Standards and Ratings for the Application of Molded-Case, Insulated-Case, and Power Circuit Breakers

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***Abstract*—Molded-case circuit breakers (MCCBs), insulated-case circuit breakers (ICCBs), and power circuit breakers (PCBs) are used by electrical engineers in power distribution system designs primarily to protect low-voltage electrical equipment and circuits. Safe application requires an understanding of their performance and ratings. Proper application of these devices can ensure continuity of power during system disturbances. This discussion focuses on domestic standards and ratings for the application of low-voltage industrial-grade MCCBs, ICCBs, and PCBs rated 600 V ac or lower for use in switchboards and switchgear. A comparison of switchboard and switchgear requirements for the devices is also included where it is useful.**

***Index Terms*—Insulated-case circuit breaker, molded-case circuit breaker, power circuit breaker, short-delay current rating, short-delay time rating.**

I. Introduction

CIRCUIT breakers are designed to meet the standards established by the American National Standards Institute (ANSI), National Electrical Manufacturers Association (NEMA), and Underwriters Laboratories (UL).

A. Molded-Case Circuit Breakers (MCCBs)

MCCBs and switchboards utilizing them have been designed and tested to meet the following NEMA and UL (ANSI) standards:

- NEMA AB-1 *Molded-Case Circuit Breakers and Molded-Case Switches* [1];
- NEMA PB2 *Deadfront Distribution Switchboards* [2];
- UL489 *Molded-Case Circuit Breakers and Circuit-Breaker Enclosures* [3];
- UL891 *Dead-Front Switchboards* [4].

B. Insulated-Case Circuit Breakers (ICCBs)

ICCBs are designed and tested to meet the same standards as MCCBs because they are a type of MCCB. There is no industry definition for ICCBs in the ANSI, NEMA, or UL standards. ICCBs were developed by MCCB manufacturers to meet some of the more stringent coordination, operating-cycle (stored energy), and maintainability requirements established for power circuit breakers (PCBs). All major circuit breaker manufacturers offer a product they market as ICCBs; however, ICCB product design and performance are not consistent among manufacturers. Since the introduction of ICCBs in the mid-1970s, the number of characteristics distinguishing them from MCCBs has decreased. MCCB ratings and performance have increased in recent years, and MCCBs now have many more features.

C. Power Circuit Breakers (PCBs)

PCBs and metal-enclosed switchgear are designed and tested to meet ANSI, NEMA, and UL standards, including the following:

- ANSI C37.13 *IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures* [5];
- ANSI C37.16 *Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors—Preferred Ratings, Related Requirements, and Application Recommendations* [6];
- ANSI C37.17 *Trip Devices for AC and General Purpose DC Low-Voltage Power Circuit Breakers* [7];
- ANSI C37.20.1 *IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit-Breaker Switchgear* [8];
- ANSI C37.50 *Low-Voltage AC Power Circuit Breakers Used in Enclosures—Test Procedures* [9];
- ANSI C37.51 *Metal-Enclosed Low-Voltage AC Power-Circuit-Breaker Switchgear Assemblies—Conformance Test Procedures* [10];
- NEMA SG3 *Low-Voltage Power Circuit Breakers* [11];
- NEMA SG5 *Power Switchgear Assemblies* [12];
- UL1066 *Low-Voltage AC and DC Power Circuit Breakers Used in Enclosures* [13];
- UL1558 *Metal-Enclosed Low-Voltage Power Circuit-Breaker Switchgear* [14].

II. Ratings

A. Frame Ratings

Industrial-grade MCCBs are available in frame sizes from 100 to 3000 A. ICCBs are available in frame sizes from 400 to 5000 A. The 400-A-frame ICCB is typically the same size and cost as the 800-A frame but is equipped with smaller ratio current sensors. PCBs are available in frame sizes from 800 to 5000 A.

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B. Short-Circuit Ratings

The short-circuit rating of a circuit breaker is defined by its interrupting capacity, the maximum current the breaker can safely interrupt. MCCBs and ICCBs are available with three-phase short-circuit current ratings that vary based on the system voltage and the breaker design. The interrupting capacity of most MCCBs is voltage dependent and at 480 V ranges from a low of 10 to a high of 100 kA. Some designs are available with integral current limiters for a rating of 200 kA. At 480 V, ICCBs have interrupting capacities ranging from 35 to 150 kA and are not normally furnished in combination with limiters.

PCBs are also available with various interrupting capacities. In accordance with ANSI standards, the preferred short time current rating of PCBs without instantaneous trip units is the same at 240, 480, and 600 V, while the short-circuit current rating of PCBs with instantaneous trip units is not. PCB interrupting capacities range from 30 to 100 kA. PCBs with integral limiters can also be provided, increasing the rating to 200 kA.

C. Short Delay Current and Time Ratings

The short delay current rating and short delay time rating define the ability of a circuit breaker to remain closed for a time interval under high fault current conditions. Short delay current and time ratings allow an upstream breaker to remain closed and power flow to a distribution system to be maintained while a downstream breaker clears a faulted circuit. This short delay capability is one of the main distinctions between an MCCB or ICCB and a PCB.

All MCCBs and ICCBs are provided with an instantaneous trip function. Even when an adjustable instantaneous trip is not furnished, the MCCB or ICCB will be equipped with a fixed instantaneous override circuit set to the highest magnetic trip setting available. The MCCB instantaneous override is typically fixed at a maximum of 10–13 times the breaker frame rating, and the maximum short delay time rating for current magnitudes below the instantaneous trip value is typically 18 cycles. The instantaneous override trip level of ICCBs is higher than that of equivalent-size MCCBs. The maximum short delay time rating for ICCBs is 30 cycles (1/2 s). Because they trip with no intentional delay for current magnitudes above their instantaneous trip setting, MCCBs and ICCBs have high interrupting capacities. However, selective coordination is sacrificed for current magnitudes in excess of the maximum short delay current rating when breakers in series have instantaneous trip elements.

Although PCB interrupting capacities are generally not as high as those of the highest rated MCCBs and ICCBs, PCBs are capable of being applied without instantaneous trips. Their short delay current rating is equivalent to their interrupting current rating, and their maximum short delay time rating is 30 cycles. The ANSI test standards for PCBs actually require fault testing for a short delay time of 30-cycle duration, then a 15-s zero-current interval followed by another fault test for a short delay time of 30-cycle duration. This short delay current and time rating allows breakers in series to be selectively coordinated. PCBs with adjustable instantaneous trip elements are available, and some of these designs have higher interrupting ratings than equivalent designs without an instantaneous trip.

TABLE I
MCCB/PCB SHORT-CIRCUIT TEST POWER FACTOR

Type of Circuit Breaker	Interrupting Rating (kA)	Power Factor Test Range	X/R Test Range
Molded Case	10 or less	0.45 – 0.50	1.98 - 1.73
Molded Case	over 10 to 20	0.25 – 0.30	3.87 - 3.18
Molded Case	over 20	0.15 – 0.20	6.6 - 4.9
Low-Voltage Power	all	0.15 max.	6.6 min.

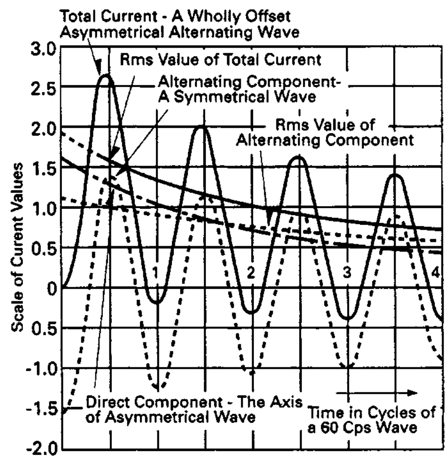

Fig. 1. Structure of an asymmetrical current wave.

TABLE II
MULTIPLYING FACTORS FOR CIRCUIT BREAKER INTERRUPTING RATINGS

% P.F.	X/R	Interrupting Rating			
		≤ 10 kA	> 10 kA ≤ 20 kA	> 20 kA	All LV PCB
50	1.7321	1.000	1.000	1.000	1.000
30	3.1798	0.847	1.000	1.000	1.000
25	3.8730	0.805	0.950	1.000	1.000
20	4.8990	0.762	0.899	1.000	1.000
15	6.5912	0.718	0.847	0.942	1.000
12	8.2731	0.691	0.815	0.907	0.962
10	9.9499	0.673	0.794	0.883	0.937
9	11.7221	0.659	0.778	0.865	0.918
7	14.2507	0.645	0.761	0.847	0.899
5	19.9750	0.627	0.740	0.823	0.874

D. Test Power Factor (X/R)

Circuit breakers are tested for a short-circuit power factor based on the interrupting rating and type of device. As shown in Table I, MCCBs, and therefore ICCBs, have short-circuit test power factors that range from 15% to 20% for interrupting ratings above 20 kA, while all PCBs are tested for a short-circuit power factor of 15% maximum. The lower the short-circuit test power factor, the more demanding the test.

Power factor, cosine θ, is a mathematical relationship between reactance (X) and resistance (R), so each test power factor has a specific corresponding test ratio X/R, or tangent θ. The lower the test power factor, the higher the X/R ratio.

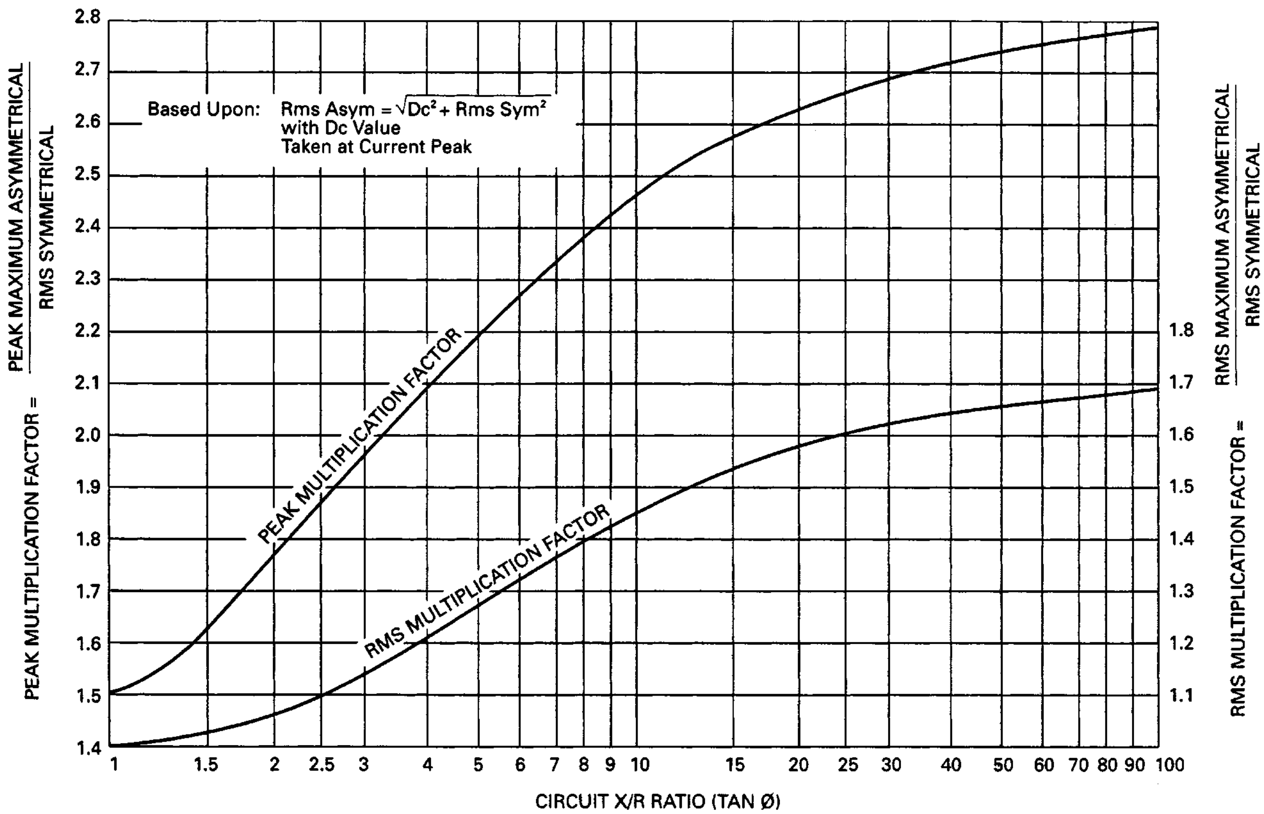

Fig. 2. Relation of X/R ratio to multiplication factor[15].

X and R represent the total reactance and resistance from the faulted point in the system back to the generating source.

The structure of a typical asymmetrical current wave is shown in Fig. 1. The effect of reactance in an ac system is to cause the initial current to be high and then decay toward steady-state value. The initial asymmetrical waveform becomes symmetrical as the direct-current component of the fault current decays. The rate of decay depends on the X/R ratio of the circuit.

The higher the X/R ratio, the greater the first peak value of the short-circuit test current. The X/R ratio determines the degree of asymmetry in the faulted circuit, or the maximum value by which the first half-cycle peak current exceeds the steady-state rms value of the fault current. The maximum rms asymmetrical current is derived from the rms symmetrical current and the dc component taken at the fault current peak. The actual degree of asymmetry depends on when the fault occurs in the voltage wave.

If the calculated short-circuit current X/R ratio is greater than the tested values of a device, a derating multiplying factor should be applied to the circuit breaker interrupting rating, as indicated in Table II.

The peak multiplication factor times the rms symmetrical fault current provides the first half-cycle peak fault current. The relationship between the short-circuit X/R ratio and the peak multiplication factor is shown in Fig. 2.

Most circuit breaker electronic trip units use peak sensing to determine the adjustable instantaneous pickup and the fixed instantaneous override circuit values. An MCCB and a PCB with identical published short delay current ratings will respond differently to the same fault current based on their individual X/R ratio design test capabilities.

This difference is important. A circuit breaker with an interrupting capacity of 100 000-A rms symmetrical and a short delay current rating of 65 000 A based on a symmetrical wave $(X/R = 0)$ would have a first half-cycle peak multiplying current of 1.41 and would begin to open instantaneously for peak current values over 1.41 $\times$ 65 000 A, or 91 650 A peak. If this circuit breaker were applied in an application that had an available fault current of 50 000-A rms symmetrical and an X/R ratio of 6.6, the peak multiplying factor would be 2.3 (see Fig. 2). The 50 000-A rms symmetrical available fault current would have a first half-cycle peak current of 2.3 $\times$ 50 000 A, or 115 000 A.

Since the available fault current of 115 000 A peak exceeds the breaker instantaneous override of 91 650 A peak, the instantaneous override would open the device instantly (with no intentional delay) rather than allow the circuit breaker short delay circuit to continue to time out and coordinate with downstream breakers. Note that, while the circuit breaker interrupting capacity is 100 000 A and the short delay current is 65 000 A, for this application the breaker would trip with no intentional delay for a fault current of 50 000 A.

The 800-A PCB in Fig. 3 has an interrupting capacity and short delay rating based on a 15% test power factor (X/R test ratio of 6.6 and peak multiplying factor of 2.3) by ANSI standards. A PCB with an interrupting rating of 65 000-A rms symmetrical would be able to withstand, without tripping or damage, 30 cycles of fault current with an initial peak of 149 500 A.

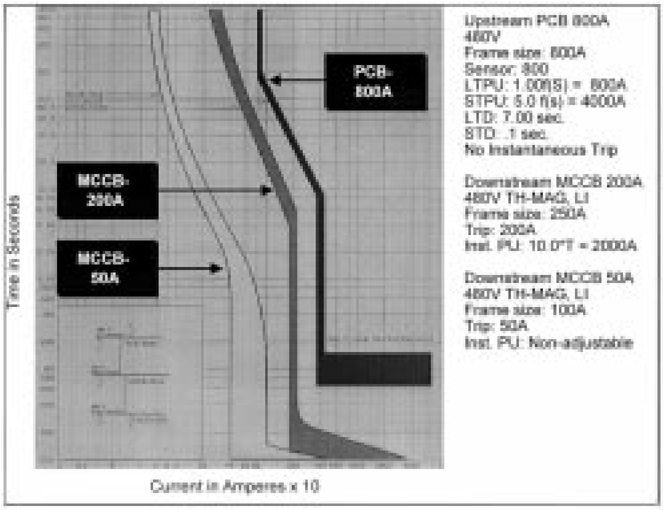

Fig. 3. Time–current curve with upstream 800-A PCB.

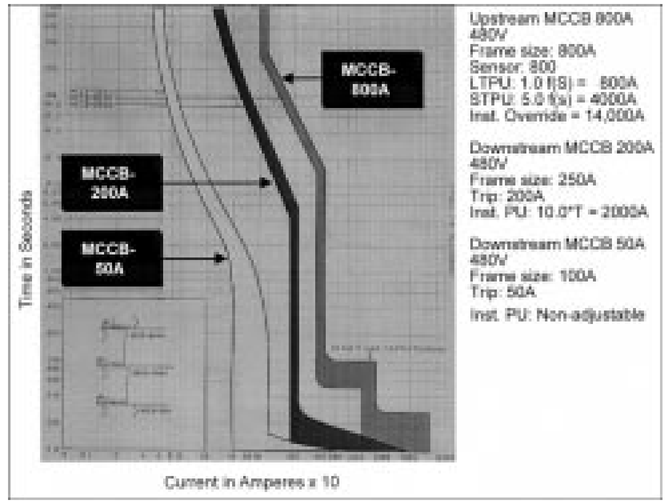

Fig. 4. Time–current curve with upstream 800-A MCCB.

The corresponding 800-A MCCB in Fig. 4, with an interrupting capacity of 65 000-A rms symmetrical at a 20% test power factor (X/R test ratio of 4.9 and peak multiplying factor of 2.2), can delay tripping only for faults below its 14 000-A fixed instantaneous setting, which corresponds to 30 800 (2.2 $\times$ 14 000) A peak.

An 800-A ICCB may have an instantaneous override at a higher level than the MCCB in this example. No standards exist other than those for MCCBs, so ratings vary greatly among manufacturers.

The short time capabilities and instantaneous trip settings are important in determining the ability to coordinate circuit breakers, and this coordination determines the degree of electrical outage for the entire building facility when a fault occurs. Although circuit breaker interrupting ratings may have to be derated based on Table II, MCCBs and ICCBs are typically available with high interrupting ratings—often higher than those of an equivalent-size PCB.

E. System Coordination and Selectivity

The coordination capabilities of MCCBs are limited by their instantaneous trip characteristics. For overloads and low-magnitude faults, the time and current settings of MCCBs can be coordinated depending on their specific adjustments and the available overcurrent. For high-magnitude faults, instantaneous trips generally cannot be coordinated, since there is no time delay for coordination purposes.

ICCBs usually have higher short delay time capabilities than most MCCBs, allowing them to be selectively coordinated for higher levels of fault current (up to the level at which they trip instantaneously).

PCBs have the greatest capability for coordination for high-magnitude faults. They can be provided without an instantaneous trip element, in which case their short delay time capability allows engineers to specify settings that are fully selective. They can also be provided with instantaneous trips where appropriate, such as for the direct feeding of individual transformer or motor loads.

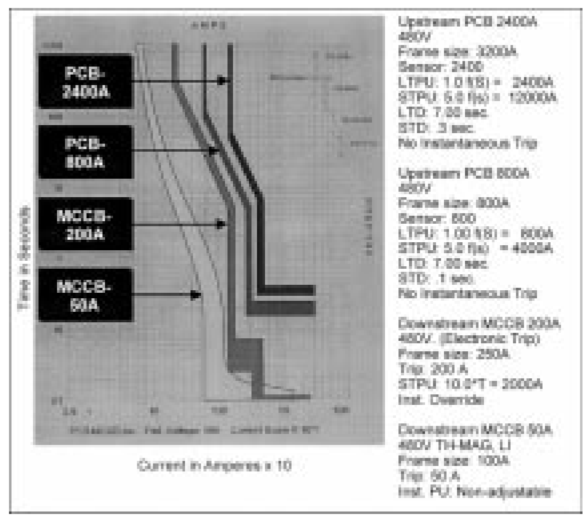

Fig. 5. Time–current curve with upstream 2400-A PCB.

The time–current curves in Fig. 5 show the degree of coordination of PCBs and MCCBs for a typical distribution system. The 2400-A main PCB and 800-A feeder PCB are fully selective, since there is time and current separation for the entire fault range between the breaker response curves. Neither device has an instantaneous trip function, and the short delay time and current settings of both devices coordinate up to the maximum available fault current.

Likewise, the 800-A feeder PCB and the 200-A feeder MCCB (which has an electronic trip unit) are fully selective for all values of fault current. Even though the 200-A MCCB has an instantaneous trip, the absence of an instantaneous trip in the upstream 800-A PCB allows the devices to coordinate up to the maximum available fault current.

However, both the 200-A MCCB and the 50-A MCCB (which has a thermal-magnetic trip unit) have instantaneous trip elements that inhibit coordination. For a downstream fault with a current magnitude above the level at which their time–current curves overlap (approximately 2000 A), both devices will trip and the entire portion of the distribution system fed by the 200-A

MCCB, not just the loads fed by the 50-A breaker, will lose power. This situation is not necessarily unreasonable for devices with such a small continuous current rating, considering the high cost of alternatives. Typically, coordination will not be lost since there is a lower level of fault current due to the high impedance of small conductors. In addition, arcing faults and faults in utilization equipment are generally low-magnitude faults.

Fig. 3 shows an 800-A PCB feeding 200-A and 50-A thermal-magnetic MCCBs. Again, the short delay pickup and time adjustments and the absence of an instantaneous trip in the PCB allow it to coordinate with the downstream devices even for a high available fault current application. The downstream MCCBs have limited coordination capabilities between their response curves due to the instantaneous trip element in their design.

Fig. 4 shows the same distribution system as Fig. 3 but with an 800-A MCCB with an electronic trip unit as the breaker. Since it has a fixed instantaneous trip set at 14 000-A rms, all the devices will coordinate up to that level. Above 14 000-A rms, all three devices may trip, causing the entire system to lose power.

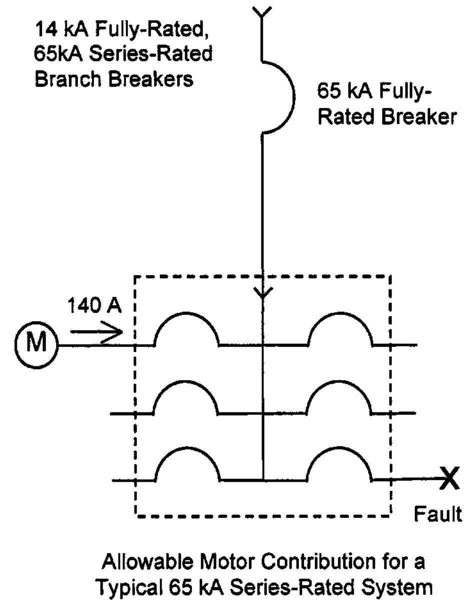

Fig. 6. Series-rated system.

III. Applications

A. Manual Operating Mechanisms

Most MCCBs have over-center handle operating mechanisms that are spring assisted for quick-make, quick-break opening and closing of the breaker. Many ICCBs and all PCBs have two-step stored-energy operating mechanisms.

Two-step stored-energy operating mechanisms allow an operator to open and close the breaker contacts on demand, either locally or remotely. Separate circuit breaker opening and closing springs are used, and the design is such that when the breaker is closed the opening spring is simultaneously charged. Charging the closing springs and then pressing the close button to release the closing springs closes the breaker. After the breaker is closed, the closing springs can again be charged. With the breaker closed and the closing springs charged, the breaker can be operated to open, close, and open (O–C–O) without the closing springs being recharged. This automatic operation is useful in many transfer schemes and in generator paralleling schemes when power is lost and circuit breaker closing is required to restore power.

B. Electrical Operating Mechanisms

For electrical operation, MCCBs typically use a motor or solenoid operator to drive the handle mechanism. Motor operators have closing and opening times of several cycles to several seconds. Solenoid operators have operating times that vary from 6 cycles to several cycles.

ICCBs and PCBs have internal motor operators that charge the closing springs within a few seconds. This charging time is independent of the circuit breaker closing and tripping time. The closing and tripping solenoid coils can close or open the circuit breaker in 5 or fewer cycles. Five-cycle closing is necessary for many transfer schemes and generator paralleling schemes.

C. Series Ratings

Series ratings permit the application of two or more circuit breakers in series, in accordance with the National Electrical Code (NEC) [16], at locations in a power system where the downstream circuit breaker interrupting capacity for an application that is not series rated is lower than the available fault current. This is possible because both breakers share the high current fault interruption.

Series-rated circuit breakers are UL tested as a combination of a fully rated upstream device, either a circuit breaker or a fuse, and a lower rated downstream device. The upstream device in a series-rated system is always fully rated, with an interrupting capacity equal to the available fault current, while the downstream device may have a lower interrupting capacity. This allows a system design less costly than systems that use devices fully rated for the available fault current.

The maximum fault current contribution of motors connected between series-rated breakers must be considered. Article 240-86(b) in the 1999 edition of the National Electrical Code states that for series ratings the sum of the motor full-load currents cannot exceed 1% of the interrupting rating of the lower rated circuit breaker. The actual fault current contribution from induction motors is about four times their full-load current (impedance value of 25%). For example, as shown in Fig. 6, if the downstream branch circuit breakers used in a series-rated combination have an interrupting rating of 14 000-A rms symmetrical for a 480-V system, the maximum allowable motor contribution to that panel from the branch circuit breakers is 140 A (1%). For typical induction motors having a per-unit impedance of 0.25, this corresponds to 35 A, or approximately 25 hp.

UL standards for the tested combinations allow the upstream device to be located in the switchboard, in the panelboard, or remotely. NEC Article 110-22 requires field marking on equipment for which series ratings are used. "Up-Over-Down" methods for application of line-side fuses are not allowed because of the dynamic impedance added by fast-acting MCCBs. In general, series ratings are available only with MCCBs. ICCBs and PCBs have high short delay current and time ratings and are not normally available in series ratings.

For smaller breakers, service continuity may be compromised in either fully rated or series-rated systems, because only lower level arcing faults are likely to be cleared by the downstream breaker alone. Under high fault current conditions, both the upstream and the downstream breakers may open. Service to that area in the electrical distribution system is then interrupted.

In a fully rated system, all breakers are rated for the full fault current at their point of application. Both circuit breakers in series having only instantaneous trips may also open under high fault conditions. However, a system design using fully rated MCCBs, ICCBs, or PCBs with selectively coordinated short delay time and current capabilities would not have service interrupted for a high-magnitude downstream fault.

Since all MCCBs and all ICCBs have instantaneous trips, service continuity may be compromised in the case of high-level faults. However, many ICCBs have higher than normal short delay time and current capabilities up to the magnitude of current at which they trip instantaneously.

PCBs are available without instantaneous trips and can have short delay time and current capabilities equal to their interrupting capacity. They are not tested for series-rated systems with downstream MCCBs, since this would compromise service continuity by requiring an instantaneous trip on the upstream PCB. PCBs are tested in combination with upstream fuses or limiters for applications in which their device ratings require higher-than-normal interrupting ratings. In these cases, the fuses or limiters are applied to protect the PCB. Since the fuses or limiters are selected to coordinate with the PCB, they are typically too large to protect MCCBs downstream of the PCB.

D. Mounting

Most MCCBs are fixed-mounted in switchboards and bolted to bus bars. Some are of the plug-in design and typically use breaker adapter units. Plug-in MCCBs should be connected or removed only when the power to the switchboard or panelboard is turned off.

Draw-out circuit breakers can be moved within a compartment from one defined position to another without manually disconnecting any connections or turning off the power to the assembly. Only the power to the load being supplied by the breaker is affected. Typically, there are four defined positions: connected–test–disconnected–withdrawn. This ability to remove the circuit breaker without deenergizing the switchboard or switchgear makes it accessible for maintenance.

ICCBs can be fixed-mounted to bus bars or provided in a draw-out design. PCBs, since they are maintainable, are normally provided in a draw-out design, although sometimes they are fixed-mounted as main or tie breakers in switchboards. Draw-out construction is recommended for critical applications because it minimizes the downtime required for servicing breakers. Draw-out construction is also typical for double-ended switchgear that utilizes two main breakers and a tie breaker, or designs with two breakers from different buses feeding the same load.

E. Switchboards versus Switchgear

MCCBs are normally mounted in switchboards designed to meet NEMA PB2 and UL891 requirements. The short-circuit design test requirement for switchboard bus is a 3-cycle test. ICCBs are mounted in switchboards built to the same standards, and again the switchboard bus must pass a 3-cycle short-circuit test.

PCBs are normally mounted in low-voltage metal-enclosed switchgear assemblies designed to meet ANSI C37.20.1, NEMA SG-5, and UL1558 standards. The short-circuit design test requirement for switchgear bus is a 4-cycle test. The PCBs and bus are also tested together to withstand short-circuit current for 30 cycles, a rating consistent with the short delay current and time ratings of PCBs. Switchgear standards require each circuit breaker to be mounted in a separate metal-enclosed compartment.

When PCBs are mounted in switchboards as main or tie breakers, the switchboard bus has a 3-cycle short-circuit rating.

F. Motor Starting

All circuit breakers are suitable for direct motor starting and can be considered “horsepower rated.” Since MCCBs have main contacts that cannot be replaced, and the stationary and moving contacts within the breaker are not intended to be inspected, they are not typically used for motor starting. Although some ICCBs have replaceable contacts, like MCCBs they are rarely used for direct motor starting.

PCB contacts are specifically designed to be inspected and to permit replacement. The application limitations relating to repetitive duty and normal maintenance of low-voltage PCBs for frequent motor starting and stopping are defined in ANSI C37.13 and C37.16. These standards include the number of operations between servicing (adjusting, cleaning, lubrication, tightening, etc.) and the number of operations for inrush current switching. The tests are conducted with closing (starting) currents up to 600% and opening (running) currents up to 100% (80% power factor or higher) of the continuous-current rating of the breaker at voltages up to the rated maximum voltage. The frequency of operation should not exceed 20 starts in 10 min, or 30 starts in 1 h. Table III shows the endurance or total number of operations (not requiring parts replacement) for motor starting duty.

IV. Design Testing

A. NEMA, ANSI, and UL Standards

The design test standards for circuit breakers are listed at the beginning of this article. Since MCCBs and ICCBs are both molded-case circuit breakers, they are listed in accordance with the requirements of UL489, *Molded-Case Circuit Breakers and Circuit-Breaker Enclosures*. PCBs are listed in accordance with the requirements of UL1066, *Low-Voltage AC and DC Power Circuit Breakers Used in Enclosures*, which demonstrates compliance with ANSI C37.50. Some of the differences in the performance requirements of the standards are detailed below.

TABLE III
MOTOR-STARTING CAPABILITIES OF POWER CIRCUIT BREAKERS*

Power Circuit Breaker Frame Size (amperes)	Number of Make-Break or Close-Open Operations			
	Between Servicing	No-Load Mechanical	Rated Continuous-Current Switching	Inrush-Current Switching
800	1750	9700	2800	1400
1600	500	3200	800	400
2000	500	3200	800	400

***ANSI C37.16-1988**

B. General Test Requirements

1) *Enclosed Testing and 100% Ratings:* NEC 220-10(b) addresses differences between applications of standard rated breakers and 100% rated breakers for noncontinuous and continuous loads. The rating of the overcurrent device and the ampacity of the conductors cannot be less than the noncontinuous load plus 125% of the continuous load. An exception is allowed in cases where the assembly, including the overcurrent devices protecting the feeders, is listed for operation at 100% of its rating.

   Standard MCCBs and ICCBs are tested in open air without an enclosure and are designed to carry 100% of their rating continuously in open air. To meet NEC 220-10(b), standard MCCBs and ICCBs applied in an enclosure are derated 20%, since their performance could be adversely affected by slow heat dissipation and temperature rise. The 20% derated breakers are then applied using 75 °C-rated cable. Some models and frame sizes are UL listed for application at 100% of their rating. The listing requires a minimum enclosure size as well as the application of 90 °C-rated conductors at their 75 °C ampacity.

   PCBs are tested as standard in an enclosure. UL1066 and ANSI C37.50 require PCBs to be fully rated when applied in an enclosure. PCBs are listed for operation at 100% of their rating for continuous and noncontinuous loads. Their application allows the use of 75 °C-rated cable in switchgear.

2) *Single-Pole Short-Circuit Test:* ANSI standards require PCBs to pass a single-pole short-circuit test at 635 V. This high-voltage test is not a requirement of UL489 for MCCBs and ICCBs. UL489 provides standards for testing the individual poles of two-pole and three-pole MCCBs. The test current is generally lower than the interrupting rating of the MCCB.

   This capability is necessary for breakers applied on corner-grounded delta systems where single line-to-ground faults may be interrupted by only a single pole of a circuit breaker with full line-to-line voltage across that single interrupting pole. MCCBs should not be used on circuits where the available fault current exceeds the level at which individual poles were short-circuit tested at line-to-line voltage.

   In applications with high-impedance grounded wye systems, a single line-to-ground fault must pass through the impedance which limits the magnitude of the ground fault. With one phase faulted to ground, a second ground fault on a different phase on the line side of a breaker can result in a line-to-line-to-ground fault. If a single pole of a circuit breaker must interrupt the fault, the voltage across the pole is line-to-line voltage and the MCCB interrupting rating is the UL individual-pole short-circuit test value. MCCBs are generally appropriate for high-impedance grounded wye systems for several reasons: two simultaneous faults are required to create the condition, the second fault must be on the supply side of the MCCB and on a different phase, one or both faults are likely to be arcing ground faults with significant impedance, and other overcurrent devices in the circuit may open simultaneously [17].

3) *Temperature Rise:* ANSI requires that the maximum allowable temperature rise for PCB contacts not exceed 85 °C and that the rise for terminal connections not exceed 55 °C. UL489 requires only that the terminal temperature rise of MCCBs and ICCBs not exceed 50 °C.

4) *Short Time Rating:* PCBs are designed to carry fully rated short time current for 30 cycles, followed by a 15-s zero-current interval and another 30 cycles of current. This duty cycle is not part of the UL test for MCCBs and ICCBs, which typically can carry only limited short time current for 18 cycles.

5) *Conductor Impedance During Testing:* UL short-circuit test circuits for MCCBs and ICCBs allow the impedance of 4 ft of cable on the line side of the circuit breaker and 10 in of cable on the load side. The short-circuit test circuit for PCBs does not allow the use of any conductor impedance.

   UL testing of MCCBs with conductors verifies their ability to protect the conductor insulation. The dynamic impedance of the breaker greatly exceeds the constant impedance of the cable during the entire interruption process. Testing circuit breakers with or without the added conductor impedance in the circuit gives similar results, with any differences being insignificant.

C. Mechanical Testing—Endurance

Table IV compares the mechanical and electrical endurance requirements of UL489, for MCCBs and ICCBs, and ANSI C37.16 and C37.50, for PCBs. In general, for equivalent frame sizes 2000 A and below, the standards require a greater number of operating cycles both with and without current for PCBs than for MCCBs and ICCBs. For 3000- and 4000-A breakers, the ratings are similar.

MCCBs and ICCBs may not be serviced to achieve these ratings, while PCBs may be serviced. Servicing includes adjusting, cleaning, lubricating, and tightening.

TABLE IV
MECHANICAL AND ELECTRICAL ENDURANCE REQUIREMENTS

Frame Size (amps)	Minimum Operation Rate (cycles/hour)		Number of Operating Cycles							
			Between Servicing		With Current		Without Current		Total	
	UL489	ANSI C37.50†	UL489*	ANSI C37.50†	UL489	ANSI C37.50†	UL489	ANSI C37.50†	UL489	ANSI C37.50†
225	300	30	-	2500	4000	4000	4000	10000	8000	14000
400	240	-	-	-	1000	-	5000	-	6000	-
600	240	30	-	1750	1000	2800	5000	9700	6000	12500
800	60	30	-	1750	500	2800	3000	9700	3500	12500
1200	60	-	-	-	500	-	2000	-	2500	-
1600	60	30	-	500	500	800	2000	3200	2500	4000
2000	60	30	-	500	500	800	2000	3200	2500	4000
2500	60	-	-	-	500	-	2000	-	2500	-
3000	60	30	-	250	400	400	1100	1100	1500	1500
4000	60	30	-	250	400	400	1100	1100	1500	1500

* Servicing not permitted.
† ANSI C37.50-1989 and ANSI C37.16-1988

TABLE V
OVERLOAD PERFORMANCE TEST REQUIREMENTS

Frame Size (amps)	Minimum Operation Rate (cycles/hour)		Number of Operating Cycles	
	UL489	ANSI C37.50*	UL489	ANSI C37.50*
225	300	60	50	50
400	240	-	50	-
600	240	60	50	50
800	60	60	50	50
1200	60	-	50	-
1600	60	60	50	38
2000	60	60	25	38
2500	60	-	25	-
3000	60	N/A	28	N/A
4000	60	N/A	28	N/A

* ANSI C37.50-1989 and ANSI C37.16-1988

D. Electrical Testing—Overload and Short Circuit

Table V compares the overload performance test requirements of UL489, for MCCBs and ICCBs, and ANSI C37.16 and C37.50, for PCBs. The number of operating cycles does not differ substantially for frame sizes 2000 A and below.

Table VI provides the short-circuit test requirements of UL489 for MCCBs and ICCBs. The circuit breaker short-circuit tests begin with an O–CO (O = opening operation, CO = close-open) three-pole test designated as Sequence Number Y. This is followed by additional short-circuit tests in Sequence Number Z using a single circuit breaker (three single-pole tests and one three-pole test).

To obtain a higher interrupting capacity rating, the design must pass additional tests. Three-pole breaker samples are subjected to O–CO tests under each of the four conditions shown at the bottom of Table VI. These tests qualify the breaker frame over a range of continuous currents. A new breaker can be used for each of the four high-interrupting-capacity test conditions.

Table VII provides the short-circuit test requirements of ANSI C37.16 and ANSI C37.50 for PCBs. The tests include five three-pole tests and three single-pole tests. Different breakers may be used for any of the tests.

V. TRIP UNITS

Smaller frame MCCBs are provided with thermal-magnetic trip units. Larger frame MCCBs, ICCBs, and PCBs are available with microprocessor-based trip units. Technology is advancing rapidly, and the sophistication of trip units for all devices is changing. While trip unit design was once a major distinguishing feature of MCCBs, ICCBs, and PCBs, the trip unit designs are now quite similar and will be even more similar in the future. In general, ICCBs and PCBs today are equipped with trip units with advanced design features as standard.

VI. FIELD TESTING/MAINTENANCE

Field testing is recommended for all circuit breakers in order to check their operating condition and verify their performance. The testing agency typically performs a 300% overload test, an instantaneous trip test, a millivolt drop test, and a meggar test. If the breaker is provided with ground fault protection, that function is also tested.

TABLE VI
SHORT-CIRCUIT TEST REQUIREMENTS OF UL489 FOR A THREE-POLE BREAKER

Test No.*	Tested In Sequence Number (Table 7.1.1.2)	Duty Cycle (Table 7.1.7.1)	Number of Poles (Table 7.1.7.1)	Maximum Rated Voltage (Table 7.1.7.1)	Actual Test Current (rms symmetrical kA) (Table 7.1.7.2) Frame Rating (amperes) 225	600	800	1200	1600	2000	2500	3000	4000
2	Z	O-CO	1	600	8.6	8.6	8.6	12.1	14	14	20	25	30
3	Z	O-CO	1	600	8.6	8.6	8.6	12.1	14	14	20	25	30
4	Z	O-CO	1	600	8.6	8.6	8.6	12.1	14	14	20	25	30
6	Z	O	3	600	10	10	10	14	–	–	–	–	–
7	Z	O	3	600	–	–	–	–	20	25	30	35	45
9	Y	O-CO	3	600	3	6	10	14	20	25	30	35	45

Test No.†	Duty Cycle	No. of Poles	Trip Rating	Actual Test Current (Tables 7.1.11.1.1 and 8.1)
A	O-CO	3	Maximum	Same as maximum interrupting capacity rating
B	O-CO	3	Maximum	I/C rating at maximum voltage rating
C	O-CO	3	Maximum	I/C at maximum kVA rating
D	O-CO	3	Minimum	Maximum I/C rating

* Tests 1 through 9 are standard interrupting capacity tests.

† Tests A through D are high interrupting capacity tests.

TABLE VII
SHORT-CIRCUIT TEST REQUIREMENTS OF ANSI C37.50*

Test No.	Tested In Sequence Number	Duty Cycle	Number of Poles	Maximum Rated Voltage	Actual Test Current (rms symmetrical kA) Frame Rating (amperes) 225	600	800	1600	2000	3000	3200	4000
1	I	O-CO	3	635	14	22	22	42	42	65	65	85
2	II	O-CO	3	508	22	30	30	50	50	65	65	85
3	II	O-CO	3	254	25	42	42	65	65	85	85	130
4	II	O-CO	1	635	12.2	19.1	19.1	36.5	36.5	56.6	56.6	74
5	II	O-CO	1	508	19.1	26.1	26.1	43.5	43.5	56.6	56.6	74
6	II	O-CO	1	254	21.8	36.5	36.5	56.6	56.6	74	74	113.1
7	III	O	3	635	14	22	22	42	42	65	65	85
8	IV	O-CO	3	635	14	22	22	42	42	65	65	85

***ANSI C37.50-1989 and C37.16-1988**

MCCBs and ICCBs require very little maintenance due to their enclosed design; however, a regular manufacturer-suggested inspection and maintenance program is recommended. All terminal connections and trip units must be tightened to the proper torque values as recommended by the manufacturer. Poorly cleaned conductors, improper conductors for the terminal used, and loose terminations are all faulty conditions that may cause undue heating and deterioration of the breaker. Infrared scanning with the breaker under load and the trim plate removed is an excellent tool for preventive maintenance.

Circuit breakers should be visually inspected and operated periodically to ensure that their contacts are clean and that mechanical linkages operate freely. In general, replacement parts are not available, and manufacturers do not recommend the repair, refurbishment, or remanufacture of these devices in the field. Circuit breakers that have been damaged in service should be replaced.

PCBs are designed to be serviced, and available replacement parts include contacts, pole assemblies, and arc chutes. As with MCCBs and ICCBs, an inspection and maintenance program is recommended. The basic rule for all electrical equipment is to keep it dry, keep it clean, and keep it tight.

VII. CONCLUSIONS

All circuit breakers provide overcurrent protection. The performance of MCCBs, ICCBs, and PCBs in a system will differ in specific applications based on the design standards and the features specified.

The engineer must consider circuit breaker interrupting capacity, short delay current and time ratings, and test power factor (X/R) to determine the capability of the device to provide system protection, coordination, and selectivity. Project requirements for manual or electrical operation and for fixed or draw-out mounting will often dictate circuit breaker design. Application requirements will determine the need for 100% ratings and other test differences. Cost is always a consideration and may dictate the use of series ratings or the choice of a circuit breaker based on frame or trip size.

The standards for circuit breakers have evolved over the last 70 years to meet the design needs of engineers. MCCBs, ICCBs, and PCBs are all available with UL listings and will provide excellent service when properly applied.

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