2002 and IEEE Std C37.100-1992)

2.1.32 molded-case switch: A device designed to open and close a circuit by nonautomatic means, assembled as an integral unit in a supportive and enclosed housing of insulating material. *Syn:* **nonautomatic switch** (deprecated). (adapted from UL 489-2002 and UL 1087-1993)

2.1.33 overcurrent: Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault. (adapted from the NEC) *See also:* **overload**.

2.1.34 overload: Operation of equipment in excess of normal, full-load rating or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload. (adapted from the NEC) *See also:* **overcurrent**.

2.1.35 panelboard: A single panel or group of panel units designed for assembly in the form of a single panel, including buses and automatic overcurrent devices, and equipped with or without switches for the control of light, heat, or power circuits; designed to be placed in a cabinet or cutout box placed in or against a wall, partition, or other support; and accessible only from the front. (adapted from the NEC) *See also:* **switchboard**.

2.1.36 peak current: The maximum instantaneous current that flows in a circuit, designated I_p . (adapted from UL 489-2002)

2.1.37 peak let-through current: The highest current flowing in the circuit after the inception of the fault that the circuit breaker and the protected system must withstand, expressed as an instantaneous rather than a root-mean-square (rms) value.

2.1.38 pickup: The root-mean-square (rms) current at which a circuit breaker tripping function is initiated. (adapted from NEMA AB 1-1993)

2.1.39 prospective fault current: The current that would flow during a short circuit if the circuit breaker and the wires used for its connection were replaced by a solid conductor of negligible impedance. (adapted from UL 489-2002) *See also:* **available short-circuit current**.

2.1.40 rated short-time withstand current: (A) The maximum root-mean-square (rms) total current that a circuit breaker can carry momentarily without electrical, thermal, or

mechanical damage or permanent deformation. The current shall be the rms value, including the dc component, at the major peak of the maximum cycle as determined from the envelope of the current wave during a given test time interval. (adapted from IEEE Std C37.100-1992) **(B)** That value of current assigned by the manufacturer that the device can carry without damage to itself, under prescribed conditions. (adapted from NEMA AB 1-1993) *Syn:* **withstand rating; short-time rating.**

2.1.41 rating plug: An interchangeable module of an electronic trip unit that, together with the sensor, sets the current rating range of the circuit breaker. For example, a 1200 A frame may contain an 800 A sensor, fixing the maximum rating that can be configured for the unit at 800 A adjustable by the following kind of settings. By installing a 600 A rating plug, the adjustable rating is correspondingly 600 A multiplied by the long-time pickup adjustment [i.e., the long-time pickup may be adjusted to “0.9,” and the ampere rating or setting is $(0.9 \times 600 \text{ A}) = 540 \text{ A}$]

2.1.42 release: A device, mechanically connected within the circuit breaker, that initiates the tripping function of a circuit-breaker. (adapted from NEMA AB 1-1993)

2.1.43 root-mean-square (rms) sensing: A term commonly used to indicate the sensing of root-mean-square (rms) value current rather than instantaneous or peak values, as by a circuit-breaker trip unit.

2.1.44 selective coordination: *See:* **coordination; selectivity.**

2.1.45 selectivity: A general term describing the interrelated performance of relays and breakers and other protective devices; complete selectivity being obtained when a minimum amount of equipment is removed from service for isolation of a fault or other abnormality. (adapted from IEEE Std C37.100-1992) *See also:* **coordination.**

2.1.46 sensor: (as applied to a circuit-breaker with an electronic trip unit) A current sensing element such as a current transformer within a circuit-breaker frame. The sensor will have a current rating less than or equal to the frame size and will provide the sensing function for a specific group of current ratings within the frame size.

2.1.47 series rating: The interrupting rating of a tested combination of a line-side (main) overcurrent protective device and a load-side (branch) circuit-breaker in which the interrupting rating of the combination is greater than the interrupting rating of the branch circuit-breaker. The interrupting rating of the series combination does not exceed the interrupting rating of the main overcurrent protective device. *Syn:* **series-connected rating.**

NOTE—See *UL Recognized Component Directory*, 2002 [B2].

2.1.48 setting: (of a circuit breaker) The value of current, time, or both at which an adjustable circuit-breaker is set to trip. (adapted from the NEC)

2.1.49 short circuit: An abnormal connection (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential. (adapted from IEEE Std C37.100-1992)

2.1.50 short-time current: The current carried by a device, an assembly, or a bus for a specified short-time interval. (adapted from IEEE Std C37.100-1992) *See also:* **rated short-time withstand current; short-time rating.**

2.1.51 short-time delay: An intentional time delay in the tripping of a circuit-breaker that is above the overload pickup setting.

2.1.52 short-time delay phase or ground trip element: A direct-acting trip device element that functions with a purposely delayed action (measured in milliseconds). (adapted from IEEE Std C37.100-1992)

2.1.53 short-time pickup: The current at which the short-time delay function is initiated. (adapted from UL 489- 2002)

2.1.54 short-time rating: A rating applied to a circuit breaker that, for reason of system coordination, causes tripping of the circuit breaker to be delayed beyond the time when tripping would be caused by an instantaneous element. (adapted from UL 489-2002) *See also:* **rated short-time withstand current; short-time current.**

2.1.55 shunt trip device: A trip mechanism energized by a source of voltage that may be derived either from the main circuit or from an independent source. (adapted from UL 489-2002)

2.1.56 stored-energy operation: Operation by means of energy stored in the mechanism before the completion of the operation and sufficient to complete it under predetermined conditions. (adapted from IEEE Std C37.100-1992)

2.1.57 switchboard: A large, single-panel, frame or assembly of panels on which are mounted, on the face, back, or both, switches, overcurrent and other protective devices, buses, and usually instruments. Switchboards are generally accessible from the rear as well as from the front and are not intended to be installed in cabinets. (adapted from the NEC) *See also:* **panelboard.**

2.1.58 switchgear: A general term covering switching and interrupting devices and their combination with associated control, metering, protective and regulating devices; also, assemblies of these devices with associated interconnections, accessories, enclosures, and supporting structures used primarily in connection with the generation, transmission, distribution, and conversion of electric power. (adapted from IEEE Std C37.100-1992)

2.1.59 transient recovery voltage (TRV): The voltage transient that occurs across the terminals of a pole of a switching device upon interruption of the current. (adapted from IEEE Std C37.100-1992)

2.1.60 tripping: The opening of a circuit breaker by actuation of the release mechanism. (adapted from UL 489- 2002)

2.1.61 trip unit: A self-contained portion of a circuit breaker that actuates the mechanism that opens the circuit-breaker contacts automatically. (adapted from UL 489- 2002)

NOTE—The terms *trip device* and *tripping device* are used in literature as alternative terms for trip unit.

2.1.62 undervoltage trip device: A trip mechanism that causes a circuit-breaker to open automatically if the voltage across the terminals of the trip coil falls below a predetermined value. (adapted from UL 489- 2002) *Syn:* **undervoltage release.**

2.1.63 withstand current: *See:* **rated short-time withstand current.**

2.1.64 withstand rating: *See:* **rated short-time withstand current.**

2.1.65 zone selective interlocking: A function provided for rapid clearing while retaining coordination. The function is a communication interconnection between the electronic trip units of two or more circuit breakers connected in series on multiple levels. By means of intercommunication between the short-time delay and/or ground fault elements, the one nearest the fault trips with minimum time delay while signaling the supply-side circuit-breaker(s) to delay for a predetermined period. *Syn:* **zone interlocking; selective interlocking.**

2.2 Acronyms and abbreviations

2.2.1 40 °C: Designates a circuit-breaker that is acceptable for use in ambient temperatures up to 40 °C.

2.2.2 AIC: Amperes interrupting capacity. Maximum current a protective device is capable of interrupting, namely, its interrupting rating. May be found in manufacturer's literature. Also see **AIR**.

2.2.3 AIR: Amperes interrupting rating. Shortened term marked on some small circuit breakers with the interrupting rating.

2.2.4 CTL: A Class CTL circuit breaker, because of its size or configuration in conjunction with the physical means provided in Class CTL panelboards, prevents more circuit-breaker poles from being installed than the number for which the assembly is designed and rated. A Class CTL panelboard is a circuit-limited lighting and appliance panelboard as referenced in Sections 408.14 to 408.16 of the NEC. Both half-size and full-sized circuit breakers may be installed.

2.2.5 HACR: Heating, air conditioning, and refrigeration. Designates compliance with the special requirements of Section 430-53(C)(3) of the NEC, as listed for group installation for use with heating, air conditioning, and refrigeration equipment. A circuit breaker with

this marking is suitable only for use with equipment marked to indicate that an HACR circuit breaker is acceptable.

2.2.6 HID: High-intensity discharge. Indicates construction suitable for switching high-intensity discharge lighting loads.

2.2.7 SWD: Switching duty. Designates compliance with requirements for circuit breakers used as switches on fluorescent lighting circuits as indicated in Section 240-83(D) of the NEC.

2.3 Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEEE Std C37.100-1992 (R2001), IEEE Standard Definitions for Power Switchgear.⁴

NEMA AB 1-1993, Molded Case Circuit Breakers and Molded Case Switches.⁵

NFPA 70-2005, National Electrical Code[®](NEC[®]).⁶

UL 489-2002, Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures.⁷

UL 1087-1993, Molded-Case Switches.

UL Molded-Case Circuit Breaker Marking Guide, 1996.

2.4 Bibliography

[B1] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition. New York: Institute of Electrical and Electronics Engineers, Inc.

[B2] *UL Recognized Component Directory*, 2002.

⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

⁵NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (<http://global.ihs.com/>).

⁶NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

⁷UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

Chapter 3

Rating and testing

3.1 Relevance of rating and testing

This chapter provides information on rating and testing of circuit breakers that will be helpful to electrical engineers in choosing low-voltage circuit breakers for an application. Ratings assigned to circuit breakers are determined by the testing done to prove their design capabilities. Therefore, a discussion of the testing requirements of the different classes of circuit breakers is fundamental to understanding their capabilities.

Other influences, such as the National Electrical Code[®] (NEC[®]) (NFPA 70-2005),¹ industry practices, and environmental considerations can also affect circuit-breaker choices. These are also discussed in areas where they relate to testing requirements. Application considerations such as choosing the type of trip unit, the type of time-current-characteristic, and the continuous current and interrupting ratings to satisfy coordination requirements are the subjects of other chapters of this book.

3.2 The ideal circuit breaker

The ideal circuit breaker (not realizable) would have no internal impedance and would carry current with no voltage drop when closed, and therefore, the circuit breaker would not produce any heat during operation. It would interrupt any overcurrent it was called on to interrupt without experiencing contact erosion, and structurally, it would be able to withstand the pressure and heat of interruption and the magnetic forces produced by the flow of fault current through it. Its connectors would be firmly attached to the circuit-breaker terminals and would hold the external circuit conductors in place regardless of the amount of fault current flow. It would provide perfect electrical isolation of the load from the normal system voltage when open, and it would be able to provide these functions indefinitely regardless of the environment.

3.3 The practical circuit breaker

Circuit breakers do not, of course, perform exactly in the fashion described in 3.2. They have internal impedance, and therefore, they develop a small voltage drop while carrying current. The product of the resistive voltage drop and the current is a measure of power loss, which is manifested as heat in the circuit breaker during normal operation. The consequence is that practical circuit breakers warm up during operation.

When properly applied within their ratings and when they are in good operating condition, practical circuit breakers can interrupt any overcurrent that occurs in the circuit in which they are applied. They can do this without undue contact erosion and can withstand the pressure and heat of interruption as well as the magnetic forces produced by fault current.

¹Information on references can be found in 3.43.

The process of interruption will not damage the operating mechanism, trip unit, or supporting frame. As their contacts do experience some erosion, they can only perform a limited number of switching and interrupting operations without maintenance. Circuit breakers that cannot be maintained should be replaced whenever wear and tear reaches certain limits. Properly sized and properly torqued connectors attached to the circuit breaker terminals can hold conductors firmly in place. That is, the connectors must fit the circuit breaker terminals, the connectors must be compatible with the conductor material (AL or CU or AL/CU), and the conductor stranding and compression must be compatible with the connector.

Circuit breakers can provide adequate disconnecting capability to isolate the load from recovery voltage transients, surges, and normal voltage, and they can provide adequate service.

3.4 Basic circuit-breaker selection criteria

The selection of a circuit breaker, for any given duty, is ultimately based on an assessment of its ability to perform the following basic functions:

- a) To carry the required current without overheating (i.e., it should have the correct current rating)
- b) To switch and isolate or disconnect the load from the source at the given system voltage (i.e., it should have the correct voltage rating)
- c) To interrupt any abnormally high operating current or short-circuit current likely to be encountered during operation (i.e., it should have the correct interrupting rating)
- d) To be able to perform these functions over an acceptably long period of time under the operating and environmental conditions that will actually prevail in the application (i.e., it should have the correct mounting provisions, enclosure, and operating endurance and have the required accessories for operation in the environment in which it is applied)

The degree to which a circuit breaker can satisfy these requirements is a measure of its applicability for a function. A circuit breaker's rating indicates these capabilities to the user because rating is established by proof testing. Hence, an understanding of how a circuit breaker is tested and given its rating will give insight into its applicability for any function.

3.5 The role of industry standards

The primary vehicle for ensuring commonality in performance among circuit breakers of the same rating produced by different manufacturers is a product standard. Standards represent the consensus of manufacturers, testing organizations, users, and others about what a given product should be able to do. Standards establish the design tests that each manufacturer must perform and pass to claim a rating and to be in compliance with that standard. Some standards include requirements for periodic follow-up testing that, in effect, continues to sample the capabilities of newly manufactured circuit breakers. This

testing assures that they maintain the capabilities of their product ratings. Standards also provide for monitoring the quality of the materials used in the construction of circuit breakers and the quality of the workmanship in the manufacturing process.

As stated, standards requirements for the different classes of circuit breakers establish a basis for minimum performance. Circuit breakers may prove by test to perform better than their product ratings indicate, but they can never be permitted to perform worse. The user, however, may never assume that a circuit breaker can perform better than its rating indicates and should realize that there are manufacturing variations among mass-produced products. The levels of performance required by the standards for the minimum acceptable performance of different classes of circuit breakers will be the primary references in the discussion that follows.

3.6 The role of safety and industry codes

Safety and industry code requirements have evolved over the years. These codes reflect experience in actual application over the years. The Occupational Safety and Health Act (OSHA) [B12]² is the primary legal safety code in the United States, and the NEC is the primary safety code for installations. The NEC is often made part of state and local law, but to be effective, it must be accepted by the authority having jurisdiction. However, it can be ignored by local bodies and it can be modified. Other safety standards are the National Electrical Safety Code[®] (NESC[®]) (Accredited Standards Committee C2-2007) [B1] sponsored by the IEEE, NFPA 70B-2002 [B10], and NFPA 70E-2004 [B11]. Industry practices vary between industries and may vary from location to location in the same industry. The NEC and other industry codes for application may either make use of available circuit-breaker product features or they may influence the development of them. The feature of the sealable cover over the trip adjusting mechanism of a circuit breaker, described later, indicates how code provisions can affect product design and installation economics.

3.7 Comparison of testing requirements

In most cases, a meaningful one-to-one comparison of test procedures will not be possible. It will be seen that tests of different types of circuit breakers differ, and without the exact testing, comparisons of the severity of tests can only be made subjectively. There are also some local differences in interpretation of the requirements of the NEC and other specific industry safety codes that make them also somewhat subjective. Only consideration and evaluation of the whole set of application requirements will permit a confident selection of a type of circuit breaker to be made. This chapter addresses many of the details that should be evaluated.

²The numbers in brackets correspond to those of the bibliography in 3.44.

3.8 Circuit-breaker classes and types

For low-voltage circuit protection in the United States, circuit-breaker designs and tests are based on the requirements of three standards organizations: the American National Standards Institute (ANSI), the Underwriters Laboratories (UL), and the National Electrical Manufacturers Association (NEMA). The two classifications of circuit breakers these organizations define are as follows:

- Molded-case circuit-breaker class
- Low-voltage power circuit-breaker class

Three types of circuit breakers are based on the two classifications above. The classifications lend their names to the first two of the three types, whereas the third type, derived from the molded-case circuit-breaker class, is known as an insulated-case circuit breaker. The three types of circuit breakers are as follows:

- Molded-case circuit breakers (MCCBs)
- Low-voltage power circuit breakers (LVPCBs)
- Insulated-case circuit breakers (ICCBs)

Some salient features of these types of circuit breakers are as follows.

MCCBs, as a class, are those tested and rated according to UL 489-1994 and whose current-carrying parts, mechanisms, and trip devices are completely contained within a molded case of insulating material. MCCBs are available in the widest range of sizes, from the smallest (15 A or less) to the largest (6000 A) and with various interrupting ratings for each frame size. They are characterized generally by fast interruption short-circuit elements. With electronic trip units, they can have limited short-delay and ground-fault sensing capability. Virtually all MCCBs interrupt fast enough to limit the amount of prospective fault current let-through, and some are fast enough and limiting enough to be identified as current-limiting circuit breakers. MCCBs are not designed to be field maintainable.

ICCBs are also rated and tested according to UL 489-1994. However, they use characteristics of design from both the power and molded-case classes. They are of the larger frame sizes, fast in interruption, but normally not fast enough to qualify as current-limiting circuit breakers. ICCBs also use electronic trip units and can have short-time ratings and ground-fault current sensing. They use stored energy operating mechanisms similar to those designed for LVPCBs, and their design is such that they are partially field maintainable.

LVPCBs are rated and tested to satisfy ANSI C37 standard requirements and are used primarily in drawout switchgear. They are generally characterized as being the largest in physical size. They have short-time ratings, but they are not fast enough in interruption to qualify as current-limiting. LVPCBs are designed to be maintainable in the field.

The ANSI C37 series of standards were jointly developed by IEEE and NEMA and apply to LVPCBs. UL 489-1994 was developed by the Underwriters Laboratory in consultation with manufacturers and users, and it applies to ICCBs and MCCBs.

3.9 Generalized application considerations

Relative to the physical details of design and application, MCCBs are most often applied fixed mounted; however, drawout mechanisms have been designed for some of the largest ones and plug-in mechanisms have been designed for some of the smaller ones. Larger MCCBs are designed to use interchangeable trip units. They can be either thermal-magnetic trip units using bimetallic overload elements and electromagnetic overcurrent trips or they can be electronic trip units incorporating electrical analog or digital logic circuits to calculate current levels and initiate tripping functions. They usually derive operating power from current sensors mounted in the circuit breakers themselves.

ICCBs are used primarily in fixed mounted switchboards, but because of their size and weight, they are frequently mounted using drawout mechanisms. ICCBs are designed primarily to use interchangeable state-of-the-art electronic trip units.

While considering the merits of maintainability in circuit breakers, it is well to remember that although MCCBs and ICCBs are not designed to be field maintainable, they are designed to have relatively high endurance capabilities that should be evaluated in any application.

LVPCBs are always used in enclosures and because of their large size and weight are essentially always applied in drawout construction. Fixed mounting is an option rarely used. Drawout mechanisms not only minimize the work required in circuit breaker installation and maintenance, but they also facilitate rapid changeout, which minimizes system downtime. It is especially important when the circuit breaker to be changed out is a main and a building or plant shutdown is necessary to change it. Drawout mechanisms also facilitate the performance of regular field inspection and maintenance services.

LVPCBs can use a variety of trip units. Some of the latest versions of electronic trip units they use are also used in large MCCBs and ICCBs. Significant differences in the total operating times of different circuit breakers using the same types of trip units are accounted for in specific time-current curves (TCCs) published for the different circuit-breaker and trip unit combinations.

3.10 References on rating and application

For new equipment, the latest version of standards should always be used for circuit-breaker information. For older equipment, the version of the standards that was in effect when the circuit breaker was manufactured should be referenced.

Preferred ratings and application recommendations for LVPCBs are given in ANSI C37.16-1997. Standards for low-voltage ac power circuit breakers used in enclosures are given in IEEE Std C37.13TM-1995, and test procedures for LVPCBs used in enclosures are

given in ANSI C37.50-1989. Application factors are discussed in the IEEE C37.20™ standards. LVPCBs are generally UL Listed and can be UL Labeled. Ratings and test procedures for MCCBs and ICCBs are found in UL 489-1994. Other *IEEE Color Books*® complement this book, offering a complete and comprehensive source of application information for all three types of circuit breakers.

3.11 Endurance considerations

Table 3-1, Table 3-2, and Table 3-3 summarize some specific mechanical and electrical endurance test parameters. The information in these tables is taken from ANSI C37.50-1989 and UL 489-1994. These standards do not lend themselves to one-to-one comparison. The tests or test conditions are different. It is necessary to make subjective judgments to determine which test procedure might be more severe than another.

Although choices may be made by subjective judgment of test procedures, an alternative method is to follow established practices that have a history of long-term successful performance. Fortunately, information on these practices is often available in the engineer's own facility, and if it is not, references such as IEEE Std 493™-1990 [B9], which discusses reliability in general and contains sets of data that can be of assistance in decision making, can be consulted. The comments in this chapter may be sufficient to resolve some questions on evaluation, but sometimes they may be sufficient only to indicate a direction for further, more detailed engineering investigation.

Other aspects of application, such as the size or weight of a circuit breaker, or its physical placement in a building or facility, spares availability or its maintenance requirements, and not factors directly pertaining to electrical rating and testing, can have an impact on the selection.

Table 3-1—Circuit-breaker endurance test parameters^a

Parameter	UL-489-1994	ANSI C37.50-1989
Enclosure	Smallest individual or open if mounted on metal plate	Minimum dimension test enclosure
Current	Rated	Rated
Voltage	100–105% Rated	100–105% Rated max (254 V, 508 V, or 635 V)
Power factor (ac)	0.75–0.80	0.85 max
Time constant (dc)	Not defined	Not covered
Frequency	48–62 Hz	48–72 Hz
Ambient	Not defined	Not defined
Ground fuse	30 A	30 A or 10 AWG (copper)

^aReprinted from: “Panel Discussion on Application of Molded-Case Circuit Breakers” [B13].

Table 3-2—Endurance test operations^d

Preferred frame sizes for MCCBs and ICCBs (A)	Number of cycles of operation			
	Per min ^a	With current	Without current	Total
50	6	6000	4000	10 000
100	6	6000	4000	10 000
125	5	4000 ^b	4000	8000 ^b
150	5	4000 ^b	4000	8000 ^b
200	5	4000	4000	8000
225	5	4000	4000	8000
400	4	1000	5000	6000
600	4	1000	5000	6000
800	1	500	3000	3500
1200	1	500	2000	2500
1600	1	500	2000	2500
2000	1	500	2000	2500
2500	1	500	2000	2500
3000	1 ^c	400	1100	1500
4000	1 ^c	400	1100	1500
5000	1 ^c	400	1100	1500
6000	1 ^c	400	1100	1500

^aFor circuit breakers rated more than 800 A, the endurance test may, at the option of the manufacturer, be conducted in groups of 100 load operations. No-load operations may be conducted between groups of load operations at the option of the manufacturer.

^bWhere tests are required on samples having ratings of 100 A or less, 250 V or less, the number of operations shall be the same as for the 100 A frame.

^cRate of operation: 1 cycle/min for first 10 operations; thereafter in groups of 5, at 1 cycle/min, with an interval between groups that is agreeable to all concerned.

^dReprinted from: Table 19.1 of UL 489-1994.

Table 3-3—Circuit-breaker mechanical/electrical endurance test comparison^f

Frame size (A)	Minimum operation rate cycles/hour		Number of operating cycles ^e							
			Between servicing ^b		With current		Without current		Total	
	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989
100	360	—	See Footnote c	—	6000	—	4000	—	10 000	—
150	300	—	See Footnote c	—	4000	—	4000	—	8000	—
225	300	30	See Footnote c	2500	4000	4000	4000	10 000	8000	14 000
400	240	—	See Footnote c	—	1000	—	5000	—	6000	—
600	240	30	See Footnote c	1750	1000	2800	5000	9700	6000	12 500
800	60	30	See Footnote c	1750	500	2800	3000	9700	3500	12 500
1200	60	—	See Footnote c	—	500	—	2000	—	2500	—
1600	60	30	See Footnote c	500	500	800	2000	3200	2500	4000
2000	60	30	See Footnote c	500	500	800	2000	3200	2500	4000

Table 3-3—Circuit-breaker mechanical/electrical endurance test comparison^f (continued)

Frame size (A)	Minimum operation rate cycles/hour		Number of operating cycles ^e							
			Between servicing ^b		With current		Without current		Total	
	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989	UL 489-1994	ANSI C37.50-1989
2500	60	—	See Footnote c	—	500	—	2000	—	2500	—
3000	See Footnote a	30	See Footnote c	250	400	400	1100	1100	1500	1500
4000	See Footnote a	30	See Footnote c	250	400	400	1100	1100	1500	1500
5000	See Footnote a	30	See Footnote c	250	400	400	1100	1100	1500	1500

^aFirst 10 at 60/h; thereafter in groups of 5 at 60/h with interval between as acceptable to all.

^bServicing means adjusting, cleaning, lubricating, and tightening.

^cServicing not permitted.

^dMay be conducted in groups of operations provided at least one group is not less than 120.

^eTests on same breaker—sequence not defined.

^fReprinted from: ANSI C37.50-1989 and UL 489-1994.

3.12 Circuit-breaker voltage rating considerations

MCCBs, ICCBs, and LVPCBs use the same standard nominal system voltages of 600 V, 480 V, and 240 V. However, MCCBs and ICCBs have additional rated voltages of 120 V, 120/240 V, 277 V, 347 V, 480Y/277 V, and 600Y/347 V, and LVPCBs have maximum voltages. A few comments on these considerations can be very instructive.

First, for MCCBs and ICCBs, the nominal voltage levels are maximum “not to exceed” voltages, whereas LVPCBs, on the other hand, have assigned “maximum” voltages of 254 V ac, 508 V ac, and 635 V ac. Second, the slash marks (/) between some voltage ratings have significance to circuit-breaker design, application, and testing. NEC 240.83 refers to straight and slash voltage marking in a fine print note (FPN), which is quoted as follows:

A circuit breaker with a straight voltage marking, e.g., 240 V or 480 V, may be applied in a circuit in which the nominal voltage between any two conductors does not exceed the circuit breaker’s voltage rating; except that a two-pole circuit breaker is not suitable for protecting a 3-phase corner-grounded delta circuit unless it is marked 1-phase/3-phase to indicate such suitability.

A circuit breaker with a slash rating, e.g., 120/240 V or 480Y/277 V, may be applied in a circuit in which the nominal voltage to ground from any conductor does not exceed the lower of the two values of the circuit breaker’s voltage rating and the nominal voltage between any two conductors does not exceed the higher value of the circuit breaker’s voltage rating.

Voltage is a sensitive factor in interruption, and circuit-breaker voltage rating is a significant factor in applications. That significance can be seen most readily in that different interrupting ratings are assigned to the same circuit breaker at different system voltages. The ratings are proven in testing.

Because of the benefits and associated limitations of different types of grounding systems, testing of slash voltage-rated circuit breakers is different from the testing of straight voltage-rated circuit breakers. IEEE Std 142™-1991 [B6] discusses grounding considerations in detail. Slash voltage-rated circuit breakers take advantage of the fact that the power system neutral is fixed at ground potential. Table 3-4 indicates the various tests required of MCCBs and ICCBs as a function of the different numbers of poles of the circuit breaker and the different voltage ratings to be applied. More detail on the tests and the circuits they are performed in follows. Table 3-4 emphasizes the significant difference in testing required for circuit breakers to be rated with a straight voltage and those to be rated with a slash voltage. The NEC FPN is an excellent reminder of the significance of voltage rating.

See Figure 3-1 for test circuit details.

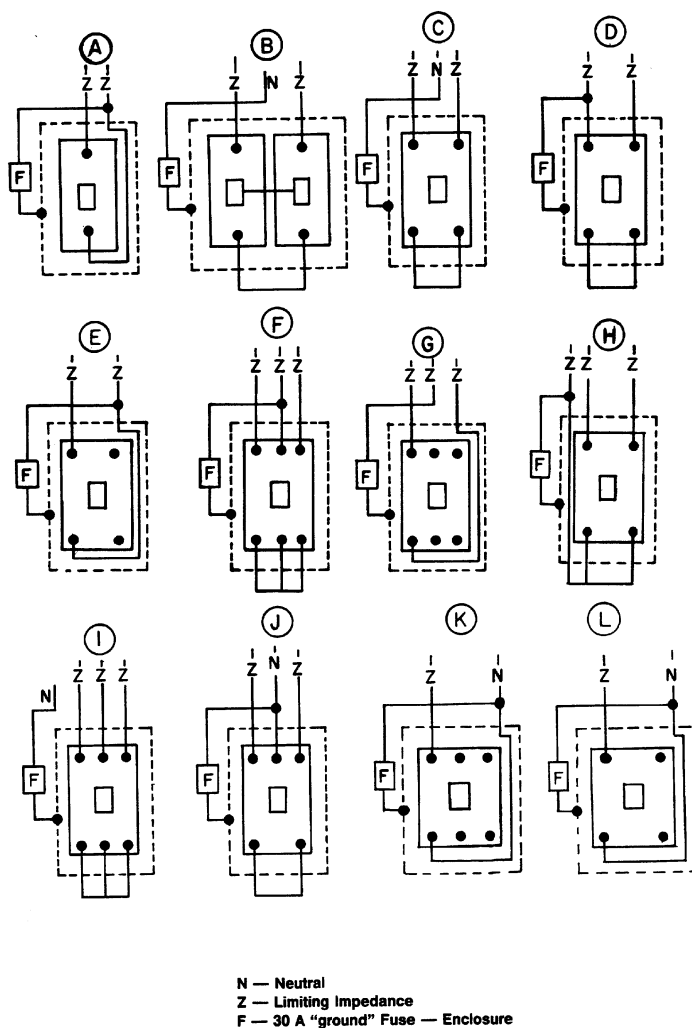
For insulation testing, LVPCBs, MCCBs, and ICCBs are subjected to a 2200 V ac dielectric withstand voltage test, or an equivalent dc test, when new.

Table 3-4—MCCB and ICCB interrupting ability operations ^{a, b}

Poles	Frame rating	Circuit-breaker ac voltage rating	Letters indicate diagram in Figure 21.1 of UL 489-1994						Total number of operations
			Operations of each pole			Common operations			
—	—	—	O	CO	O	O	CO	O	—
—	—	—	—	—	—	—	—	—	—
1	All	120, 240, 277, 347, 480, or 600	A	A	A	—	—	—	3
1	All	120/240 (tested in pairs)	—	—	—	B	B	B	3
2	All	240, 480, or 600	E	E	—	D	—	—	5
2	All	120/240	—	—	—	C	C	C	3
2	0–1200 A	480Y/277 or 600Y/347	L	L	—	C	—	—	5
2	All	1ϕ—3ϕ	E	E	—	H	—	—	5
3	0–1200 A	240, 480, or 600	G	G	—	F	—	—	7
3	1201–Up	240, 480, or 600	G	G	—	F	—	—	7
3	All	120/240	—	—	—	J	J	J	3
3	0–1200 A	480Y/277, 600Y/347	K	K	—	I	—	—	7
3	1200–Up	480Y/277, 600Y/347	K	K	—	I	—	—	7

^aFor the 125/250 V dc rating, the number of operations is the same as for the 120/240 V ac rating. For the 250 V dc rating, the number of operations is the same as for the 240 V ac rating.

^bReprinted from: Table 22.1 of UL 489-1994.



Reprinted from: Figure 22.1 of UL 489-1994.

Figure 3-1—Interrupting ability test ability diagrams

3.13 Frequency rating and considerations

In the United States, MCCBs, ICCBs, and LVPCBs are all basically rated for 60 Hz operation. Whenever they are capable of being applied at other frequencies, they are marked to indicate those other frequencies. For operation at any frequency not specifically indicated as applicable, the manufacturer should be consulted. Sometimes no changes are required in performance specifications. Sometimes it may simply be necessary to recalibrate a circuit-breaker trip unit for operation at the new frequency. Other times, for application at both lower or higher frequencies or for dc, a different trip unit may have to

be used or the circuit breaker may have to be de-rated. Occasionally, application of a given circuit breaker might have to be absolutely prohibited at another frequency or dc.

At higher frequencies, the phenomena of eddy currents and skin effect have significance. They affect circuit-breaker components such as the primary current-carrying conductors or the iron cores of sensors and/or accessory devices. The extent of their effects on operation determines whether a given circuit breaker can be de-rated for use or cannot be used at all at higher frequency. At lower frequencies or dc, the method of current sensing may dictate whether a given circuit breaker can or cannot be used. Obviously, a circuit breaker using transformer action for current sensing in its trip unit cannot be used for dc applications.

3.14 Temperature considerations

Temperature affects circuit-breaker operation in that below some limiting low temperature, mechanism operation will not be reliable due to possible freezing of condensation inside the circuit breaker, freezing of lubricants, and/or mechanical interference effects caused by changes in physical dimensions of components. Also, physical properties of materials may change. With extreme cold, some materials might tend toward brittleness. Temperature also affects circuit-breaker operation in that above some limiting high temperature, the mechanism operation will not be reliable because the physical or electrical strength limits of some materials may be reduced to marginal levels. Some materials can begin to melt, and the useful life of insulation will be seriously reduced. Each of these factors should be considered in detail by the circuit-breaker designer and taken into account by the application engineer.

Total temperatures to which some insulating materials in LVPCBs may be subjected are listed in Table 3-5. These data are used by circuit-breaker designers. Users of circuit breakers need only ensure that operation of the complete equipment will take place within the maximum and minimum limiting ambient temperatures.

The standard operating ambient temperature range for MCCBs and ICCBs is -5°C to $+40^{\circ}\text{C}$ (23°F to 104°F). The standard operating ambient temperature range for LVPCBs is also -5°C to $+40^{\circ}\text{C}$ (23°F to 104°F), but IEEE Std C37.20.1TM-1993 permits the temperature of the cooling air surrounding the enclosure of low-voltage switchgear to be within the range of -30°C to $+40^{\circ}\text{C}$ (-22°F to $+104^{\circ}\text{F}$).

Since circuit breakers applied in temperatures outside their operating ranges may malfunction, the user should provide the operating conditions required to keep the temperature surrounding the assemblies and circuit breakers in their safe operating range. Sometimes it will mean that space heaters are required inside an enclosure to prevent condensation. Other times, special enclosures will be required not only for temperature control, but also possibly for environmental protection against contamination by particulate matter, liquids, or gas vapors. When extreme cold or hot ambient conditions are possible, the addition of separate heating or air cooling systems is necessary.

Table 3-5—Limits of temperature in circuit-breaker components ^c

	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 166 insulation	115	155
Class 180 insulation	140	180
Class 220 insulation	180	220
Circuit-breaker contacts, conducting joints, and other parts (except the following)	85	125
Fuse terminals	See Footnote a	See Footnote a
Series coils with over class 220 insulation or bare	See Footnote a	See Footnote a
Terminal connections	55	95

^aNo specified limit except not to damage adjacent parts.

^bTerminal connection temperatures are based on connections to bus in low-voltage metal-enclosed 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.

^cSource: IEEE Std C37.13-1995.

Sometimes forced ventilation alone can be sufficient to transfer enough heat to maintain an acceptable temperature, and therefore, the use of increased forced air flow rather than the addition of air cooling equipment can be of economic advantage. When ventilating fans are used to establish current-carrying capability, it should be remembered that the current-carrying capability so obtained is now dependent on the operation of the fans, and fan performance may need monitoring.

Any necessary separate heating or air cooling equipment that is required for an application should be provided in the system design. It should be kept in mind that this equipment can be costly, can be heavy, and will occupy space. However, to obtain design life operation of switchgear and circuit breakers, ambient temperature limitations should be observed.

3.15 Enclosure considerations

All circuit breakers are fully rated for operation in free air at their listed maximum ambient temperature. All LVPCBs are applied in enclosures and all are fully rated for

operation in their design enclosures with maximum design ambient temperature. LVPCBs are therefore said to be 100% rated. Some MCCBs are also 100% rated.

The requirements for 100% rating of MCCBs are given in paragraph 19.25 of UL 489-1994. Parts of some pertinent details concerning 100% rating are as follows:

- a) “A circuit breaker may be rated for continuous operation at 100% of its ampere rating if it (1) is of a frame size rated 250 A or more or a multi-pole type of any ampere rating and rated higher than 250 V...”
- b) The candidate circuit breaker is tested for compliance with the 100% rating criteria in “an enclosure that is representative of the smallest enclosure with which the circuit breaker is likely to be used.”
- c) For compliance, “The temperatures of the insulating materials used in the circuit breaker shall not exceed the limits for the material involved,” and “The temperature rises (1) where connections are made to external bus bars, when bus bars are used; or (2) on a wiring terminal at a point to which the insulation of a wire is brought up... shall not exceed 60 °C (140 °F)...”

When the total terminal temperature in contact with insulation is 90 °C (194 °F), then a 90 °C (194 °F) rated conductor should be used. The minimum enclosure size for 100% rated application of MCCBs is indicated on the instruction sheet furnished with the circuit breaker and on the circuit breaker nameplate.

MCCBs that are not 100% rated are capable of operation in an enclosure at their rated maximum temperature at 80% of their free air current rating. Effective de-rating to 80% in application results from NEC rules stating that (1) the circuit must be wired for and the rating of the overload device shall not be less than the noncontinuous load plus 125% of the continuous load and that the circuit must be wired for 125% of full load ampacity, and (2) the circuit breaker must be applied according to the ampacity of the circuit. NEC Section 215.3, Exception #1 points out that the circuit-breaker rating should not be less than the non-continuous load plus 125% of the continuous load. Even with all continuous load, this results in the circuit breaker effectively being applied at no more than 80% of conductor ampacity or 80% of its own free air current rating.

NEC rules account for the application of 100% rated MCCBs by stating that

Where the assembly, including the over current devices protecting the feeder(s), is listed for operation at 100 percent of its rating, the allowable ampacity of the feeder conductors shall be permitted to be not less than the sum of the continuous load plus the noncontinuous load.

Because circuit breakers are tested and rated to account for these factors, engineers should be aware of all aspects of the application and installation environment and specify circuit breakers tested to satisfy all of them.

3.16 Cable, wire, and conductor considerations

The type, size, strand configuration, and compression of cable or wire conductor intended to be connected to a circuit breaker is an important application consideration and should satisfy at least two size requirements. First, the NEC requirement for load-carrying ability states that feeder conductors shall have sufficient ampacity to supply the load served. Rules of the NEC should be followed to establish the minimum acceptable wire size for the circuit. Second, if the 75 °C rated wire size of Table 3-6 is not used for the circuit, then it should be used in the last 4 ft of the circuit to satisfy the circuit breaker requirements. To satisfy voltage drop requirements, the circuit conductors might be sized a little larger, but they must always be able to fit into the circuit breaker connectors. They can never be sized a little smaller. Circuit-breaker conductors also serve as conductive heat sinks for the circuit breaker. It is for the heat sinking requirement that the conductors should have a minimum cross-sectional conductor area equal to the cross-sectional conductor area of the 75 °C (167 °F) rated wire specified in Table 3-6 for a given terminal current. The wire insulation temperature rating should, of course, match the application.

Even though MCCBs are designed to operate in a 40 °C (104 °F) maximum ambient, the operating ambient temperature is not always 40 °C (104 °F). UL 489-1994 allows for the surface of conductor insulation to rise 35 °C (rise 63 °F) above the normal ambient, which might be 25 °C (77 °F), a common normal room temperature, giving a total temperature of 60 °C (140 °F). With the maximum permissible rise of 50 °C (90 °F rise) on the terminals during temperature test, and again with a 25 °C (77 °F) ambient, the total temperature would be 75 °C (167 °F). These numbers are the basis for the 60 °C or 75 °C or 60 °C/75 °C conductor insulation ratings specified for the conductors used with MCCBs rated 125 A or less. For MCCBs rated greater than 125 A, the 75 °C conductor insulation rating is normal (called rated wire). When an MCCB is 100% rated, the maximum permissible terminal temperature rise during test is 65 °C (117 °F rise). When added to a 25 °C (77 °F) ambient, the total is 90 °C (194 °F). UL 489-1994 rules require that if the terminal temperature rise during 100% rating test exceeds 50 °C (90 °F rise), then the circuit breaker should be marked “For use with 90 °C (194 °F) wire and the wire size.” The nameplate, in that case, would be marked accordingly.

Designers may want to use smaller, higher temperature rated wire. The application engineer should remember that when 90 °C (194 °F) insulated conductor is specified for a given ampacity, the cross-sectional area of the metal conductor inside the 90 °C (194 °F) rated insulation will generally be smaller than the cross-sectional area of the normal 75 °C (167 °F) rated conductor that was used to proof test the circuit breakers. If it is smaller, it will not be able to provide sufficient heat sinking capacity for normal circuit-breaker performance and should not be used. Therefore, conductors connected to circuit breakers should always have a cross-sectional area equal to at least that of the 75 °C (167 °F) rated conductor specified for the application.

A properly sized conductor, in addition to having sufficient ampacity, will also be stranded to satisfy the requirements of the circuit-breaker terminals or connectors. It will have a sufficient cross section to adequately heat sink the circuit breaker, it will be insulated for the temperature conditions existing in all spaces through which it will pass, and it will be able to withstand fault-interrupting forces and temperature changes without

experiencing inordinate damage. Circuit breakers are tested with a rated conductor to prove these capabilities. Therefore, the rated wire size is sufficient for normal operation.

Many operating problems with circuit breakers start at the terminals. Therefore, all connectors used to connect conductors to circuit breakers at both the line side and the load side should be properly matched for size, material, and temperature rating, and it should always be confirmed that they fit the circuit-breaker terminals, that they are clean, properly coated with anti-oxidants when required and that they are torqued properly when installed. The connectors should be able to firmly hold the conductors in place against the forces that are imposed on them during short circuits. Standard interruption tests prove they can. It may be necessary to rope-tie conductors into place in some cases. When this approach is necessary, instruction sheets describe how it is to be done. The number of strands making up stranded conductor is an important factor in how well connectors can hold conductors against magnetic forces. See Table 8 of Chapter 9 of the NEC for a listing of normal conductor stranding to be used for circuit-breaker wiring, and see the notes below that table. The NEC requires stranding for conductors of size 8 AWG and larger.

Note that very flexible, finely stranded conductor, sometimes called welding cable, should not be used unless the connector is designed for it because the fine stranding is difficult or impossible to constrain under some standard terminal clamps. Sometimes the fine strands squeeze out from under the clamp, gradually loosening the connection. At the other extreme, conductors with fewer strands, but not compressed, can sometimes be tightly held with the first tightening, but as the conductor goes through heat expansion and contraction cycles or if the conductor is forced to move physically, the strands can rearrange themselves under the clamp, again resulting in a loose connection. Nothing could be worse for a circuit breaker. The higher resistance of loose conductors generates excess heat with rated current flow. The connectors specified by the manufacturer of the circuit breaker should be used because they are the ones used in proof testing. For more information on connectors and conductors, the interested reader is referred to the UL 486 series of standards on connectors (UL 486A-1991 [B14], UL 486B-1991 [B15], UL 486C-1991 [B16], UL 486D-1993 [B17], and UL 486E-1994 [B18]).

These factors affect circuit-breaker operating temperature and are as important as ampacity. They are taken into account in the design and proof testing of circuit breakers.

As referred to previously, UL 489-1994 requires in paragraph 49.30 that

A circuit breaker, circuit breaker frame or interchangeable trip unit rated 125 A or less shall be marked as being suitable for 60 °C(140 °F), 75 °C (167 °F) only or 60/ 75 °C (140/167 °F) wire.

The UL listed wire size and type should be used. Table 3-6 lists “rated wire sizes” for the various terminal currents or circuit currents. For proper circuit-breaker application, these wire sizes are a necessity. They are the sizes used in proof testing of circuit-breaker designs.

Table 3-6—Terminal current and conductor size ^d

Terminal current (A) ^a	Copper conductor			Aluminum or copper-clad aluminum conductor		
	No. of conductors	Size (AWG or kcmil)		No. of conductors	Size (AWG or kcmil)	
		60 °C	75 °C		60 °C	75 °C
15 or less	1	14	14	1	12	12
20	1	12	12	1	10	10
25	1	10	10	1	10	10
30	1	10	10	1	8	8
40	1	8	8	1	6	8
50	1	6	6	1	4	6
60	1	4	6	1	3	4
70	1	4	4	1	2	3
80	1	3	4	1	1	2
90	1	2	3	1	1/0	2
100	1	1	3	1	1/0	1
110	1	1	2	1	—	1/0
125	1	1/0	1	1	—	2/0
150	1	—	1/0	1	—	3/0
175	1	—	2/0	1	—	4/0
200	1	—	3/0	1	—	250
225	1	—	4/0	1	—	300
250	1	—	250	1	—	350
275	1	—	300	1	—	500
300	1	—	350	1	—	500
325	1	—	400	2	—	4/0
350	1	—	500	2	—	4/0
400	2	—	3/0	2	—	250
	1 ^c	—	500	1 ^c	—	750
450	2	—	4/0	2	—	300
500	2	—	250	2	—	350
550	2	—	300	2	—	500
600	2	—	350	2	—	500
700	2	—	500	3	—	350

Table 3-6—Terminal current and conductor size (continued)^d

Terminal current (A) ^a	Copper conductor			Aluminum or copper-clad aluminum conductor		
	No. of conductors	Size (AWG or kcmil)		No. of conductors	Size (AWG or kcmil)	
		60 °C	75 °C		60 °C	75 °C
800	3	—	300	3	—	400
1000	3	—	400	4	—	350 600
1200	4 3	—	350 500	4	—	500
1400	4	—	500	5	—	500
1600	5 4	—	400 600	5	—	600
2000	5	—	400 600	6	—	600
2500	8 7 6	—	400 500 600	8 7 9	—	600 750 500
3000	9 8 7	—	400 500 600	10 9 8	—	500 600 750
4000	12 11 10	—	400 500 600	13 12 11	—	500 600 750
5000 ^b	15 13 12	—	400 500 600	16 15 13	—	500 600 750
6000 ^b	18 16 15	—	400 500 600	19 18 16	—	500 600 750

^aFor a terminal current other than that indicated, the next higher rating is to be used (e.g., if rated 35 A, enter at 40 A).

^bCircuit breakers rated at more than 4000 A are to be considered as being bus- or cable-connected unless indicated otherwise in marking.

^cSee 13.19 of UL 489-1994.

^dReprinted from: Table 9.1 of UL 489-1994.

Maintenance personnel should remember that when a fault occurs, the conductors should be inspected for damage, and all damaged components should be repaired or replaced before reclosing the circuit breaker.

In summary, all conductors intended to be connected to circuit breakers should start with the size of the 75 °C conductor used to establish their rating. They should

- a) Be rated to carry the required maximum full-load current.

- b) Be large enough to limit voltage drop to an acceptable application level.
- c) Be large enough to withstand circuit-breaker fault interruption let-through current.
- d) Be small enough to fit into the circuit-breaker connectors where they can be held tightly in place during a fault.
- e) Be insulated for the rated system voltage.
- f) Be of the correct stranding and construction to permit proper torquing.
- g) Have an insulation temperature rating and composition suitable for the total application.
- h) Be coated with the proper anti-oxidant whenever required, i.e., aluminum conductor terminations.

Testing with wire confirms these considerations.

3.17 De-rating for ambient temperature

MCCBs, ICCBs, and LVPCBs all should be de-rated for their current-carrying capacity when operated in ambient temperatures above their rated maximum. The manufacturer of the circuit breaker should be consulted for the applicable de-rating information for a particular unit. There are formulas for calculation of current de-rating that are based on simplifying assumptions and empirical factors. These formulas should be used with discretion.

For LVPCBs and ICCBs, formula 8.4.1 of IEEE Std C37.20.1™-1993 can be used to determine a continuous-load current capability based on actual ambient temperature, as shown in Equation (3.1):

$$I_a = I_r \left[\frac{\theta_{max} - \theta_a}{\theta_r} \right]^{1/2.0} \quad (3.1)$$

where

- I_a is the allowable de-rated current (A) (never to be more than two times I_r)
- I_r is the rated continuous current (A)
- θ_{max} is the allowable hottest spot total temperature = ($\theta_r + 40$ °C)
- θ_a is the actual ambient temperature (°C) expected
- θ_r is the allowable hottest spot temperature rise (°C) at rated current

The specifying engineer should always refer to the manufacturer for the best possible guidance in de-rating.

For MCCBs using bimetallic overload trips, it is best to consult the manufacturer's temperature de-rating tables for the particular circuit breaker of interest because different bimetallic pairs operate at different temperatures. Obviously, trip mechanism designs and calibration methods can vary. However, the following general guidelines can be used to make rough estimates of expected thermal performance capability. Assuming temperature