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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
Industrial and Commercial Power Systems Department
of the
IEEE Industry Applications Society**

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

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Introduction

(This introduction is not a part of IEEE Std 1015-1997, IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems.)

This recommended practice is a result of a 13-year effort by members of the Low-Voltage Protection Subcommittee of the Power System Protection Committee of The IEEE Industrial Applications Society. This publication, known as the IEEE Blue Book, will be added to the present IEEE Color Book series sponsored by the IAS Industrial and Commercial Power Systems Department.

In the past it was often very difficult and time consuming for an engineer to decide what type of low-voltage circuit breaker to use for a particular application, and how to apply the circuit breaker. The application guidelines and tables were dispersed over many different documents and standards. There was also confusion caused by biases based on the competitiveness between the different product classes. Thus, a working group was formed among the members of the Low-Voltage Protection Subcommittee to write a recommended practice that provides a comprehensive reference source for the selection and application of low-voltage circuit breakers. 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.

To the many members of the working group who wrote and developed this recommended practice, we owe a debt of gratitude for the many hours that were spent writing and editing the IEEE Blue Book chapters. These individuals deserve our many thanks for their excellent contributions.

This IEEE Recommended Practice serves as a companion publication to the following other Recommended Practices prepared by the IEEE Industrial and Commercial Power Systems Department:

- IEEE Std 141-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book).
- IEEE Std 142-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book).
- IEEE Std 241-1990, IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (IEEE Gray Book).
- IEEE Std 242-1986, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book).
- IEEE Std 399-1990, IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE Brown Book).
- IEEE Std 446-1995, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (IEEE Orange Book).

- IEEE Std 493-1990, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book).
- IEEE Std 602-1996, IEEE Recommended Practice for Electric Systems in Health Care Facilities (IEEE White Book).
- IEEE Std 739-1995, IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities (IEEE Bronze Book).
- IEEE Std 1100-1992, IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (IEEE Emerald Book).

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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 ground-fault circuit interrupters (GFCIs), marine circuit breakers, definite purpose circuit breakers, and supplementary circuit protectors. This recommended practice also does not discuss dc applications.

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 the following:

- 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 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 489-1991.¹ 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 489-1991. As with other MCCBs, ICCB current-carrying parts, mechanisms, and trip units are contained within a molded case of insulating material. The case is designed so 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 Std C37.16-1988
- ANSI Std C37.17 -1979
- ANSI Std C37.50-1989
- IEEE Std C37.13-1990
- UL 1558-1993

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.

¹Information on references can be found in 1.7.

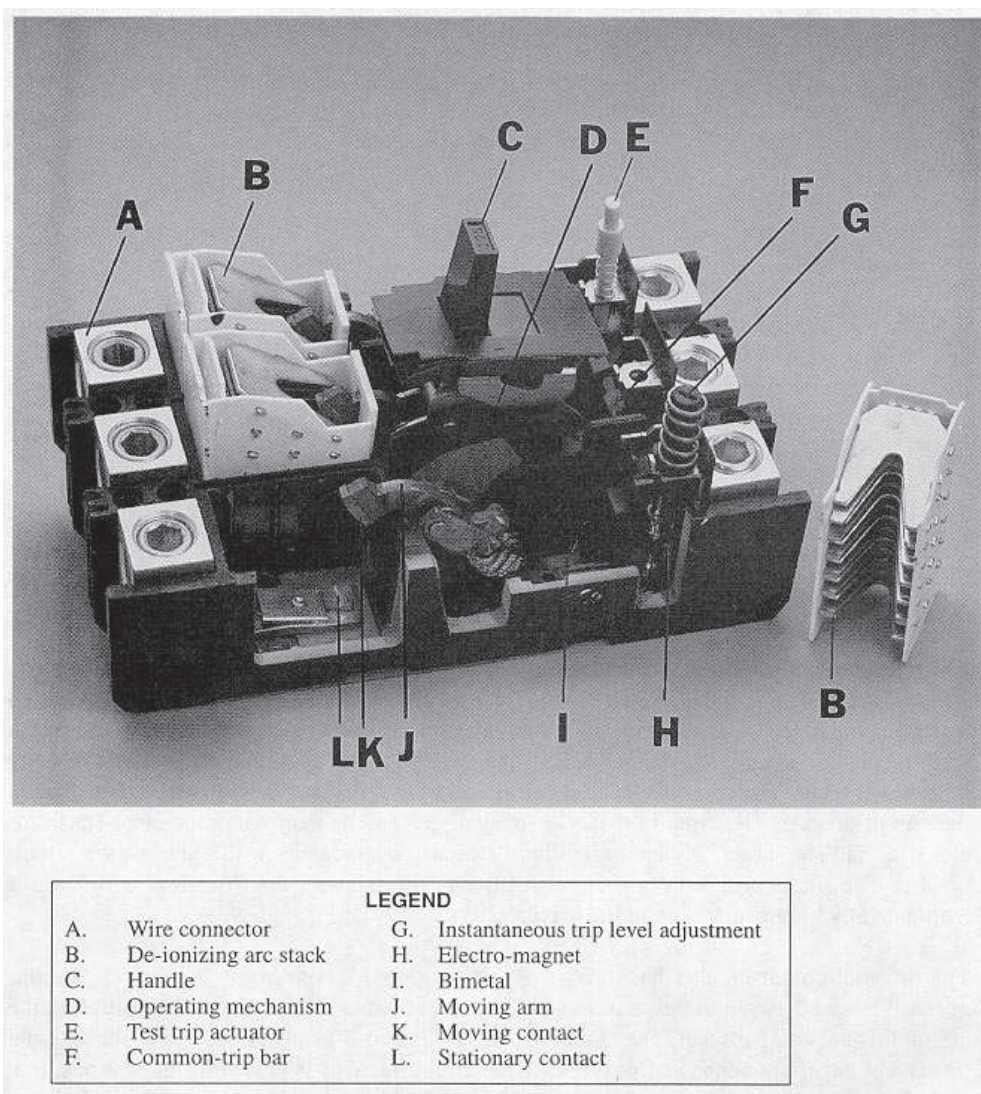
1.3 Description of a molded-case circuit breaker

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 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. Other 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

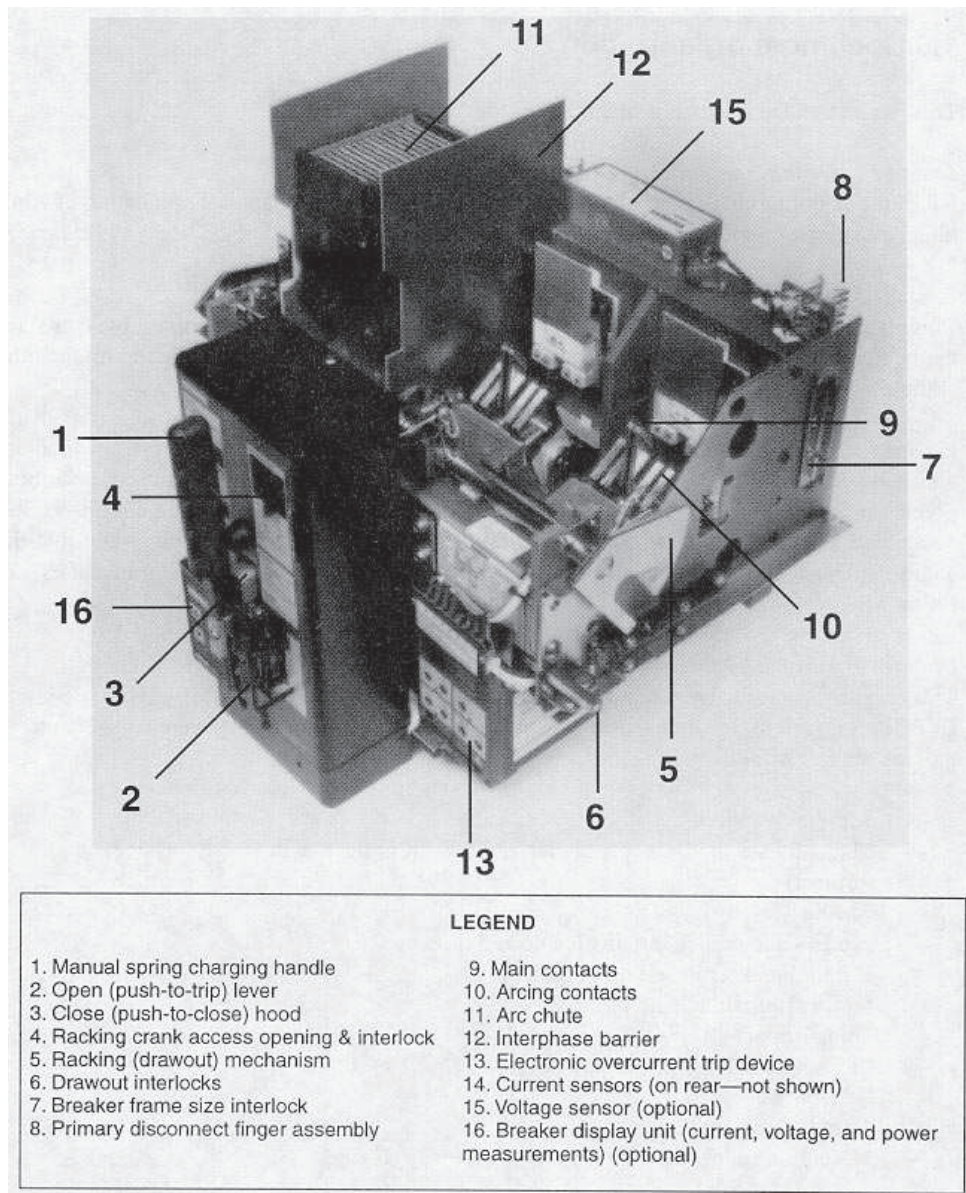
Figure 1-2 is a view of a partially disassembled, manually operated, drawout LVPCB. The open construction permits access to the circuit-breaker parts for maintenance and parts replacement. Numbers are used to indicate the various elements of the circuit breaker. A description of each element is listed in the legend. The following is a description of the operation of the circuit breaker starting with the open position. The circuit breaker condition “open” is indicated on the face of the circuit breaker. In order 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: “connected,” “test,” and “disconnected.” 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 connected 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 connected position and control circuits in the connected and test positions, respectively.



Source: Square D Company.

Figure 1-1 — Cutaway view of a typical MCCB



Source: Siemens Energy & Automation, Inc.

**Figure 1-2—Low-voltage ac power circuit breaker—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 and acronyms.

All of the major terms used in other chapters are defined in this chapter. For a listing of additional electrical definitions, refer to IEEE Std 100-1996 and IEEE Std C37.100-1992.

Chapter 3: Rating and testing.

This chapter summarizes the application parts of recognized low-voltage circuit breaker standards. For more details in 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, the National Electrical Code[®] (NEC[®]) (NFPA 70-1996), Section 110-3(b), 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 include the following:

- Service entrances
- Mains (buses and busway, feeder and branch protective devices, and line-side transformers)
- Bus tie
- 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

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

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.

In order 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 NEC and ANSI protection requirements. Coordination between devices is often sacrificed when continuity of service is not critical because of the additional equipment cost. This chapter shows how to coordinate different combinations of devices, and provides typical settings.

Chapter 6: Special-purpose circuit breakers.

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

- Instantaneous only
- Mine duty
- Current limiting
- Molded-case switch
- Integrally fused

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.

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. A circuit breaker may be damaged during shipment, or defective components may be present. This chapter provides instructions for performing and documenting test results. Some of the 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 ensures the correct operation of circuit breakers 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 switching or tripping. 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 making a decision 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 References

This chapter shall be used in conjunction with the following publications:

ANSI C37.16-1988 (Reaff 1995), American National Standard for Switchgear—Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors—Preferred Ratings, Related Requirements, and Application Recommendations.²

ANSI C37.17-1979 (Reaff 1988), American National Standard for Trip Devices for AC and General Purpose DC Low-Voltage Power Circuit Breakers.

ANSI C37.50-1989 (Reaff 1995), American National Standard for Switchgear—Test Procedures for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms.³

IEEE Std C37.13-1990 (Reaff 1995), IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures (ANSI).

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

NFPA 70-1996, National Electrical Code[®] (NEC[®]).⁴

UL 489-1991, Molded-Case Circuit Breakers and Circuit-Breaker Enclosures (DoD).⁵

UL 1558-1993, Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

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⁵UL standards are available from Global Engineering, 1990 M Street NW, Suite 400, Washington, DC, 20036, USA.

Chapter 2

Definitions and acronyms

2.1 Definitions

Definitions of terms used in this recommended practice are noted in this chapter. Definitions taken from other references identify the source in parentheses following the definition.

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 and/or time within a predetermined range. (NFPA 70-1996)¹

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.

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. (NFPA 70-1996)

2.1.6 continuous current: A current that is expected to continue for three hours or more.

2.1.7 coordination: Properly localizing a fault condition to restrict outages to the equipment affected, accomplished by a choice of selective fault-protective devices. (NFPA 70-1996)
Syn: **selectivity.**

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 to a value less than the I^2t of a 1/2 cycle wave of the symmetrical prospective current. (UL 489-1991)
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, will reduce the current flowing in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device were

¹Information on references can be found in 2.3.

replaced with a solid conductor having comparable impedance. (NFPA 70-1996) *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 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 disconnected positions only when the breaker contacts are in the open position. (NEMA AB 1-1993)

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

2.1.12 electrical operator: A controlling device that is used to open, close, and reset a circuit breaker. Editor's note: The term motor operator is sometimes used when the operating device is a motor. (UL 489-1991)

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. (UL 489-1991)

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. (UL 489-1991)

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

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. (NFPA 70-1996)

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: $I^2t = I^2(t) dt$ over the stated period, in units of amperes-squared seconds. (UL 489-1991) (NEMA AB 1-1993)

2.1.20 instantaneous pickup: The nominal value of current at which an adjustable circuit breaker is set to trip instantaneously. (NEMA AB 1-1993)

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. (NFPA 70-1996)

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 dampening action to ride through initial motor transients. (NEMA AB 1-1993)

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. (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. (NFPA 70-1996)

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. (NFPA 70-1996)

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 breaker's inverse time characteristic. (NEMA AB 1-1993)

2.1.29 long-time pickup: The current at which the long-time delay function is initiated. (NEMA AB 1-1993)

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 also, 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 3000 V dc and below, but not including molded-case circuit breakers. (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. (UL 489-1991) (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. (NEMA AB 1-1993) (UL 1087-1993) *Syn:* Nonautomatic switch (deprecated).

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. (NFPA 70-1996) *See also:* **overload**.

2.1.34 overload: Operation of equipment in excess of normal, full-load rating, or 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. (NFPA 70-1996) *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, 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 or partition and accessible only from the front. (NFPA 70-1996) *See also:* **switchboard**.

2.1.36 peak current: The maximum instantaneous current that flows in a circuit, designated I_p . (NEMA AB 1-1993)

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

2.1.38 pickup: The rms current at which a circuit breaker tripping function is initiated. (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. (UL 489-1991) *See also:* **available short-circuit current**.

2.1.40 rated short-time withstand current: (A) The maximum 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. (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. (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. (NEMA AB 1-1993)

2.1.43 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. (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. *See:* UL Recognized Component Directory, 1996 [B1].²

2.1.48 setting: (of a circuit breaker) The value of current and/or time at which an adjustable circuit-breaker is set to trip. (NFPA 70-1996)

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. (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. (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 which 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). (IEEE Std C37.100-1992)

²The numbers in brackets correspond to those of the bibliography in 2.4.

2.1.53 short-time pickup: The current at which the short-time delay function is initiated. (NEMA AB 1-1993)

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. See also: rated short-time withstand current, short-time current. (UL 489-1991)

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. (UL 489-1991)

2.1.56 stored-energy operation: Operation by means of energy stored in the mechanism itself prior to the completion of the operation and sufficient to complete it under predetermined conditions. (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 or back or both, switches, overcurrent and other protective devices, busses, 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. (NFPA 70-1996) *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. (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. (IEEE Std C37.100-1992)

2.1.60 tripping: The opening of a circuit breaker by actuation of the release mechanism. (NEMA AB 1-1993)

2.1.61 trip unit: A self-contained portion of a circuit-breaker that actuates the mechanism that opens the circuit-breaker contacts automatically. (NEMA AB 3-1991)

NOTE—The terms *trip device* and *tripping device* are used in literature as alternate 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. *Syn:* undervoltage release. (UL 489-1991)

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

The following acronyms and abbreviations are commonly used in marking and designating circuit-breaker ratings.

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

2.2.2 AIR: Amperes Interrupting Rating. Shortened term marked on some small circuit-breakers with the interrupting rating.

2.2.3 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 the NEC, Sections 384-14 to 384-16. Both “half sized” and “full sized” circuit-breakers may be installed.

2.2.4 HACR: Heating, Air Conditioning, and Refrigeration. Designates compliance with the special requirements of NEC Section 430-53(c)(3) 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.

2.2.5 HID: High-Intensity Discharge. Indicates construction suitable for switching high-intensity discharge lighting loads.

2.2.6 SWD: Switching Duty. Designates compliance with requirements for circuit-breakers used as switches on fluorescent lighting circuits as indicated in NEC Section 240-83(d).

2.3 References

This chapter shall be used in conjunction with the following publications:

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

IEEE Std C37.100-1992, IEEE Standard Definitions for Power Switchgear (ANSI).³

NEMA AB 1-1993, Molded Case Circuit Breakers and Molded Case Switches (DoD).⁴

NEMA AB 3-1991, Molded Case Circuit Breakers and Their Application.

NFPA 70-1996, National Electrical Code[®] (NEC[®]).⁵

UL 489-1991, Molded-Case Circuit Breakers and Circuit-Breaker Enclosures (DoD).⁶

UL 1087-1993, Molded-Case Switches.

UL Molded-Case Circuit Breaker Marking Guide, 1988.

2.4 Bibliography

Additional information may be found in the following source:

[B1] UL Recognized Component Directory, 1996.

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

⁴NEMA publications can be obtained from the National Electrical Manufacturers Association, 1300 N. 17th Street, Suite 1847, Rosslyn, VA 22209, USA.

⁵The NEC is available from Publication Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA. It is also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

⁶UL standards are available from Global Engineering, 1990 M Street NW, Suite 400, Washington, DC, 20036, USA.

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 an electrical power systems engineer or specifying engineer in choosing the type of low-voltage circuit breaker to specify 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 70-1993),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 use 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 would not produce any heat during operation. It would interrupt any overcurrent it was called upon 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

Practical circuit breakers do not, of course, perform exactly in the fashion described above. They have internal impedance and therefore they develop a small voltage drop across them 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

¹Information on references can be found in 3.43.

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 the flow of fault current. They will not damage the operating mechanism, trip unit, or supporting frame. Since their contacts do experience some erosion, they can only perform a limited number of switching and interrupting operations without maintenance where maintenance is possible. 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 properly constructed conductors firmly in place in service.

Practical circuit breakers can provide adequate disconnecting capability to isolate the load from recovery voltage transients, surges, and normal voltage once they are opened and they can provide adequate service for an economically acceptable period of time.

3.4 Basic circuit breaker selection criteria

The selection of any 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 full-load 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 possible abnormally high operating current or short-circuit current likely to be encountered during operation (i.e., it should have the correct interrupting rating), and
- 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 accessories for operation in the environment in which it is to be 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 of any given type is tested will give insight to its applicability for any function.

3.5 The role of 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 about what a given product should be able to do as a *minimum*. Standards establish the design tests that each manufacturer must perform and pass in order to claim a rating and to be in compliance with that standard. Some standards include requirements for periodic follow-up testing which, in effect, continues to sample the capabil-

ities of newly manufactured circuit breakers. This assures that they maintain the capabilities of their product ratings. Standards provisions 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 previously, 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 U.S. and the NEC is the primary safety code for construction. 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 C2-1997) [B1] sponsored by the IEEE; NFPA 70B-1994, Electrical Equipment Maintenance [B10]; and NFPA 70E-1995, Electrical Safety Requirements for Employee Workplaces [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 already 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, 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 same 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 U.S., circuit breaker designs and tests are based on the requirements of three standards organizations—the American National Standards Institute (ANSI), 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 themselves lend their names to the first two of the three types, while 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)

The following are some of the salient features of these types of circuit breakers.

MCCBs, as a class, are those tested and rated according to UL 489-1991 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 489-1991. However, they utilize 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 utilize electronic trip units and can have short-time ratings and ground-fault current sensing. They utilize 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 and UL 489-1991 were jointly developed by IEEE and NEMA and apply to LVPCBs and ICCBs/MCCBs, respectively.

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 utilize 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 utilizing drawout mechanisms. ICCBs are designed primarily to utilize 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 unmaintained 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 facilitate rapid changeout, which minimizes system down-time. This 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 utilize a variety of trip units including the latest versions of electronic trip units that are used in large MCCBs and ICCBs as well. Significant differences in the total operating times of different circuit breakers using either different types of trip units or the same type of electronic trip unit 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

The latest versions of standards should always be referenced for circuit breaker information. Preferred ratings and application recommendations for LVPCBs are given in ANSI C37.16-1988. Standards for low-voltage ac power circuit breakers used in enclosures are given in IEEE Std C37.13-1990, and test procedures for LVPCBs used in enclosures are given in ANSI C37.50-1989. Application factors are discussed in the IEEE Std C37.20 series. LVPCBs are generally UL Listed and can be UL Labeled. Ratings and test procedures for MCCBs and ICCBs are found in UL 489-1991. Other IEEE Color Books complement this book, offering a very complete and comprehensive source of application information for all three types of circuit breakers.

3.11 Endurance considerations

Tables 3-1 through 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 489-1991. 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 [B8], which discusses reliability in general and contains sets of data that can be of assistance in decision making, can be referred to. 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, or its maintenance requirements, and not factors directly pertaining to electrical rating and testing, can have as great an effect on the decision of what type of circuit breaker to choose in some cases.

Table 3-1 — Circuit breaker endurance test parameters

Parameter	UL 489	ANSI C37.50
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)

Source: [B13].

Table 3-2—Endurance test operations

Preferred frame sizes for MCCBs and ICCBs (A)	Number of cycles of operation			
	Per min (See NOTE 1)	With current	Without current	Total
50	6	6000	4000	10 000
100	6	6000	4000	10 000
125	5	4000 (See NOTE 2)	4000	8000 (See NOTE 2)
150	5	4000 (See NOTE 2)	4000	8000 (See NOTE 2)
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 (See NOTE 3)	400	1100	1500
4000	1 (See NOTE 3)	400	1100	1500
5000	1 (See NOTE 3)	400	1100	1500
6000	1 (See NOTE 3)	400	1100	1500
NOTES 1—For 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. 2—Where 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. 3—Rate 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.				

Source: UL 489, October 24, 1990, Table 19.1.

3.12 Voltage rating considerations

MCCBs, ICCBs, and LVPCBs utilize 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, while 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 of the voltage ratings have

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

Frame size (A)	Minimum operation rate cycles/hour		Number of operating cycles (see NOTE 5)							
			Between servicing (see NOTE 2)		With current		Without current		Total	
	UL 489	ANSI C37.50 (see NOTE 4)	UL 489	ANSI C37.50	UL 489	ANSI C37.50	UL 489	ANSI C37.50	UL 489	ANSI C37.50
100	360	—	See NOTE 3	—	6000	—	4000	—	10 000	—
150	300	—	See NOTE 3	—	4000	—	4000	—	8000	—
225	300	30	See NOTE 3	2500	4000	4000	4000	10 000	8000	14 000
400	240	—	See NOTE 3	—	1000	—	5000	—	6000	—
600	240	30	See NOTE 3	1750	1000	2800	5000	9700	6000	12 500
800	60	30	See NOTE 3	1750	500	2800	3000	9700	3500	12 500
1200	60	—	See NOTE 3	—	500	—	2000	—	2500	—
1600	60	30	See NOTE 3	500	500	800	2000	3200	2500	4000
2000	60	30	See NOTE 3	500	500	800	2000	3200	2500	4000
2500	60	—	See NOTE 3	—	500	—	2000	—	2500	—
3000	See NOTE 1	30	See NOTE 3	250	400	400	1100	1100	1500	1500
4000	See NOTE 1	30	See NOTE 3	250	400	400	1100	1100	1500	1500

NOTES

- 1—First 10 at 60/h; thereafter in groups of 5 at 60/h with interval between as acceptable to all.
 2—Servicing means adjusting, cleaning, lubricating, and tightening.
 3—Servicing not permitted.
 4—May be conducted in groups of operations provided at least one group is not less than 120.
 5—Tests on same breaker—sequence not defined.

Sources: ANSI C37.50-1989 and UL 489, December 30, 1991.

significance to circuit breaker design, application, and testing. NEC Section 240-83 refers to straight and slash voltage marking in a fine print note (FPN), which is quoted below:

“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 voltage rating makes a difference in application. That difference can be seen most readily in the different interrupting ratings given for 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 [B5] 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—Circuit breaker interrupting ability operations^a

Poles	Frame rating	Circuit breaker ac voltage rating		Letters indicate diagram in Figure 21.1 of UL 489-1991										Total number of operations
				Operations on each pole				Common operations						
				O	CO	O	O	CO	O	CO	O			
—	—	—	—	—								—	—	
—	—	—	—	—								—	—	
1	All	120, 240, 277, 347, 480, or 600		A	A	A	A	—	—	—	—	—	3	
1	All	120/240 (tested in pairs)		—	—	—	—	B	B	B	B	—	3	
2	All	240, 480, or 600		E	E	—	—	D	—	—	—	—	5	
2	All	120/240		—	—	—	—	C	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	J	—	3	
3	0–1200 A	480Y/277, 600Y/347		K	K	—	—	I	—	—	—	—	7	
3	1201–Up	480Y/277, 600Y/347		K	K	—	—	I	—	—	—	—	7	

Source: UL 489, December 30, 1991, Table 22.1.

^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.

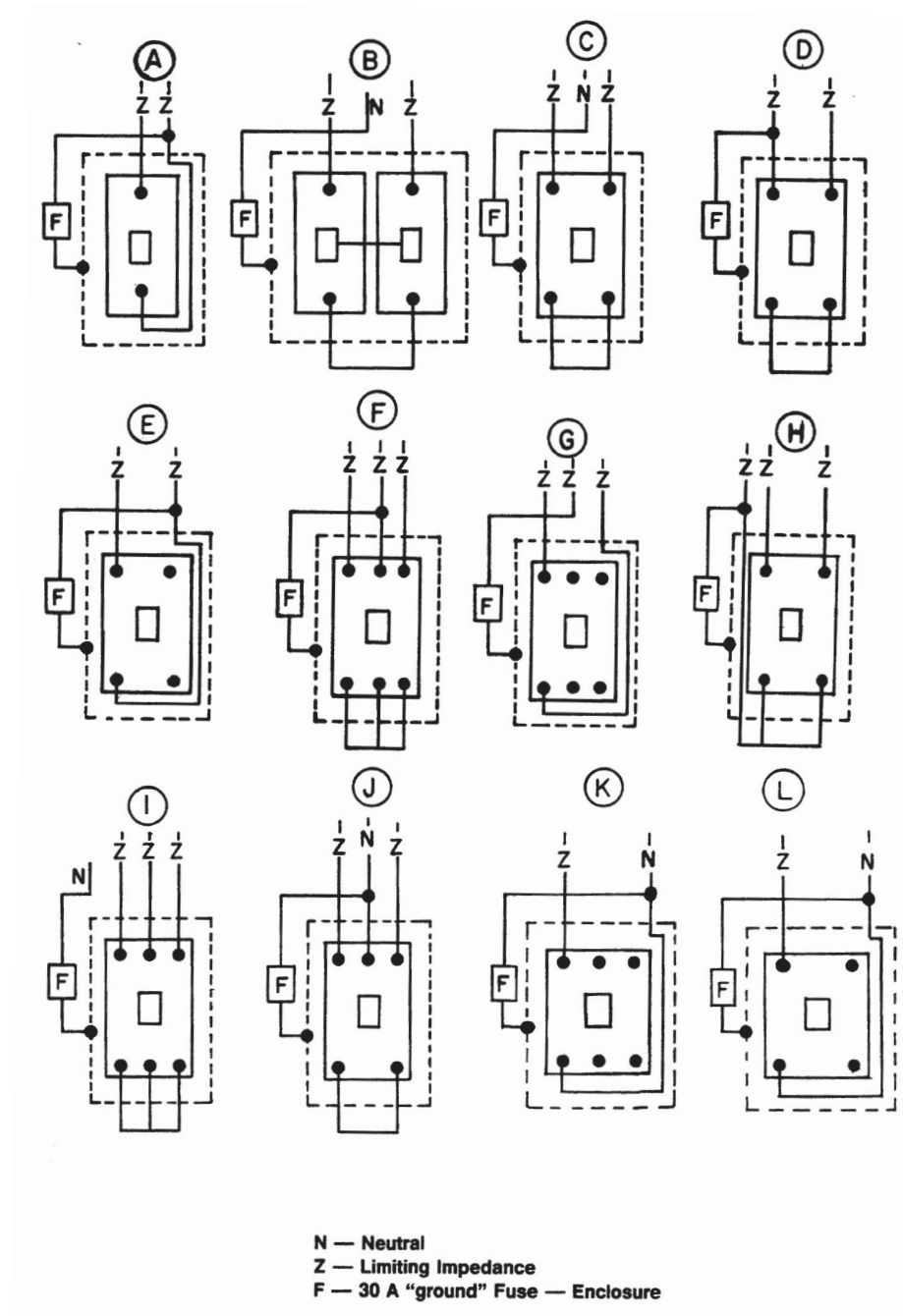


Figure 3-1—Interrupting ability test connection diagrams

Source: UL 489, October 9, 1991, Figure 22.1.

3.13 Frequency rating and considerations

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

With 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 frequency or dc, the method of current sensing may dictate whether a given circuit breaker can or cannot be used. Obviously, a circuit breaker utilizing transformer action for current sensing in its trip unit can not 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, 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 to are listed in Table 3-5. This table is taken from IEEE Std C37.13-1990. 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 $+40^{\circ}\text{C}$ (41°F to 104°F). The standard operating ambient temperature range for LVPCBs is also -5°C to $+40^{\circ}\text{C}$ (41°F to 104°F) but IEEE Std C37.20.1-1993 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 $+104^{\circ}\text{F}$).

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

	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 NOTE 1	See NOTE 1
Series coils with over class 220 insulation or bare	See NOTE 1	See NOTE 1
Terminal connections (See NOTE 2)	55	95
NOTES 1—No specified limit except not to damage adjacent parts. 2—Terminal 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.		

Source: IEEE Std C37.13-1990.

Since circuit breakers applied in temperatures outside their operating ranges may malfunction, the user should provide the necessary operating conditions required to keep the temperature surrounding the assemblies and circuit breakers in their safe operating range. Sometimes this 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.

Sometimes forced ventilation alone can be sufficient to transfer heat in a given ambient and 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 upon 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 also 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 489-1991. Parts of some of the 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 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 220-10 (b) points out that the circuit breaker rating should not be less than the noncontinuous 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 an exception to Section 220-10 (b). The 1993 NEC version of the exception states:

“Where the assembly including the overcurrent devices protecting the feeder(s) are listed for operation at 100% of their rating, neither the ampere rating of the overcurrent device nor the ampacity of the feeder conductors shall be 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, and strand configuration of cable or wire conductor intended to be connected to a circuit breaker is an important application consideration and should satisfy at least two requirements. First, the safety code 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. In order to satisfy voltage drop requirements, the conductors might be sized a little larger, but they can never be sized a little smaller; wires should always fit the connectors. Circuit breaker conductors also serve as conductive heat sinks for the circuit breaker. As heat sinks, 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 for that circuit breaker. They should also be properly constructed in stranding and compression and should have the correct insulation temperature rating.

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 489-1991 allows for the surface of conductor insulation to rise 35 °C (95 °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 (122 °F) 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 (149 °F). When added to a 25 °C (77 °F) ambient, the total is 90 °C (194 °F). UL 489-1991 rules require that if the terminal temperature rise during 100% rating test exceeds 50 °C (122 °F), 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 have a cross-sectional area equal to that of the 75 °C (167 °F) rated conductor specified for the application.

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 sufficient cross-section to adequately heat sink the circuit breaker, it will be insulated for the temperature conditions existing in all of the 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 rated conductor to prove these capabilities. Therefore, 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, 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 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. It is not surprising, therefore, to hear comments to the effect that most circuit breaker problems are manifested at the terminals. 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 ([B14] through [B18]).

All 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 489-1991 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 indicated wire size and type should be used. Table 3-6 lists what are referred to as “rated wire sizes” for the various terminal currents or circuit currents. From the circuit breaker point of view, 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

Terminal current (A) (See NOTE 1)	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
NOTES 1—For a terminal current other than indicated, the next higher rating is to be used (e.g., if rated 35 A, enter at 40 A). 2—Circuit breakers rated at more than 4000 A are to be considered as being bus- or cable-connected unless indicated otherwise in marking. 3—See 13.19 of UL 489, December 30, 1991.						

Source: UL 489, December 30, 1991, Table 9.1.

Table 3-6—Terminal current and conductor size (Continued)

Terminal current (A) (See NOTE 1)	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
400	2	—	3/0	2	—	250
	1 (See NOTE 3)	—	500	1 (See NOTE 3)	—	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
800	3	—	300	3	—	400
1000	3	—	400	4 3	—	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 (See NOTE 2)	15 13 12	—	400 500 600	16 15 13	—	500 600 750
6000 (See NOTE 2)	18 16 15	—	400 500 600	19 18 16	—	500 600 750
NOTES 1—For a terminal current other than indicated, the next higher rating is to be used (e.g., if rated 35 A, enter at 40 A). 2—Circuit breakers rated at more than 4000 A are to be considered as being bus- or cable-connected unless indicated otherwise in marking. 3—See 13.19 of UL 489, December 30, 1991.						

Source: UL 489, December 30, 1991, Table 9.1.

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 re-closing the circuit breaker.

In summary, all conductors intended to be connected to circuit breakers should

- a) Be large enough 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, and
- g) Have an insulation temperature rating and composition suitable for the total application.

Testing with wire confirms all these considerations.

3.17 De-rating for ambient temperature

MCCBs, ICCBs, and LVPCBs all should be de-rated in 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 formulae for calculation of current de-rating that are based on idealized simplifying assumptions and empirical factors. These formulae should be used with discretion.

For LVPCBs and ICCBs, the formula of 4.4.3.2 of IEEE Std C37.010-1979 can be used to determine a continuous-load current capability based on actual ambient temperature. That equation is as follows.

$$I_a = I_r \frac{(\theta_{max} - \theta_a)^{1/1.8}}{\theta_r} \quad (3-1)$$

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 = $(\theta_r + 40^\circ\text{C})$;
- θ_a is the actual ambient temperature ($^\circ\text{C}$) expected;
- θ_r is the allowable hottest spot temperature rise ($^\circ\text{C}$) at rated current.

IEEE Std C37.010-1979 points out that the exponent generally has a range of 1/1.6 to 1/2.0 and that 1/1.8 is a compromise suitable for that application guide. The specifying engineer should always refer to the manufacturer for the best possible guidance in de-rating. Care should always be taken to ensure that the net result obtained is indeed that which was anticipated.

For MCCBs utilizing 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 rule can be used to make rough estimates of expected thermal performance capability. Assuming temperature rise proportional to current squared, and taking the ratio of a known condition to an unknown condition, de-rated current can be solved as follows:

$$I_2 = I_1 \sqrt{(T_2 - A_2) / (T_1 - A_1)} \quad (3-2)$$

where

- T_1 is the circuit breaker bimetallic element temperature, or the total terminal temperature for electronically tripped circuit breakers (°C) at rated current of I_1 amperes with rated ambient temperature A_1 °C;
- T_2 is assumed to remain approximately the same as T_1 , not being too much affected by the practical difference in ambient temperatures;
- A_2 is the new ambient temperature (°C);
- I_2 is an estimate of the current (A) the circuit breaker is likely to be able to carry in an ambient temperature of A_2 °C.

This equation does not take into account any built-in compensation and as suggested can even be used to estimate thermal de-rating of electronically tripped circuit breakers by using the total terminal temperature for T_1 and T_2 . For example, assuming a 50 °C (122 °F) terminal rise over a 40 °C (104 °F) ambient for a total temperature of 90 °C (194 °F) gives $T_1 = T_2 = 90$ °C (194 °F) for rough estimating. The engineer should know the internal temperatures more accurately to reproduce manufacturer's de-rating data, but in the absence of manufacturer's data, this equation gives some guidance.

It should be remembered that the properties of the materials used in the construction of circuit-breaker components determine the maximum limiting temperature allowable for any given circuit breaker and they therefore also determine the amount of de-rating necessary for any given overtemperature condition. The properties of materials used in different circuit breakers can be different even when circuit breakers are similar in rating.

3.18 Circuit-breaker humidity limitations

The effect of humidity on any circuit breaker is a function of temperature. NEMA AB 1-1993 sets an operating limit on relative humidity in clean air at a level of not more than 50% at a maximum temperature of 40 °C. However, it recognizes that a higher level of as much as 90% relative humidity at a lower temperature of 20 °C could be satisfactory as long as consideration is given to the fact that moderate condensation is possible.

The detrimental effects of condensation are multiplied when water-soluble contaminants can also be present inside an enclosure. NEMA standardized enclosure types are available for

various application conditions. When condensation is known to be possible in the application area, the circuit-breaker enclosures should at least be equipped with space heaters intended to prevent internal condensation by heating the air a small amount and allowing gravity to keep the internal air in motion.

3.19 Circuit-breaker altitude limitations

The altitude of an installation is important since, as altitude increases, atmospheric pressure and air density decrease. The reduced insulation and heat transfer properties of less dense air require that circuit breakers be de-rated for voltage withstand and current-carrying capacity as a function of altitude, assuming the temperature remains constant. Current de-rating can be compensated for to some degree if the temperature at the higher altitude is lower, but voltage withstand capability is essentially unaffected by lower temperature.

MCCBs and ICCBs should be de-rated for voltage, current-carrying capacity, and sometimes interrupting capacity, when applied at more than 6000 ft (1830 m) above mean sea level.

LVPCBs should be de-rated when applied 6600 ft (2000 m) above mean sea level. Table 3-7, taken from IEEE Std C37.13-1990, lists the specific altitude rating correction factors for LVPCBs. The manufacturers of MCCBs and ICCBs should be consulted for specific information on de-rating for altitude.

Table 3-7—Altitude rating correction factors

Altitude		Rated continuous current	Rated voltage
(ft)	(m)		
6600 and below	2000 and below	1.00	1.00
8500	2600	0.99	0.95
13000	3900	0.96	0.80
NOTE—Values for intermediate altitudes may be derived by linear interpolation.			

Source: IEEE Std C37.13-1990, Table 4.

There are few test sites in the world where actual altitude testing can be performed, and simulated altitude test facilities are few and far between. Instead, test voltage levels adjusted for the normal altitude conditions of the manufacturing site are used to test insulation integrity and, if necessary, rules based on theory and confirmed by experience are applied to answer practical interruption performance questions. The theoretical guidelines established for this purpose have proven to be quite satisfactory in application.

3.20 Circuit-breaker ampere rating

MCCB ampere ratings are characterized by a very wide range starting with the smallest single-pole lighting circuit breakers and ending with ratings shared by the largest LVPCBs. ICCB ampere ratings tend to be toward the high end of the MCCB range. LVPCB ampere ratings overlap a wide range of both MCCB and ICCB ratings with smallest power circuit breaker ratings in the neighborhood of a few hundreds of amperes.

Within a circuit breaker frame size, whenever trip units are interchangeable, the trip unit chosen determines the ampere rating of a particular circuit breaker. The trip units may be magnetic-only, thermal-magnetic, or electronic. In recent years, specialized high-technology trip units have been designed in packages that make them suitable for application in a number of the larger frame size circuit breakers of all three types.

3.21 National Electrical Code considerations

NEC Article 240, titled “Overcurrent Protection,” gives guidance to the application engineer and the circuit breaker designer. NEC Section 240-3 states “Conductors, other than flexible cords and fixture wires, shall be protected against overcurrent in accordance with their ampacities as specified in Section 310-15...”. Circuit breaker tests with wire and bus prove that circuit breakers can protect conductors. Standard wire ampacities are therefore of interest to the systems engineer and the circuit breaker designer when deciding on ampere ratings. Since the circuit breaker should protect the conductors, the choice of circuit breaker and conductor are related. When circuit breakers have trip units that fit into a single large frame, the following NEC consideration can be important to the circuit breaker and trip unit choice.

The ampere rating of a circuit breaker is as described in NEC Section 240-6, which lists the standard ampere ratings to be considered and further states “The rating of an adjustable trip circuit breaker having external means for adjusting the long-time pickup (ampere rating or overload) setting shall be the maximum setting possible.” This ruling could affect project economics were it not for exception (b) to the rule. Without the exception, the rule would require wiring to be for the maximum circuit breaker trip level instead of for the maximum load current.

The exception to the rule states, “Circuit breakers that have removable and sealable covers over the adjusting means, or are located behind bolted equipment enclosure doors, or are located behind locked doors accessible only to qualified personnel, shall be permitted to have ampere ratings equal to the adjusted (set) long-time pickup settings.” This exception gives the circuit breaker design engineer and the power system design engineer some latitude to affect power system economics. A simple feature like the provision of a sealable cover for the circuit breaker trip unit will allow a larger frame circuit breaker to be applied on a smaller ampacity circuit with the correct overload ampere trip setting. This feature makes it possible to keep the conductor size proportional to the circuit ampacity, thereby reducing the cost of the circuit conductors required, and it makes possible realization of economic benefits in commonality in the type of circuit breakers used and in the stocking of spares. Circuit breaker testing with different trip units make this possible.

NEC rules, of course, apply to all types of circuit breakers and consistent with the primary purpose of these rules and the exception (i.e., to protect the wire or bus and to do so safely), all circuit breakers are tested with rated wire or bus. This safety code provision recognizes the efficacy of circuit breaker test methods and offers the benefits of this demonstrated circuit breaker capability to users.

3.22 Preferred current ratings

The preferred frame sizes for MCCBs and ICCBs are listed in the first column of Table 3-2. Frame sizes for LVPCBs are listed in column 5 of Tables 3-8 and 3-9. It is from these lists that circuit breaker frame sizes are chosen. Table 3-10 indicates preferred ratings for LVPCBs that are integrally fused and utilize instantaneous direct-acting phase trip elements.

Table 3-8—Current ratings for low-voltage ac power circuit breakers with instantaneous direct-acting phase trip elements

Line no.	System nominal voltage (V)	Rated maximum voltage (V)	Insulation (dielectric) withstand (V)	3-phase short-circuit current rating (symmetrical A) ^a	Frame size (A)	Range of trip-device current ratings (A) ^b
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6
1	600	635	2200	14 000	225	40–225
2	600	635	2200	22 000	600	40–600
3	600	635	2200	22 000	800	100–800
4	600	635	2200	42 000	1600	200–1600
5	600	635	2200	42 000	2000	200–2000
6	600	635	2200	65 000	3000	2000–3000
7	600	635	2200	65 000	3200	2000–3200
8	600	635	2200	85 000	4000	4000
9	480	508	2200	22 000	225	40–225
10	480	508	2200	30 000	600	100–600
11	480	508	2200	30 000	800	100–800
12	480	508	2200	50 000	1600	400–1600
13	480	508	2200	50 000	2000	400–2000
14	480	508	2200	65 000	3000	2000–3000
15	480	508	2200	65 000	3200	2000–3200
16	480	508	2200	85 000	4000	4000
17	240	254	2200	25 000	225	40–225
18	240	254	2200	42 000	600	150–600
19	240	254	2200	42 000	800	150–800

Table 3-8—Current ratings for low-voltage ac power circuit breakers with instantaneous direct-acting phase trip elements (Continued)

Line no.	System nominal voltage (V)	Rated maximum voltage (V)	Insulation (dielectric) withstand (V)	3-phase short-circuit current rating (symmetrical A) ^a	Frame size (A)	Range of trip-device current ratings (A) ^b
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6
20	240	254	2200	65 000	1600	600–1600
21	240	254	2200	65 000	2000	600–2000
22	240	254	2200	85 000	3000	2000–3000
23	240	254	2200	85 000	3200	2000–3200
24	240	254	2200	130 000	4000	4000

^aRatings in this column are rms symmetrical values for single-phase (2-pole) circuit breakers and three-phase average rms symmetrical values of three-phase (3-pole) circuit breakers. When applied on systems where rated maximum voltage may appear across a single pole, the short-circuit current ratings are 87% of these values. See 5.6 of IEEE Std C37.13-1981.

^bFor preferred trip-device current ratings, see Table 22 of ANSI C37.16-1988. Note that the continuous-current-carrying capability of some circuit-breaker trip-device combinations may be higher than the trip-device current rating. See 10.1.3 of IEEE Std C37.13-1981.

Source: ANSI C37.16-1988, Table 1.

Table 3-11 lists current values taken from NEC Section 240-6.

Circuit breaker manufacturers design trip units for the various preferred ampere levels spanned by different frame sizes. All circuit breakers are tested with the various trip units installed to demonstrate both their time-current tripping characteristics and the circuit breaker's interrupting capability with that trip unit installed. The ability of a circuit breaker to protect rated cable or bus is demonstrated simultaneously since the test circuit is made up with specified size bus or wire of "rated wire size." See the individual manufacturer's literature for available trip unit ampere ratings.

Table 3-12 lists the preferred trip-device current ratings or settings for LVPCBs.

**Table 3-9—Preferred current ratings for LVPCBs without instantaneous direct-acting phase trip elements
(short-time-delay element or remote relay)**

Line no.	System nominal voltage (V)	Rated maximum voltage (V)	Insulation (dielectric) withstand (V)	Three-phase short-circuit current rating or short-time current rating (symmetrical A) ^{a, b}	Frame size (A)	Range of trip-device current ratings (A) ^c		
						Setting of short-time-delay trip element	Minimum time band	Maximum time band
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8
1	600	635	2200	14 000	225	100–225	125–225	150–225
2	600	635	2200	22 000	600	175–600	200–600	250–600
3	600	635	2200	22 000	800	175–800	200–800	250–800
4	600	635	2200	42 000	1600	350–1600	400–1600	500–1600
5	600	635	2200	42 000	2000	350–2000	400–2000	500–2000
6	600	635	2200	65 000	3000	2000–3000	2000–3000	2000–3000
7	600	635	2200	65 000	3200	2000–3200	2000–3200	2000–3200
8	600	635	2200	85 000	4000	4000	4000	4000
9	480	508	2200	14 000	225	100–225	125–225	150–225
10	480	508	2200	22 000	600	175–600	200–600	250–600
11	480	508	2200	22 000	800	175–800	200–800	250–800
12	480	508	2200	42 000	1600	350–1600	400–1600	500–1600
13	480	508	2200	50 000	2000	350–2000	400–2000	500–2000
14	480	508	2200	65 000	3000	2000–3000	2000–3000	2000–3000