# Circuit Breaker Interrupting Capacity and Short-Time Current Ratings

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*Abstract*—**Low-voltage circuit breakers have interrupting capacity ratings and short-time current ratings that an engineer uses for their application. Interrupting capacity and short-time current ratings define different circuit breaker performance characteristics. A good understanding of interrupting capacity and short-time current ratings allows the electrical engineer to make a proper comparison of various circuit breaker designs.**

**While interrupting capacity rating levels of circuit breakers are somewhat consistent throughout the electrical industry, short-time current rating levels are often inconsistent. It is important to understand the performance characteristics of the specific device in order to apply it properly. The present emphasis on higher interrupting ratings, current limiting, and series ratings has impacted the short-time current ratings of circuit breakers. This paper will examine the interrupting capacity and short-time current ratings of molded-case circuit breakers, insulated-case circuit breakers, and low-voltage power circuit breakers and their effect on time-current coordination. It will review resistive and reactive X/R ratios and explain the short-time current and instantaneous trip characteristics of microprocessor-based trip units.**

## I. Introduction

The interrupting capacity of a circuit breaker is the maximum current a circuit breaker is rated to safely interrupt at a specific voltage. This short-circuit current rating is normally expressed in rms symmetrical amperes and is specified by current magnitude only. If the circuit breaker is provided with instantaneous phase trip elements, the interrupting capacity is the maximum rating of the device with no intentional delay. If the circuit breaker is provided without instantaneous phase trip elements, the interrupting capacity is the maximum rating of the device for the rated time interval. An engineer can safely apply a circuit breaker in a power system where the maximum available short-circuit current on the source side of its point of application does not exceed its interrupting capacity rating.

The short-time current rating of a circuit breaker relates to the performance of the circuit breaker over a specific current range for a period of time. It defines the ability of the breaker to remain closed for a time interval under high fault current conditions. It is specified by both current magnitude and time magnitude. The short-time rating is used by the engineer to determine the ability of the circuit breaker to protect itself and other devices and to coordinate with other circuit breakers so the system will trip selectively.

## II. Trip Units

Until the late 1960s the circuit breaker trip units available were thermal-magnetic designs. The magnetic trip element was often referred to as the instantaneous trip element, and the terms were used interchangeably. For an overload current below the magnetic pickup level, the thermal trip element provided overload protection by tripping the molded-case circuit breaker (MCCB) after a time delay. For a high-magnitude fault current, the magnetic trip element tripped the MCCB with no intentional delay and provided short-circuit protection. The interrupting rating was the maximum available fault current at rated voltage at which the MCCB could be applied. MCCBs are manufactured to meet UL489 standards [1].

Low-voltage power circuit breakers (LVPCBs) with thermal-magnetic trip units responded to an overload in a similar manner as MCCBs; however, LVPCBs had a 30-cycle short-time current rating consistent with ANSI standards [2]. This allowed them to be used without a magnetic (instantaneous) trip element. The interrupting capacity rating of an LVPCB was the rating of the circuit breaker with magnetic trip elements. An engineer who applied an LVPCB without magnetic trip elements would need to ensure that the short-time current rating of the device equaled or exceeded the available short-circuit current. LVPCBs are manufactured to meet UL1066 standards [3].

The introduction of solid-state and microprocessor-based trip units allowed improved time-current curve shaping for all types of circuit breakers. Trip units were developed with adjustments for long-time pickup and delay, short-time pickup and delay, instantaneous pickup, and ground-fault pickup and delay. Because they are capable of having a short-time delay current rating in applications without instantaneous trip elements, LVPCBs could take full advantage of these improvements. MCCBs, despite their high interrupting capability, could take only limited advantage of these developments. MCCBs were provided with instantaneous trip elements set at ten to thirteen times the frame rating, and this was the limit of their short-time current rating. The various trip unit adjustments were adjustable only up to the maximum instantaneous trip level. If MCCB trip units were specified without instantaneous trip adjustments, an instantaneous override function was supplied.

In the mid-1970s insulated-case circuit breakers (ICCBs) were introduced. These are specially designed UL489 molded-case circuit breakers that include some LVPCB features. Like all molded-case circuit breakers, ICCBs have an instantaneous trip element. It is set at a much higher trip level than those of existing MCCB designs, allowing limited short-time current ratings for ICCBs.

## III. Circuit Breaker Ratings

With all circuit breaker designs, when a higher short-circuit current rating is required, either a higher interrupting capacity (IC) design is selected or limiters are applied with the circuit breaker. For an MCCB, the short-time current rating is limited to the magnetic pickup level, and that level generally does not increase as a higher interrupting capacity design is chosen. For example, as seen in Table I, a 400-ampere frame molded-case circuit breaker has an instantaneous pickup of 4 kA to 5 kA whether it has an interrupting capacity of 35 kA or 100 kA rms symmetrical amperes. ICCBs often feature extended short-time current ratings. Although these ratings are not consistent throughout the electrical industry, overall the time and current capabilities of ICCBs are lower than those of LVPCBs.

Although the high interrupting capacity ratings of molded-case circuit breakers and insulated-case circuit breakers typically exceed the interrupting capacity ratings of low-voltage power circuit breakers, the short-time pickup and delay ratings of an LVPCB exceed those of an ICCB. In any case, the ratings of both greatly exceed those of an MCCB.

TABLE I
TYPICAL 400-AMPERE FRAME MOLDED-CASE CIRCUIT BREAKERS[a]

| MCCB Design | Low IC | High IC |
|---|---|---|
| Interrupting Capacity (kA @ 480 V) | 35 | 100 |
| Maximum Magnetic Adjustment (kA) | 4 | 4 |
| Instantaneous Override (kA) | 5 | 5 |

[a]The minimum frame size for most ICCBs and LVPCBs is 800 amperes.

Tables I through III indicate typical ratings for 400-ampere frame MCCBs and 800- and 1600-ampere frame MCCBs, ICCBs, and LVPCBs. The ratings given for MCCBs are representative of those offered in the industry. The ratings for ICCBs vary greatly, and many designs offered are not capable of the highest short-time ratings indicated (51 kA and 30 cycles) in the tables. LVPCB short-time current ratings are relatively consistent because they are better defined by ANSI standards [4].

MCCBs and ICCBs have a high interrupting capacity because they do not need to withstand a high current for an extended time delay. Rather, they trip with no intentional delay when experiencing a high fault current that exceeds their instantaneous pickup setting or instantaneous override value. This results in economic advantages over LVPCBs for an equivalent interrupting capacity since the LVPCB must be constructed to not trip at high currents.

The trends in modern circuit breaker design vary by the type of design, and comparing them is complicated. Molded-case circuit breakers have higher interrupting capacity ratings and current-limiting (CL) capabilities not available in earlier models. Interrupting capacity ratings of insulated-case circuit breakers also have increased, but

TABLE II
TYPICAL 800-AMPERE FRAME CIRCUIT BREAKERS

| Type of Device | MCCBs | | ICCBs | | | LVPCBs | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Low IC | High IC | Low IC | High IC | CL | Low IC (Internal Inst. Trip) | High IC (Internal Inst. Trip) | CL (Internal Inst. Trip) | Low IC (No Inst. Trip) | High IC (No Inst. Trip) |
| Interrupting Capacity (kA @ 480 V) | 50 | 100 | 50 | 150 | 150 | 30 | 100 | 200 | 30 | 85 |
| Instantaneous Override or Max. Short-time Current Rating (kA) | 6 – 9 | 6 – 9 | 25 | 25 | 30 | 30 | 85 | 30 | 30 | 85 |
| Short-time Delay (cycles) | 18 | 18 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |

TABLE III
TYPICAL 1600-AMPERE FRAME CIRCUIT BREAKERS

| Type of Device | MCCBs | | ICCBs | | | LVPCBs | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Low IC | High IC | Low IC | High IC | CL | Low IC (Internal Inst. Trip) | High IC (Internal Inst. Trip) | CL (Internal Inst. Trip) | Low IC (No Inst. Trip) | High IC (No Inst. Trip) |
| Interrupting Capacity (kA @ 480 V) | 65 | 100 | 65 | 150 | 150 | 50 | 100 | 200 | 42 | 85 |
| Instantaneous Override or Max. Short-time Current Rating (kA) | 17 | 17 | 35 | 51 | 30 | 42 | 85 | 30 | 42 | 85 |
| Short-time Delay (cycles) | 18 | 18 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |

some short-time current ratings have been lowered. Power circuit breaker interrupting capacity ratings have increased, especially when instantaneous trip elements are provided. Some newer LVPCB designs have increased short-time current ratings, but high interrupting capacity or current-limiting models often have lower short-time current ratings.

## IV. INSTANTANEOUS SETTINGS — ADJUSTABLE VERSUS FIXED

When instantaneous trip elements are provided, two types of designs are available for circuit breakers: instantaneous designs with a magnitude level that is externally adjustable and instantaneous designs with a magnitude level that is internally fixed. Whether or not the circuit breaker trip unit is provided with an externally adjustable instantaneous setting is a consideration when the engineer is coordinating devices.

All MCCBs and ICCBs include an internal fixed-magnitude instantaneous override set at the maximum for the frame. For an MCCB this is often set by the manufacturer at about thirteen times the frame ampere rating; however, the magnitude for an ICCB may be higher. If the circuit breaker trip unit has an external setting adjustment for the instantaneous pickup, the adjustment range is typically five to ten times the frame continuous-ampere rating. This trip element adjustment limit will inhibit the use of any higher instantaneous pickup available for that frame size. It may also inhibit the use of any short-time current rating.

Most MCCB short-time current ratings are negligible due to their low instantaneous trip setting, but as seen in Table II an 800-ampere frame ICCB may have a short-time current rating of 25 kA for 30 cycles. For this device the internal fixed-magnitude instantaneous override is set to pick up at 25 kA. If that same circuit breaker has an external adjustment for the instantaneous trip element, the maximum adjustment is usually ten times the frame ampere rating, or 8 kA. For any fault current in excess of 8 kA, the ICCB with an external adjustment for the instantaneous trip element will trip with no intentional delay even though that device could have been applied with a 25 kA override instantaneous response. This is an important issue, because system coordination often is achieved through the use of device short-time capabilities. Short-time capabilities can only be used below the level of the instantaneous pickup. LVPCBs are capable of even greater short-time ratings. To achieve selectivity, the use of instantaneous trip units that are externally adjustable should be limited to applications where they add value. Typically the applications utilizing LVPCBs with adjustable instantaneous trip elements are feeder circuit breakers feeding individual large motors or a single dry-type transformer.

## V. ASYMMETRICAL FAULT CURRENTS

Despite initial appearances, not all circuit breaker ratings can be directly compared. Circuit breaker types have defined short-circuit power factors (X/R ratios) based on NEMA, ANSI, and UL standards [5]. Because fault currents typically are asymmetrical, the degree of asymmetry is a consideration. The lower the rated short-circuit power factor—and consequently the higher the X/R ratio—the higher the peak instantaneous current value corresponding to the rated rms symmetrical current. The peak maximum asymmetrical current can be calculated from the rms symmetrical current using a multiplication factor that corresponds to the X/R ratio.

As seen in Table IV, ANSI standards require LVPCBs to be tested at a higher X/R ratio than the ratios required by NEMA standards for MCCBs and ICCBs [6]. The rms symmetrical current ratings of LVPCBs are actually higher than the equivalent rms symmetrical current ratings of MCCBs and ICCBs. For example, an LVPCB with a 50 kA rms symmetrical interrupting capacity can be applied in

TABLE IV
CIRCUIT BREAKER ASYMMETRICAL RATINGS

| Type of Device | MCCB | ICCB | LVPCB |
|---|---|---|---|
| Test PF (%) | 20 | 20 | 15 |
| X/R | 4.9 | 4.9 | 6.6 |
| Peak Mult. Factor | 2.2 | 2.2 | 2.3 |

a system with 115 kA peak asymmetrical fault current available, while an MCCB with a 50 kA rms symmetrical interrupting capacity can only be applied in systems with a maximum available peak asymmetrical fault current of 110 kA.

The short-circuit power factor (PF) ratings established by the standards adequately address most applications. However, applications involving large generators in parallel, transformers with ratings higher than 2500 kVA, transformers with higher than normal impedances, network systems, or systems with current-limiting reactors may require special consideration.

## VI. EQUIPMENT PROTECTION

Protection and coordination are often competing objectives. Engineers use MCCBs, ICCBs, or LVPCBs to protect transformers, motors, conductors, and other system components. Applied within their ratings, circuit breakers safely protect both themselves and the electrical system. Selective tripping is necessary when continuity of service is desired. Coordination often is achieved through the use of circuit breaker short-time ratings. An intentional tripping delay may be applied only when downstream equipment has an adequate short-time current rating or is self-protecting. For example, conductors have $I^2t$ ratings that must be evaluated, while a fully rated circuit breaker is self-protecting. Many NEMA and UL equipment standards require only 3-cycle bus ratings, and equipment designed with these minimum ratings must be protected within its short-time limits [7].

In some cases it is desirable to use series ratings as allowed by NEC Article 240.86 [8]. Two or more circuit breakers, applied in series, can be safely applied at locations in power systems where the available fault current exceeds the rating of the downstream circuit breaker alone. Series ratings are UL-tested combinations. Because both breakers share the high fault current interruption, tripping delays are not appropriate. Series ratings are available only for circuit breakers with instantaneous trips. No device with a short-time delay and without an instantaneous trip element would be used in these applications.

Manufacturers have also developed nonfused current-limiting circuit breakers, designed to protect downstream equipment or to obtain a higher interrupting capacity rating for the circuit breaker. Again, a short-time delay would not be appropriate in these applications because the circuit breaker trips in the first half-cycle for a high-magnitude fault. Smaller-frame current-limiting MCCBs can be series rated to protect downstream equipment, but in general circuit breakers above 400-ampere frame size cannot be series rated. Larger-frame current-limiting MCCBs, ICCBs, and LVPCBs are usually applied for their high interrupting capacity. The current-limiting capabilities may limit arc flash hazards and do allow space-saving applications, but selective coordination typically is sacrificed due to the instantaneous tripping.

## VII. COORDINATION

A review of Table II indicates that typical short-time current ratings for 800-ampere frame circuit breakers are 6 kA to 9 kA for molded-case circuit breakers, 25 kA for insulated-case circuit breakers, and 30 kA to 85 kA for power circuit breakers. Each of these devices has models available with an interrupting rating of 65 kA. For downstream applications in power distribution systems a low short-time current rating may be acceptable, but for applications such as feeder circuit breakers in a main switchboard or switchgear it may not be.

A 2500 kVA transformer has an ANSI standard impedance of 5.75% (±7½%). With 250 MVA available at the primary terminals of the transformer and a secondary voltage of 480Y/277 volts, the available three-phase fault current from the transformer at the secondary bus is 44.6 kA rms symmetrical. Assuming 100% motor load for an industrial application, the additional rms symmetrical short-circuit current contributed by the motors to the secondary switchboard or switchgear bus is 12 kA. A feeder circuit breaker in the secondary equipment would have an available fault current of 56.6 kA rms symmetrical. If a 3000 kVA pad-mounted transformer were provided for this application, the available fault current at the secondary bus could exceed 65 kA rms symmetrical.

For the feeder circuit breakers under consideration in this example, those with a 6 kA, 9 kA, or 25 kA short-time current rating would trip for a high-magnitude fault rather than allowing a downstream device to isolate and clear the fault. The entire feeder would be lost if the short-circuit current exceeded 25 kA. To prevent this loss of power, low-voltage power circuit breakers could be selected with a 65 kA short-time current rating that would allow them to coordinate with downstream devices for a fault of any magnitude.

Circuit breakers in series that include instantaneous trip elements will all trip for high fault currents exceeding their instantaneous pickup setting. For example, the circuit breaker time-current curves in Fig. 1 indicate the coordination of a system with an 800-ampere molded-case circuit breaker as the feeder to a downstream 250-ampere molded-case circuit breaker for high available fault current. The time-current curves of both circuit breakers overlap in the instantaneous range and will not coordinate for faults in excess of 5500 amperes.

Circuit breakers in series without instantaneous trip elements can be set to delay tripping in order to coordinate with other devices having short-time current ratings, while downstream devices that include instantaneous trip elements trip and clear the fault current. The circuit breaker time-current curves in Fig. 2 indicate the coordination of a system with an 800-ampere power circuit breaker as the feeder to a downstream 250-ampere molded-case circuit breaker for high available fault current. The time-current curves of both circuit breakers do not overlap and selectively coordinate for faults up to and including the maximum available fault current. The benefit of a high short-time current rating is that it often allows improved coordination with other devices.

The conductor impedance from the feeder circuit breaker in the main switchgear to the protected distribution equipment has to be taken into account. If this impedance limits the fault current to a value below the instantaneous setting of an MCCB or ICCB, then coordination can still be achieved with the downstream devices. Current-limiting circuit breakers have higher interrupting capacities but lower withstand ratings, so selective coordination is difficult when applying current limiting devices. While cost, the importance of the application, and physical size may affect the choice of protective device, selectivity and coordination are important electrical considerations.

## VIII. Conclusion

MCCBs and ICCBs have excellent interrupting ratings but have limited short-time current ratings due to their instantaneous trip elements. To allow improved system selectivity, an engineer normally would select an MCCB or ICCB with instantaneous trip elements that have a pickup set at a fixed internal level rather than one with trip elements that have an external adjustment. LVPCBs are available without instantaneous trip elements and are recognized for their high short-time current ratings, but newer models with high interrupting ratings and low short-time current ratings are being introduced. When specifying protective devices, the engineer should be aware that a circuit breaker with a high interrupting capacity—even if it is a low-voltage power circuit breaker—might not have a high short-time current rating.

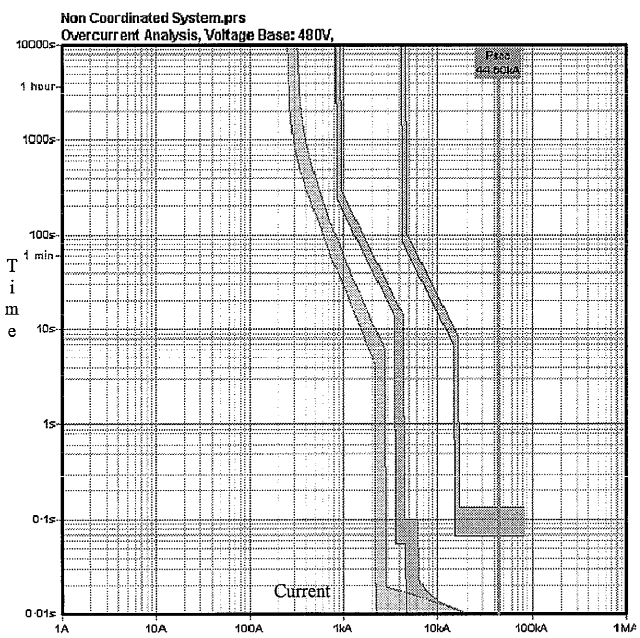


Fig. 1 Time-current curves for a non-coordinated system

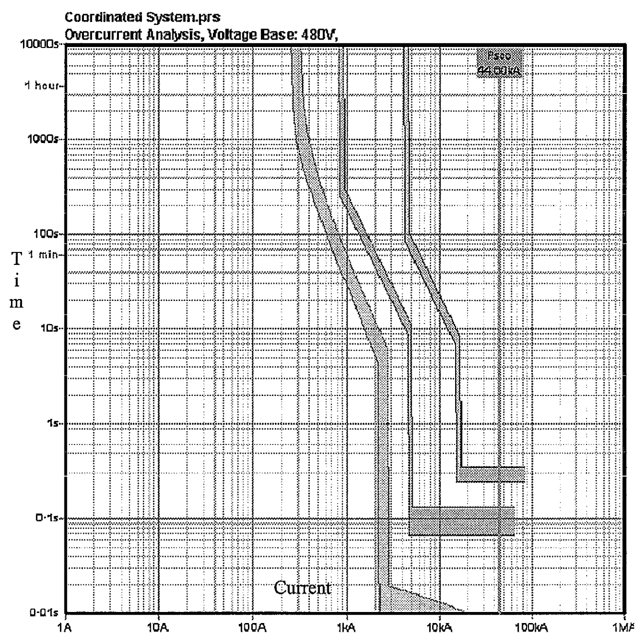


Fig. 2 Time-current curves for a coordinated system

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