

IEEE Std 3004.5™-2025

IEEE Recommended Practice for the
Application of Low-Voltage Circuit
Breakers in Industrial and
Commercial Power Systems



IEEE STANDARDS ASSOCIATION

IEEE Recommended Practice for the Application of Low-Voltage Circuit Breakers in Industrial and Commercial Power Systems

Developed by the

Industrial and Commercial Power Systems Standards Development Committee
of the
IEEE Industry Applications Society

Approved 12 February 2025

IEEE SA Standards Board

Abstract: The material in this recommended practice was originally published in the first edition of IEEE Std 1015™ (*IEEE Blue Book*™) in 1997 and is an update of the material in Chapter 1 through Chapter 4, and Chapter 6 of the 2006 edition. It also encompasses the material in Chapter 7 of IEEE Std 242™-2001 (*IEEE Buff Book*™). Information for selecting the proper circuit breaker for a particular application is provided. Application engineers are aided in specifying the type of circuit breaker, ratings, trip functions, and accessories. Circuit breakers for special applications, e.g., instantaneous only and switches are discussed. In addition, information for applying circuit breakers at different locations in the power system and for protecting specific components is provided.

Keywords: circuit breakers, circuit breaker evaluation, IEEE 242™, IEEE 3004.5™, IEEE Blue Book™, IEEE Buff Book™, insulated case, insulated-case circuit breakers, low-voltage circuit breaker, low-voltage power circuit breaker, low-voltage protection, low-voltage protection device, miniature circuit breaker, molded case, molded-case circuit breaker, overcurrent protection, power circuit breaker, rating

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Introduction

This introduction is not part of IEEE Std 3004.5-2025, IEEE Recommended Practice for the Application of Low-Voltage Circuit Breakers in Industrial and Commercial Power Systems.

IEEE 3000 Standards Collection™

This recommended practice was developed by the Technical Books Coordinating Committee of the Industrial and Commercial Power Systems Department of the Industry Applications Society as part of a project to repackage the popular IEEE Color Books®. The goal of this project is to speed up the revision process, eliminate duplicate material, and facilitate use of modern publishing and distribution technologies.

When this project is completed, the technical material in the thirteen IEEE Color Books will be included in a series of new standards. The new standard will cover the fundamentals of planning, design, analysis, construction, installation, startup, operation, and maintenance of electrical systems in industrial and commercial facilities. Approximately 60 additional dot standards will be organized into the following categories:

- Power Systems Design (3001 series)
- Power Systems Analysis (3002 series)
- Power Systems Grounding and Bonding (3003 series)
- Protection and Coordination (3004 series)
- Emergency, Standby Power, and Energy Management Systems (3005 series)
- Power Systems Reliability (3006 series)
- Power Systems Maintenance, Operations, and Safety (3007 series)

In many cases, the material in a dot standard comes from a particular chapter of a particular IEEE Color Book. In other cases, material from several IEEE Color Books has been combined into a new dot standard.

IEEE Std 3004.5™

This recommended practice provides an engineer a comprehensive reference source to aid in deciding what type of low-voltage circuit breaker to use for a particular application, and how to apply the circuit breaker. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems based on North American product standards. Similar related devices are covered by other standards, including International Electrotechnical Commission (IEC) standards, predominant in Europe and other regions. 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.

The material in this recommended practice was originally published in the first edition of IEEE Std 1015™ (*IEEE Blue Book™*) in 1997 and is an update of the material in Chapters 1 through 4, and Chapter 6 of the 2006 edition. It also encompasses the material in Chapter 7 of IEEE Std 242™-2001 (*IEEE Buff Book™*).

Contents

1. Overview	12
1.1 Scope	12
1.2 Word usage	12
1.3 Low-voltage circuit breaker classifications	12
1.4 Description of a molded-case circuit breaker	14
1.5 Description of a low-voltage power circuit breaker	17
2. Normative references	20
3. Definitions, acronyms, and abbreviations	20
3.1 Definitions	20
3.2 Acronyms and abbreviations	26
4. Rating and testing	26
4.1 Relevance of rating and testing	26
4.2 The ideal circuit breaker	27
4.3 The practical circuit breaker	27
4.4 Basic circuit breaker selection criteria	27
4.5 The role of industry standards	28
4.6 The role of safety and industry codes	29
4.7 Comparison of testing requirements	29
4.8 Generalized application consideration	29
4.9 References on rating and application	30
4.10 Endurance considerations	31
4.11 AC circuit breaker voltage rating considerations	33
4.12 Frequency rating and considerations	35
4.13 Temperature considerations	35
4.14 Enclosure considerations	36
4.15 Cable, wire, and conductor considerations	37
4.16 Rerating for ambient temperature	40
4.17 Circuit breaker humidity limitations	42
4.18 Circuit breaker altitude limitations	42
4.19 Circuit breaker ampere rating considerations	42
4.20 National Electrical Code considerations	43
4.21 Preferred current ratings	44
4.22 Load effects	47
4.23 The effect of nonlinear loads on circuit breakers	47
4.24 The effect of high inrush loads	48
4.25 Overload testing of circuit breakers	48
4.26 Forced-air cooling of LVPCBs	50
4.27 Short-circuit interrupting rating	51
4.28 Fault-current calculation considerations	51
4.29 Circuit breaker interrupting ratings	52
4.30 Single-pole fault interruption testing	52
4.31 Circuit breaker evaluation in standards for testing	53
4.32 Blow-open contact arms	58
4.33 Circuit breaker useful life	58
4.34 Considerations on interrupting duty and maintenance	59
4.35 Integrally fused devices	59
4.36 Series-connected ratings	60
4.37 Cascade arrangement	61
4.38 Short-time rating	61

4.39 Circuit breaker evaluation for X/R ratio or short-circuit power factor	62
4.40 Single-pole interrupting capability and power system design considerations.....	62
4.41 Applying ac thermal-magnetic molded-case circuit breakers using their UL 489 dc rating.....	64
5. Specific applications.....	67
5.1 Scope.....	67
5.2 Selection considerations.....	67
5.3 Selection approach for electrical ratings	68
5.4 Selection approach for electrical ratings	79
5.5 Normal versus abnormal conditions	82
5.6 Considerations for applying MCCBs, ICCBs, and LVPCBs	83
5.7 Service requirements and protection.....	83
5.8 Main circuit breaker	83
5.9 Tie circuit breakers	85
5.10 Arc flash risk control.....	87
5.11 Arc Energy Reduction.....	87
6. Fused and special-purpose circuit breakers	88
6.1 Introduction	88
6.2 Instantaneous-trip circuit breakers.....	88
6.3 Mine-duty circuit breakers	90
6.4 Current-limiting circuit breakers	92
6.5 Molded-case switches	94
6.6 Fused circuit breakers	94
6.7 Circuit breaker and ground-fault circuit interrupter.....	96
6.8 Circuit breaker and arc fault circuit interrupter	96
6.9 Supplementary protectors.....	97
6.10 Solid-state circuit breakers (SSCBs) and Solid-state hybrid circuit breakers (SSHCBs).....	98
Annex A (informative) Bibliography	100

IEEE Recommended Practice for the Application of Low-Voltage Circuit Breakers in Industrial and Commercial Power Systems

1. Overview

1.1 Scope

This recommended practice covers the selection and application of low-voltage circuit breakers listed to North American Product Safety Standards used in industrial and commercial power systems.

1.2 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

1.3 Low-voltage circuit breaker classifications

For low-voltage circuit protection in North America, circuit breaker designs are based on the requirements of four standards organizations: the American National Standards Institute (ANSI), Underwriters

⁶ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

Laboratories (UL), the National Electrical Manufacturers Association (NEMA), and the Institute of Electrical and Electronics Engineers (IEEE).

The two classifications of circuit breakers these organizations define are as follows:

- a) Molded-case circuit breaker (MCCB) class
- b) Low-voltage power circuit breaker (LVPCB) class

The two cited standards, UL 489 and IEEE Std C37.13™, define the MCCB and the LVPCB classes.⁸

1.3.1 MCCB types

Because of the very large number of MCCBs which are produced for a great variety of applications, several types of MCCBs are widely recognized within the industry. Two of the more popular sub-types of MCCBs are insulated-case circuit breakers (ICCBs) and miniature circuit breakers (MCBs). Each one of these circuit breakers has different design characteristics and, in many cases, different application requirements.

These are discussed in more detail below, but it should be noted that because these types are not separately defined within UL 489, the distinguishing characteristics described are usual and commonly provided within the market however are not guaranteed and may vary from one brand to another.

NOTE—UL 1077 defines devices called supplementary protectors which provide some circuit breaker-like functions but are not circuit breakers within the context of applicable North American standards and hence are used to supplement other overcurrent protection within the guidelines prescribed by the National Electrical Code® (NEC®) (NFPA 70®) and UL 1077. This IEEE recommended practice does not cover supplementary protectors.⁹

MCCBs, as a class, are tested and rated in accordance with UL 489. Their 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. Many MCCBs interrupt fast enough to limit the amount of prospective fault current let-through, and some limit enough current and operate fast enough to be identified as current-limiting circuit breakers. 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 trip units. Electronic trips may offer significant adjustability and advanced protective capabilities such as ground fault sensing, overvoltage sensing, curve shaping and more, or they may only offer limited adjustability that mostly simulates the performance of a thermal magnetic circuit breakers. 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 internal field-installable accessories. MCCBs are available in stationary, bolt-on, or plug-in construction with circuit breaker enclosures that can be flush or surface mounted.

In the industry the term “miniature circuit breaker” may be encountered. That term has no single set definition and may be used to describe small MCCB typically used in residential and commercial lighting panel applications, it or may also be used in industrial control panel applications, typically DIN rail mounted where UL 489 compliant circuit breakers are required but look similar to UL 1077 listed supplemental protectors. How the term miniature MCB is used varies by manufacturer and context. The term is not defined in standards. ICCBs are also tested and rated in accordance with UL 489. However, they use characteristics of design from both the power and molded-case classes. They are of the larger frame sizes, fast in interruption, but normally not fast enough to qualify as current-limiting circuit breakers. As with MCCBs, ICCB current-carrying parts, mechanisms, and trip units are contained within a molded case of insulating material. The

⁸ Information on references can be found in Clause 2.

⁹ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

case is designed so that it can be opened for inspection of contacts and arc chutes and for limited maintenance. Most manufacturers offer designs that permit installation or replacement of internal accessories, and some designs permit replacement of the main contacts such that they are partially field maintainable. ICCBs are available in both stationary and drawout construction. They are generally characterized by a two-step stored energy mechanism similar to those designed for LVPCBs, larger frame sizes, and higher short-time withstand ratings than other MCCBs. ICCBs also use electronic trip units and can have short-time capability and ground-fault current sensing.

UL 489 (U.S.) is a tri-national standard, meaning that it has been harmonized with Canadian Standards Association (CSA) C22.2 No. 5 (Canada) and Asociación Nacional de Normalización y Certificación del Sector Eléctrico, A.C. (ANCE) NMX-J-266 (Mexico). A tri-national standard means that all three standards read the same, with the possible exception of a few country-specific requirements. Further, National Electrical Manufacturers Association (NEMA) AB1, the NEMA molded-case circuit breaker standard, has been withdrawn, and superseded by UL 489.

1.3.2 LVPCB types

LVPCBs are tested and rated according to the following standards:

- IEEE Std C37.17™, IEEE Standard for Trip Devices for AC and General Purpose DC Low Voltage Power Circuit Breakers.
- ANSI C37.50, NEMA Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures—Test Procedures.
- IEEE Std C37.13™, IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.
- IEEE Std C37.14™, IEEE Standard for Low-Voltage DC Power Circuit Breakers Used in Enclosures.
- UL 1066, Low-Voltage AC and DC Power Circuit Breakers Used in Enclosures.
- CSA 22.2 No. 268, Power circuit breakers up to 1000 VAC and 1500 VDC used in enclosures.

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. They have short-time ratings, but they are not fast enough in interruption to qualify as current-limiting. They are rated and tested to satisfy the IEEE C37 series of standard requirements, and they are used primarily in drawout switchgear. When the circuit breaker is removed from its enclosure, the current-carrying parts and operating parts, depending on the design, may be partially or fully 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.

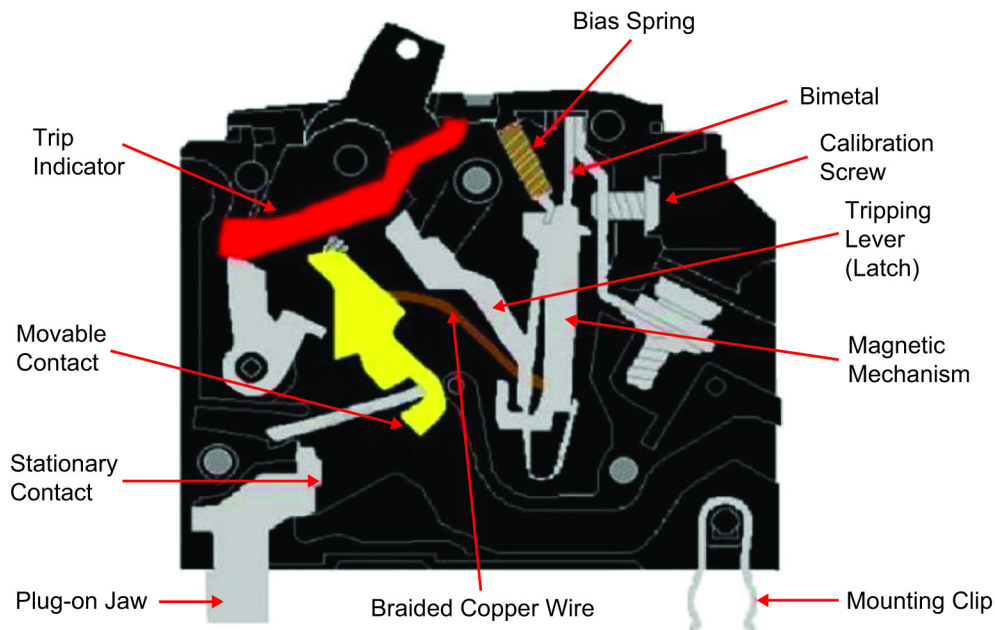
UL 1066 (U.S.) is a bi-national standard, meaning that it has been harmonized with Canadian Standards Association (CSA) C22.2 No. 268 (Canada). A bi-national standard means that both standards read the same, with the possible exception of a few country-specific requirements.

1.4 Description of a molded-case circuit breaker

Figure 1 illustrates the internal construction of a typical small MCCB. 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 helps ensure that the speed at which the breaker contacts are opened or closed is independent of the speed at which the handle is moved. This toggle mechanism is also trip-free, which means that the circuit breaker cannot be

prevented from tripping by holding or locking the handle in the ON position. When the circuit breaker trips open automatically, the handle will assume either an intermediate position between ON and OFF or the OFF position. If the handle moves to the intermediate position, it must be manually moved slightly past the OFF position to reset the mechanism. Instructions for resetting a particular circuit breaker after it trips should be marked on the circuit breaker and/or indicated on the equipment where the circuit breaker is installed. It should be noted that trip-free mechanisms are also required for LVPCBs in the appropriate UL, IEEE, and ANSI standards where the performance requirements are prescribed.

Small multi-pole MCCBs may be built by riveting single pole units together (Figure 2) or by housing the individual pole assemblies in a single case (Figure 3). In either case, each pole has its own mechanism, and each mechanism is mechanically linked such that all poles open and close simultaneously. Further, the tripping mechanisms are linked such that an overcurrent in one pole will cause all poles to open simultaneously.



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Figure 1—Internal construction of a small MCCB



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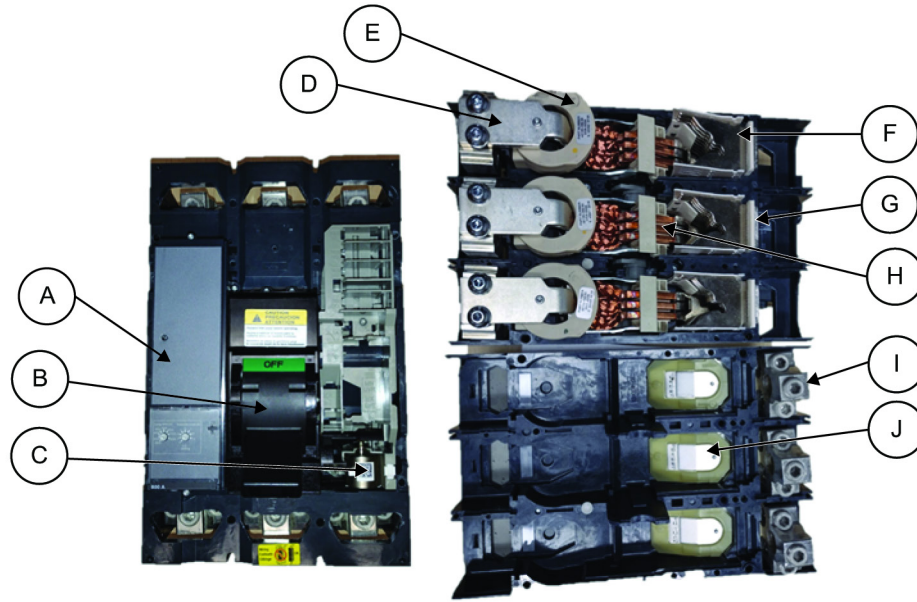
Figure 2—Small multi-pole MCCB, riveted case construction



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Figure 3—Small multi-pole MCCB, single case construction

Figure 4 is a partially disassembled view of a typical larger 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 helps ensure that the speed at which the breaker contacts are opened or closed is independent of the speed at which the handle is moved. This toggle mechanism is also trip-free, which means that the circuit breaker cannot be prevented from tripping by holding or locking the handle in the ON position. When the circuit breaker trips open automatically, the handle will assume either an intermediate position between ON and OFF or the OFF position. If the handle moves to the intermediate position, it must be manually moved slightly past the OFF position to reset the mechanism. Instructions for resetting a particular circuit breaker after it trips should be marked on the circuit breaker and/or indicated on the equipment where the circuit breaker is installed.



A.	Trip Unit	F.	De-ionizing Arc stack
B.	Mechanism / Handle	G.	Filter
C.	Flux Shifter / Solenoid	H.	Movable Pole/Contact
D.	Line Terminal	I.	Wire Connector
E.	Current Transformer	J.	Fixed Pole/Contact

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Figure 4—Disassembled view of a typical larger MCCB

The following description of the operation of an ICCB starts with the open position. The circuit breaker condition OPEN is indicated on the face of the circuit breaker. To close the circuit breaker, which is described as a two-step operation, a spring mechanism for the closing and opening must be charged. The springs are charged by pulling down and releasing the manual spring charging handle as needed, or by a spring charging motor on an electrically operated circuit breaker. The spring condition CHARGED is indicated on the face of the circuit breaker. The circuit breaker is then able to close manually by depressing the close (push-to-close) button, or it is electrically closed by energizing the close coil on an electrically operated circuit breaker. The circuit breaker status as 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 or by energizing the trip coil on an electrically operated circuit breaker.

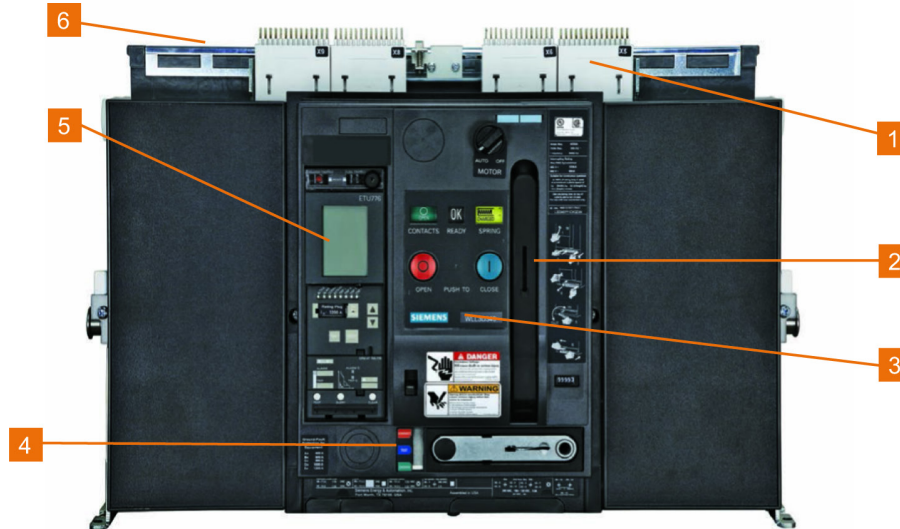
1.5 Description of a low-voltage power circuit breaker

Figure 5 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. Newer designs such as shown in Figure 5 may not offer the degree of maintenance and repair that older designs did, however, they may not need it due to their longer life expectancy (see Table 3). (Consult the manufacturer for service information.) Numbers are used to indicate the various elements of the circuit breaker. A description of each element is listed in the legend.

The following description of the operation of LVPCB starts with the open position. The circuit breaker condition OPEN is indicated on the face of the circuit breaker. To close the circuit breaker, which is described as a two-step operation, a spring mechanism for the closing and opening must be charged. The springs are

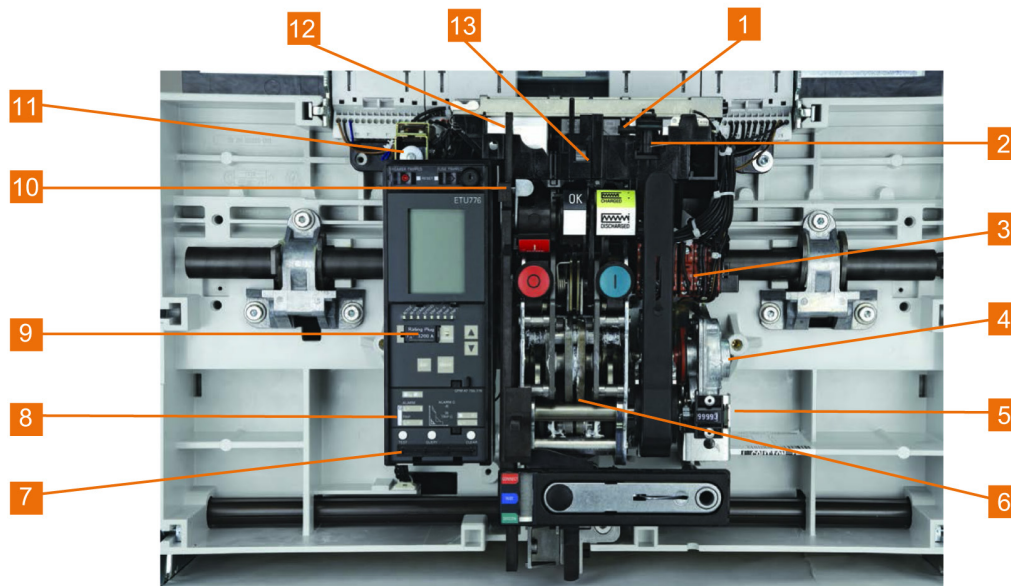
charged by pulling down and releasing the manual spring charging handle as needed, or by a spring charging motor on an electrically operated circuit breaker. The spring condition CHARGED is indicated on the face of the circuit breaker. The circuit breaker is then able to be closed manually by depressing the close (push-to-close) button or it is electrically closed by energizing the close coil on an electrically operated circuit breaker. The circuit breaker status as 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 or by energizing the trip coil on an electrically operated circuit breaker.

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



Exterior breaker features

- | | |
|---------------------------------------|--|
| 1. Sliding secondary control contacts | 4. Integral racking handle |
| 2. Spring charging handle | 5. Electronic trip unit with LCD display |
| 3. Centralized operator panel | 6. Arc chutes |



Interior breaker features

- | | |
|--|---|
| 1. Remote closing coil | 8. Optional ground fault module with alarm and trip functions |
| 2. Dual shunt trip or UV release | 9. Interchangeable current rating plug |
| 3. Auxiliary switch | 10. Breaker status sensor (BSS) |
| 4. Automatic charging motor | 11. Bell alarm contact with remote reset |
| 5. Operation counter | 12. Shunt trip coil |
| 6. Riveted breaker operating mechanism | 13. Ready-to-close-contact |
| 7. Electronic trip unit (ETU) | |

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Figure 5—Low-voltage ac power circuit breaker—drawout type (shown partially disassembled to show internal features)

2. Normative references

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

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

CSA C22.2 No. 5, Molded-case circuit breakers, molded-case switches, and circuit-breaker enclosures.

CSA C22.2 No 268, Power circuit breakers up to 1000 VAC and 1500 VDC used in enclosures.

CSA C22.1, Canadian Electrical Code, Part 1.

IEEE Std C37.17™, IEEE Standard for Trip Systems for Low-Voltage (1000 V and below) AC and General Purpose (1500 V and below) DC Power Circuit Breakers.^{10,11}

IEEE Std C37.13™, IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

IEEE Std C37.14™, IEEE Standard for Low-Voltage DC Power Circuit Breakers Used in Enclosures.

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

NFPA 70, National Electrical Code (NEC).

UL 489, Standard for Safety for Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures.⁶

UL 943-2023, Standard for Safety for Ground-Fault Circuit-Interrupters.

UL 1066, Low-Voltage AC and DC Power Circuit Breakers Used in Enclosures.

UL 1077, Standard for Supplementary Protectors for Use in Electrical Equipment.

UL 1699, Standard for Safety for Arc-Fault Circuit-Interrupters.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹²

¹⁰ The IEEE standards or products referred to in Clause 2 are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.

¹¹ IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

¹² *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

adjustable circuit breaker: A circuit breaker that has adjustable time/current tripping characteristics. These may include inverse-time (such as continuous current, long time, and/or short time), instantaneous, and ground-fault. (adapted from UL 489)

alarm switch: A switch that only operates to open or close a circuit upon the automatic opening of the circuit breaker with which it is associated. (adapted from UL 489)

ambient temperature: The temperature of the surrounding medium that comes in contact with the circuit breaker or switch. For an enclosed device, it is the temperature of the medium outside the enclosure.

amperes interrupting capacity: Maximum current a protective device is capable of interrupting, namely, its interrupting rating. May be found in the manufacturer's literature. *See also:* **amperes interrupting rating.**

amperes interrupting rating: Shortened term marked on some small circuit breakers with the interrupting rating.

authority having jurisdiction (AHJ): An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

NOTE—The phrase authority having jurisdiction or its acronym, AHJ, is used in NFPA documents in a broad manner since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

auxiliary switch: A switch that operates to open or close an auxiliary (control) circuit upon the opening, closing, or tripping of the circuit breaker with which it is associated. (adapted from UL 489)

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.

available short-circuit current: (at a given point in a circuit) The maximum current, typically expressed in rms units at a specific X/R or power factor, 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.**

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

class circuit total: A class circuit total limiting circuit breaker, because of its size of 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 Section 408.13 to Section 408.34 in the 2005 and earlier editions of the NEC. Both half-size and full-sized circuit breakers may be installed.

close and latch rating: maximum prospect fault current value, expressed in rms units at a maximum X/R value, that a circuit breaker can close and latch into.

continuous load: A load where the maximum current is expected to continue for three hours or more. (adapted from the NEC)

coordination (selectivity): The selection and/or setting of protective devices to provide coordinated protection of system components and circuits. In terms of overcurrent protection that means that minimum circuit interruption is achieved for different types and magnitudes of faults and over-currents. A system may be said to be selective when coordination is achieved. The activity of studying systems characteristics and determining optimum device settings and selection is called a coordination study.

NOTE—The NEC uses the term “selective coordination” to mean selectivity up to prospective short circuit current (Def. Coordination, Selective, NFPA 70-2023) and makes it a requirement in some circuits. Article 517.31(G) (NFPA 70 2023) defines coordination for essential electrical systems in health care facilities as coordinated for the period of time that a

fault's duration extends beyond 0.1 second. However, common engineering practice is to achieve selective coordination up to practicable fault values which may be below the maximum prospective short circuit current but could range into the short circuit protective range of OCPD.

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. (adapted from UL 489) *See also:* **current-limiting overcurrent protective device**.

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

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

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

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

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

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 document, the alternate terms *solid state trip unit* and *static trip unit* are commonly used in literature.

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

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

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

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

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 rms current levels less than those required to protect conductors from damage through the operation of a supply-circuit overcurrent device that senses the zero-sequence current. (adapted from the NEC)

heating, air conditioning, and refrigeration: Designates compliance with the special requirements of Section 430.53(C)(3) of the NEC, as listed for group installation for use with heating, air conditioning, and refrigeration equipment. A circuit breaker with this marking is suitable for use with equipment marked to indicate that an HACR circuit breaker is acceptable.

high-intensity discharge: Indicates construction suitable for switching high-intensity discharge lightning loads as indicated in Section 240.83(D) of the NEC.

I^2t : An expression related to the energy available as a result of current flow over time. Demonstrates that the energy input from current over time is proportional to the square of the current and has a linear relationship with time.

instantaneous override protection: Typically, non-adjustable fast instantaneous trip which will cause the circuit breaker to trip instantaneously when its current threshold is exceeded. It protects the circuit breaker at currents above its withstand capability. The threshold is typically stated as root mean square (rms) current value.

instantaneous pickup: The nominal value of current threshold typically expressed in rms units, at which an adjustable circuit breaker is set to trip instantaneously. (adapted from UL 489)

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

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 may be permitted to include a transient damping action to ride through initial motor transients. (adapted from UL 489)

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 two-step stored energy mechanism.

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. (based on 2.36 of UL 489)

interrupting rating: The highest rms current at rated voltage, at a maximum X/R value, that a device is intended to interrupt under standard test conditions. (adapted from the NEC)

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

I_p : See: **peak current**.

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

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

low-voltage power circuit breaker (LVPCB): A mechanical switching device capable of making, carrying, and breaking currents under specified normal and abnormal circuit conditions. An LVPCB is designed per the requirements of IEEE Std C37.13TM, IEEE Std C37.14TM, and tested per procedures in ANSI C37.50.

making current release (MCR): A trip function used to help ensure that a circuit breaker does not attempt to close into a fault of a magnitude above its close and latch capability.

molded-case circuit breaker (MCCB): A circuit breaker that is assembled as an integral unit in a supporting and enclosing housing of insulating material. MCCBs are most often available in two or three pole versions and are typically rated from 240 V to 600 V. (adapted from and IEEE Std C37.100TM [B19])¹³

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

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

¹³ Numbers in brackets correspond with those in Annex A.

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

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

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

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

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

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

rated short-time withstand current: (A) The maximum root-mean-square (rms) total current that a circuit breaker can carry momentarily without electrical, thermal, or mechanical damage or permanent deformation. The current shall be the rms value, including the dc component, at the major peak of the maximum cycle as determined from the envelope of the current wave during a given test time interval. (adapted from IEEE Std C37.100™-1992 [B19]) (B) That value of current assigned by the manufacturer that the device can carry without damage to itself under prescribed conditions. (adapted from NEMA AB 1) *Syn:* **withstand rating, short-time rating**.

rating plug: An interchangeable module used with some electronic trip units that, together with the sensor, sets the current rating range of the circuit breaker.

NOTE—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 $(0.9 \times 600 \text{ A}) = 540 \text{ A}$]. Rating plugs may also include user adjustments. Some AHJ will use the rating plug to determine the smallest conductors size that may be employed in the circuit.

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

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

selective coordination: *See:* coordination (selective).

sensor: (as applied to a circuit breaker with an electronic trip unit) A current sensing element such as a current transformer, air core sensor (Rogowski coil), or other type of sensing mechanism within a circuit breaker frame that provides a signal used by the electronics to determine current flowing through the protected circuit. The sensor will usually 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. Sensors may be tapped to provide multiple ranges, particularly in older LVPCB and trip kits used to upgrade the trip operation of older circuit breakers.

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**. Series ratings are obtained through UL 489 test protocols and are UL recognized.

NOTE—See UL Product iQ, Product Sourcing and Certifications Database [B33].

setting: (of a circuit breaker) A user selected value (aka threshold) of current, time or other operating parameter that regulates how a circuit breaker may trip or provide any protective or alarm function. Within the context of NEC language, the term is intended to apply to only current and time user adjustments.

short circuit: An abnormal connection (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential. (adapted from IEEE Std C37.100 [B19])

short-time current: The current carried by a device, an assembly, or a bus for a specified short-time interval. (adapted from IEEE Std C37.100™ [B19]) *See also:* **rated short-time withstand current; short-time rating.**

short-time delay phase or ground trip element: A direct-acting trip device element that functions with a purposely delayed action (measured in milliseconds). (adapted from IEEE Std C37.100™ [B19])

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

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

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

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

stored-energy operation: Operation by means of energy stored in the mechanism before the completion of the operation and sufficient to complete it under predetermined conditions. (adapted from IEEE Std C37.100™ [B19])

supplementary protector: A manually resettable device designed to open the circuit automatically on a predetermined value of time versus current or voltage within an appliance or other electrical equipment. It may also be provided with manual means for opening and closing the circuit. (adapted from UL 1077)

switchboard: A type of switchgear assembly that consists of one or more panels with electric devices mounted thereon and associated framework. Low-voltage switchboards are listed per UL 891.

NOTE—Switchboards may be classified by function, that is, power switchboards or control switchboards. Both power and control switchboards may be further classified.

switchgear assembly: A switchgear assembly is a type of switchgear (indoor or outdoor) that is constructed from components including, but not limited to, one or more of the following: switching, interrupting, control, metering, protective, and regulating devices, together with supporting structures, enclosures, conductors, electric interconnections, and accessories. Low-voltage power switchgear assemblies are designed in accordance with IEEE Std C37.20.1™ and may be listed per UL 1558.

switchgear: A general term covering switching and interrupting devices and their combination with associated control, metering, protective, regulating devices, and 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. Switchgear is designed in accordance with the IEEE C37 series of standards.

switching duty: Designates compliance with requirements for circuit breakers used as switches on fluorescent lighting circuits and indicated in Section 240.83(D) of the NEC.

transient recovery voltage (TRV): The voltage transient that occurs across the terminals of a pole of a switching device upon interruption of the current. (adapted from IEEE Std C37.100™ [B19])

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

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

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

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

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

zone selective interlocking: A function provided for rapid clearing while retaining coordination. The function requires an interconnection between trip units or relays that signals the upstream device that the downstream device has sensed the fault current and is reacting to it. By means of intercommunication between the devices, the instantaneous, short-time delay and/or ground fault elements in the upstream device may be delayed sufficiently to allow the downstream device to clear. The one nearest the fault trips with a selected time delay while signaling the supply-side circuit breaker(s) to delay for an additional predetermined period. Zone selective interlocking is commonly available in modern electronic trip and modern electronic relays. *Syn:* **zone interlocking; selective interlocking.**

NOTE—In zone: Overcurrent devices are implemented to protect a specific set of conductors. Those conductors, and equipment or devices directly connected to those conductors, are considered to be the protected zone for the overcurrent device. A fault on those conductors or devices is considered to be an in-zone fault for the overcurrent device. A fault that is in the protection zone of a downstream overcurrent device is considered to be an out-of-zone fault.

3.2 Acronyms and abbreviations

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

40 °C	Forty degrees Celsius
AIC	amperes interrupting capacity
AIR	amperes interrupting rating
CTL	class circuit total limiting
HACR	heating, air conditioning, and refrigeration
HID	high-intensity discharge
SWD	switching duty

4. Rating and testing

4.1 Relevance of rating and testing

This clause provides information on rating and testing of circuit breakers that will be helpful to electrical engineers in choosing low-voltage circuit breakers for an application. Ratings assigned to circuit breakers are determined by the testing done, per applicable standards, 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), industry practices, and environmental considerations can also affect circuit breaker choices. These are also discussed in areas where they relate to testing requirements. Application considerations such as choosing the type of trip unit, the type of time-current-characteristic, and the continuous current and interrupting ratings to satisfy coordination requirements are the subjects of other clauses of this recommended practice.

4.2 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; therefore, the circuit breaker would not produce any heat during operation. It would interrupt any overcurrent it was called on to interrupt without experiencing contact erosion, and structurally, it would be able to withstand the pressure and heat of interruption and the magnetic forces produced by the flow of fault current through it. Its connectors would be firmly attached to the circuit breaker terminals and would hold the external circuit conductors in place regardless of the amount of fault current flow. It would provide perfect electrical isolation of the load from the normal system voltage when open, and it would be able to provide these functions indefinitely regardless of the environment.

4.3 The practical circuit breaker

Circuit breakers do not perform exactly in the fashion described in 4.2. They have internal impedance, and therefore, they develop a small voltage drop while carrying current. The product of the resistive voltage-drop and the current is a measure of power loss, which is manifested as heat in the circuit breaker during normal operation. The consequence is that practical circuit breakers warm up during operation.

When properly applied within their ratings and when they are in good operating condition, practical circuit breakers can interrupt any overcurrent that occurs in the circuit in which they are applied. They can do this without undue contact erosion and can withstand the pressure and heat of interruption as well as the magnetic forces produced by fault current. The process of interruption will not damage the operating mechanism, trip unit, or supporting frame. As their contacts do experience some erosion, they can only perform a limited number of switching and interrupting operations without maintenance. Circuit breakers that cannot be maintained should be replaced whenever wear and tear reach certain limits. Properly sized and properly torqued connectors attached to the circuit breaker terminals can hold conductors firmly in place. That is, the connectors must fit the circuit breaker terminals, the connectors must be compatible with the conductor material (AL, or CU, or AL/CU), and the conductor stranding, and compression must be compatible with the connector. Copper Clad Aluminum can be used in the U.S. only if the circuit breaker is marked for its use such as AL/CU or permission included in printed material provided with the circuit breaker manufacturer.

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

4.4 Basic circuit breaker selection criteria

The selection of a circuit breaker for any given duty must be based at a minimum on an assessment of its ability to perform the following basic functions:

- a) To carry the required current without overheating (i.e., it should have the correct current rating)
- b) To switch and isolate or disconnect the load from the source at the given system voltage (i.e., it should have the correct voltage rating)

- c) To interrupt any abnormally high operating current or short-circuit current likely to be encountered during operation (i.e., it should have the correct interrupting rating) and to do so without extensive damage to the electrical equipment of the circuit
- d) To be able to perform these functions over an acceptably long period of time under the operating and environmental conditions that will prevail in the application (i.e., it should have the correct mounting provisions, enclosure, and operating endurance and have the required accessories for operation in the environment in which it is applied)

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

Additional selection criteria should be considered when selecting circuit breakers. Regulatory or safety considerations may make these considerations mandatory. The additional criteria are:

- e) Selective capability within the intended application
- f) Arc flash related performance
- g) Remote control (shunt trip, motor operated, etc.)
- h) Remote diagnostics
- i) Maintenance considerations

4.5 The role of industry standards

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

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

Circuit breaker performance tested within standard guidelines is tested in laboratory conditions with test protocols that are expected to simulate or exceed real application situations. However, real applications may expose devices to conditions that are not explicitly tested under standard guidelines. When application conditions vary significantly from those defined for the circuit breakers, the circuit breaker manufacturer should be consulted to determine suitability for the intended application and if any specific performance impact or change needs to be considered.

4.6 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 time. The Occupational Safety and Health Act (OSHA) [B26] is the primary legal safety code in the United States, and the NEC is the primary safety code for installations. The NEC is a model code, and to be effective, must be adopted by an authority having jurisdiction (AHJ) either amended or unamended (see NEC Article 100 for the definition of 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®) (IEEE C2) [B17] sponsored by IEEE, NFPA 70B [B23], and NFPA 70E [B24]. Industry practices vary between industries and may vary from location to location in the same industry. The NEC and other industry codes may either make use of available circuit breaker product features, or they may influence the development of them for some applications. 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.

In Canada, the electrical installation code is CSA C22.1, Canadian Electrical Code Part 1, which is adopted by the provinces and territories much like the NEC is adopted by the states or local jurisdictions in the United States. Canada does not have a national health and safety act; rather the individual provinces have their own laws such as the Ontario Health and Safety Act and the Ontario Occupational Health and Safety Regulations for Industrial Establishments.

In Mexico, the electrical installation code is NOM-001-SEDE, Mexican Electrical Code [B25], which is adopted by the states much like the NEC is adopted by the states or local jurisdictions in the United States. The document utilizes a large part of the NEC. Mexico's Department of Labor and Social Welfare (STPS) is an equivalent to OSHA in the United States.

4.7 Comparison of testing requirements

In most cases, a meaningful one-to-one comparison of test procedures will not be possible. It will be seen that tests of different types of circuit breakers differ, and without the exact testing, comparisons of the severity of tests can be made only 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 clause addresses many of the details that should be evaluated.

4.8 Generalized application consideration

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

Most low-voltage circuit breakers can operate, at least, basic overcurrent protection function in a self-power mode. This means that though they may require connection to a separate source of control power for advanced functionality such as communications or metering, basic overcurrent protection can operate properly using the current flowing through the circuit breaker as a source of power (through an iron core current transformer) or they can derive power from line voltage. The current transformers used for control power can be the same ones used for current measurement. There may be minor performance differences in the protection when

operating from self-power versus separately provided control power. These differences should be documented in the product literature. ICCBs can be provided in switchboards, using either fixed (stationary) mounting methods or mounted using drawout mechanisms with an engaged, test and fully drawn out (disconnected) positions. ICCBs are designed primarily to use interchangeable electronic trip units.

Traditionally, it is expected that LVPCBs are more maintainable than ICCBs, and ICCBs are more maintainable than traditional MCCBs. However, modern circuit breaker designs are erasing some of these differences while simultaneously providing devices with potentially less need for maintenance due to improvements in device life and operations capability.

LVPCBs are always used in enclosures, and because of their large size and weight, they are almost always applied in drawout construction. Fixed mounting is rare. Drawout construction facilitates inspection, testing and maintenance as well as replacement of the circuit breaker when necessary. Furthermore it facilitates a method to provide visible disconnection and lock-out-tag-out practices.

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

Low-voltage circuit-breaker TCCs should be provided by the manufacturer to represent the entire circuit-breaker protection system and include the various components that make up system operation and all applicable tolerances. These include:

- a) Sensing variability
- b) Algorithm or sensing mechanism operation
- c) Mechanical operation time and variation
- d) Clearing time and variation (under worst case trip conditions)

This means that the circuit-breaker TCC is a complete representation of the circuit-breaker system operation from when the trip unit or mechanism acquires the data with which it commits to assert a trip, to the maximum clearing time under worst case fault conditions. It is possible that all curves are not provided this way and hence the manufacturer should be consulted to ensure an understanding of what is represented by provided curves and if any additional representation or information is needed.

4.9 References on rating and application

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

The preferred ratings, application, standards for low-voltage ac power circuit breakers used in enclosures are given in IEEE Std C37.13, and the preferred ratings, applications, and standards for low-voltage dc power circuit breakers used in enclosures are given in IEEE Std C37.14. Test procedures for LVPCBs used in enclosures are given in ANSI C37.50. Application guide factors are discussed in IEEE Std C37.13, and unusual service conditions for LV switchgear are discussed in IEEE Std C37.20.1. LVPCBs are generally Listed and can Labeled per UL 1066. Ratings and test procedures for MCCBs and ICCBs are found in UL 489.