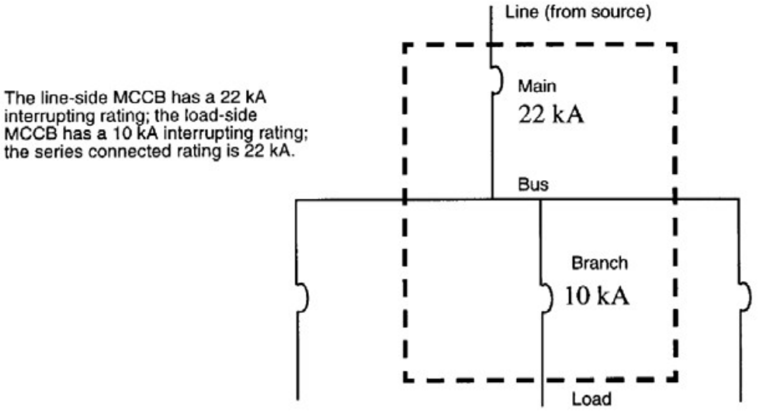


**Figure 4-8—Series-connected rating**

Equipment containing MCCBs, such as switchboards, panelboards, and residential service entrance equipment, must be tested and assigned a UL short-circuit rating when based on the rating of the series combination of circuit breakers used (tests may cover other main overcurrent protective devices).

Protective device series ratings are not limited to devices located in the same enclosure, such as panelboard main and branch circuit breakers. They can be located in different equipment, such as a residential metering distribution panelboard circuit breaker and a load-side residential load center, or a line-side switchboard and a load-side panelboard. Equipment will have rating labels that show short-circuit ratings when protected by series-connected rated line-side devices.

The load-side circuit breaker of a series combination must be located in equipment that is listed and marked for use with series-connected ratings that include that circuit breaker.

Series-connected ratings for each manufacturer's equipment using series combinations of MCCBs are established by that manufacturer with testing witnessed by UL and the Canadian Standards Association (CSA). A series-combination should not use different manufacturers' circuit breakers, even though the manufacturers have similar designs, because no testing has been done to verify a series-connected rating.

The principal benefit of series ratings is the cost savings realized by using load-side circuit breakers whose interrupting rating is less than the available short-circuit current. However, there are disadvantages. The following should be considered when applying circuit breakers in a series combination:

a) One disadvantage of series combination is loss of selective coordination at high-fault currents. A fully rated system might be arranged to avoid tripping the main circuit breaker for a feeder short circuit, but the series combination requires both the main and the feeder circuit breakers to trip when the available short-circuit current is above the instantaneous trip of the main circuit breaker. This is necessary to protect the load-side circuit breaker despite the disadvantage that opening the main circuit breaker interrupts power to all feeder loads that could have continued to operate in a selective system.

b) Series ratings require certain considerations in their applications that have to be handled by a power systems engineer. The line-side circuit breaker or other device opens to protect the underrated load-side circuit breaker when the short-circuit current exceeds the load-side circuit-breaker interrupting rating but is equal to or less than the line-side device rating. Both the line-side device and the load-side circuit breaker may operate in this situation.

c) Series ratings cannot be applied if motors, or other equipment that contributes to a short-circuit current, are connected between the line-side MCCB or other device and the load-side MCCB.

d) To accomplish selectivity, the circuit breakers shall have adjustable trip devices set to operate on the minimum level of short-circuit current. This permits them to be selective while distinguishing between short-circuit current and permissible load-current peaks. The circuit breakers should function in the minimum time possible and still be selective with other overcurrent protective devices in series. When these two requirements are met, the damage to equipment or the inconvenience caused by loss of power will be held to a minimum.

e) Series-connected ratings may be applicable when lowest first cost is the primary consideration and when selectivity, continuity of service, and lower maintenance costs are secondary considerations. When selectivity and reliability are more important than the first cost, the use of fully rated equipment is recommended.

f) A portion of a specific manufacturer's UL listing of series-connected ratings for MCCBs is given in Table 4-1.

### Table 4-1—Representative MCCB series-connected interrupting ratings

| Main device | | | Branch breaker | | | Interrupting rating rms | | |
|---|---|---|---|---|---|---|---|---|
| Type | A | Poles | Type | A | Poles | Sym-metrical A | V ac | Phase |
| SKH | 300–1200 | 2,3 | TK4V | 400–1200 | 3 | 65000 | 240 | 1,3 |
| SKH | 300–1200 | 2,3 | TJJ | 125–400 | 2,3 | 65000 | 240 | 1,3 |
| SKH | 300–1200 | 2,3 | TJK | 125–600 | 2,3 | 65000 | 240 | 1,3 |
| SKH | 300–1200 | 2,3 | TJ4V | 150–600 | 2,3 | 65000 | 240 | 1,3 |
| SKH | 300–1200 | 2,3 | TFJ,<br>TFK | 70–225 | 2,3 | 65000 | 240 | 1,3 |
| SKH | 300–1200 | 2,3 | TED | 110–150 | 3 | 65000 | 240 | 1,3 |
| SKH | 300–1200 | 2,3 | TFJ,<br>TFK | 70–225 | 2,3 | 25000 | 480 | 1,3 |

### Table 4-1—Representative MCCB series-connected interrupting ratings *(continued)*

| Main device | | | Branch breaker | | | Interrupting rating rms | | |
|---|---|---|---|---|---|---|---|---|
| **Type** | **A** | **Poles** | **Type** | **A** | **Poles** | **Symmetrical A** | **V ac** | **Phase** |
| SKH | 300–1200 | 2,3 | TJK | 250–600 | 2,3 | 35000 | 480 | 1,3 |
| SKH | 300–1200 | 2,3 | TJ4V | 150–600 | 3 | 35000 | 480 | 1,3 |
| SKH | 300–1200 | 2,3 | TKM | 300–1200 | 2,3 | 35000 | 480 | 1,3 |
| SKH | 300–1200 | 2,3 | TK4V | 400–1200 | 3 | 35000 | 480 | 1,3 |
| SKH | 300–1200 | 2,3 | TJJ | 400 | 2,3 | 35000 | 480 | 1,3 |
| SKH | 300–1200 | 2,3 | SFH | 70–250 | 2,3 | 35000 | 480 | 1,3 |
| SKL | 300–1200 | 2,3 | SFH | 70–250 | 2,3 | 100000 | 240 | 1,3 |
| SKL | 300–1200 | 2,3 | SFH | 70–250 | 2,3 | 65000 | 480 | 1,3 |
| SKP | 300–1200 | 2,3 | SFH,<br>SFL | 70–250 | 2,3 | 200000 | 240 | 1,3 |
| SKP | 300–1200 | 2,3 | SFH,<br>SFL | 70–250 | 2,3 | 100000 | 480 | 1,3 |
| SKL | 300–1200 | 2,3 | SKH | 300–1200 | 2,3 | 100000 | 240 | 1,3 |
| SKL | 300–1200 | 2,3 | SKH | 300–1200 | 2,3 | 65000 | 480 | 1,3 |
| SKH | 300–1200 | 3 | SFH | 70–250 | 3 | 25000 | 600 | 1,3 |
| TPV | 200–3000 | 3 | SKH | 300–1200 | 2,3 | 100000 | 240 | 1,3 |
| TB4 | 125–250 | 3 | SED,<br>SEH,<br>SEL | 15–150 | 2,3 | 100000 | 480 | 1,3 |
| TJJ | 125–600 | 2,3 | SED | 15–150 | 2,3 | 25000 | 480 | 1,3 |
| THFK | 70–225 | 2,3 | SED | 15–150 | 2,3 | 25000 | 480 | 1,3 |
| THED | 110–125 | 2,3 | SED | 15–150 | 2,3 | 25000 | 480 | 1,3 |
| THLC2 | 225 | 2,3 | SED,<br>SEH,<br>SEL | 15–150 | 2,3 | 200000 | 480 | 1,3 |
| THLC2 | 225 | 2,3 | SED,<br>SEH,<br>SEL,<br>SEP | 15–150 | 2,3 | 150000 | 277 | 1 |
| THLC2 | 225 | 2,3 | SED,<br>SEH,<br>SEL,<br>SEP | 15–150 | 2,3 | 150000 | 480 | 1,3 |

### Table 4-1—Representative MCCB series-connected interrupting ratings *(continued)*

| Main device | | | Branch breaker | | | Interrupting rating rms | | |
|---|---|---|---|---|---|---|---|---|
| **Type** | **A** | **Poles** | **Type** | **A** | **Poles** | **Sym-metrical A** | **V ac** | **Phase** |
| THLC4 | 225–400 | 3 | SED,<br>SEH,<br>SEL | 15–150 | 2,3 | 100000 | 480 | 1,3 |
| THLC4 | 225–400 | 3 | SED,<br>SEH,<br>SEL | 15–150 | 2,3 | 200000 | 240 | 1,3 |
| THLC4 | 225–400 | 3 | SED,<br>SEH,<br>SEL | 15–150 | 2,3 | 100000 | 277 | 1 |
| THLC4 | 225–400 | 3 | SED,<br>SEH,<br>SEL,<br>SEP | 15–150 | 2,3 | 150000 | 480 | 1 |
| TEL | 150 | 3 | SED,<br>she | 15–150 | 2,3 | 100000 | 240 | 1,3 |
| TEL | 150 | 3 | SED,<br>she | 15–150 | 2,3 | 65000 | 480 | 1,3 |
| THLC4 | 225–400 | 3 | SED,<br>SEH,<br>SEL | 15–150 | 2,3 | 200000 | 120/240 | 1 |
| TLB4 | 225–400 | 3 | SED,<br>she | 15–150 | 2,3 | 65000 | 480 | 1,3 |
| TLB4 | 225–400 | 3 | SED,<br>she | 15–150 | 2,3 | 85000 | 240 | 1,3 |
| TLB4 | 225–400 | 3 | SED,<br>she | 15–150 | 2,3 | 65000 | 277 | 1 |
| TLB4 | 225–400 | 3 | SED,<br>she | 15–150 | 2,3 | 85000 | 120/240 | 1 |

NOTE—These ratings are specific to manufacturer, MCCB type, ampere, and voltage ratings.

#### 4.4.5.2.1 Example of a fully rated versus a series-connected rated system

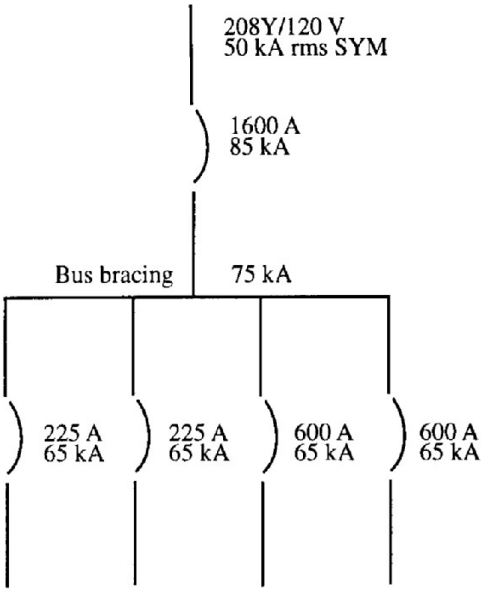
The following list discusses the difference between fully rated and series-connected rated systems:

a) A fully rated system has an available short-circuit current less than or equal to the short-circuit rating of the lowest rated component in the equipment. As shown in Figure 4-9, each protective device in a fully rated system is rated to interrupt the available short-circuit current.

b) An alternative system uses a UL Listed panelboard containing UL Recognized series-rated combinations of circuit breakers whose individual short-circuit ratings may be below the available short-circuit current. For example, if it can be shown by test that a main circuit breaker with a 22 kA interrupting rating and a branch circuit breaker with a 10 kA interrupting rating will interrupt a 22 kA fault (see Figure 4-8), then the combination is series rated for 22 kA.

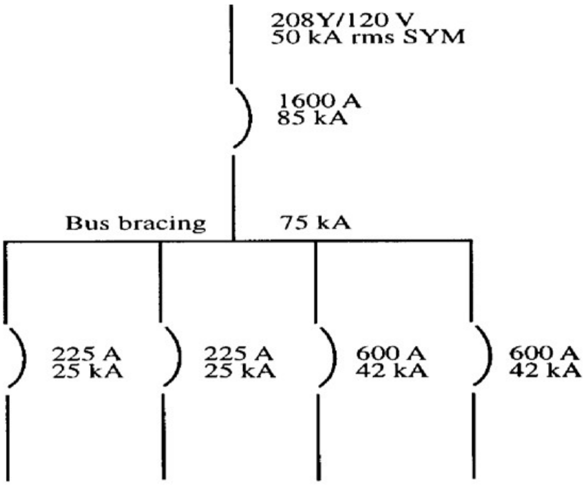
c) In the example series-connected rated system (see Figure 4-10), the combination of a 1600 A main circuit breaker with an interrupting capacity (IC) of 85 kA connected in series with either a 225 A circuit breaker with 25 kA IC or a 600 A circuit breaker with 42 kA IC has been tested and assigned a series-connected rating of 65 kA, which is less than the main circuit-breaker rating, but more than the rating of the feeder circuit breakers.

d) Regardless of whether the protective devices are fully rated or series rated, the bus bracing of the equipment must be equal to or exceed the available short-circuit current of the system as shown in Figure 4-9 and Figure 4-10. An exception is when the line-side device is current limiting and tests have demonstrated a higher rating for the bus in series with the current-limiting device.



An example of a fully-rated system on a 208 Y/120 V circuit with 50 kA symmetrical rms available; 1600 A main rated 85 kA IC connected to two 225 A and two 600 A breakers, all 65 kA IC.

**Figure 4-9—Fully rated system**



Combinations of 1600 A main breaker with 225 A or 600 A feeder breakers have been tested and assigned a series-connected rating of 65 kA IC. Equipment short-circuit rating is 65 kA.

**Figure 4-10—Series-connected rated system**

### 4.4.6 Arcing ground-fault protection for solidly grounded systems

In solidly grounded systems, the arcing line-to-ground fault current is normally considerably lower than the value of a three-phase bolted fault. For example, in a 480 Y/ 277 V system, the arcing fault level can be as low as 38% of the three-phase value. Such arcing faults, because of their destructive nature, must be removed as quickly as possible. Unfortunately, the magnitude of this current may be so low that low-voltage circuit-breaker long-time-delay characteristics allow it to persist too long.

As it is the circuit impedance that limits the current flowing in an arcing fault, an equipment bonding (grounding) conductor is often included with the phase conductors, to provide a lower reactance ground path. The resulting higher ground-fault current is more readily detected and removed in a shorter period of time.

The best protection against this type of fault is to select a trip unit with a ground trip function; the second most suitable protection is a circuit breaker with a low-range instantaneous trip. (A more thorough discussion of this problem is given in Chapter 7 of IEEE Std 242-2001.) A ground-fault trip function may be required (refer to Sections 230.95, 240.13, and 215.10 of the NEC).

## 4.5 Modifications and accessories for specific applications

Some modifications and accessories for low-voltage circuit breakers are available in kit form for field installation. However, many are available factory-installed and cannot be added later in the field.

### 4.5.1 Shunt trip device

A shunt trip is used to electrically trip a circuit breaker, manually or automatically, through a contact or switch located remotely from the breaker. The shunt trip circuit must be energized by some ac or dc control power source. The shunt trip device can be used for tripping from a separate protective relay, or for local or remote control.

When used for tripping from a protective relay

a) A reliable control power source should be used. It may be a station battery or an uninterruptible power supply (UPS). If ac must be used, then it is necessary to also provide a capacitor trip device for each shunt trip device.

b) The short-time short-circuit rating of the circuit breaker shall exceed the available short-circuit current at the point of application.

When used for control purposes, the reliability of the control power source depends on the application. When used for remote control, the shunt trip device may be powered from the remote source.

### 4.5.2 Undervoltage release

An undervoltage release trips the circuit breaker whenever the voltage being monitored falls below a predetermined level. They are available with either time delay or instantaneous operation. The two types of undervoltage releases available are as follows:

a) *Electromechanical automatic reset used in combination with undervoltage release*. When the voltage falls below a predetermined level, a solenoid mechanism will initiate tripping of the circuit breaker. The circuit breaker cannot be closed until the voltage returns to approximately 85% of normal.

b) *Handle reset*. The handle reset undervoltage release spring is cocked or precharged through the circuit-breaker handle mechanism. The major advantage of this type is that the circuit-breaker mechanism cannot be latched when there is no power on the undervoltage release coil. It prevents circuit-breaker mechanism damage due to repeated attempts to close the circuit breaker with a de-energized undervoltage release coil.

NOTE—One design consideration for the use of both types of undervoltage release, as indicated above, is that they do not depend on control power to trip the circuit breaker.

The undervoltage release can be used to open the circuit breaker during a system undervoltage condition, in applications such as motor protection for cases where a magnetic contactor is not available to drop out, or where a sequenced restart is desired as opposed to full start-up of all devices and loads when power is restored.

### 4.5.3 Auxiliary switches

An auxiliary switch consists of "normally open" or "normally closed" contacts mounted in the circuit breaker that change state whenever the circuit breaker is opened or closed. To avoid confusion, the contacts are defined as "a" contacts that are *open* when the circuit breaker is open or tripped and "b" contacts that are *closed* when the circuit breaker is open or tripped.

Auxiliary switches may be used with an indicating device to show the position of the circuit breaker and are used in the control circuit for interlocking purposes.

For more information, see 4.5.3 of IEEE Std C37.2™-1996.

### 4.5.4 Mechanism operated cell (MOC) switch

Used with drawout circuit breakers, MOC switches are similar to auxiliary switches, except that they are mounted within a cubicle and are operated mechanically by the circuit-breaker mechanism. The "a" and "b" designations are the same as on auxiliary switches. They can be set to function in both the "Test and Connect" or the "Connect" only position. They are used when more auxiliary contacts are required than are available on the circuit breaker.

For more information, see 4.5.3 of IEEE Std C37.2-1996.

### 4.5.5 Truck operated cell (TOC) switches, cell switches, or position switches

Used with drawout circuit breakers, TOC switches change state when the circuit breaker is moved between the connected (operating) position and the test or disconnected position. A normally open contact is open when the breaker is *not* in the connected position. A normally closed contact is closed when the circuit breaker is *not* in the operating position. The TOC switch may be used with an indicating device to show the position of the circuit breaker, or in the control circuit to prevent operation of the circuit breaker in one of its positions.

For more information, see 4.5.3 of IEEE Std C37.2-1996.

### 4.5.6 Alarm switches

Alarm switches, sometimes referred to as bell alarm contacts, differ from auxiliary switches in that they function only when the circuit breaker trips automatically, not with the manual opening of the circuit breaker.

An alarm switch consists of a normally open and/or normally closed contact that changes state when the circuit breaker trips due to an overload, short-circuit, or ground fault. The contacts remain in this changed state until reset by a push button on the circuit breaker. Alarm switches are also available with an electrical reset mechanism that allows remote resetting.

An alarm switch may be used with an indicating device to show that the circuit breaker has tripped due to operation of the trip device, or it may be used in the control circuit to prevent closing of itself or another circuit breaker, until reset.

### 4.5.7 Motor operators on MCCBs

The motor operator, once it is activated by the remote push button or pilot device, will cause the circuit breaker to open or close. A motorized mechanism moves the MCCB handle from the tripped position to the closed position. This type of operation allows remote control of a circuit breaker. However, it is slow compared with the electrical close mechanisms on LVPCBs and ICCBs and may not be fast enough for applications such as synchronizing circuits.

### 4.5.8 Electrical close mechanism on LVPCBs and ICCBs

An electrical close mechanism consists of a stored energy closing mechanism, spring charging motor, and solenoid release. It includes anti-pump circuitry to prevent cycling. When the spring charging circuit is energized, the springs are charged. Once charged, operation of a remote push button, switch, or pilot device operates a solenoid that releases the springs, thus allowing the circuit breaker to close. After the circuit breaker is closed, the springs are recharged for the next trip–close-trip cycle of operations.

### 4.5.9 Mechanical interlocks

There are several methods of mechanically interlocking circuit breakers. These methods are walking beam, sliding bar, and key interlock. Each method results in the interlocking of two breakers so that only one may be closed (ON) at the same time, yet both may be open (OFF) simultaneously. The type of interlock that may be used depends on the circuit breaker and the equipment in which it is mounted.

### 4.5.10 Moisture, fungus, and corrosion treatment

For an environment having a high moisture content or where fungus growth is prevalent, a special tropical treatment should be specified for the circuit breakers.

NOTE—Circuit breakers should not be exposed to corrosive environments. If there is no alternative, specially treated circuit breakers that are resistant to corrosive environments should be specified.

### 4.5.11 Terminal shields

Terminal shields protect personnel from accidental contact with energized current-carrying parts.

### 4.5.12 Handle locks

Handle locks are available to prevent accidental or deliberate manual operation of the circuit breaker. The lock does not prevent opening of the circuit breaker by its trip device.

### 4.5.13 Handle ties

Handle ties are used to connect two or more circuit-breaker handles together to enable manual operation of all poles simultaneously. The handle tie does not prevent opening of the circuit breaker by its trip device.

### 4.5.14 Shutters

Shutters are used to provide isolation from the primary contacts when the circuit breaker is withdrawn. They are not circuit-breaker accessories but are used in equipment with circuit breakers. Shutters are applied only with draw-out circuit breakers.

## 4.6 Normal versus abnormal conditions

Normal environmental and operating conditions are as follows:

- Ambient temperature between –5 °C and 40 °C
- Altitude does not exceed 2000 m (6600 ft)
- Seismic zone 0
- Frequency of 60 Hz

Abnormal environmental and operating conditions that should be considered are as follows:

- Operation at ambient temperatures below –5 °C or above 40 °C
- Operation at altitudes above 2000 (6600 ft)
- Exposure to corrosive materials
- Exposure to explosive fumes or dust
- Exposure to dust or moisture
- Seismic zone 1, 2, 3, or 4
- Abnormal vibrations
- Unusual operating duties
- Harmonics
- Repetitive duty cycle, which results in several operations in a short period of time on a regular basis
- Capacitor bank switching
- Frequent switching
- Circuits with high X/R ratios
- Single-pole interruption with three-pole circuit breakers
- Frequencies other than 60 Hz
- Occurrence of frequent and/or severe faults

## 4.7 Considerations for applying MCCBs, ICCBs, and LVPCBs

Certain significant design, construction, or testing differences between low-voltage circuit breaker types may determine the choice of circuit-breaker type to be selected. ICCBs are considered to be a type of MCCB and are tested in accordance with MCCB standards unless specifically stated otherwise by the manufacturer. However, ICCBs do have some of the features of LVPCBs. Refer to Table 4-2 for a comparison of circuit-breaker features. Table 4-2 can be helpful in the selection process.

**Table 4-2—Comparison of features**

| LVPCB | ICCB | MCCB |
|---|---|---|
| Selective trip over full range of fault currents up to interrupting rating. | Selective trip over partial range of fault currents within interrupting rating. | Selective trip over a smaller range of fault currents within interrupting rating. |
| Type of operators: mechanically operated, two-step stored energy, and electrical two-step stored energy. | Types of operators: mechanically operated, two-step stored energy, and electrical two-step stored energy. | Type of operators: mechanically operated over-center toggle or motor operator. |
| Available in draw-out construction permitting racking to a distinct “test position” and removal for maintenance. | Available in draw-out construction permitting racking to a distinct “test position” and removal for maintenance. | Some are available in plug-in design allowing removal for inspection and maintenance. Large frame sizes may be available in draw-out construction. |
| Operation counter is available. | Operation counter is available. | Operation counter is available. |
| Interrupting duty at 480 V ac: 22–130 kA without fuses and up to 200 kA with fuses. | Interrupting duty at 480 V ac: 22–100 kA. | Interrupting duty at 480 V ac: 22–65 kA without fuses and up to 200 kA with integral fuses or for current-limiting type. |
| Current limiting available only with fuses. | Current limiting not available. | Current limiting available with and without fuses. |
| Usually most costly. | Usually mid-range cost, but depends on the enclosure selected. | Usually least costly. |
| Small number of frame sizes available. | Small number of frame sizes available. | Large number of frame sizes available. |
| Extensive maintenance possible on all frame sizes. | Limited maintenance possible on larger frame sizes. | Limited maintenance possible on larger frame sizes. |
| Used in enclosures, switchgear, and switchboards. | Used in enclosures, switchgear, and switchboards. | Used in enclosures, panelboards, and switchboards. |

Table 4-2—Comparison of features *(continued)*

| LVPCB | ICCB | MCCB |
|---|---|---|
| Not available in series ratings. | Not available in series ratings. | Available in series ratings. |
| 100% continuous-current rated in its enclosure. | 80% continuous-current rated, unless specifically stated to be rated 100% in an enclosure. | 80% continuous-current rated, unless specifically stated to be rated 100% in an enclosure. |
| IEEE Std C37.13™-1990 | UL 489-2002 | UL 489-2002 |

## 4.8 Service requirements and protection

Section 230, Parts V1 and V11, from the NEC contain the many requirements for service disconnects of 600 V or less systems, i.e., permissible number of disconnects, sizing, rating of disconnects, overcurrent protection for ungrounded and grounded conductors, location, and ground-fault protection requirements.

## 4.9 Main circuit breakers

The main circuit breaker, as shown in Figure 4-11, is used for switching, servicing, and protecting the main bus of an assembly of low-voltage equipment, such as a line-up of switchgear, or a switchboard, panelboard, or MCC. It is often an integral part of the assembly but can be separately located from the distribution assembly, if desired. When part of a service entrance, it is the service disconnecting means, as defined in the NEC. When the circuit breaker is located in the secondary of a stepdown transformer, it serves as the transformer secondary main circuit breaker and should be located as close to the transformer terminals as possible. A main circuit breaker is not always mandatory, but the advantages it provides should be considered.

### 4.9.1 Disconnecting means

Opening the main circuit breaker isolates the load from the power source. It is used to de-energize the system and is very useful when it is necessary to quickly turn OFF the power, such as when a fire occurs in the facility. For this reason, it is mandatory in a service entrance application, if the service has more than six feeders or branches. It is useful during maintenance of the equipment to safely lockout/tagout everything downstream, when inspecting and maintaining the main bus and connections. The main breaker is also useful for reenergizing the system in an orderly fashion.

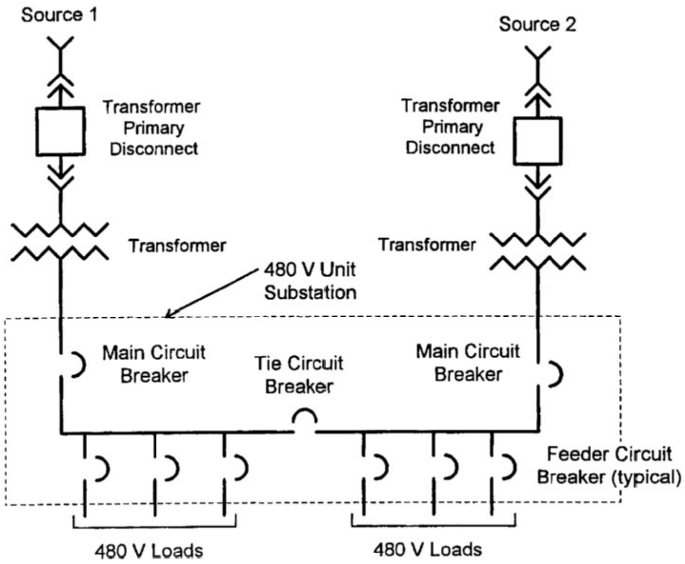


**Figure 4-11—Typical double-ended unit substation**

### 4.9.2 Protection device

#### 4.9.2.1 Overload protection

The main circuit breaker provides overload protection for the main bus of the distribution equipment as well as for the incoming power conductors to the circuit breaker. If applied at the transformer secondary, the main circuit breaker provides overload protection for that transformer. The main circuit breaker normally provides better overload protection than the transformer primary protective device. The primary device has a higher current rating or setting to prevent the device from tripping on transformer inrush current during transformer energization.

#### 4.9.2.2 Short-circuit protection

The main circuit breaker provides short-circuit (fault) protection for the conductors (cable and/or bus) between the main circuit breaker and the branch or feeder circuit breakers. For example, it provides short-circuit protection for the main bus in the assembly, as well as for the tap-offs to the branch or feeder devices. It also provides backup protection for an uncleared feeder fault.

#### 4.9.2.3 Ground-fault protection

This optional protection is desirable for the main circuit breaker on solidly grounded systems of more than 150 V to ground because of the possibility of low-magnitude arcing ground faults that can occur in the main bus bars that are normally not insulated. Ground-fault protection may be required by the NEC (refer to Article 100, 230.95 and 240.13).

#### 4.9.2.4 General application considerations

General application considerations for the main circuit breaker are as follows:

a) The preferred trip functions for selective trip are long-time and short-time (and ground fault, if required). For coordination purposes, instantaneous should be provided only if necessitated by the circuit-breaker interrupting rating.
b) May require key interlocking with a high-voltage switch on the transformer primary.
c) May require key or electrical interlocking with a tie circuit breaker.

## 4.10 Tie circuit breakers

The tie circuit breaker, as indicated in Figure 4-11, is used for switching, servicing, and protecting the main bus of an assembly of low-voltage equipment, such as a line-up of switchgear, or a switchboard, panelboard, or MCC. It is often an integral part of the assembly but can be separately located from the distribution assembly, if desired. It is also used for sectionalizing or isolating a section of bus and to allow for maintenance of the main circuit breaker or transformer. A tie circuit breaker is never mandatory, but the advantages it provides should be considered. The functions performed by the tie circuit breaker include those described in 4.10.1 and 4.10.2.

### 4.10.1 Disconnecting means

Opening the tie circuit breaker along with one of the main circuit breakers isolates the included bus section from the power source. The tie circuit breaker is used to de-energize a portion of a system and is useful when it is necessary to quickly turn OFF the power. Opening one main circuit breaker and closing the tie circuit breaker enables the system to remain energized while the main circuit breaker or transformer is being maintained. It is useful during maintenance of the equipment to safely lockout/tagout everything downstream, when inspecting and maintaining the main bus and connections. The tie circuit breaker is also useful for reenergizing the system in an orderly fashion.

### 4.10.2 Protection device

#### 4.10.2.1 Overload protection

The tie circuit breaker provides overload protection for a portion of the main bus of the distribution equipment as well as for the upstream power conductors.

#### 4.10.2.2 Short-circuit protection

The tie circuit breaker provides short-circuit (fault) protection for the conductors between the tie circuit breaker and the branch or feeder circuit breakers on that portion of the bus.

For example, it provides short-circuit protection for the main bus in the assembly as well as for the tap-offs to the branch or feeder devices. It also provides backup protection for an uncleared feeder fault.

#### 4.10.2.3 Ground-fault protection

This optional protection is desirable for the tie circuit breaker on solidly grounded systems of more than 150 V to ground because of the possibility of low-magnitude arcing ground faults that can occur in the main bus bars, which are normally not insulated. This may limit the number of feeders that are de-energized in a fault condition (refer to 4.4.6). A ground-fault trip function may be selected to provide ground-fault coordination with the main and feeder circuit breakers

#### 4.10.2.4 General application considerations

General application considerations for the circuit breaker are as follows:

a) The preferred trip functions for selective trip are long-time and short-time (and ground fault, if required or if desired, for coordination). For coordination purposes, instantaneous trip functions should be provided only if necessitated by the circuit-breaker interrupting rating.

b) May require key or electrical interlocking with main breakers to prevent paralleling or synchronism check equipment to monitor paralleling.

c) On four-wire multisource systems, ground-fault protection is complex and requires careful consideration.

## 4.11 Feeder protection

Feeder circuit breakers, like the main and tie circuit breakers, function as a disconnecting means for various types of loads as described in the paragraphs that follow. The feeder circuit breaker contains a protective device with the trip functions [overload, short circuit, and ground fault (if required)]. Feeder circuit protection is also covered in great detail in Chapter 9 of IEEE Std 242-2001.

### 4.11.1 Feeder circuit protection

#### 4.11.1.1 Overload protection of cables

Overload protection is covered in Section 240.3 of the NEC under the provision requiring all conductors to be protected in accordance with their ampacity. In general, the ampacity of cables is determined from the tables contained in Section 310.15 of the NEC, which concern the installation of conductors. The tables in Section 310.15 of the NEC also offer rules for derating cables. In general, no specific NEC rules are presented to coordinate insulation heating characteristics with the overcurrent devices concerning temperature versus time.

Overload protection cannot be applied until the ampacity of a cable is determined.

The normal ampacities of cable under the jurisdiction of the NEC are tabulated in its current (2002) issue or amendments thereto. The ampacity of cables under general operating conditions that may not come under the jurisdiction of the NEC are published by the Insulated Cable Engineers Association (ICEA). See 9.5 of IEEE Std 242-2001.

Derating may be required; refer to Section 310.15 of the NEC.

Short-time overloading may be permissible in emergencies; details are examined in Chapter 9 of IEEE Std 242-2001.

#### 4.11.1.2 Short-circuit protection

Feeder conductors must be protected from overheating due to excessive short-circuit current. The task of providing cable protection during a short-circuit condition involves obtaining the following information:

a) Maximum available short-circuit currents

b) Maximum operating temperature of the insulation

c) Maximum conductor temperature that will not damage the insulation

d) Cable conductor size and material affecting $I^2R$ value and the capability to contain heat

e) Longest time that the short-circuit will exist and the short-circuit current will flow (see Table 4-3)

f) Cable short-circuit current damage curve (see Figure 4-12, Figure 4-13, and Figure 4-14)

This subject is discussed in detail in 9.4 of IEEE Std 242-2001.

#### 4.11.1.3 Ground-fault protection

On solidly grounded systems of more than 150 V to ground, advantage should be taken of the enhanced protection offered by integral ground-fault trip devices available on most LVPCBs, ICCBs, and MCCBs. Phase-to-ground faults are more likely to occur than other types of short-circuits. An integral ground trip provides sensitive protection with its low pickup current, which is usually a percentage of the circuit-breaker long-time-delay pickup or current sensor rating (refer to 4.4.6). A ground-fault trip function is selected to provide ground-fault coordination with the main and tie circuit breakers and coordination with the load protective devices. Where several steps of coordination are required, it may be necessary to ignore the residual method for determining ground-fault current, and instead choose an external source that measures the true ground-fault current, such as a current transformer that encircles all current-carrying conductors or a current transformer that measures current in the power transformer neutral-to-ground conductor. A separate ground-fault protective device may be required for feeders rated 1000 A or higher (refer to Section 215.10 of the NEC).

### Table 4-3—Estimated clearing times of low-voltage circuit breakers

| LVPCBs | | |
|---|---|---|
| | **Frame size** | |
| | **225–600 A** | **1600–4000 A** |
| Instantaneous, cycles | 2–3 | 3 |
| Short time, cycles | 10-30 | 10–30 |
| Long time, seconds | Over 100 | Over 100 |
| Ground fault, cycles | 10–30 | 10–30 |

| MCCBs | | |
|---|---|---|
| | **Frame size** | |
| | **100 A** | **225–4000 A** |
| Instantaneous, cycles | 1.1 | 1.5 |

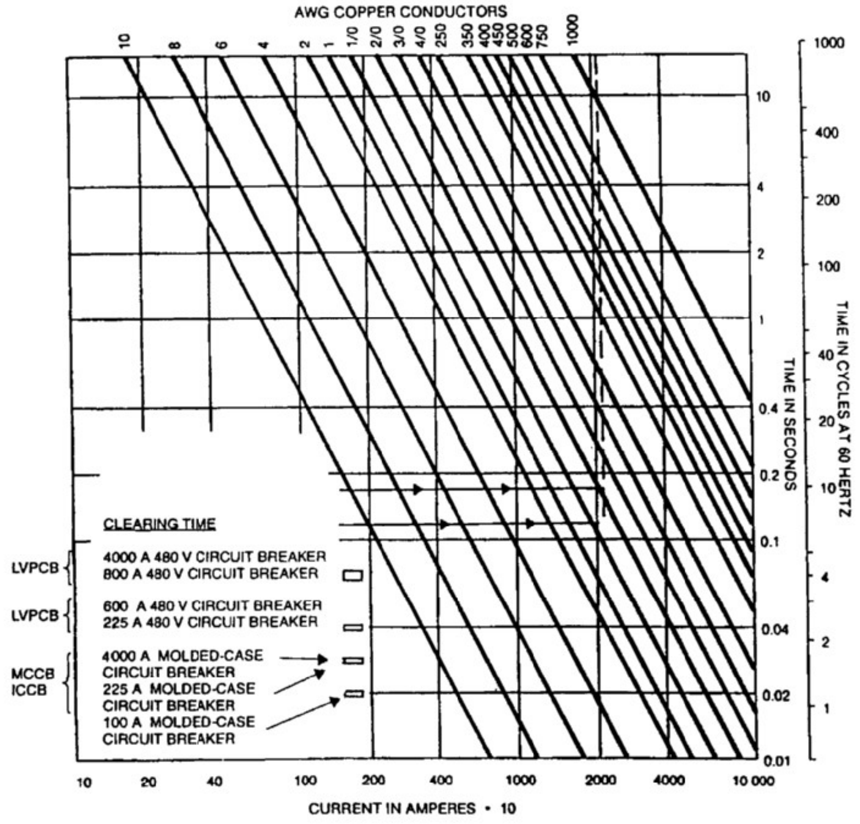


Figure 4-12—Maximum short-circuit current for insulated copper conductors (initial temperature 75 °C; final temperature 200 °C; for other temperatures, use correction factors of Figure 4-14)

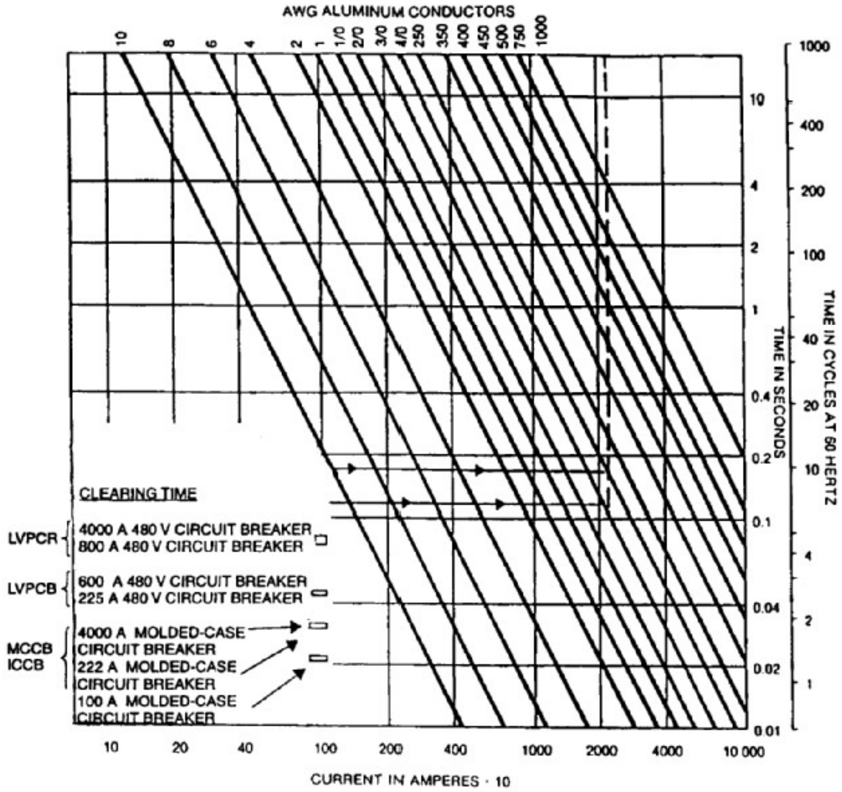
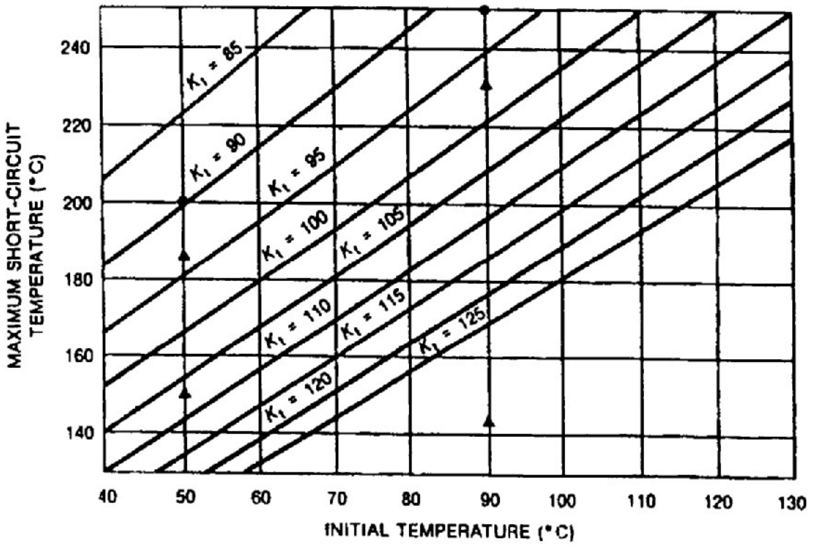


Figure 4-13—Maximum short-circuit for insulated aluminum conductors (initial temperature 75 °C; final temperature 200 °C; for other temperatures, use correction factors of Figure 4-14)



When using the factor $K_t$,the available short-circuit current should be multiplied by $K_t$ and the resulting product should be used in Figure 4-12 and Figure 4-13.

**Figure 4-14—Correction factors ($K_t$) for initial and maximum short-circuit temperatures**

### 4.11.1.4 Example of feeder protection

Selecting and coordinating a low-voltage circuit breaker is done by plotting the time-current curves of the protected cable and the low-voltage circuit breaker on the same log–log graph paper (refer to Chapter 5).

The time-current curve of the circuit breaker should always be below and to the left of the maximum short-circuit current-damage curve (see Figure 4-15 and Figure 4-16) of the protected cable. Figure 4-15 and Figure 4-16 illustrate that a 600 V, Rated, No. 4/0 AWG copper insulated cable may be protected by an instantaneous tripping function of an LVPCB (see Figure 4-15) or MCCB (see Figure 4-16).

NEC 220.10 for branch circuits and 215.3 for feeder circuits requires that, for a continuous load, a circuit breaker must be rated at least 125% of the continuous load. For a noncontinuous plus continuous load, a circuit breaker must be rated not less than the noncontinuous load plus 125% of the continuous load. An exception is provided for each allowing the ampere rating to be selected at not less than the sum of the noncontinuous load plus the continuous load if the circuit breaker is listed for operation at 100% of its rating. All LVPCBs and only some MCCBs are 100% rated and may be applied at 100% of the continuous load. The load of Figure 4-16 is assumed to be noncontinuous, and a 225 A MCCB is applicable. The thermal or long-time characteristic plotted in Figure 4-16 is less than the 230 A allowable cable ampacity. Refer to Table 310.16 of the NEC for 75 °C insulated conductor ampacities.

Electronic trip devices provide better protection than thermal-magnetic trips. The MCCB provides short-circuit protection because the MCCB curve is below and to the left of the cable's maximum short-circuit current (damage) curve. For safe cable protection, the cable should be selected and protected in the same manner as described in the preceding paragraph.

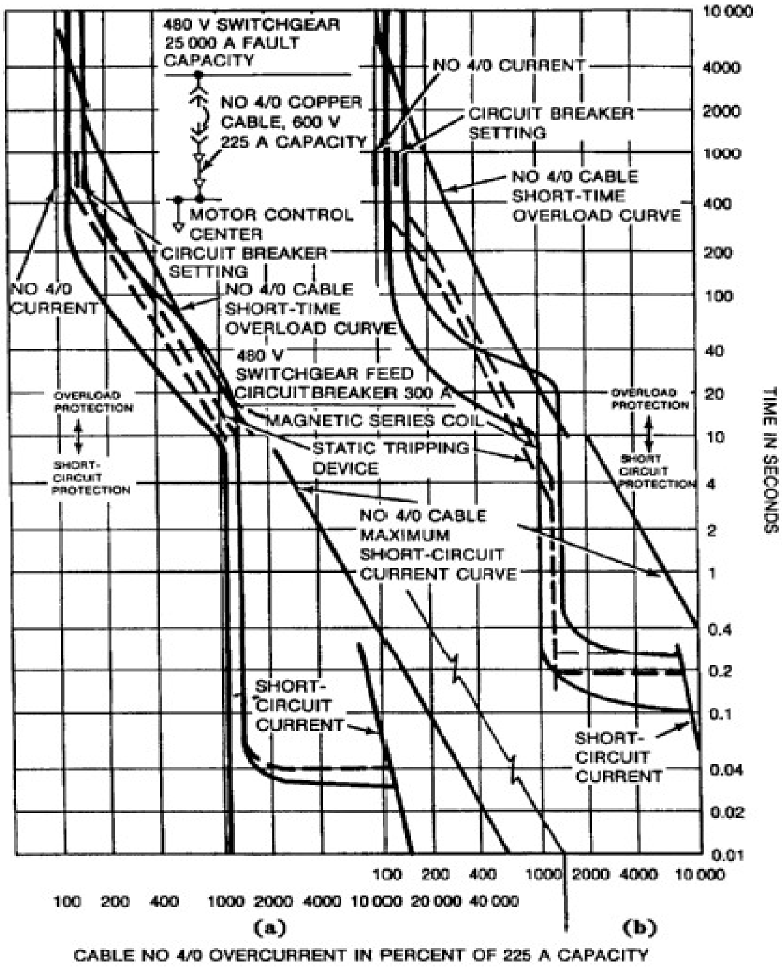


Figure 4-15—Short-circuit and overload protection of 600 V cables: (a) Long-time and instantaneous equipped LVPCBs and (b) long-time and short-time equipped LVPCBs

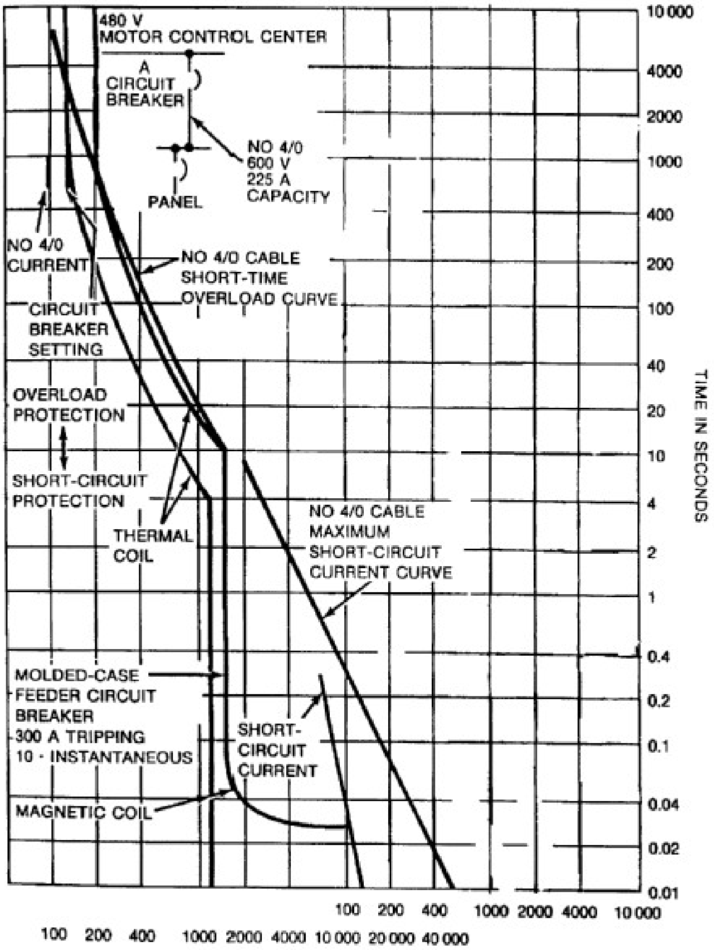


**Figure 4-16—Short-circuit and overload protection of 600 V cables—Thermal-magnetic MCCBs**

### 4.11.2 Protection of busway

A busway may be considered a single replacement for several smaller cables. To contribute to the high reliability expected, it should be provided with the best possible protection, to minimize the number and duration of outages.

The two basic busway types are feeder and plug-in busway. Both are available in variations providing higher or lower impedance and with differing losses, enclosures, ventilation, or insulation features. See 9.8 of IEEE Std 242-2001.

### 4.11.2.1 Typical busway protective device

Like any other circuit, busways are subject to overloads and bolted short-circuits. In addition, busways are subject to arcing ground faults on solidly grounded systems having line-to-ground voltages greater than 150 V. Although no single element incorporates all necessary characteristics, it is possible to assemble several elements into a single device. A particularly effective device is the fused or current-limiting circuit breaker equipped with ground-trip protection. In such a device, the circuit-breaker elements provide operation in the overload and low short-circuit current range, whereas the coordinated current-limiting capability functions during high short-circuit currents. The ground-trip sensor detects those arcing short-circuit currents that go to ground and, even though they may be low magnitude, signals the circuit breaker to open. The integral ground trips that are available on most LVPCBs, ICCBs, and larger size MCCBs provide fast and sensitive protection; the ground current pickup is usually a fraction of long-time delay pickup or sensor or plug rating.

### 4.11.2.2 Busway thermal and mechanical high-current capabilities

The busway has a thermal overload and short-circuit withstand capability similar to cable. Table 4-4 lists busway minimum short-circuit current ratings. The time-temperature conserved-heat formulas for short-time high currents previously specified for cable also apply to busway. Thermal withstand lines on a log–log plot similar to those of Figure 4-12 and Figure 4-13 can be calculated knowing an initial temperature and the permissible transient total temperature for the busway insulation.

Table 4-4—Busway minimum short-circuit current ratings

| **Continuous-current rating of busway (A)** | | **Minimum short-circuit current ratings (A)** | |
|---|---|---|---|
| **Plug-in** | **Feeder** | **Symmetrical** | **Asymmetrical** |
| 100 | — | 10 000 | 10 000 |
| 225 | — | 14 000 | 15 000 |
| 400 | — | 22 000 | 25 000 |
| 600 | — | 22 000 | 25 000 |
| — | 600 | 42 000 | 50 000 |
| 800 | — | 22 000 | 25 000 |
| — | 800 | 42 000 | 50 000 |
| 1000 | — | 42 000 | 50 000 |
| — | 1000 | 75 000 | 85 000 |
| 1350 | — | 42 000 | 50 000 |

### Table 4-4—Busway minimum short-circuit current ratings *(continued)*

| **Continuous-current rating of busway (A)** | | **Minimum short-circuit current ratings (A)** | |
|---|---|---|---|
| **Plug-in** | **Feeder** | **Symmetrical** | **Asymmetrical** |
| — | 1350 | 75 000 | 85 000 |
| 1600 | — | 65 000 | 75 000 |
| — | 1600 | 100 000 | 110 000 |
| 2000 | — | 65 000 | 75 000 |
| — | 2000 | 100 000 | 110 000 |
| 2500 | — | 65 000 | 75 000 |
| — | 2500 | 150 000 | 165 000 |
| 3000 | — | 85 000 | 100 000 |
| — | 3000 | 150 000 | 165 000 |
| — | 4000 | 200 000 | 225 000 |
| — | 5000 | 200 000 | 225 000 |

The busway short-circuit rating, however, defines a mechanical limit that is lower than the thermal capability. This mechanical limit, therefore, applies for high currents below but near the short-circuit rating. Permissible flow times for these high currents, longer than the three cycles at 60 Hz (0.05 s) required at rating, are obtained from a constant $I^2t$ mechanical limit characteristic.

For currents below one half of the short-circuit current rating, where stresses reduce to one quarter of those at 100% of rating, the mechanical limit becomes less important and the thermal capability determines protection requirements. The thermal capability at high current is constant $I^2t$, and this joins the busway continuous-current rating through a smooth transition.

In addition, the damage due to arcing ground faults should be considered for solidly grounded systems with line-to-ground voltages greater than 150 V (see 9.8.2.2 of IEEE Std 242-2001).

#### 4.11.2.3 Examples of busway protection

The following two examples illustrate busway phase overcurrent protection by low-voltage circuit breakers whose time-current characteristics are below the busway thermal-mechanical capability characteristics. See Figure 4-17 and Figure 4-18.

In the first example (Figure 4-17), an 800 A plug-in busway has a 22 kA short-circuit rating. It is assumed that the busway is applied where the bolted short-circuit duty is equal to the 22 kA busway rating, indicated on Figure 4-18 by B enclosed in a triangle. The LVPCB protecting the busway must clear this maximum bolted short-circuit current in the three-cycle busway permissible time and must therefore be instantaneously tripped. For high currents, this circuit breaker cannot be selectively coordinated with busway plug fuses or circuit breakers that are instantaneously tripped. The busway protecting circuit-breaker instantaneous pickup is set as high as possible, without crossing the busway limit curve, and coordination with busway plug devices is achieved for short-circuit currents lower than this pickup. The short-time characteristic provides relatively fast tripping for currents in the arcing fault region, at A enclosed in a triangle and below. The curves of Figure 4-17 illustrate coordination with a 400 A busway plug MCCB having an instantaneous pickup of 10×, equaling 4000 A. If the largest busway plug device has a lower instantaneous pickup, the LVPCB short-time pickup should be correspondingly reduced to provide better short-time protection for arcing faults.

The long-time pickup of the protecting LVPCB should be no more than the next higher rating, in conformance with the requirements of Sections 368.10 and 368.11 of the NEC. For solidly grounded systems of more than 150 V to ground, the electronic trip should also be equipped with a ground-trip function to provide fast, sensitive protection for arcing ground short-circuits. The ground-trip pickup can be set at a fraction of the busway rated current.

An ICCB or large-size MCCB with electronic trips can provide essentially the same busway protective characteristic as the LVPCB of this example.

The obvious disadvantage of the first example is the loss of selective coordination between the busway plug MCCB and the busway protection LVPCB. A severe short-circuit on the plug circuit could trip both the plug and the LVPCB and interrupt other healthy circuits plugged into the busway. This disadvantage is removed by using a busway with a higher short-circuit rating, as shown in the second example (Figure 4-18). As shown in Figure 4-18, the 800 A plug-in busway has a 65 kA short-circuit rating.

The LVPCB protecting the busway does not have an instantaneous trip and therefore coordinates selectively with busway plug fuses and circuit breakers that are instantaneously tripped. In other respects, the comments of the first example also apply to the second. If an ICCB was used instead of the LVPCB, the ICCB would still have a short-time and instantaneous unit as in the first example. Thus, there would be a loss of selective coordination between the busway plug MCCB and the busway protection ICCB.

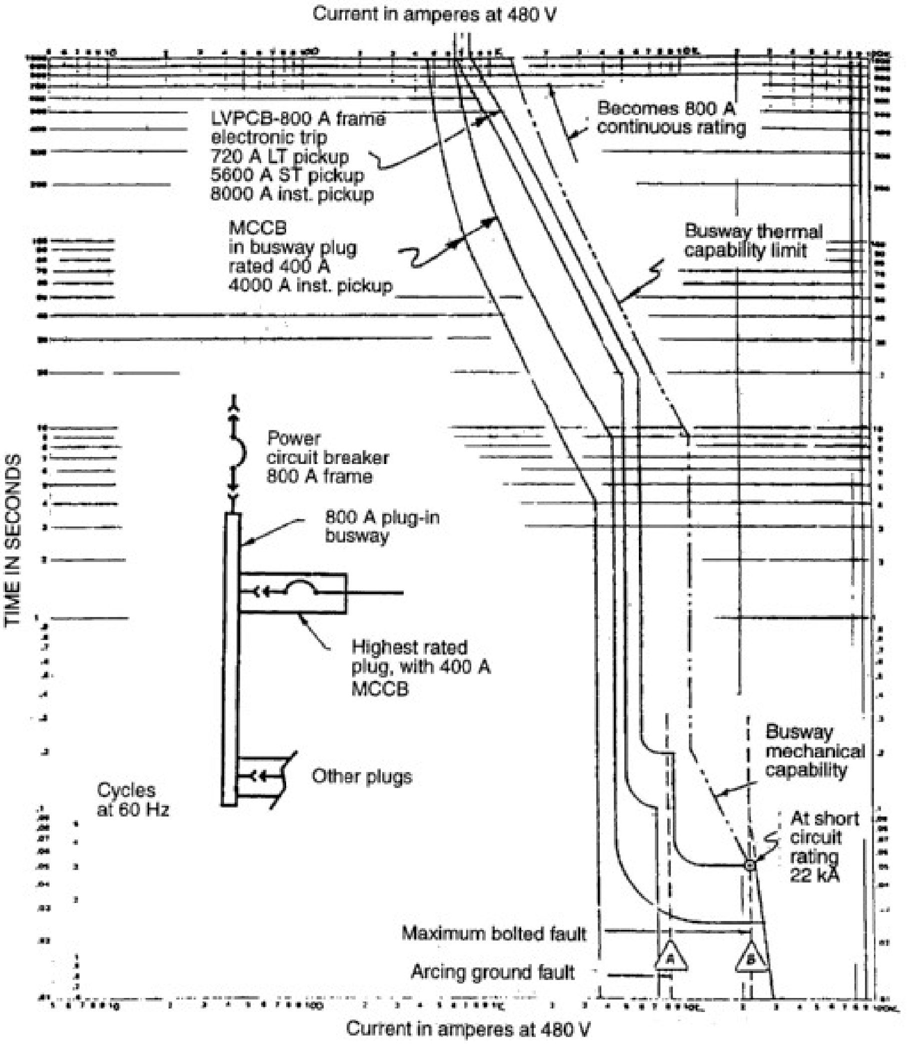


Figure 4-17—Short-circuit and overload protection of busway 22 kA short-circuit rating

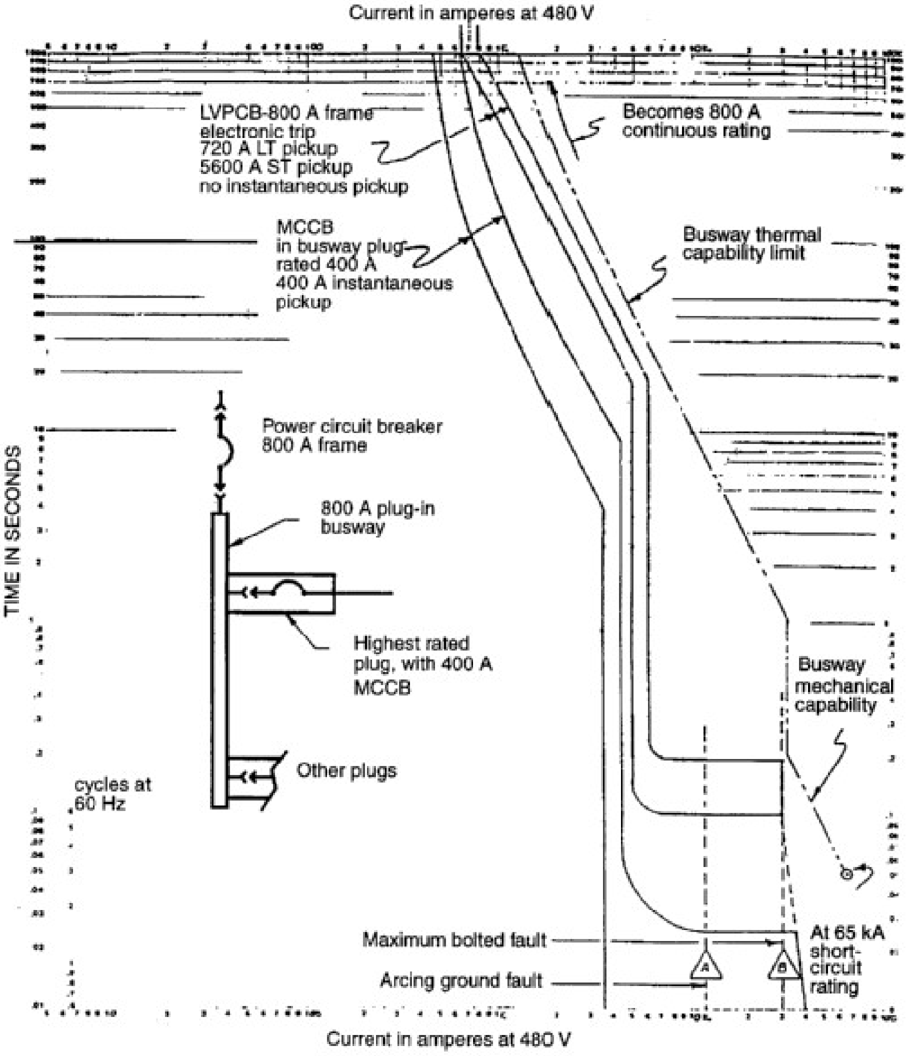


Figure 4-18—Short-circuit and overload protection of busway 65 kA short-circuit rating

In summary, the short-circuit rating of the busway should be selected as high as possible to achieve selectivity.

The examples in Figure 4-17 and Figure 4-18 show how an alternative selection of equipment short-circuit capabilities, along with trip unit characteristics/functions, can change a nonselective system to a selective system.

These examples apply to busway conforming to UL 489, with a fault withstand rating of three cycles. “Metal-enclosed bus” (commonly referred to as “bus duct”) that conforms to

IEEE Std C37.23™ has a momentary withstand of 10 cycles (0.167 s) and a short-time rating of 2 s. The limitations stated in the text would not be as stringent if applied to a metal-enclosed bus constructed to meet IEEE Std C37.23.

#### 4.11.2.4 Protection of switchgear bus

The switchgear bus is a component of a prefabricated switchgear assembly manufactured according to standards. Accordingly, as stated in 5.4.3 of IEEE Std C37.20.1™-2002, "The rated short-time withstand current of a LV ac switchgear assembly is the designated limit of available (prospective) current at which it shall be required to withstand its short-time duty cycle (two periods of 0.5 s current flow, separated by a 15 s interval of zero current) at rated maximum voltage under the prescribed test conditions. "Similarly, as stated in 5.4.4 of IEEE Std C37.20.1-2002, "The rated short-circuit withstand current of a LV ac switchgear assembly…is the designated limit of available (prospective) current at rated maximum voltage that it shall be required to withstand for a period of no less than 4 cycles on a 60 Hz basis under the prescribed test conditions. "Both are first-cycle rms symmetrical current ratings. Assemblies including the switchgear bus shall be capable of withstanding these duties with all degrees of current asymmetry produced by three-phase or single-phase circuits having a short-circuit power factor of 15% or greater (X/R ratio of 6.6 or less). The ratings are equal to the corresponding ratings of the smallest frame size circuit breaker used in the assembly.

These ratings determine that the switchgear bus will not be damaged by currents flowing while connected circuit breakers are interrupting external short-circuits.

The source or tie circuit breakers that carry currents to the switchgear bus may be set to provide long-time thermal overload and short-circuit protection for the bus, but the outgoing feeder circuit breakers act to provide protection against short-circuit currents that flow through the bus to faults external to the bus. Because of the short-time thermal ratings of the switchgear bus, the main, tie, and feeder protective devices on LVPCBs may have a short- time delay of up to 0.5 s at maximum short-circuit current, per IEEE Std C37.20.1-2002.

For sensitive tripping of arcing phase-to-ground faults on solidly grounded systems of more than 150 V to ground, advantage should be taken of the enhanced protection offered by integral ground trips available on most LVPCBs, ICCBs, and on larger size MCCBs. Switchgear arcing phase-to-ground fault currents could be small with respect to the main circuit breaker long-time pickup and, without the sensitive ground-trip protection, might remain undetected, causing severe damage. The ground trips act fast and have low pickup currents, usually a fraction of the long-time pickup setting.

#### 4.11.2.5 Protection of switchboard bus

A switchboard bus is a component of a prefabricated switchboard assembly manufactured according to standards. According to UL 891-1998 and NEMA PB 2-2001, switchboards are tested for three cycles at a power factor of 50%, 30%, or 20% for short-circuit ratings of 10 000 A, 10 001–20 000 A, or 20 001–200 000 A rms symmetrical current, respectively. As a result, LVPCBs, ICCBs, and MCCBs must interrupt a fault within three cycles at maximum short-circuit current to protect the bus. It may necessitate using an instantaneous unit on the main circuit breaker to protect the bus at the sacrifice of obtaining selectivity.

The source or tie circuit breakers that carry current to the switchboard bus are set to provide long-time thermal overload and short-circuit protection for the bus, but the outgoing feeder circuit breakers act to provide protection against short-circuit currents that flow through the bus to faults external to the bus. Due to lack of short-time testing requirements, the outgoing feeder circuit breakers should be instantaneously tripped to meet the three-cycle testing time limit. For sensitive tripping of switchboard arcing phase-to-ground faults on solidly grounded systems of more than 150 V to ground, advantage should be taken of the enhanced protection offered by integral ground trips available on larger size MCCBs and on most LVPCBs. Switchboard arcing phase-to-ground fault currents could be small with respect to main circuit-breaker long-time pickup and, without the sensitive ground-trip protection, might remain undetected, causing severe damage. The ground-fault trips act fast and have low pickup currents, usually a fraction of the long-time pickup setting.

### 4.11.3 Protection of motor feeders and motors

#### 4.11.3.1 Motor feeders

Motor feeders receive particular attention from Article 430 from the NEC, which governs the selection of the current-carrying capacity of conductors used for motor applications. After the cable size is selected in accordance with this article, the overload, short-circuit, and ground-fault protection are applied in accordance with Articles 240 and 430 from the NEC. Motor overload protection is discussed in Article 430, Part III, from the NEC. Short-circuit and ground-fault protection for both individual and grouped motor applications are discussed in Article 430, Parts IV and V, from the NEC. Maximum rating or settings of motor branch-circuit, short-circuit, and ground-fault devices is provided in Table 430.52 from the NEC. Ground-fault trip units may be required on motor feeders to obtain coordination with ground-fault trip units on the supply devices.

Article 430 from the NEC requires the continuous-current rating of the circuit breaker to be no less than 115% of motor full-load amperes (FLAs). The trip setting for an inverse time circuit breaker should not exceed 250% of motor full-load amperes (refer to Table 430.52 from the NEC). Exceptions of 300% for over 100 A and 400% for under 100 A full-load ampere are permitted, if necessary for starting [refer to Section 430.52, Exception 2(c), of the NEC]. It is desirable to use the lowest value of continuous-current rating, which ensures nuisance-free starting with its maximum instantaneous trip setting.

#### 4.11.3.2 Motors

Selection considerations for motors are as follows:

a) Motor and branch-circuit overcurrent protection

b) Motor and branch-circuit short-circuit protection

See Figure 4-20 for an example of individual motor and branch-circuit protection. The 70 A circuit breaker is primarily intended to protect against short-circuits. It should not generally be used as a switch to energize or de-energize motors. A contactor in a motor controller, rather than a circuit breaker, should be used for switching a frequently started motor ON and OFF. For large motors that are started infrequently, LVPCBs may be applied (see Table 4-5 and Table 4-6).

High-efficiency (NEMA Class E) motors, because of their low-loss designs, have higher starting current than standard NEMA motors of the same horsepower and code letters. It is not uncommon for certain high-efficiency motors to reach locked-rotor magnitudes of 800% of full-load current. If this is not taken into account in setting the breaker, then nuisance tripping will be the result. The circuit breaker's instantaneous setting must be set just above the motor starting current to avoid nuisance tripping when the motor is started. This may involve trial and error.

Other potential application limitations that should be reviewed with the manufacturer are as follows:

- Frequent starting duty
- Extended starting times
- Ground fault coordination

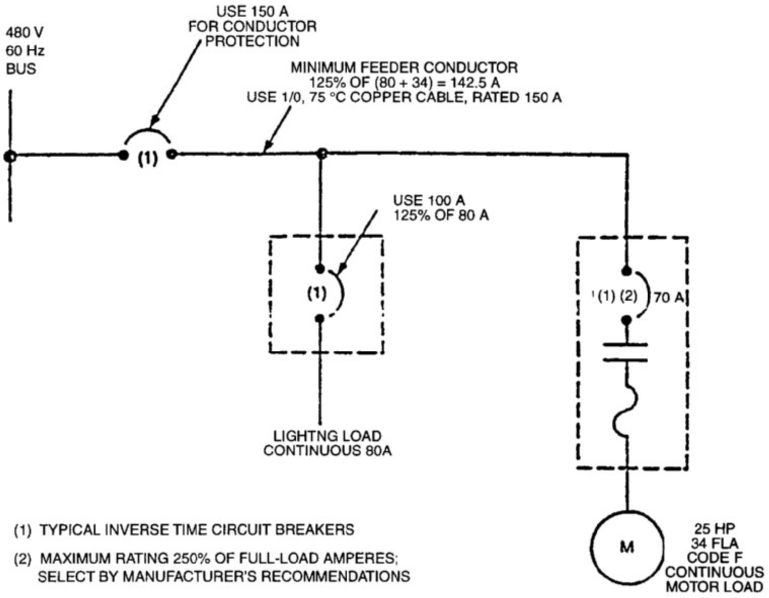


**Figure 4-19—Typical feeder circuit (lighting load and single fixed motor load)**

## Table 4-5—Application of low-voltage ac power circuit breakers to full-voltage motor starting and running duty of three-phase, 60 Hz, 40 °C rise motors$^{a, c}$

| Line no. | Horsepower rating of three-phase ac motors | | | | | | | | Trip device current rating (A)$^{b}$ | | Motor full-load current $^{(A)}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Induction motors | | 100% power-factor synchronous motors | | | 80% power-factor synchronous motors | | | | | | |
| | 230 V | 460 V | 575 v | 220 V | 440V | 550 V | 220 V | 440 V | 550 V | | Min | Max |
| | Col 1 | Col 2 | Col 3 | Col 4 | Col 5 | Col 6 | Col 7 | Col 8 | Col 9 | Col 10 | Col 11 | Col 12 |
| 1 | 10 | 25 | 30 | — | 30 | 40 | — | 25 | 25; 30 | 40 | 26 | 35 |
| 2 | 15 | 30 | 40 | — | 40 | 50 | — | 30 | 40 | 50 | 32 | 44 |
| 3 | 20 | 40 | 50; 60 | 25 | 50 | 60 | — | 40 | 50 | 70 | 45 | 61 |
| 4 | 25; 30 | 50; 60 | 75 | 30 | 60 | 75 | 25 | 50 | 60 | 90 | 58 | 78 |
| 5 | — | — | — | 40 | 75 | 100 | 30 | 60 | 80 | 100 | 64 | 87 |
| 6 | 40 | 75 | 100 | 50 | 100 | 125 | 40 | 75 | 100 | 125 | 80 | 109 |
| 7 | 50 | 100 | 125 | 60 | — | 150 | — | — | — | 150 | 96 | 131 |
| 8 | — | — | 150 | — | 125 | — | 50 | 100 | 125 | 175 | 112 | 152 |
| 9 | 60 | 125 | — | 75 | 150 | 200 | 60 | 125 | 150 | 200 | 128 | 174 |
| 10 | 75 | 150 | 200 | — | — | — | — | — | — | 225 | 144 | 196 |
| 11 | — | — | — | 100 | 200 | — | 75 | 150 | 200 | 250 | 160 | 218 |
| 12 | 100 | 200 | 250$^{a}$ | — | — | — | — | — | — | 300 | 192 | 261 |
| 13 | — | 250$^{a}$ | 300 | 125 | — | — | 100 | 200 | — | 350 | 224 | 304 |
| 14 | 125 | — | 350 | — | — | — | 125 | — | — | 400 | 256 | 348 |

### Table 4-5—Application of low-voltage ac power circuit breakers to full-voltage motor starting and running duty of three-phase, 60 Hz, 40 °C rise motors[a, c] *(continued)*

| Line no. | Horsepower rating of three-phase ac motors | | | | | | | | Trip device current rating (A)[b] | | Motor full-load current (A) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Induction motors | | 100% power-factor synchronous motors | | | 80% power-factor synchronous motors | | | | | | |
| | 230 V | 460 V | 575 v | 220 V | 440V | 550 V | 220 V | 440 V | 550 V | | Min | Max |
| | Col 1 | Col 2 | Col 3 | Col 4 | Col 5 | Col 6 | Col 7 | Col 8 | Col 9 | Col 10 | Col 11 | Col 12 |
| 15 | 150 | 300; 350 | 400; 450 | — | — | — | — | — | — | 500 | 320 | 435 |
| 16 | 200 | 400 | 500 | — | — | — | — | — | — | 600 | 384 | 522 |
| 17 | 250[a] | 450; 500 | — | — | — | — | — | — | — | 800 | 512 | 696 |
| 18 | 300; 350 | — | — | — | — | — | — | — | — | 1000 | 640 | 870 |
| 19 | 400 | — | — | — | — | — | — | — | — | 1200 | 768 | 1044 |
| 20 | 450; 500 | | | | | | | | | 1600 | 1023 | 1392 |

NOTE 1—*Locked-rotor current and instantaneous trip setting.* Circuit breakers selected from this table are suitable for all motors having locked-rotor kilovoltampere per horsepower, indicated by code letters A through J, inclusive, as listed in Section 430.7 from the NEC. For motors with higher locked-rotor currents, care must be taken to ensure that an instantaneous trip setting high enough to permit motor starting is available. It may be necessary to choose the circuit breaker with the next higher continuous-current rating, provided that the calibration limitations given in Footnote b are not exceeded. If motor locked-rotor current exceeds 600% of the circuit-breaker frame size, a shorter service life than that shown in ANSI C37.16-2000 can be expected.

NOTE 2—*Applications to motors other than those listed.* For motors with horsepower ratings not listed in this table or for motors with other than normal speed or torque characteristics, it will be necessary to determine the full-load current and locked-rotor current as specified by the motor manufacturer. Find the cur rent range in columns 11 and 12 that matches the full-load current to determine the circuit breaker with the proper continuous rating. Check locked-rotor current according to NOTE 1.

[a] Characteristics of motors of more than 200 hp vary widely, and the manufacturer of the motor should be consulted for specific details in these cases.

[b] *Election of trip-device current rating and circuit-breaker frame size.* The trip-device rating listed is a preferred rating from ANSI C37.16-2000. In accordance with NEC 430.110, this rating is at least 115% of the maximum motor full-load current (column 12). With trip devices having the lowest calibration point at 80% of the trip-device rating, the requirement of NEC 430.32 can be met for the minimum full-load current (column 11). NEC 430.32 requires that the trip device be set at a calibration point that does not exceed the following:

1. 140% of motor full-load current for motors with a marked service factor not less than 1.15 or for motors with a marked temperature rise not over 40 °C.
2. 130% of motor full-load current for all other motors.

Any value listed in column 10 may also be a trip-device setting if this current can be carried continuously and if additional adjustments allow compliance with NEC 430.34.

Trip devices having a higher current rating may be used provided that they have a suitable calibration point below 80% of the trip-device rating. The circuit-breaker frame size should be selected based on the applicable trip-device rating as well as the short-circuit current available. See Tables 1 and 2 of ANSI C37.16-2000 for guidance.

[c] Reprinted from: ANSI C37.16-2000.

**Table 4-6—Application of integrally fused low-voltage ac power circuit breakers to full-voltage motor starting and running duty of three-phase, 60 Hz, 40 °C rise motors—Maximum short-circuit current rating: 200 000 rms symmetrical current[c]**

| Line no. | Horsepower rating of three-phase ac motors[a] | | | | | | | | Trip device current rating (A)[b] | | Typical rating of current limiting fuse (A)[c] | Motor full-load current (A) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Induction motors | | 100% power-factor synchronous motors | | | 80% power-factor synchronous motors | | | | | | | |
| | 230 V | 460 V | 575 v | 220 V | 440V | 550 V | 220 V | 440 V | 550 V | | Min | Min | Max |
| | Col 1 | Col 2 | Col 3 | Col 4 | Col 5 | Col 6 | Col 7 | Col 8 | Col 9 | Col 10 | Col 11 | Col 12 | Col 13 |
| 1 | 40 | 75 | 100 | 50 | 100 | 125 | 40 | 75 | 100 | 125 | 400 | 80 | 109 |
| 2 | 50 | 100 | 125 | 60 | — | 150 | — | — | — | 150 | 600 | 96 | 131 |
| 3 | — | — | 150 | — | 125 | — | 50 | 100 | 125 | 175 | 600 | 112 | 152 |
| 4 | 60 | 125 | — | 75 | 150 | 200 | 60 | 125 | 150 | 200 | 600 | 128 | 174 |

## Table 4-6—Application of integrally fused low-voltage ac power circuit breakers to full-voltage motor starting and running duty of three-phase, 60 Hz, 40 °C rise motors—Maximum short-circuit current rating: 200 000 rms symmetrical current[c] *(continued)*

| Line no. | Horsepower rating of three-phase ac motors[a] | | | | | | | | Trip device current rating (A)[b] | | Typical rating of current limiting fuse (A)[c] | Motor full-load current (A) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Induction motors | | 100% power-factor synchronous motors | | | 80% power-factor synchronous motors | | | | | | | |
| | 230 V | 460 V | 575 v | 220 V | 440V | 550 V | 220 V | 440 V | 550 V | | Min | Min | Max |
| | Col 1 | Col 2 | Col 3 | Col 4 | Col 5 | Col 6 | Col 7 | Col 8 | Col 9 | Col 10 | Col 11 | Col 12 | Col 13 |
| 5 | 75 | 150 | 200 | — | — | —[a] | — | — | — | 225 | 800 | 144 | 196 |
| 6 | — | | —[a] | 100 | 200 | — | 75 | 150 | 200 | 250 | 800 | 160 | 218 |
| 7 | 100 | 200 | — | — | —[a] | — | — | — | —[a] | 300 | 1000 | 192 | 261 |
| 8 | — | —a | — | 125 | — | — | 100 | 200 | — | 350 | 1200 | 224 | 304 |
| 9 | 125 | — | — | — | — | — | 125 | —[a] | — | 400 | 1200 | 256 | 348 |
| 10 | 150 | — | — | — | — | — | — | — | — | 500 | 1600 | 320 | 435 |
| 11 | 200 | — | — | — | — | — | — | — | — | 600 | 2000 | 384 | 522 |

NOTE 1—*Locked-rotor current and instantaneous trip setting.* Circuit breakers selected from this table are suitable for all motors having locked-rotor kilovoltampere per horsepower, indicated by code letters A through J, inclusive, as listed in Section 430-7 from the NEC. For motors with higher locked-rotor currents, care must be taken to ensure that an instantaneous trip setting high enough to permit motor starting is available. It may be necessary to choose the circuit breaker with the next higher continuous-current rating, provided that the calibration limitations given in Footnote b are not exceeded.

If motor locked-rotor current exceeds 600% of the circuit-breaker frame size, a shorter service life than that shown in ANSI C37.16-2000 can be expected.

NOTE 2—*Applications to motors other than those listed.* For motors with horsepower ratings not listed in this table, or for motors with other than normal speed or torque characteristics, it will be necessary to determine the full-load current and locked-rotor current as specified by the motor manufacturer. Find the current range in columns 12 and 13 that matches the full-load current to determine the circuit breaker with the proper continuous rating. Check the locked-rotor current according to NOTE 1.

[a] The characteristics of motors at more than 200 hp vary widely, and the manufacturers of the motor should be consulted for specific details in these cases.

[b] *Selection of trip-device current rating and circuit-breaker frame size.* The trip-device rating listed is a preferred rating from ANSI C37.16-2000. In accordance with NEC 430.110, this rating is at least 115% of the maximum motor full-load current (column 13). With trip devices having the lowest calibration point at 80% of the trip-device rating, the requirement of NEC 430.34 can be met for the minimum full-load current (column 12). NEC 430.34 requires that the trip device be set at a calibration point that does not exceed the following:

1. 140% of motor full-load current for motors with a marked service factor not less than 1.15 and for motors with a marked temperature rise not over 40 °C.
2. 130% of motor full-load current for all other motors.

Any value listed in column 10 may also be a trip-device setting if this current can be carried continuously and if additional adjustments allow compliance with NEC 430.34.

Trip devices having a higher current rating may be used provided that they have a suitable calibration point below 80% of the trip-device rating. The circuit-breaker frame size should be selected based on the applicable trip-device rating as well as the short-circuit current available. See ANSI C37.16-2000 for guidance.

[c] These ratings are based on the use of a direct-acting phase trip device with instantaneous trip element. Where information is available, the fuse rating may be selected to suit the particular application based on (1) motor current, (2) overcurrent trip characteristics, (3) fuse melting time characteristics, and (4) system coordination requirements.

[d] Reprinted from: ANSI C37.16-2000.

#### 4.11.3.3 Special-purpose circuit breakers

Combination motor starters contain instantaneous only circuit breakers, which are discussed in Chapter 6.

#### 4.11.3.4 Examples of feeder and branch-circuit protection

Figure 4-20 and Figure 4-21 are one-line diagrams of typical applications of circuit breakers used as mains and feeders. Figure 4-20 shows a typical MCC with a main MCCB and a motor starter with an instantaneous only circuit breaker. Figure 4-21 shows typical switchboard applications. The switchboard at the top has a main LVPCB and a feeder LVPCB. The lower switchboard has lugs only on the incoming cables and feeder MCCBs. One MCCB is a feeder circuit breaker to an individual motor starter. Example setting calculations for these applications are given in 15.7.2 of IEEE Std 242-2001. Example coordination curves are given in Chapter 5 of this recommended practice and Chapter 15 of IEEE Std 242-2001.

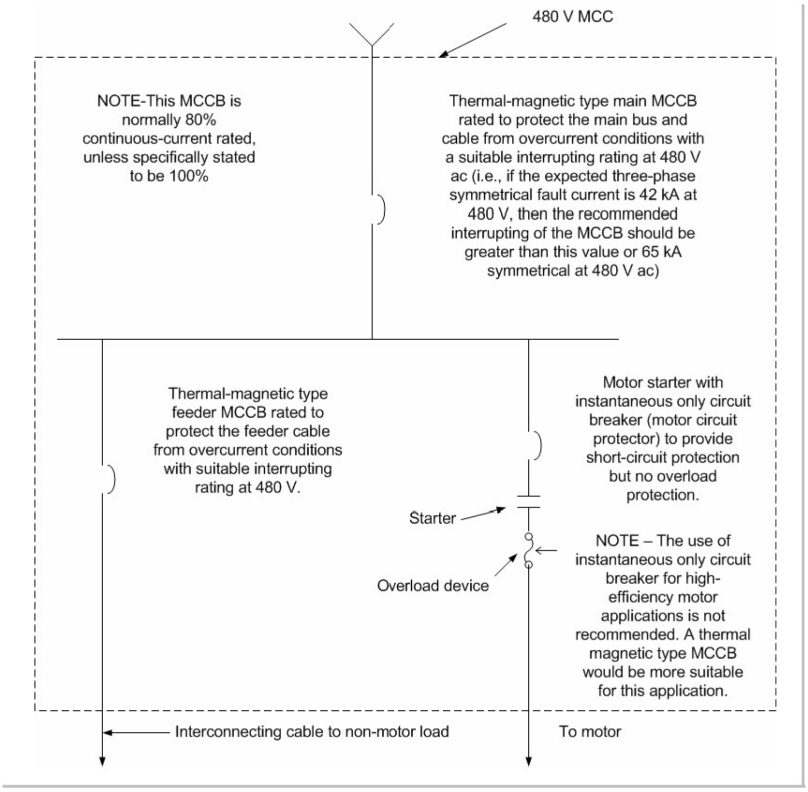


Figure 4-20—Typical MCC application

NOTE—It may be necessary to add a ground-fault trip function to the MCC feeders to obtain coordination with the ground-fault devices on the line-side devices or, if necessary, to specify shunt-trip devices for the feeder MCCBs.

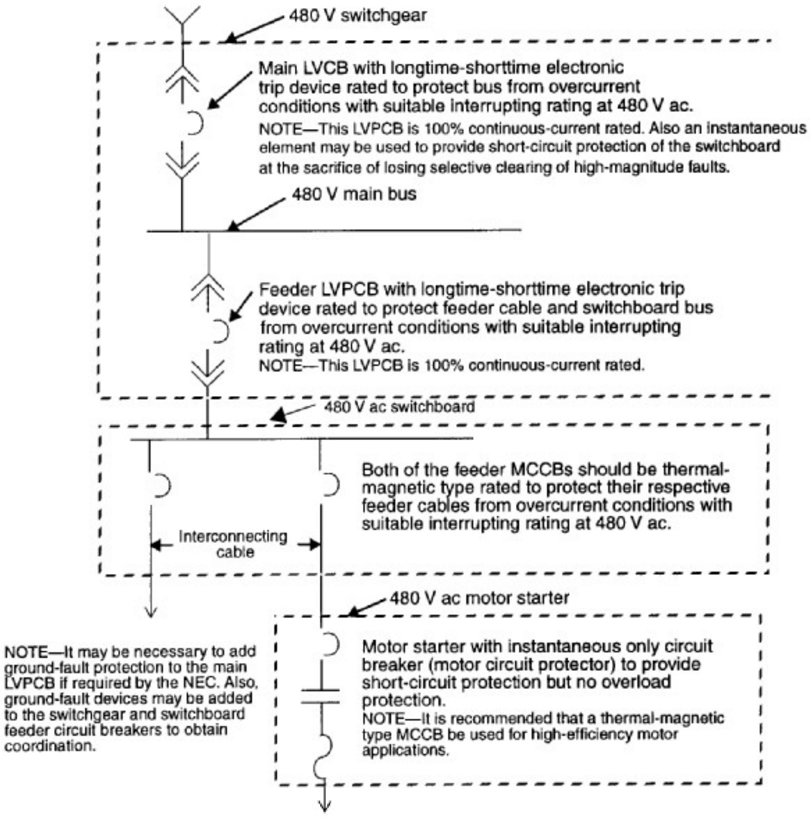


Figure 4-21—Typical switchgear/switchboard application

### 4.11.4 Protection of generators

#### 4.11.4.1 Overcurrent protection

NEC Section 445.12 and Chapter 12 of IEEE Std 242-2001 discuss protection of generators.

#### 4.11.4.2 Application considerations

Considerations for applying circuit breakers for generator applications should include the following:

a) Isolated or parallel operation
b) Short-circuit duty
c) Overload and extended short-circuit capability
d) Generator ratings
e) Type of grounding

### 4.11.4.3 Generator classifications

The following classifications of generators are defined in Chapter 12 of IEEE Std 242-2001:

a) Single isolated generators
b) Multiple isolated generators
c) Large industrial low-voltage generators

#### 4.11.4.3.1 Single isolated generators

Single isolated generators do not operate in parallel with the utility source. They are often used for emergency or standby power. If a transfer switch does not separate the generator breaker from the system bus, a mechanical or electrical means should be provided to prevent paralleling. If their type of service requires automatic starting and shutdown, electric close, shunt trips, and auxiliary contacts are often necessary.

#### 4.11.4.3.2 Multiple isolated generators

Multiple isolated generators may operate in parallel with each other but not with the utility source. The ability to operate in parallel will involve synchronizing circuits that require a quick-closing electrically operated breaker. Other control and protection devices may necessitate shunt trips and auxiliary contacts.

#### 4.11.4.3.3 Large industrial low-voltage generators

Large industrial low-voltage generators may operate in parallel with a utility source. For synchronous generators, control and protection schemes will require quick-closing electrically operated breakers with shunt trips and auxiliary contacts.

### 4.11.4.4 Overcurrent protection

Circuit-breaker trip devices for generator circuits should generally include the following characteristics:

a) Long-time for protection against prolonged low-level overload conditions.
b) Short-time for selectivity with feeder breakers to protect against bus faults and system faults not cleared by feeder breakers.
c) Instantaneous to trip on faults in the generator or leads that are being fed from elsewhere in the system if the generator is paralleled with the utility system.
d) Ground-fault protection, which is required by the NEC in some specific applications.

### 4.11.4.5 Short-circuit considerations

The short-circuit rating of the generator circuit breaker should be equal to or greater than the short-circuit current available to it from the system, which is generally higher than that available from the generator. In addition, most generators have an extremely rapid decrement of short-circuit current to almost zero. If the circuit breaker is to be tripped due to short-circuit, the time-current characteristic of the protective device must be below the generator's short-circuit decrement curve. For detailed protection considerations, refer to Chapter 12 of IEEE Std 242-2001.

#### 4.11.4.6 Additional protection considerations

The electronic trip device on circuit breakers is sufficient protection for many small generators. Larger, more costly generators may require additional protection as outlined in Chapter 12 of IEEE Std 242-2001.

If additional protective or control devices are desired, appropriate accessories should be included on the circuit breaker.

a) Protective relays will require a shunt trip on the circuit breaker, which, in turn, will necessitate a reliable source of control power or a capacitor trip device.
b) Automatic startup will require electrical operators.
c) Synchronizing will require a quick-closing electrically operated circuit breaker.

### 4.11.5 Protection of capacitors

A circuit breaker can be used to provide the overcurrent protection for low-voltage capacitor systems as required by Section 460.8 from the NEC. The circuit breaker should have a voltage rating suitable for the rated voltage of the capacitor system. In addition, the circuit breaker must have an interrupting rating greater than the fault current available at its line-side terminals. However, the NEC, in the same section, only requires that "the rating or setting of the overcurrent device shall be as low as practicable." Therefore, selection of the overcurrent rating of a circuit breaker for protection of capacitor systems needs to be given further consideration.

#### 4.11.5.1 Application considerations

Considerations in the application of low-voltage breakers for unit capacitor supply should include the following:

a) Transient inrush current for isolated bank or parallel bank switching configurations
b) Transient overvoltages generated during opening operations by restrikes
c) Protective device characteristics
d) Frequent switching requirements
e) High-frequency inrush currents
f) Continuous-current requirements

NOTE—Parallel bank fault duty contribution has traditionally been ignored because of its rapid decay.

### 4.11.5.2 Conductor and protective device sizing

The capacitor circuit conductors and disconnecting means are required to have an ampacity not less than 135% of the rated current of the capacitor per Section 460.8 from the NEC. Capacitors are generally manufactured with a tolerance range of 0% and +15%, so that a 100 kvar capacitor may actually draw a current equivalent to a 115 kvar capacitor. In addition, the current drawn by a capacitor varies directly with the line voltage. A variation in the line voltage from a pure sine wave, such as during a switching transient, causes the capacitor to draw an increased current. Also, system harmonics will be a contributing factor to increased current. Considering these factors, the actual current in an installed capacitor system can amount to 135% of the rated current of the capacitor. A typical circuit breaker and capacitor circuit are shown in Figure 4-22.

As with the conductors and disconnecting means, the overcurrent protective device should also be rated for at least 135% of the capacitor bank current rating. However, it must be rated low enough to protect the capacitor bank from violent damage. Due to the variations mentioned above, manufacturers generally recommend values over 150% of the capacitor bank current ratings (typically in the 165% to 200% range). It is suggested that the specific application be discussed with the manufacturers of the capacitors and circuit breakers before deciding on the rating or setting of the circuit breaker. To achieve improved protection, capacitor banks with multiple cans per phase may have the individual cans fused.

### 4.11.5.3 Ambient temperature considerations

For application in ambients higher than the rated ambient of the circuit breaker, the manufacturer should be consulted to determine the rating of the circuit breaker required to meet the minimum of 135% capacitor rating. In locations where temperatures vary greatly, ambient compensating circuit breakers may be desirable.

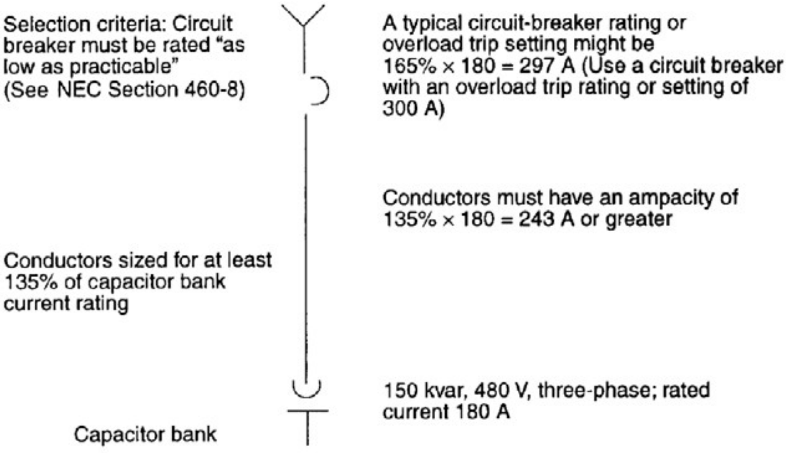


Figure 4-22—Capacitor protection

### 4.11.6 Protection of transformers

Low-voltage circuit breakers can be used for the transformer protection required by Section 450.3 from the NEC. Refer to this section for the specific primary and secondary protection requirements for transformers over 600 V nominal and equal to or less than 600 V nominal. The protection discussed in this section of the NEC is intended to protect the transformer only. Protection of the primary and secondary conductors may be obtained by proper selection of cables.

#### 4.11.6.1 Application considerations

Considerations for the application of low-voltage circuit breakers for transformer protection include the following:

a) Will they clear the system for short-circuits within the transformer?
b) Will they prevent the transformer from becoming overloaded beyond its ability?
c) Will they protect the transformer from damage during a through-fault condition on the load side?
d) Do they have adequate interrupting ratings for faults at their load-side terminals?
e) Will they handle the transformer inrush current without nuisance tripping?
f) Can they tolerate the current transients during inrush and during other operating conditions?
g) Do they provide conductor protection?
h) Is ground-fault protection provided (if required)?

#### 4.11.6.2 Transformer with a primary rated over 600 V

When the transformer primary is over 600 V and the secondary is 600 V or less, low-voltage circuit breakers might be used as the secondary transformer protection. The rating of this secondary protection must not exceed 125% of the transformer rated secondary current, or the next higher standard rating or setting for unsupervised transformer applications per Section 450.3(B) from the NEC and allows 250% of the transformer rated secondary current for “supervised” installations.

As shown in Figure 4-23, the secondary circuit breaker’s overload trip rating or setting must be below 751 A, or the next higher standard rating or setting. Refer to NEC 450.3(B).

#### 4.11.6.3 Transformer primary and secondary rated 600 V or below

##### 4.11.6.3.1 Primary protection only

The overload ratings or settings determined by the following paragraph do not necessarily provide conductor protection. For example, NEC 240.4(F) states that transformer secondary conductors (other than two-wire or delta-delta connected three-wire) are not considered to be protected by the primary overcurrent protection. Before making the final selection of the circuit-breaker rating, conductor protection must be verified.

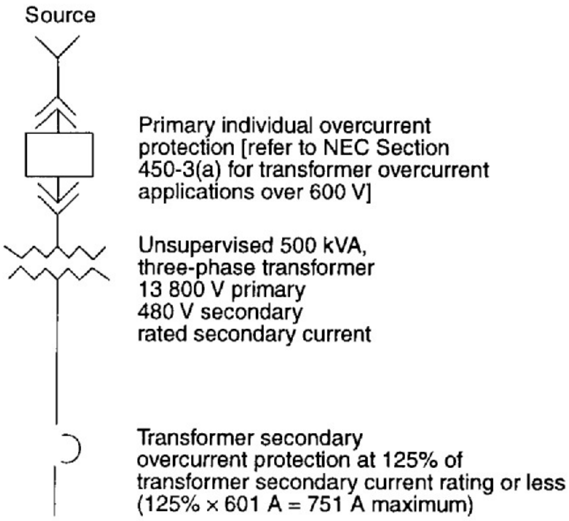


**Figure 4-23—Transformer with primary and secondary protection**

Table 450.3(B) from the NEC states that if only primary protection is to be used for a transformer of 600 V or less, that protection shall be an individual overcurrent device on the primary side, rated or set at not more than 125% of the rated primary current of the transformer as shown in Figure 4-24. If the primary current rating of the transformer is less than 9 A, Table 450.3B allows the overcurrent device to be rated up to, but no more than, 167% of the transformer primary current rating. If the primary current rating of the transformer is less than 2 A, Table 450.3B allows the overcurrent device to be rated up to, but no more than, 300% of the transformer primary current rating.

### 4.11.6.3.2 Transformers with secondary protection

When the transformer has secondary protection, an individual overcurrent device is not required on the primary side if

a) The overcurrent device on the secondary side is rated or set at not more than 125% of the transformer secondary rating

b) The primary feeder overcurrent device is rated or set at not more than 250% of the transformer primary current rating [refer to NEC 450.3(B)]

An example of this protection is shown in Figure 4-25.

The NEC guidelines provide the maximum circuit-breaker ratings/settings; lower ratings/settings are recommended for improved protection. Protective devices on the transformer primary and secondary circuits are recommended for the best transformer protection.

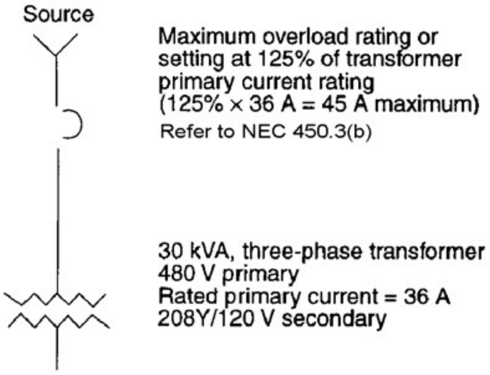


Figure 4-24—Individual circuit breaker in transformer primary for an "unsupervised" transformer

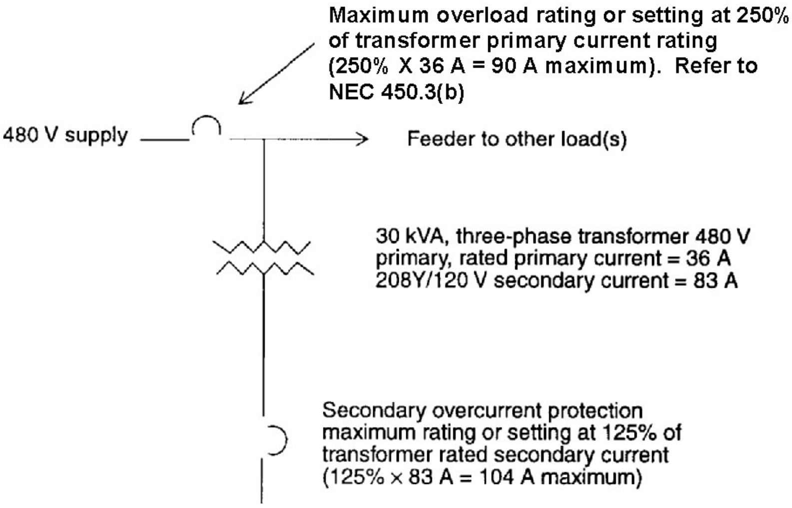


Figure 4-25—Circuit-breaker protecting feeder supplying a transformer and other load(s)

### 4.11.6.4 Other considerations for protecting transformers

Selecting the current ratings is only part of the job of protecting the transformer. The answers to some of the questions in 4.11.2 involve considerations of time as well as current. Transformer damage curves, current inrush data, overload capabilities, and information on transient tolerances can be obtained from the manufacturers of the transformers and IEEE standards. Refer to the IEEE C57™ Collection and IEEE Std 242-2001. This type of information will help the designer determine the proper trip-unit settings. Selective coordination examples are shown in Chapter 5. To obtain reliable operation, proper acceptance testing and maintenance of circuit breakers is required (refer to Chapter 7).

## 4.12 Normative references

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

ANSI C37.16-2000, American National Standard for Switchgear-Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors-Preferred Ratings, Related Requirements, and Application Recommendations.[4]

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

ICEA P-32-382-1994, Short-Circuit Characteristics of Insulated Cable.[5]

IEEE Std 141™-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*™).[6, 7]

IEEE Std 241™-1990 (R1997), IEEE Recommended Practice for Electric Power Systems in Commercial Buildings *(IEEE Gray Book*™*).*

IEEE Std 242™-2001 (R1991), IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (*IEEE Buff Book*™).

IEEE Std C37.13™-1990, IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

IEEE Std C37.20.1™-2002, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

IEEE Std C57.12.01™-1998, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those with Solid Cast and/or Resin-Encapsulated Windings.

IEEE Std C57.109™-1993 (R2000), IEEE Guide for Liquid-Immersed Transformer Through-Fault-Current Duration.

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

[5] ICEA publications are available from ICEA, P.O. Box 411, South Yarmouth, MA 02664, USA.

[6] The IEEE standards or products referred to in this chapter are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

[7] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

Gregory, G., “Single-pole short-circuit interruption of MCCBs,” *IEEE Transactions on Industry Applications*,

NEMA AB 3-2001, Molded Case Circuit Breakers and Their Application.[8]

NEMA PB 2-2001, Deadfront Distribution Switchboards.

NFPA 70-2005, National Electrical Code® (NEC®).[9]

UL 489-2002, Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures.[10]

UL 891-1998, Dead-Front Switchboards (DoD).

## 4.13 Bibliography

[B1] UL Recognized Component Directory, vol. 1, 1996.

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

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

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

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

## 5.1 Introduction

A selectively coordinated power system has protective devices that isolate the smallest portion of the system when interrupting a short-circuit or overload and thus limit damage to components. This result is accomplished with low-voltage circuit breakers by the selection of appropriate operating ratings, trip characteristics, and trip settings so that only the closest circuit breaker on the source side of an overcurrent condition clears the abnormality.

Information on dc breaker ratings is in Chapter 3, and information on selective coordination of dc systems can be found in IEEE Std 1375™-1998.[1]

### 5.1.1 Time-current curves

The low-voltage circuit breaker has a protective element that operates in response to the magnitude and duration of current passing through it. It is direct acting in that the current through it provides energy to release the opening mechanism. The characteristic time-current curve has a band of operating area. The upper limit of the band represents the maximum total clearing time for the circuit breaker. The lower limit of the band shows the maximum resettable delay, i.e., the maximum time that a given amount of through current (e.g., a fault or overload) may persist and then subside without tripping the circuit breaker.

Bands indicating the pickup current (vertical asymptote) of the characteristic show the tolerance of the pickup point. Currents less than the lower limit of the long-time pickup band can be sustained without tripping the circuit breaker. Currents at or above the upper limit of the band will result in tripping of the circuit breaker.

## 5.2 Low-voltage power circuit breakers

The low-voltage power circuit breaker (LVPCB) may be found in two general varieties, those with electromechanical trip devices and those with electronic trip devices. Each has some combination of long-time delay, short-time delay, instantaneous, and ground-fault trip elements. ANSI C37.17-1997 defines those characteristics and their limits. Dual trip devices have long-time and instantaneous elements. Selective trip devices have long-time and short-time elements. Triple selective devices have long-time, short-time, and instantaneous elements.

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[1] Information on references can be found in 5.6.

### 5.2.1 Electromechanical trip devices

The electromechanical trip (refer to Figure 5-1) uses a magnetic circuit directly applied to the circuit-breaker current-carrying conductor. A variety of springs, dashpots, and escapements provide the time-current characteristic. The time-delay band is relatively broad due to the tolerance of the mechanical devices, temperature, wear, age, etc. Sensitive ground-fault protection must be provided by external sensing and remote tripping devices. Those remote devices must trip the LVPCB by a shunt trip.

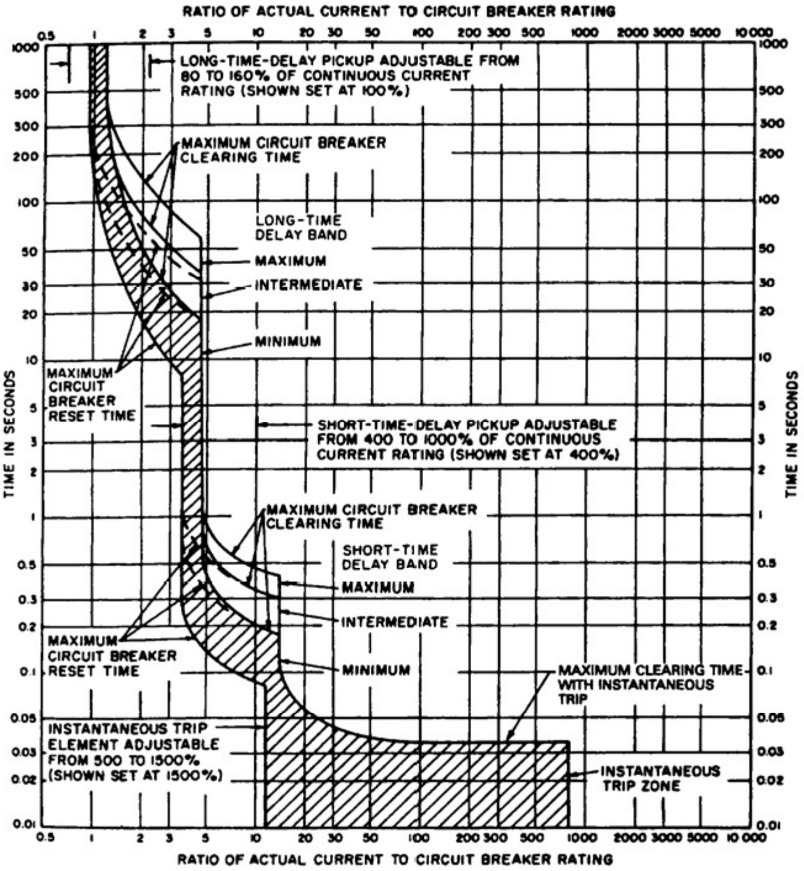

**Figure 5-1—Typical time-current plot for electromechanical trip devices**

### 5.2.2 Electronic trip devices

Since about 1970, the electronic trip device (refer to Figure 5-2) has become the industry standard. Sensors detect the current and provide tripping energy. The time-current characteristic is electronically developed and is more accurate with narrower tolerances than for the electromechanical device. The long-time element provides overload protection, and the short-time and instantaneous elements provide fault protection. Their characteristics are described in 5.2.2.1 through 5.2.2.4.

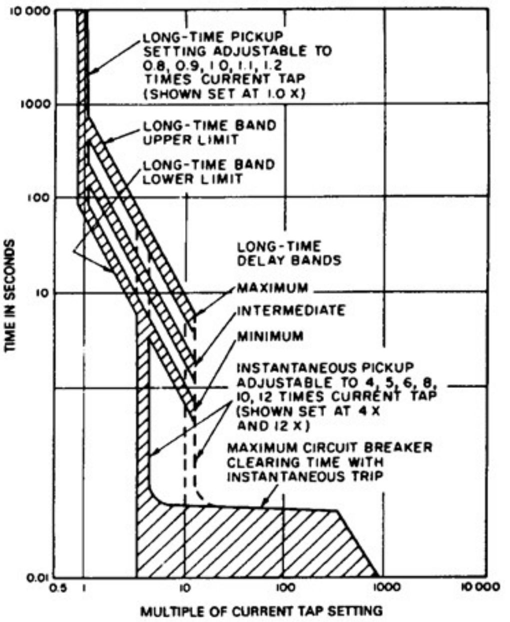

**Figure 5-2—Typical time-current plot for electronic trip devices**

### 5.2.2.1 Long-time delay protection

For the example in Figure 5-2, the pickup value of the long-time delay element is ±10% of the selected current. Currents greater than 90% of the pickup setting may eventually result in circuit-breaker tripping. The tolerance of the pickup value may vary between manufacturers; therefore, the characteristic curves should be used for the device selected. The long-time delay is a constant $I^2t$ inverse time characteristic to simulate the conductor and load equipment heating. Its pickup should be set for conductor and equipment overload protection as called for in the National Electrical Code® (NEC®) (NFPA 70-2005). Its delay should be set as low as possible, but coordinated with load-side devices. With some manufacturers' trip devices, adjustment of the long-time pickup setting will shift the long-time delay curve left or right; with others, the curve extends as the pickup setting is decreased, or it is chopped off as the pickup is increased. The pickup setting is usually some multiple of the unit's plug rating.

### 5.2.2.2 Short-time delay protection

The short-time delay element provides a definite time delay. Adjustment allows selectivity with load-side instantaneous or faster short-time trip elements. Some devices offer an $I^2t$ pickup, which provides an inverse characteristic between the pickup current and the fixed time delay (see Figure 5-3). This characteristic may provide an opportunity to better coordinate with load-side fuses. The short-time and instantaneous pickup currents are set above normal operating conditions (i.e., motor starting, transformer inrush, etc.).

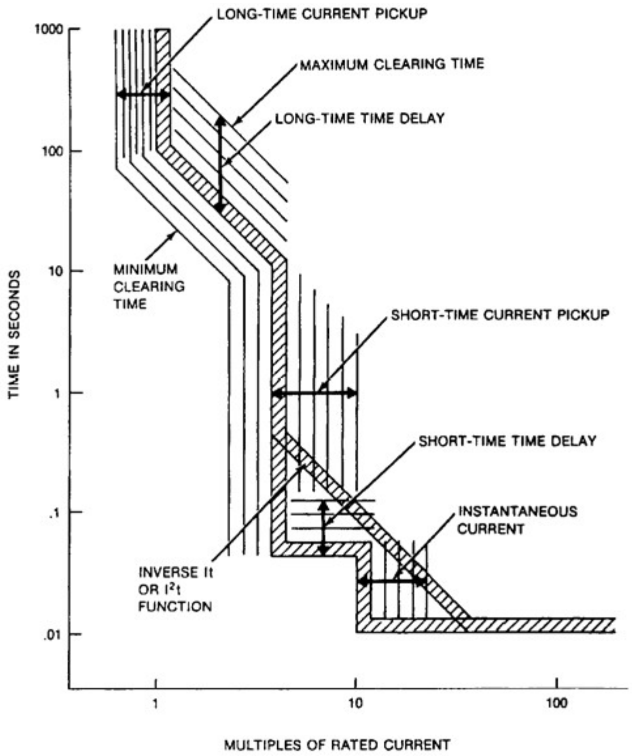

Figure 5-3—Time-current curve with short-time $I^2t$ pickup

### 5.2.2.3 Instantaneous protection

An instantaneous trip has historically meant "no intentional delay." However, the electronic trip unit is desensitized near its pickup value to avoid nuisance tripping. This approach results in an "inverse instantaneous" pickup. Some manufacturers employ a fault-closing discriminator. In this instance, a circuit breaker closing on a fault may trip instantaneously even though there is no instantaneous pickup setting on the trip device.

### 5.2.2.4 Ground-fault protection

Sensitive ground-fault protection is generally accomplished using the sum of the three-phase currents and adding the neutral current of four-wire systems. The resultant is the ground-fault current. Other systems use ground sensors that enclose all three-phase conductors (zero sequence CTs), and the neutral of four-wire systems, to sense ground current. Still others sense the current flowing between the grounding electrode and the transformer neutral.

Pickup currents are limited to 1200 A maximum to be consistent with the NEC. However, pickup settings are normally set more sensitive than 1200 A to reduce equipment damage and other hazards of arcing ground faults. Consideration should be given to the arc flash hazard to personnel, particularly on solidly grounded systems, when selecting the pickup value and time delay for ground fault protection. Refer to NFPA 70E-2004 [B3][2] and IEEE Std 1584™-2002 [B2] for additional information on arcing ground fault hazards.

For electronic trip units, the ground current characteristic time delay settings are similar to the phase current characteristic short-time delay settings. As with short-time delay, the ground-fault trip characteristic may have the option of $I^2t$ pickup.

## 5.3 Low-voltage MCCBs and ICCBs

As with the LVPCBs, low-voltage molded-case circuit breakers (MCCBs) are found in two general varieties: those with thermal-magnetic trip devices and those with electronic trip devices. The insulated-case circuit breakers (ICCBs) generally have electronic trip devices, but some may have thermal-magnetic trip devices. A special type of MCCB is the instantaneous only breaker used in combination motor starters. This device is discussed in Chapter 6 of this book. UL 489-2002 defines the requirements for both MCCBs and ICCBs.

### 5.3.1 Thermal-magnetic circuit breakers

The thermal-magnetic circuit breaker (refer to Figure 5-4) uses a bimetal or other similar device to establish its long-time delay characteristic and a spring and magnetic circuit for its instantaneous element. The long-time pickup is generally not adjustable. Sensitive ground-fault protection must be provided by auxiliary add-on or external devices, some using a shunt trip to open the circuit breaker. This shunt trip must be specified at the time of purchase.

### 5.3.2 Electronic trip devices

An electronic trip device is available on certain larger MCCBs and ICCBs. Some of these larger circuit breakers also have a limited short-time delay capability.

### 5.3.3 Long-time and short-time delay protection

For either the thermal-magnetic or the electronic trip device, the long-time pickup tolerance is –0% and not more than +25%. The circuit breaker will carry its pickup setting current without tripping. At 125% current, the circuit breaker will ultimately trip.

The long-time delay of the thermal-magnetic device is a good simulation of device heating, provided that the ambient temperatures are similar. The electronic long-time delay unit has an adjustable time, $I^2t$ characteristic. MCCBs and ICCBs may have a short-time characteristic that gives a definite time delay, up to the instantaneous pickup current.

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[2] The numbers in brackets correspond to those of the bibliography in 5.7.

### 5.3.4 Instantaneous protection

Electronic devices have one of several types of instantaneous trips. Pickup current might be adjustable, or nonadjustable at a high-pickup current, or there may be a fault closing discriminator (see 5.2.2.3). Even though there is no indication of an instantaneous trip on the trip device, some devices instantaneously trip under heavy fault conditions.

### 5.3.5 Ground-fault protection

Ground-fault protection is available with the electronic trip device. The operating characteristic may be definite time, with or without an $I^2t$ pickup.

Enhanced ground-fault protection for some equipment can be achieved by zone-selective interlocking. Typically, as shown in Figure 5-5, a main circuit breaker will be interconnected with each of its feeders. The main circuit-breaker ground-fault trip device will operate in either of two modes. It will trip in a fast time if a ground fault is sensed in the main bus zone. For a ground fault on a feeder, the feeder circuit breaker will send a blocking signal to the main circuit-breaker ground-fault trip, transferring it to a slow trip mode, allowing the feeder circuit breaker to clear the fault. Should the feeder fail to clear the fault, the delayed-trip main circuit breaker provides backup protection.

## 5.4 Other coordinating devices

The selection and settings of the low-voltage devices may be affected by other device settings. Following is an overview of other devices that may affect the coordination.

### 5.4.1 Low-voltage fuses

Low-voltage fuses, whether separate or part of a low-voltage circuit breaker, have a time-current band between two curves—the total clearing time curve (including the melting time tolerance and arcing time) and the minimum melting time curve.

### 5.4.2 Medium-voltage fuses

Medium-voltage fuses also have a time-current band between two curves. The total clearing time curve shows the maximum time from initiation of fault to total clearing of the circuit. The minimum melting time curve shows through currents that can be sustained without damage to the element. The minimum melting time curve may not show the effects of preloading currents.

### 5.4.3 Overcurrent relays

The operating characteristic of an overcurrent relay will be shown on the time-current curve as a line. The actual current interrupting time will depend on the reaction time of other components. Positive tolerance factors include auxiliary relay operating time, circuit-breaker operating time, and current transformer saturation. Negative tolerance factors include disk over travel and current offset.

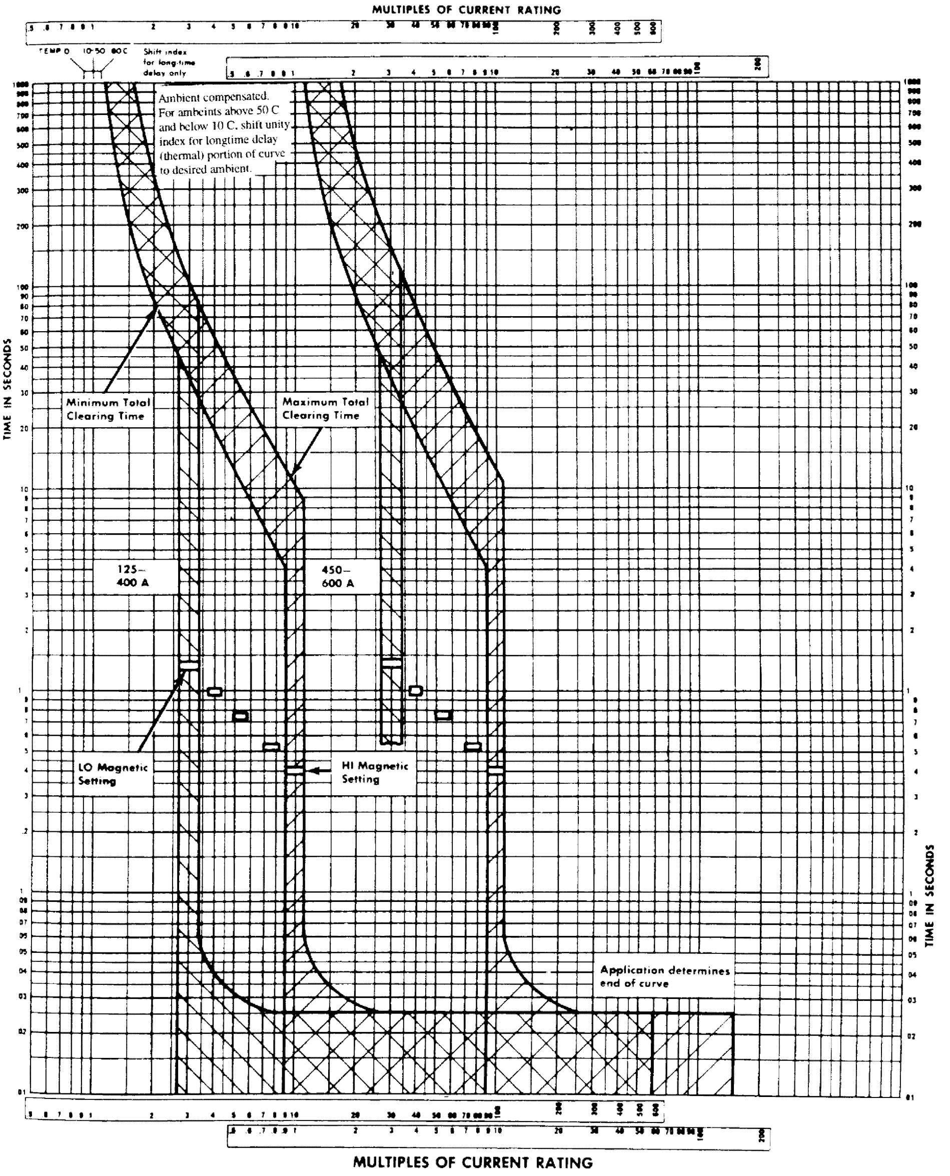

Figure 5-4—Time-current curves for 125–600 A MCCBs

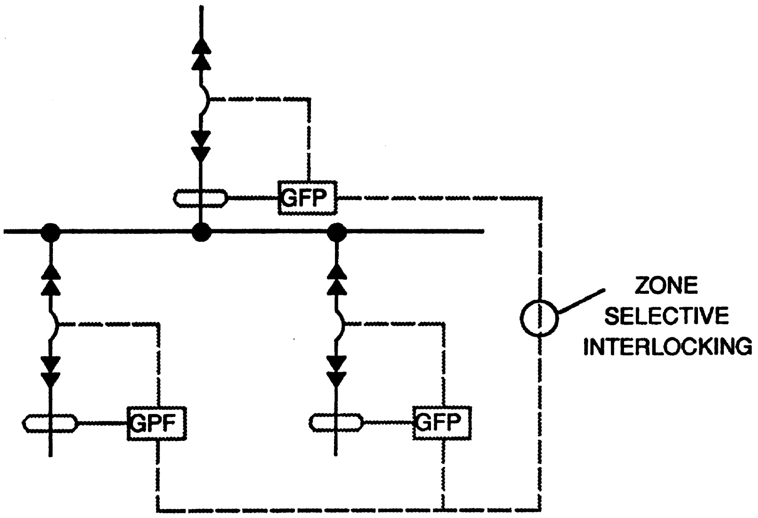

Figure 5-5—Zone-selective interlocking

## 5.5 Coordination examples

To demonstrate coordination of several protective devices installed in series, the operating characteristics may be plotted on log–log graph paper with appropriate current scaling among various voltage levels. Most devices used in low-voltage protection have characteristic curves with a band showing the minimum and maximum tripping times. As long as there is daylight between the curves, the devices should be selective. When coordinating with devices that are represented with a line, the breaker operating time, relay overtravel, and tolerances must be accounted for to ensure selectivity. These coordination margins between devices are discussed in greater detail in IEEE Std 242™-2001.

### 5.5.1 Single-line diagram

The single-line diagram of Figure 5-6 will be used to illustrate a selective and nonselective coordination of a simple system. Medium-voltage metal-clad switchgear with time overcurrent and instantaneous relays (device 50/51) fed by current transformers protect a delta-wye 2000 kVA 4160–480Y/277 V transformer. The 480 V main is a LVPCB that serves four motor control centers (MCCs). The four feeders to the MCCs illustrate the various types of low-voltage breakers that may be used for MCC main breakers. The coordination plots of each MCC illustrate the selectivity of upstream and downstream devices of various types of motor branch circuit short-circuit protection and various types of MCC main devices. The largest feeder in each MCC is shown with a 100 A thermal-magnetic circuit breaker as the protective device.

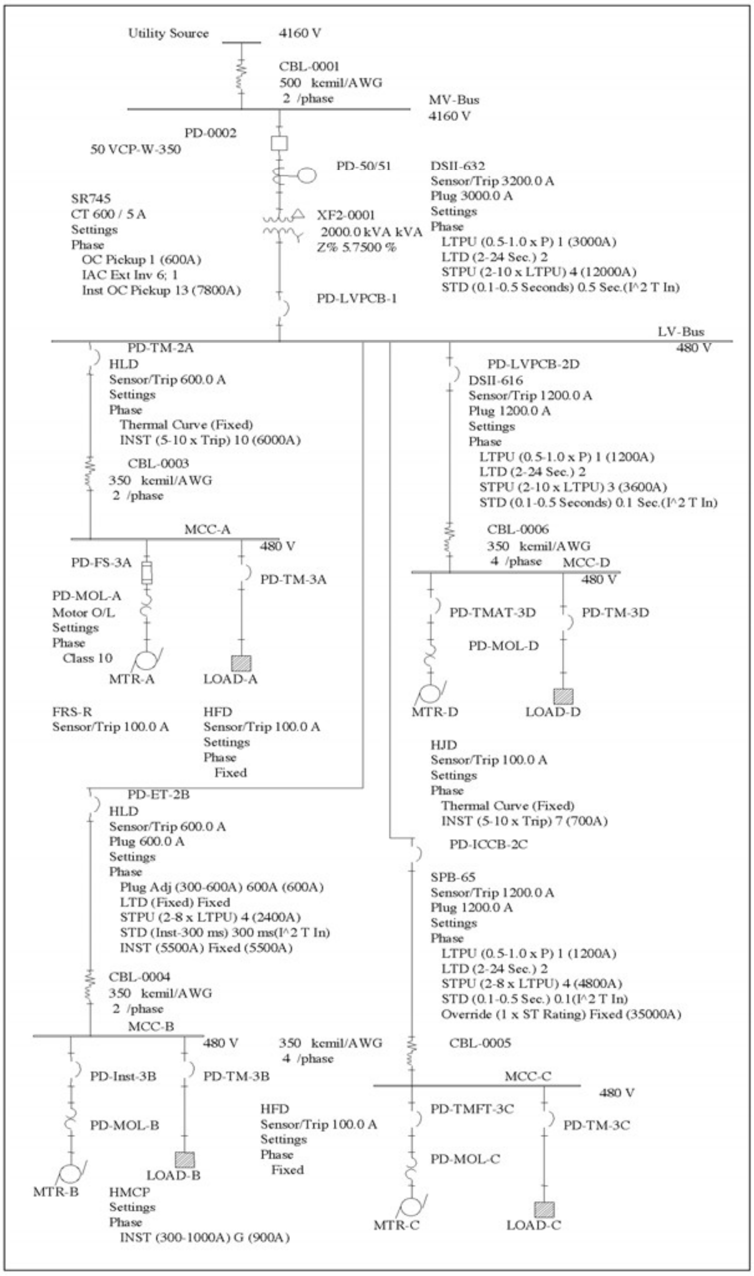

**Figure 5-6—One-line diagram for coordination study**

### 5.5.2 Fuse and circuit breaker

Figure 5-7 shows apparent selective coordination between a thermal-magnetic circuit breaker PD-TM-2A and a load-side current limiting fuse PD-FS-3A, represented in the figure by its minimum melting and total clearing characteristics. The motor branch circuit is protected by a fuse PD-FS-3A and a thermal overload device PD-MOL-A. To ensure coordination for critical applications, it is also necessary to examine the sub-half-cycle region (times less than 0.01 s). The no-operate lower current boundary of the magnetic element, although shown as a vertical line, actually bends to the right for times less than 0.01 s to 0.02 s. This inverse no-operate boundary must be compared with the fuse let-through characteristic to ensure selective coordination. Microprocessor-type trip devices may have to be examined more closely due to their sampling rate.

If a larger fuse was used and the total clearing time overlapped the tripping region of the upstream breaker, then there would be obvious nonselectivity between the two devices. If this was the situation, then the fuse and the upstream breaker would both open for high fault currents.

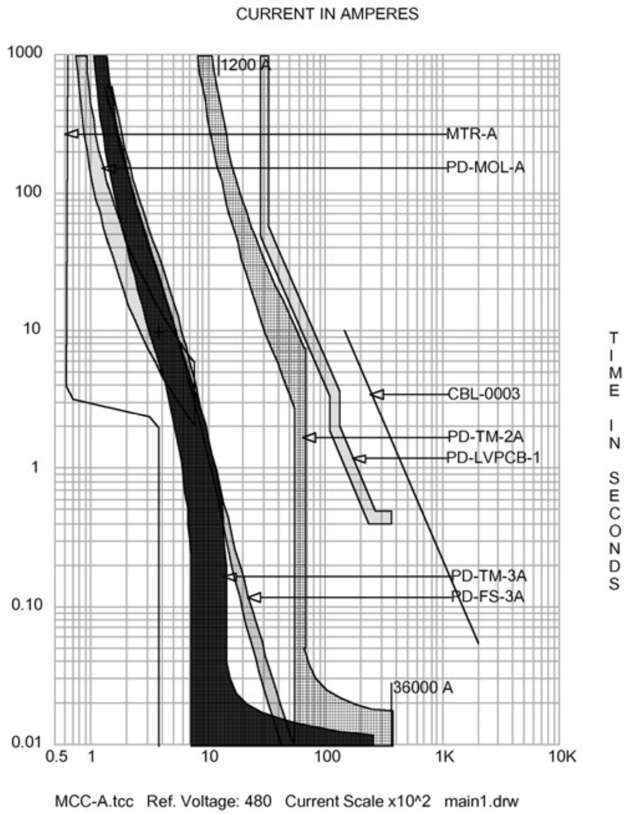

**Figure 5-7—MCC-A coordination plot showing nonselective coordination between feeder breaker PD-TM-3A and the MCC main thermal magnetic breaker PD-TM-2A and selective coordination between the motor short-circuit protective device (fuse) PD-FS-3A and the MCC main PD-TM-2A**

### 5.5.3 Series MCCBs

The coordination plot for MCC-A is shown in Figure 5-7. The plot shows the nonselective coordination between the 100 A thermal magnetic feeder breaker (fixed trip) PD-TM-3A in the MCC and 600 A thermal-magnetic breaker (adjustable trip) serving as the MCC main PD-TM-2A. The two thermal magnetic breakers are nonselective in the instantaneous region above the pickup level of the main (about 6000 A). For this situation, overcurrents up to 6000 A will open just the load-side circuit breaker, whereas faults above 6000 A may open both.

MCCBs in series, recognized by the UL as series-connected devices, have limited selective coordination, essentially as illustrated by Figure 5-7. UL 489-2002 recognizes specific combinations of two MCCBs (and of line-side current-limiting fuses and a load-side MCCB) for an available short-circuit current higher than the interrupting rating of the load-side MCCB (provided there are no motor loads on any of the branch circuits between the downstream and the upstream devices). Refer to Chapter 3 of this recommended practice for the proper application of series combination devices. For a recognized combination of two MCCBs, the line-side circuit breaker must have an instantaneous trip setting less than the interrupting rating of the load-side circuit breaker. Selective coordination is limited to currents below the instantaneous pickup of the line-side circuit breaker. For any fault downstream of the load-side MCCB having a current greater than the instantaneous pickup of the line-side MCCB, both circuit breakers trip, and power is interrupted to unfaulted circuits fed by the line-side circuit breaker. In a fully coordinated system, power to these unfaulted circuits would not be interrupted, except for a momentary voltage dip.

### 5.5.4 Instantaneous only and electronic trip element MCCBs

The coordination plot for MCC-B is shown in Figure 5-8. The plot shows the nonselective coordination between the 100 A instantaneous only MCCB on the motor circuit with a setting of 900 A PD-Inst-3B in the MCC and 600 A molded-case circuit breaker (electronic trip unit) serving as the MCC main PD-ET-2B.

The molded-case circuit breaker with an electronic trip element has adjustable settings of long-time pickup, long-time delay, short-time pickup, and short-time delay, and an instantaneous override at 5500 A. The two breakers are nonselective in the instantaneous region above the pickup level of the main (about 5500 A). For this situation, overcurrents up to 5500 A will open just the load-side circuit breaker, whereas faults above 5500 A may open both.

All MCCBs and most ICCBs with a short-time delay have an instantaneous override. If selective coordination is required for fault currents above the instantaneous override level, a power circuit breaker defined as an LVPCB with a short-time delay option, as shown in Figure 5-11, should be considered.

For low-level motor faults and overloads, the overload device PD-MOL-B should operate and open the contactor of the motor circuit. Contactors are generally tested to open 10 times the rated full-load current given in Table 430.150 of the NEC. Care should be taken when setting the instantaneous only device to ensure the contactor is protected at its test value. Note that the instantaneous only breaker does not provide any backup protection for the overload device. Refer to the IEEE article by Gregory and Padden [B1] for more information on the application of instantaneous only breakers.

Molded-case circuit breakers are generally 80% rated devices allowing the continuous operating current to be 80% of the breaker rating.

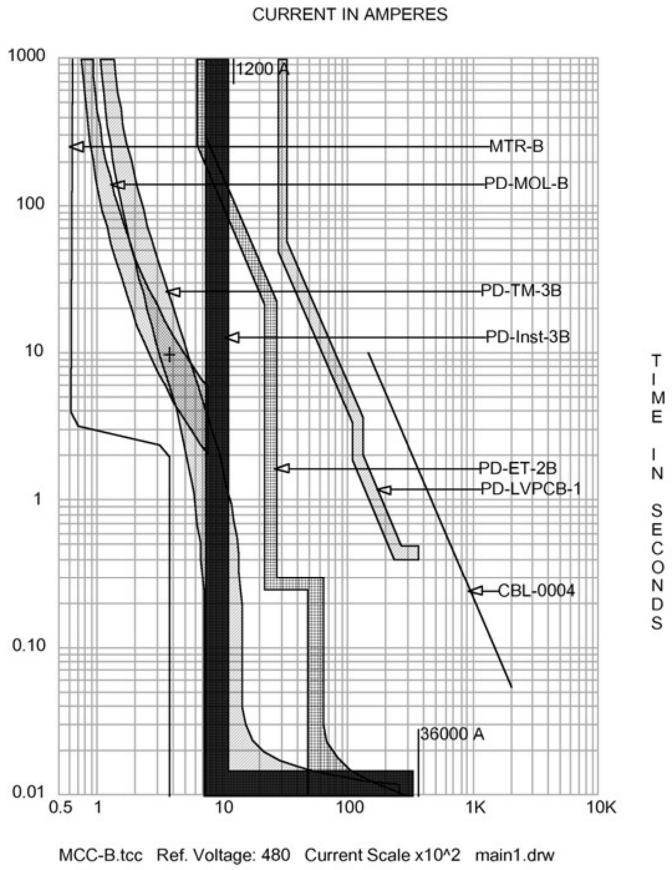

Figure 5-8—MCC-B coordination plot showing nonselective coordination between feeder breaker PD-TM-3B, motor short-circuit protective device (instantaneous only circuit breaker) PD-Inst-3B and the MCC main electronic trip element PD-ET-2B

### 5.5.5 Thermal-magnetic MCCBs and insulated case circuit breakers

ICCBs can be either 80% or 100% rated devices allowing the continuous operating current to be either 80% or 100% of the breaker rating.

The coordination plot for MCC-C is shown in Figure 5-9. The plot shows the selective coordination between the 100 A thermal-magnetic fixed MCCB on the motor circuit PD-TMFT-3C in the MCC and 1200 A insulated case circuit breaker (ICCB) with electronic trip unit serving as the MCC main PD-ICCB-2C. The thermal-magnetic breaker does provide some backup protection for the motor overload device PD-MOL-C.

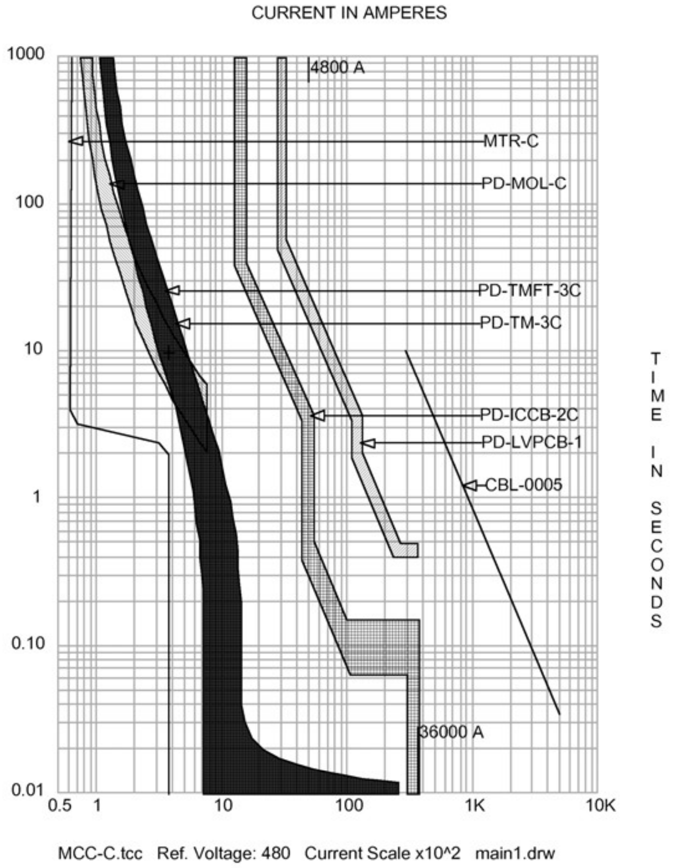

**Figure 5-9— MCC-C coordination plot showing selective coordination between feeder breaker PD-TM-3C, motor short-circuit protective device (fixed trip thermal magnetic breaker) PD-TMFT-3C and the MCC main insulated case circuit breaker PD-ICCB-2C**

The ICCB has an electronic trip element with adjustable settings of long-time pickup, long-time delay, short-time pickup, short-time delay, and an instantaneous override at 35 000 A. For this case, the instantaneous override is above the available fault current of the downstream device and is therefore selective. It should be noted that if the fault current is above the short-time rating (instantaneous override), then the ICCB will not be selective with downstream devices that also have instantaneous trips. Another item to note regarding ICCBs is that their clearing time in the instantaneous region is generally longer than that of a thermal-magnetic breaker and needs to be considered when setting the short-time delay for upstream devices. See Figure 5-10 for an example.

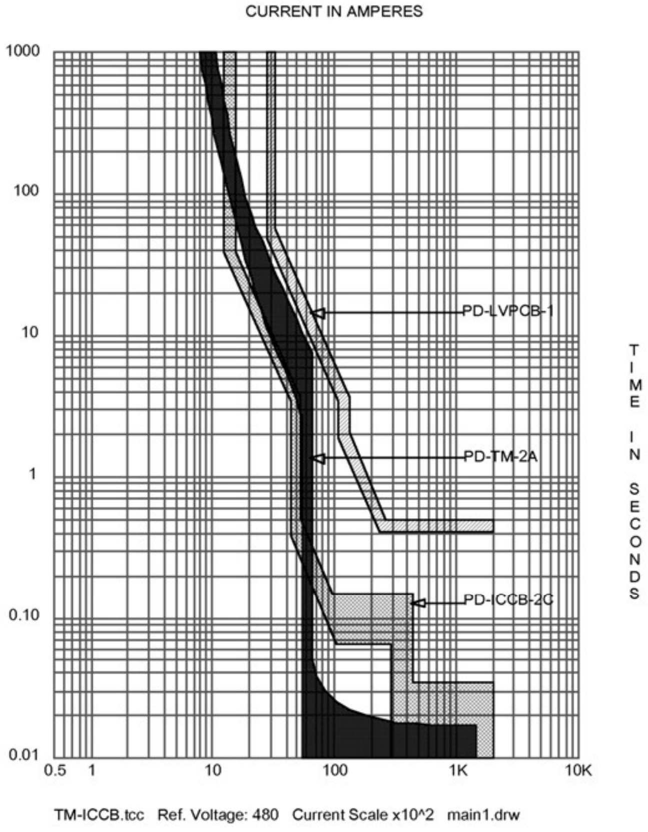

**Figure 5-10—Illustration of the tripping time in the instantaneous region of a thermal magnetic breaker PD-TM-2A and an insulated-case circuit breaker PD-ICCB-2C**

### 5.5.6 MCCB and LVPCB

The coordination plot for MCC-D is shown in Figure 5-11. The plot shows selective coordination between the 100 A thermal-magnetic breaker (adjustable instantaneous trip) PD-TMAT-3D in the MCC and 1200 A low-voltage power circuit breaker (LVPCB) serving as the MCC main PD-LVPCB-2D.

The LVPCB trip device will have adjustable settings of long-time pickup, long-time delay, short-time pickup, and short-time delay. An instantaneous trip element is not used on the MCC main because it would not be selective with the instantaneous trip element of the load-side 100 A MCCB. LVPCBs are 100% rated devices so they can have load currents up to the continuous current rating. The short-time delay should be set to allow for the instantaneous devices downstream to clear without tripping the LVPCB upstream.

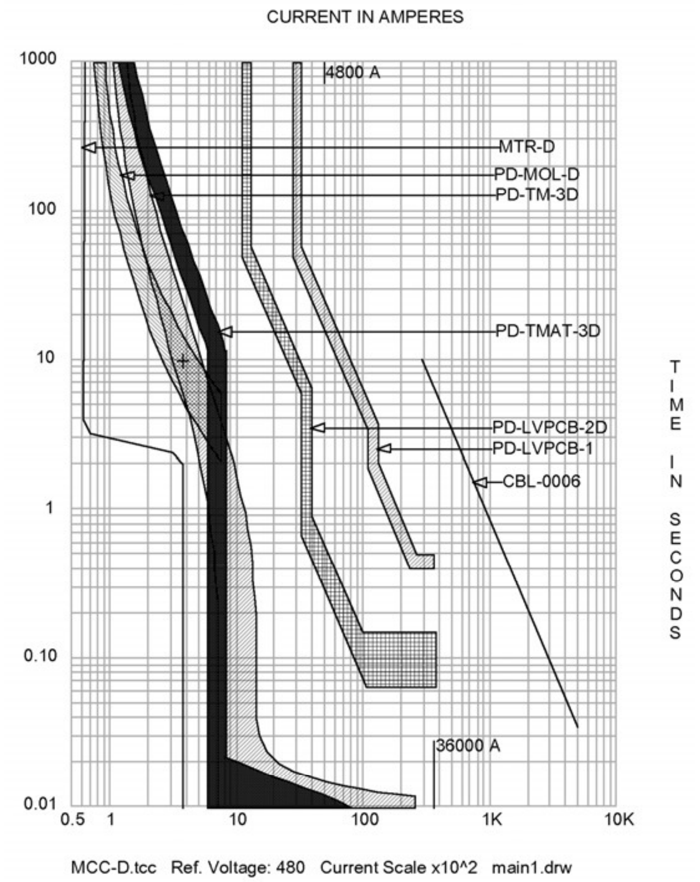

**Figure 5-11—MCC-D coordination plot showing selective coordination between feeder breaker PD-TM-3D, motor short-circuit protective device (adjustable trip thermal magnetic breaker) PD-TMAT-3D, and the MCC main low-voltage power circuit breaker PD-LVPCB-2D**

### 5.5.7 Transformer secondary circuit breaker

The 3000 A main LVPCB PD-LVPCB-1 also has adjustable long-time pickup, long-time delay, short-time pickup, and short-time delay settings, but no instantaneous setting. A 480 V LVPCB used for transformer secondary protection will typically have its long-time pickup set at 125% of the transformer full-load current. Its remaining settings provide moderately longer operating times than for the largest downstream feeder protective devices, as shown in Figure 5-7, Figure 5-8, Figure 5-9, and Figure 5-11. The secondary device should also protect the transformer from damage (through-fault protection curve XF2-0001) during through-faults as illustrated in Figure 5-12.

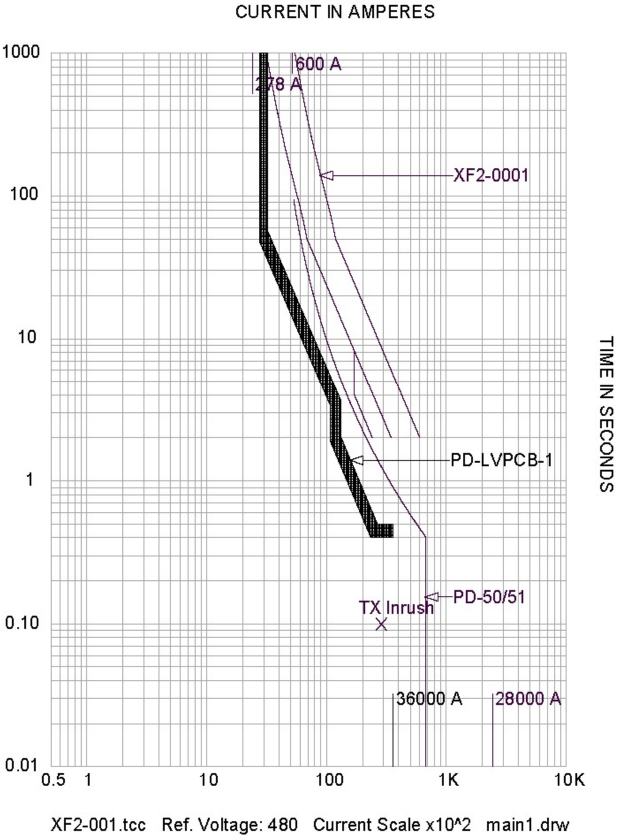

**Figure 5-12—Transformer primary 50/51 relay protection for transformer showing coordination with PD-LVPCB-1**

### 5.5.8 Primary overcurrent relay (device 50/51)

For proper coordination, the transformer primary relay (device 50/51) should be set in accordance with several criteria: transformer protection, conductor protection, no false tripping on through-faults or inrush, and selectivity with downstream and upstream devices. The NEC requires that the primary pickup must not exceed six times the transformer full-load current (this assumes that the transformer impedance is less than 6%). The transformer's primary inverse time delay relay (device 51) must protect the transformer for its through-fault withstand and yet should provide sufficient delay to exceed the time delay tripping of the low-voltage main circuit breaker. As illustrated by Figure 5-12, the primary device 51 setting should coordinate with the secondary protection, LVPCB-1, on the transformer load side, whereas the device 51's time-current curve, PD-50/51, must not cross the time-current curve of the downstream (load-side) device, LVPCB-1, up to the maximum available short-circuit current. Should the time-current curves cross, a potential lack of selective coordination exists.

The device 51 setting should protect the transformer from physical damage during three-phase through-faults as illustrated in Chapter 11 of IEEE Std. 242-2001, whereby the 51 characteristic is below and to the left of the through-fault protection curve of the transformer (transformer through-fault protection curves are also shown in ANSI C57). For delta-wye transformers with a solidly grounded secondary, the 51 setting should also protect for 57% of three-phase fault current for line-to-ground through-faults. For transformers with delta-wye high resistance grounded secondary or ungrounded secondary, the 51 setting should also protect for 86.6% of the three-phase fault current for line-to-line-through-faults.

The primary device 51 on a delta-wye transformer has a further consideration in that for a secondary phase-to-phase fault, one primary circuit will see 16% more current than a three-phase fault of the same secondary current magnitude. Figure 5-13 shows this fault current development. Because of this effect, an additional 16% coordination margin should be considered between primary and secondary transformer protective devices.

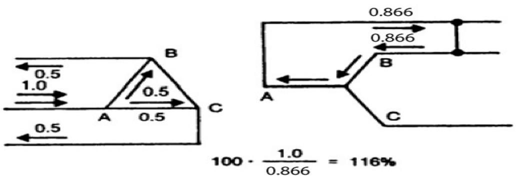

Figure 5-13—Currents in a delta-wye transformer for secondary phase-to-phase fault

The primary instantaneous element (device 50) should be set low enough to pickup faults on the transformer primary without falsely tripping on transformer inrush or for secondary through-faults. Device 50 should be set higher than the transformer inrush (approximately 8–12 times full load for 0.1 s). Device 50 should also be set high enough so it does not trip for secondary through-faults or about 1.6 times the secondary three-phase momentary through-fault current reflected to the primary voltage level. For the example, Figure 5-12 shows the coordinated elements, PD-50/51, XF2-0001, and PD-LVPCB-1.

### 5.5.9 Current-limiting circuit breakers

Figure 5-14 shows a typical time-current curve for a current-limiting MCCB. Figure 5-15 shows the additional information (sub-half-cycle unlatching time) required to draw the full time-current curve so that a coordination study can be performed. As with standard circuit breakers, current-limiting circuit breakers will coordinate with other line-side and load-side devices as long as the time-current curves do not cross. If the curves do cross, coordination is achieved up to the point where the curves intersect. When coordinating a current- limiting circuit breaker or those with dynamic impedance, the manufacturer should be consulted to determine what effect the circuit breaker will have on the fault current that flows through other service devices. Dynamic impedance is a term used to describe devices that quickly establish an impedance in the faulted circuit to limit current and, therefore, limit component damage.

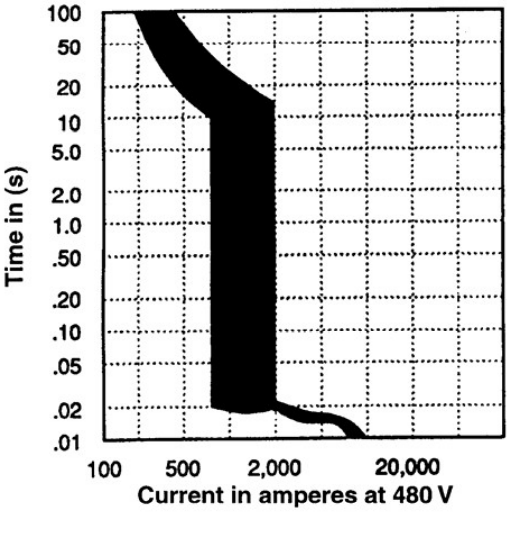

Figure 5-14—Current-limiting circuit breaker

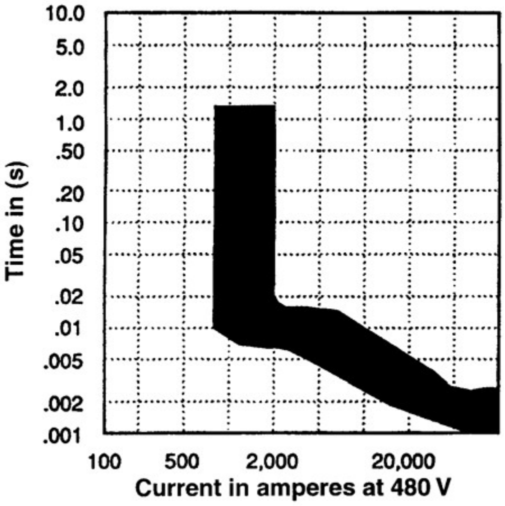

Figure 5-15—Current-limiting circuit breaker with unlatching characteristic

### 5.5.10 Ground fault

Selective coordination of ground-fault trip devices among low-voltage circuit breakers is readily accomplished in most cases as the trip characteristics consist of several bands of nearly constant time (see Figure 5-16). It is also important to check the characteristics of the ground-fault tripping device of each feeder with the largest load-side phase overcurrent device without ground fault. This check is done because a single phase-to-ground fault will involve those two devices.

When a large fuse, or motor starter without a ground-fault trip device, is used on the load (as shown in Figure 5-16), a judgment may be required to use an $I^2t$ pickup on the ground-fault trip (of course checking the impact on line-side devices), raising the ground pickup setting, raising the ground delay setting, some combination of these, or accepting some miscoordination. A few systems require special attention—double-ended four-wire ground, zone interlocking, and arcing ground fault memory, to name a few. The manufacturer's application information should be consulted. Another area that warrants additional consideration in systems with high ground-fault currents is coordinating the ground-fault tripping characteristic of a load-side device with both the ground-fault and the phase overcurrent trip characteristics of the next line-side device.

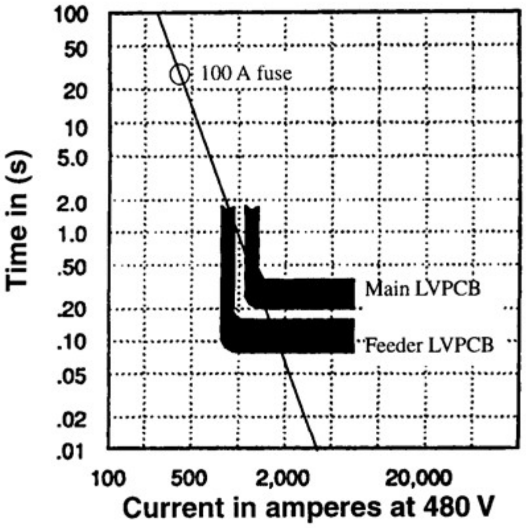

**Figure 5-16—Main and feeder circuit-breaker ground-fault coordination with load-side fuses**

## 5.6 Normative references

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

ANSI C37.17-1997, American National Standard for Trip Devices for AC and General Purpose DC Low-Voltage Power Circuit Breakers.[3]

IEEE Std 141™-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*™).[4, 5]

IEEE Std 241™-1990 (R1997), IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (*IEEE Gray Book*™).

IEEE Std 242™-2001 (R1991), IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (*IEEE Buff Book*™).

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

[4] The IEEE standards or products referred to in this chapter are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

[5] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

IEEE Std 1375™-1998 (R2003), IEEE Guide for the Protection of Stationary Battery Systems.

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

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

## 5.7 Bibliography

[B1] Gregory, G. D., and Padden, L. K., "Application guidelines for instantaneous-trip circuit breakers in combination motor starters," *IEEE Transactions on Industry Applications*, vol. 34, pp 697–704, July/Aug. 1998.

[B2] IEEE 1584™-2002, IEEE Guide for Performing Arc Flash Hazard Calculations.

[B3] NFPA 70E-2004, Electrical Safety Requirements for Employee Workplaces.

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

[7] UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA

# Chapter 6
# Fused and special-purpose circuit breakers

## 6.1 Introduction

This chapter covers application considerations for fused circuit breakers and selected special-purpose circuit breakers. These are circuit breakers other than conventional molded-case circuit breakers (MCCBs) or low-voltage power circuit breakers (LVPCBs). The chapter acknowledges that a wide variety of special circuit-breaker products exists, and that those selected here do not comprise the complete selection of special-purpose circuit breakers and their derivatives.

In this chapter, the following circuit breakers and their derivatives will be discussed:

- Instantaneous-trip circuit breakers
- Mine-duty circuit breakers
- Current-limiting circuit breakers
- Molded-case switches
- Fused circuit breakers
- Circuit-breaker and ground-fault circuit interrupters
- Arc-fault circuit interrupters
- Supplementary protectors

## 6.2 Instantaneous-trip circuit breakers

Instantaneous-trip circuit breakers (motor circuit protectors) provide adjustable short-circuit protection but no overload protection. As external overload protection must be used with these breakers, they cannot be used for branch circuit protection. These breakers are primarily used as components in motor circuits in combination with motor starters to provide the short-circuit protection function. They may also serve as the motor disconnecting means. The most typical applications are in motor control centers or individual combination motor controllers or combination motor starters. They are also used in welding equipment for short-circuit protection only. Figure 6-1 shows typical instantaneous-trip circuit breakers.

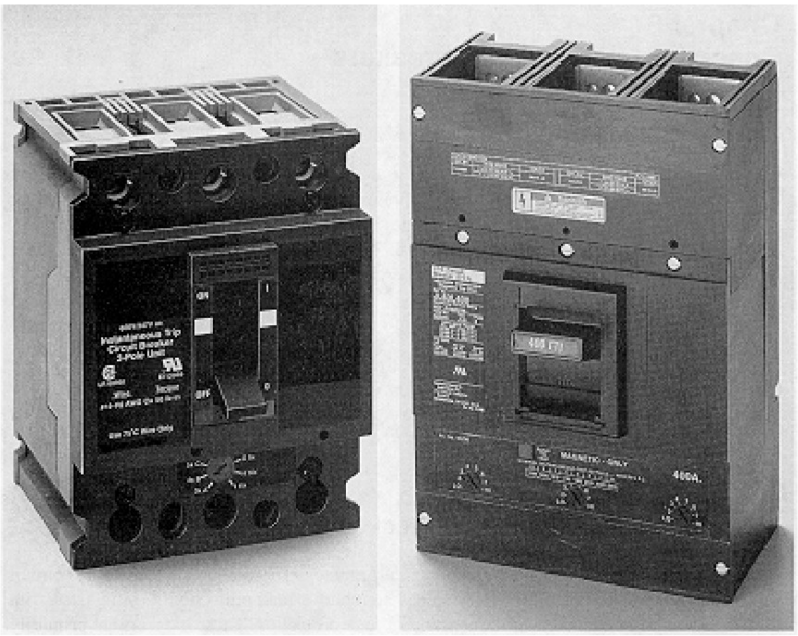
### 6.2.1 Ratings

Instantaneous-trip circuit breakers have a maximum continuous-current-carrying capacity. Prolonged continuous currents exceeding this rating may cause damage to the circuit breaker due to overheating.

Instantaneous-trip circuit breakers do not carry an interrupting rating by themselves under industry standards. Instantaneous-trip circuit breakers are most often applied in conjunction with motor controllers. Combination controllers are short-circuit tested with the starter and instantaneous-trip circuit breaker installed. The short-circuit rating that is applied is marked on the combination controller as a result of this test.

NOTE—Per UL 508-1999[1] test requirements, after a short-circuit has occurred, the circuit breaker and wires must be capable of continued service. However, the overload relay, contactor, or both may require repair or replacement.[2]

UL component recognized breakers are short-circuit tested by themselves at limited available (standard) levels as a basic requirement even though they do not carry an interrupting rating.



Reprinted from: Square D Company (left photo).
Siemens Energy & Automation, Inc. (right photo).

Figure 6-1—Example of instantaneous-trip circuit breakers

### 6.2.2 Current-limiting attachments

Several manufacturers have add-on current-limiting attachments that, if added to the load-side of the instantaneous-trip circuit breaker, will significantly raise the short-circuit withstand current rating of the combination starter. Current-limiting attachments contain specially designed fuses that open and limit the current that flows under high-level fault

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[1] Information on references can be found in 6.10.

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

conditions. Low-level fault currents will be interrupted by the instantaneous-trip circuit breaker without opening the current-limiting attachment fuses. High-level fault currents are interrupted by both the current-limiting module and the circuit breaker. The current-limiting attachment must be replaced after interrupting.

### 6.2.3 Code considerations

Section 430.52 of the National Electrical Code® (NEC®) (NFPA 70-2005) states that

> An instantaneous-trip circuit breaker shall be used only if adjustable and if part of a listed combination motor controller having coordinated motor overload and short-circuit and ground-fault protection in each conductor, and the setting is adjusted to no more than the value specified in Table 430.52. (FPN): For the purpose of this article, instantaneous-trip circuit breakers may include a damping means to accommodate a transient motor inrush current without nuisance tripping of the circuit breaker.
>
> *Exception No. 1:* Where the setting specified in Table 430.52 is not sufficient for the starting current of the motor, the setting of an instantaneous-trip circuit breaker shall be permitted to be increased but shall in no case exceed 1300% of the motor full-load current for other than Design B energy efficient motors and no more than 1700% of full-load motor current for Design B energy efficient motors. Trip settings above 800% for other than Design B energy efficient motors and above 1100% for Design B energy efficient motors shall be permitted where the need has been demonstrated by engineering evaluation. In such cases, it shall not be necessary to first apply an instantaneous-trip circuit breaker at 800% or 1100%.
>
> *Exception No. 2:* Where the motor full-load current is 8 amperes or less, the setting of the instantaneous-trip circuit breaker with a continuous current rating of 15 A or less in a listed combination motor controller that provides coordinated motor branch-circuit overload and short-circuit and ground-fault protection shall be permitted to be increased to the value marked on the controller.

Table 430.52 of the NEC identifies the maximum rating or setting of the instantaneous-trip circuit breaker as 800% for motors other than Design B energy efficient motors and as 1100% for Design B energy efficient motors other than the above exceptions.

### 6.2.4 Setting of instantaneous-trip circuit breakers

When used in a combination controller, the overload relays provide time delay for starting as well as overcurrent protection up to the locked rotor motor current range. By setting the instantaneous-trip circuit breaker trip level just above the motor starting current, maximum protection can be achieved without nuisance tripping on startup. Most manufacturers publish recommended continuous-current ratings and magnetic-trip ranges for commonly available motors.

When information is not otherwise available and the motor *is* available to the engineer, starting current can be estimated by taking the motor code from its nameplate and using the code letter to estimate locked rotor current from Table 430.7(B) of the NEC.

Asymmetrical starting current in rms amperes will be approximately two times locked rotor current.

When information is not otherwise available and the motor is *not* available, locked rotor current can be estimated by using Table 430.251 (A) or (B) of the NEC. Asymmetrical starting current in rms amperes can be estimated to be two times locked rotor current.

## 6.3 Mine-duty circuit breakers

Mine-duty circuit breakers are specifically designed for mining duty applications and permit the user to comply with mandatory mining standards. The normal operation of self-propelled mining equipment subjects its trailing cable to extreme and frequent flexing, twisting, and crushing. As a result, electrical faults in trailing cables occur much more frequently than wiring in normal, stationary installations. Additionally, the presence of loose coal dust and other combustible materials makes the occurrence of such faults hazardous. For these reasons, adequate trailing cable protection is extremely important.

Mine-duty circuit breakers typically have adjustable instantaneous-trip settings with tighter tolerances, dust shields and gaskets, non-moisture-absorbing materials, heavy-duty operating mechanisms, heavy-duty undervoltage releases with an external push button, and corrosion-resistant nameplates. Mine-duty circuit breakers are available with voltage ratings up to 1000 V ac and 300 V dc.

### 6.3.1 Magnetic trip setting

CFR, Title 30, Section 75.601, Part 75 indicates that

> Circuit breakers providing short-circuit protection for trailing cables shall be set so as to not exceed the maximum allowable instantaneous settings specified in this section; however, higher settings may be permitted by an authorized representative of the Secretary when he has determined that special applications are justified.

Mine-duty circuit breakers offer adjustable magnetic-trip settings or at least several settings that comply with the required maximum allowable trip settings in Table 6-1.

### Table 6-1—Maximum allowable circuit-breaker instantaneous setting[a]

| Conductor size (AWG or kcmil) | Setting (A) |
|---|---|
| 14 | 50 |
| 12 | 75 |
| 10 | 150 |
| 8 | 200 |
| 6 | 300 |
| 4 | 500 |
| 3 | 600 |
| 2 | 800 |
| 1 | 1000 |
| 1/0 | 1250 |
| 2/0 | 1500 |
| 3/0 | 2000 |
| 4/0 | 2500 |
| 250 | 2500 |
| 300 | 2500 |
| 350 | 2500 |
| 400 | 2500 |
| 450 | 2500 |
| 500 | 2500 |

[a] Reprinted from: Chapter 1, Section 75.601-1 of the CFR, Title 30.

### 6.3.2 Testing requirements

Section 75.900-2, Part 75, CFR, Title 30, states that

> Circuit breakers protecting low- and medium-voltage alternating current circuits serving three phase alternating current equipment and their auxiliary devices shall be tested and examined at least once each month by a person qualified as provided in 75.153. In performing such tests, actuating any of the circuit breaker auxiliaries or control circuits in any manner which causes the circuit breaker to open, shall be

considered a proper test. All components of the circuit breaker and its auxiliary devices shall be visually examined and such repairs or adjustments as are indicated by such tests and examinations shall be carried out immediately.

### 6.3.3 Circuit-breaker location

MCCBs used to protect underground circuits are required to be located in areas that are accessible for inspection and testing and have a safe roof.

### 6.3.4 Additional application requirements

Mine-duty circuit breakers feeding three-phase ac circuits are required to be equipped with devices to provide protection against undervoltage, grounded phase, short-circuits, and overcurrent.

Frequently, mine-duty circuit breakers are specified to be equipped with an undervoltage release. The undervoltage release can serve the following three different purposes:

a) To trip the circuit breaker during an undervoltage or power outage condition
b) To provide a tripping mechanism that can be used with ground-fault or interlock circuits
c) To provide an emergency tripping device that can be activated by a remote switch or push-button

## 6.4 Current-limiting circuit breakers

UL 489-2002 defines a current-limiting circuit breaker as follows:

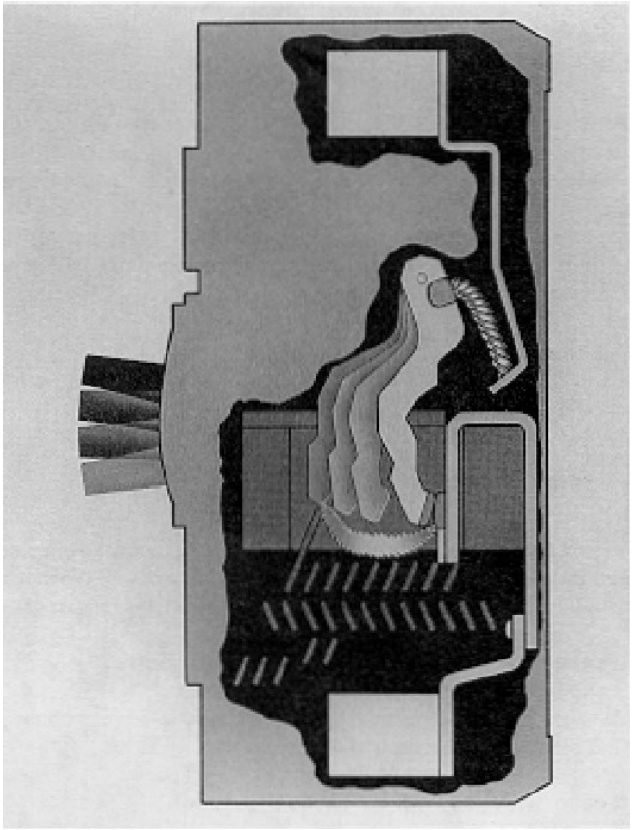
> A circuit breaker that does not employ a fusible element and that when operating within its current limiting range, limits the let-through $I^2t$ to a value less than the $I^2t$ of a 1/2 cycle wave of the symmetrical prospective current.

### 6.4.1 Description

Current-limiting circuit breakers are available from 15 A to 1200 A, rated up to 600 V, and have interrupting ratings up to 200 000 rms symmetrical A. These circuit breakers completely clear the faulted circuit within the first half-cycle.

Current-limiting circuit breakers are basically conventional thermal-magnetic or electronic-trip circuit breakers, designed so that high-speed contact separation is achieved under high-level fault conditions. This high-speed contact separation effectively limits potentially high-level fault currents and is achieved by closely spaced parallel contact arms carrying current in opposite directions. One form of a current-limiting circuit breaker with high-speed contacts is illustrated in Figure 6-2.

Current-limiting circuit breakers can be reset and service can be restored in the same manner as conventional circuit breakers even after clearing maximum-level fault currents. Of course, whenever a fault has occurred, it is important to remove the fault and its cause before reenergizing. If indications are that the fault was a significant short-circuit, the circuit breaker should be examined before reenergizing. If there are cracks in the circuit-breaker housing, if operation is difficult, or if there is severe discoloration, the circuit breaker should be replaced before reenergizing. NEMA AB 4-2000 contains more detailed information on testing and inspecting circuit breakers that have been in service.



Reprinted from: Square D Company.

**Figure 6-2—Current-limiting circuit breaker**

### 6.4.2 Applications

Current-limiting circuit breakers not only provide high interrupting ratings, but also limit let-through current and energy to load-side devices and conductors.

The current-limiting action is sufficient to reduce peak current, $I_{p,}$ and $I^2t$ let-through to values that lesser rated downstream circuit breakers can interrupt. A common application of this is using the current-limiting circuit breaker as either an integral or remote main breaker for lighting panelboards on systems with high available fault currents. This is called a series rating. It is important to note that manufacturers must test to demonstrate that the downstream device is protected in order to achieve a UL Recognized series rating. There is currently no accurate method of calculating this protection.

### 6.4.3 Series ratings

UL recognized series ratings are available using upstream circuit breakers or fuses with current-limiting capability in series with lower rated downstream breakers. These recognized combinations have been tested to verify that the current-limiting circuit breaker will protect the downstream device under the test conditions. Individual manufacturers of UL recognized series-connected ratings are published and may be found in the UL Recognized Component Directory. It is important to note that series ratings are not limited to current-limiting circuit breakers. Refer to Chapter 3 for additional information.

It should be noted that selective coordination will not be provided above any current level at which the circuit-breaker trip characteristic curves overlap. Where continuity of service is desired, or required, series-connected ratings are not recommended.

## 6.5 Molded-case switches

Molded-case switches are essentially circuit breakers with the thermal overcurrent protection removed. The magnetic short-circuit protection may also be removed. When high-level magnetic protection is provided, that fact will be indicated on the switch markings.

### 6.5.1 Molded-case switches without magnetic protection

Standard molded-case switches have no thermal- or magnetic-tripping elements. The term *nonautomatic* has been used with these switches in the past.

### 6.5.2 Molded-case switches with magnetic protection

Molded-case switches with magnetic-trip elements do not provide overcurrent protection. However, they do include a preset nonadjustable magnetic-trip element that serves to protect the switch against the damaging effects of high-level fault currents. For most applications, the standard (nonautomatic) and automatic switches can be used interchangeably.

### 6.5.3 Ratings

Molded-case switches have a maximum continuous-current rating that, if exceeded for long periods of time, may cause damage to the switch due to overheating. Neither standard nor automatic molded-case switches have interrupting ratings, as they are intended only to be a disconnecting switch, not a protective device. Molded-case switches must be protected by an overcurrent protective device of an equivalent or lower current rating.

Even when protected by an overcurrent protective device, molded-case switches should not be applied on systems capable of delivering fault current in excess of their withstand rating. Molded-case switches may carry a withstand rating from 5000 A to 200 000 A and are labeled for use in series with a specific overcurrent protective device or devices. The short-circuit rating test is conducted with the switch in series with the overcurrent device or devices specified.

### 6.5.4 Applications

Molded-case switches provide a simple and compact disconnecting means. Additionally, they meet the requirements of Section 430.109 of the NEC, which lists the specific devices that are permitted for use as a disconnecting means.

Molded-case switches are capable of making and breaking load currents up to six times their marked rating. As a result, these switches can be applied where horsepower ratings are required.

## 6.6 Fused circuit breakers

Fused circuit breakers are available in both molded-case and power circuit-breaker constructions. They provide high interrupting capability through the use of specially designed current-limiting fuses, termed *limiters* in this application to distinguish them from commercially available Class R, J, or L fuses. Such fuses are assembled into the housing of the circuit breaker or, in the case of high-ampere power circuit breaker frames, in a separate fuse truck. The limiters in these devices are designed to open, and need replacement, only after a high-level fault. The circuit-breaker portion is interlocked so that when any limiter opens, the circuit breaker will automatically trip, opening all poles of the circuit breaker and eliminating the possibility of single phasing caused by the opening of one of the limiters. Additionally, many circuit breakers are equipped with a mechanical interlock that prohibits the circuit breaker from closing with a missing limiter.

In the MCCB construction, the limiters are generally located within an added housing and are separated from the sealed trip unit of the circuit breaker for easy access. In power circuit-breaker construction, the limiters are mounted on the rear of the circuit-breaker frame or in a separately mounted fuse truck. Both mounting methods provide easy access to the limiters.

### 6.6.1 Applying fused circuit breakers

For ideal coordination within the fused circuit breaker, fuses should be selected so that overcurrents and low-magnitude faults are cleared by thermal or long-time/short-time tripping action; intermediate-level short-circuits are cleared by short-time delay, magnetic, or instantaneous tripping action; high-level short-circuits are cleared by the current-limiting fuse and instantaneous tripping action. This selection is usually made by the manufacturer, although optional fuse selections are sometimes available that may affect this coordination.

The short-time delay characteristic is beneficial if coordination in the intermediate current range is desired. There is a lack of coordination with the load-side protective devices when currents are in the current-limiting range of the fuse.

When applied on high short-circuit current capacity systems, the effects of the let-through characteristics of the fused circuit breakers on downstream equipment must be considered. The presence of the current-limiting fuse as part of the fused circuit breaker does not necessarily imply that the downstream equipment can adequately withstand these effects. It is important to note that manufacturers must test to ensure that in all combinations the downstream device is protected. There is no accurate method of calculating this protection.

Fused circuit breakers may be used where very high fault currents are available. In addition, some fused MCCBs provide series short-circuit ratings with other MCCBs. These series ratings are higher than the load-side circuit-breaker rating.

It should be noted that fused circuit breakers do not have any current-limiting effect until the current associated with the fault exceeds the threshold current of the limiter. Using fused breakers to protect standard breakers downstream is sound design, provided the manufacturer's coordination data are applied carefully. It needs to be understood that reduced size limiters may be necessary, but the use of these limiters could result in less than ideal coordination within the fused circuit breaker. This may cause frequent blowing of the limiters. In no case should combinations of trip devices and fuses that are not approved by the manufacturer be installed. Where fuses of different manufacture are being considered for the same system, the characteristics and peak let-through current of a given fuse rating may vary substantially between manufacturers.

It is important to note that electrical distributors who stock ordinary current-limiting fuses rarely stock these limiters. To distinguish these fuses from more common current limiting fuses, they are most typically termed *limiters* by standards such as UL 489-2002 and by many distributors. It is wise to consider keeping at least one set of spare limiters of each size used.

## 6.7 Circuit breaker and ground-fault circuit interrupter

A ground-fault circuit interrupter (GFCI) "is a device whose function is to interrupt the electric circuit to a load when a fault current to ground exceeds some predetermined value that is less than that required to operate the overcurrent protective device of the supply circuit," according to UL 943-2002. The Class A GFCI opens the circuit when the current to ground is 6 mA or more. A common form of GFCI protection is one in which a MCCB is packaged together with the GFCI in a single unit, which combines the functions of overcurrent protection and GFCI protection. The circuit-breaker function is the same as for any MCCB.

The purpose of a GFCI is protection of personnel from the potentially deadly effects of current passing through the human body. The 6 mA value is below the current level at which a person would be unable to let go of a conducting part. It is also below the value at which ventricular fibrillation is likely for adults or children (see Roberts [B1][3]).

Circuit-breaker GFCIs are typically rated 120 Vac, single pole and 120/240 or 240 Vac, two-pole with current ratings from 15 A to 60 A. Under the NEC, GFCIs are required in many locations in which, because of the presence of water or other conditions, electrocutions have resulted. Residential and commercial locations include bathrooms, kitchens, rooftops, spray washers, repair garages, swimming pools and other water recreation facilities, and similar locations.

## 6.8 Arc-fault circuit interrupter

The arc-fault circuit interrupter (AFCI) is packaged together with MCCBs to provide protection against effects of arcing occurrences that could start fires. As with the GFCI, the unit has the full function of a circuit breaker and in addition has the function of the AFCI.

The AFCI recognizes characteristics of current or voltage waves unique to arcing and causes the MCCB to trip when it recognizes an arc within a predetermined range of current. It must distinguish between potentially hazardous conditions and wave shapes of normal power that may look similar to that of a hazardous arc. Motors with brushes and some equipment with bimetallic temperature sensors, such as flat irons, have arcs that are normal power. Light dimmers, banks of computers, and equipment with filters sometimes have wave shapes that could look like an arc but are normal power.

“Branch/Feeder” AFCIs detect arc faults line-to-neutral or in series with it in a circuit capable of delivering 75 A or more. Arcing current will be less than the available current. Commercially available Branch/Feeder AFCIs will also detect line-to-ground arcs of 50 mA or more. The 75 A value is the lowest fault current level found in a survey of receptacle locations in residences within the United States. The primary purpose of the Branch/Feeder AFCI is protection of fixed wiring. The branch/feeder AFCI also protects against line-to-neutral or line-to-ground arcing in the branch circuit extension wiring. It addresses the category of fires caused by lower level short-circuits that would not open an overcurrent protective device fast enough to avoid fire.

“Combination” AFCIs detect arc faults line-to-neutral, line-to-ground, or in series with it in a circuit of 5 A or more. It is intended to detect arcing current in fixed wiring and extension wiring that are likely to cause fire. The term “combination” means that this device combines protection needed for fixed wiring with that needed for extension wiring connected to receptacle outlets.

Although the primary application for AFCIs under the NEC is residential, they are also required in some commercial units used as dwellings. They also find application in commercial and industrial applications in which detection of arcing current is needed, although not required for these applications.

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[3] The numbers in brackets correspond to those of the bibliography in 6.11.

AFCIs are rated 15 A and 20 A and are available in one-pole units rated 120 V and in two-pole units rated 120/240 V. The product standard is UL 1699-2000.

## 6.9 Supplementary protectors

A supplementary protector resembles a circuit breaker and shares many characteristics; however, it does not meet the requirements of UL 489-2002 and is not usable as branch circuit protection. These devices are identified in the NEC and by UL as "supplementary protectors" and are covered by UL 1077-1999. UL 1077-1999 defines a supplementary protector as follows:

> 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.

When comparing this definition with the NEC definition of a circuit breaker, obvious similarities are apparent, but there are also important differences. Both devices may open automatically on a predetermined value of current, but beyond that the devices may be different. Some potential key differences are as follows:

— The definition states that a supplementary protector may be provided with manual means for opening and closing the circuit, manual operability is not required. A circuit breaker is defined as a device designed to open and close the circuit by manual means.

— Supplementary protectors are intended to be installed within an appliance or other end-use electrical equipment, which means that these devices may not be used in distribution equipment such as a panelboard or switchboard where branch-circuit overcurrent protective devices are required.

Supplementary protectors are not intended as a substitute for branch-circuit overcurrent devices. This is clearly noted in Section 240-10 of the NEC. As the name implies, they are intended as supplementary, or additional, protection to the branch-circuit overcurrent device that must be present.

Unlike general-purpose branch-circuit protectors, which are UL Listed, supplementary protectors are Recognized Components and are intended for use in equipment. They are typically intended to provide more specialized protection for a specific purpose, or even for a particular type of equipment. Some have horsepower ratings for use with motors, and some do not have horsepower ratings. Supplementary protectors have ratings and functionality depending on their intended use. Some have manual switching means, and some do not. Some trip on current levels, and some trip on voltage levels. There are many differences in the UL standards; a few important specific instances are as follows:

*Overload protection*—UL 489-2002 requires all circuit breakers to be tested at 6 times rating, but UL 1077-1999 only requires overload testing at 1.5 times rating. However, if the supplementary protector carries a horsepower rating, it is also tested at 6 times rating.

*Short-circuit ratings*—UL 489-2002 requires a minimum short-circuit interrupting rating of 5000 A for circuit breakers rated 250V and less, and 10 000 A for circuit breakers rated more than 250 V. UL 1077-1999 devices do not have short-circuit ratings, but the standard does require a limited short-circuit test at a maximum current of 5000 A. The actual test value varies from 200 A to 5000 A depending on the rating. The tests and the acceptable results at the conclusion of the test are also different. UL 489-2002 requires the circuit breaker to interrupt the circuit twice. After these tests, the circuit breaker must still be functional and pass a dielectric test. UL 1077-1999 requires the supplementary protectors to be subjected to three operations. However, the device is allowed to be wired in series with a branch-circuit overcurrent protector such as a fuse or circuit breaker. The branch-circuit overcurrent protection is allowed to open during the test. It is acceptable for the supplementary protector to become inoperable during the tests, but it cannot become a hazard.

*Spacings*—UL 1077-1999 spacing requirements for supplementary protectors depend on the application such as general industrial use, household appliances, household kitchen appliances, or commercial appliances. For example, a 600V UL 489-2002 circuit breaker requires a spacing of 25.4 mm (1 in) through air and 50.8 mm (2 in) over surface, whereas a UL 1077-1999 supplementary protector for 600 V general industrial use only requires a spacing of 19.1 mm (3/8 in) through air and 12.7 mm (1/2 in) over surface.

## 6.10 Normative references

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

Code of Federal Regulations (CFR), Title 30—Mineral Resources, Chapter 1—Mine Safety and Health Administration. (USA).[4]

NEMA AB 3-2001, Molded Case Circuit Breakers and Their Application.[5]

NEMA AB 4-2000, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications.

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

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

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[4] The Code of Federal Regulations is available from the Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20037, USA.

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

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

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

UL 508-1999, Industrial Control Equipment.

UL 943-2002, Ground-Fault Circuit Interrupters.

UL 1699-2000, Arc Fault Circuit Interrupters.

UL 1077-1999, Supplementary Protectors for Use in Electrical Equipment.

UL Recognized Component Directory, 2002.

## 6.11 Bibliography

[B1] Roberts, E. W., *Undercurrents and Overcurrents*. Mystic, CT: Reptec, 1996.

# Chapter 7
# Acceptance and maintenance requirements

## 7.1 Scope

This chapter provides guidelines and instructions for developing an acceptance and maintenance testing program for low-voltage circuit breakers (LVCBs). Such items as maintenance planning, establishment of baseline data, training considerations, safety considerations, testing considerations, acceptance criteria, and documentation requirements are discussed.

## 7.2 Maintenance program

The time to begin planning for maintenance of circuit breakers, or any kind of equipment, is when the equipment is being installed. It is good practice for the organization that will be responsible for maintenance to be present, if possible, when the circuit breakers and associated equipment are initially installed and checked out. This initial familiarity will help maintenance personnel feel more comfortable with the equipment and provide information that will save time and questions when maintenance or troubleshooting becomes necessary.

If an organization plans on maintaining the LVCBs themselves, they should obtain the proper training for their personnel. Such training is often available from the manufacturer or other service organizations that are dedicated to maintenance activities.

The first order of business of any viable LVCB maintenance program is preparing a detailed procedure based on what has been learned from initial installation, test data, manufacturer's information, and training. The procedure should provide a step-by-step guide to performing the desired level of maintenance. The procedure should provide identifiable guidelines and acceptance criteria such that maintenance personnel will know what is and is not acceptable.

Different documents exist that will aid in developing this detailed procedure, including the following:

a) Single line diagrams
b) Elementary (control) diagrams
c) Relay setting sheets
d) Circuit-breaker manufacturer trip curves
e) Technical requirement(s) from specifications
f) Vendor wiring/connection diagram (as applicable)
g) Vendor instruction manual (as applicable)
h) Personnel qualifications, certifications, and training

A maintenance schedule for LVCBs should be established. The schedule might be based on the manufacturer's recommendations and may be adjusted based on previous experience (Appendix H4 of NFPA 70B-2002[1] provides good maintenance guidelines for all low-voltage equipment). The schedule will also be dependent on production demands, number of LVCB operations, and the environment in which the breaker is located. Of these three, the environment in which an LVCB is located is most important.

Environmental conditions encountered in the field must be evaluated to determine the optimum frequency for the performance of maintenance. Some pieces of equipment exhibit characteristics that require maintenance procedures to be performed on a more frequent basis to ensure proper operation regardless of the environment in which they are placed. When a circuit breaker is placed in a clean, well-conditioned environment, it may sit idle for a significant period of time with little or no adverse effects and operate properly when required.

When a circuit breaker is in a dusty, dirty, or corrosive atmosphere, it might either become inoperative or it may malfunction if it should attempt to interrupt a fault that is well within its capacity. The frequency of preventive maintenance, inspection, and cleaning must be high to ensure the integrity of operation.

Once the appropriate technical procedures and maintenance schedules have been prepared, safety aspects of the job must also be considered before the actual work is performed. Procedures and schedules may have to be modified as a result.

The safety of personnel performing maintenance inspection, testing, and repair should be a prime requirement of any maintenance program. Persons performing periodic maintenance on LVCBs should be familiar with the electrical system(s) in which the breakers are used. They should know where and how the breaker they are working on is isolated from energized portions of the circuit. Testing should be performed before proceeding with any maintenance work to ensure that all sources of electrical potential have been removed. This type of work should be performed by trained personnel only.

Low-voltage power circuit breakers (LVPCBs) shall be totally disconnected from the switchgear bus connections before performing tests or checks on the actual breaker. If work on the racking mechanism or any components within the breaker cubicle is to be performed, isolation of the line-side stabs is necessary. Some circuit configurations exist such that the load-side terminals are energized from another source. This type of condition is known as a backfeed. In such a case, isolation of the load-side stabs would also be required before working within the cubicle. Where possible, the preferred method of stab isolation is to de-energize the circuit remote from the cubicle location. If de-energization is not possible, the stabs may be covered. Most manufacturers provide covers or isolators for the stabs. However, extreme caution must be exercised when covering energized stabs.

Even after LVPCBs are withdrawn from the cubicle to test and observe the operation, there may still be a hazard due to the stored energy mechanisms. Awareness must be

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[1] Information on references can be found in 7.11.

maintained throughout the duration of the testing so that hands and fingers are kept clear of pinch points on LVPCBs.

The only method of total isolation of molded-case circuit breakers (MCCBs) is de-energization of the source and load. Removal of an MCCB from a panel must not be done if the panel remains energized, unless the breaker is of a plug-on or draw-out type construction.

## 7.3 Maintenance of MCCBs

Field maintenance of MCCBs, which includes motor circuit protectors (MCPs), is normally limited to a visual inspection, cleaning, and tightening of connections. However, periodic overcurrent protection testing of MCCBs and MCPs should be completed as indicated below. Per NFPA 70B-2002 (18-4 Frequency of Tests), the optimum testing and maintenance cycle depends on the use of the equipment and typically ranges from 6 months to 3 years. Any MCCB or MCP found to have a cracked case when inspected should be replaced because the stresses on the breaker that occur when interrupting a fault could cause a catastrophic failure of the case.

One other observable phenomenon that requires attention is tracking. Tracking is an electrical discharge phenomenon indicated by a leakage path that is directionally erratic (similar to the pattern of a lightning stroke). This phenomenon forms from electrical stress over a long period of time, especially in unclean environments, and it will eventually lead to a flashover. As a result, the cause of the tracking should be determined and corrected. The circuit breaker should be inspected for degradation and cleaned, and if the stress markings are still visible, the circuit breaker should be replaced.

MCCBs and MCPs are designed and manufactured to require no internal maintenance throughout their lifetime. MCCBs and MCPs are factory calibrated and sealed, and the breaker should not be tampered with. However, some MCCBs and MCPs have a removable cover that is intended only for installing trip units. This does not mean that maintenance can be performed on the MCCB or MCP with the cover off. The manufacturer did not intend this to be the case.

The following items should be checked on an MCCB or MCP during periodic maintenance schedule:

a) *Breaker overheating*. Check the breaker for overheating when it is operating under normal load and in its normal operating environment. Thermal imaging equipment is available to determine the area(s) where an overheating condition may exist. If the breaker is experiencing overheating, it should be removed from service and checked further to determine the cause of the overheating.

b) *Connection check*. Visually check the breaker and bus/cable connections for evidence of overheating. Overheated copper connections can usually be cleaned and dressed satisfactorily for reuse. Overheated aluminum connectors must be replaced. All connections must be tightened to proper torque levels specified after cleaning or replacement.

c) *Mechanical operation.* All MCCBs and MCPs should be exercised (opened and closed) several times to ensure proper mechanical operation. Exercising an aged breaker is particularly important, considering many breakers are never called on to operate by an overcurrent condition. Exercising the breaker can free binding mechanisms.

d) *Breaker testing.* Many breakers are fitted with thermal-magnetic trip units or magnetic (instantaneous) trip units only. These magnetic trip only breakers are often referred to as MCPs. MCPs are typically applied in conjunction with a device that provides overload protection, such as an overload relay in a motor starter. Some modern MCCBs and insulated-case circuit breakers (ICCBs) on the market today contain electronic trip devices (ETDs).

    1) *Thermal unit test.* The MCCB is tested by passing 300% of the MCCBs ampere rating through each pole of the MCCB. The test results should be compared with the manufacturer's time-current characteristics (curve sheet). For multi-pole MCCBs, these curve sheets are based on current in all poles of the breaker and are used for coordination purposes; thus, the curve sheet should be examined for maximum single-pole trip time. Not all curve sheets specify a maximum single-pole trip time, but when one is available it should be noted. (In lieu of one not provided, Table 5-3 of NEMA AB 4-2003 provides a maximum trip time for a range of continuous current breakers tested at 300% rated continuous current.)

    2) *Magnetic unit (instantaneous) test.* The MCCB (thermal-magnetic, electronic trip, or MCP) is tested by passing the magnetic rated trip amperes through each pole of the circuit breaker. The circuit breaker should trip within the following parameters:

       Adjustable: +40% to –30% of setting.

       Nonadjustable: +25% to –25% of manufacturer's trip range The testing of instantaneous trip units usually requires a high current test set for all, but the smallest frame sizes of MCCBs. Care must be taken when checking the instantaneous unit with high current to ensure that the thermal-trip unit is not the cause of the MCCB tripping. The high current should be placed on the MCCB for very short periods of time with adequate cool down time allowed between applications. When testing the instantaneous trip of MCPs, additional consideration may be needed for the proper operation of the overload protective device, such as the overload relay for a motor starter, to assure complete overcurrent protection.

    3) *Shunt trip.* Shunt-trip devices are used to trip an MCCB via some external device operation (e.g., ground-fault relay). If an MCCB is equipped with a shunt-trip coil (solenoid), the unit can be verified by applying the rated voltage across the coil, with the MCCB closed. The shunt-trip device trips a mechanical latch (or trip mechanism) that trips the MCCB.

    4) *Insulation resistance.* All poles should be tested in accordance with standard insulation resistance testing guidelines at 1000 V dc. Resistance values of less than 1 MΩ should be considered inadequate, and the cause should be investigated. Insulation tests should be performed between the line and load

terminals with the MCCB open, between adjacent poles, and from each pole to the grounded parts of the MCCB.

5) *Contact resistance*. Contact resistance should be measured using an ohmmeter capable of measurements into the micro-ohm range. Contact resistance measurements on some of the smaller sized MCCBs are not practical where the test lead clip is larger than the MCCBs' terminal. The manufacturer should be contacted to obtain acceptable contact resistance levels for the breaker under test.
6) *Rated load test*. A rated load hold-in test can be run if there is some doubt of the MCCBs' ability to carry rated load. With the MCCB in free air, all three poles are connected in series with jumpers of a short length and adequate capacity. Applying rated load current for a minimum of 30 min should not cause the breaker to trip.

## 7.4 Maintenance of LVPCBs

Maintenance performed on LVPCBs should follow the manufacturers' inspection and maintenance instructions whenever possible. These instructions are detailed to the particular breaker and usually provide drawings, photographs, or sketches to point out items that must be maintained. Inspection of LVPCBs should follow a maintenance schedule established for the particular site. The first inspection should occur after an initial operating period as prescribed by the manufacturer. A thorough inspection should also be performed after the LVPCB has interrupted a short-circuit current.

Whenever a maintenance inspection procedure is being performed on an LVPCB, the following specific points of inspection should be performed:

a) Operate the LVPCB several times to make certain that the circuit breaker operates freely. Operate both manually and electrically, if so equipped, to be sure all electrical components function properly.
b) Clean all dust and dirt from the LVPCB.
c) Remove and inspect the arc chutes for any cracking, breakage, or extensive burning that would indicate a need for replacement.
d) Check the condition of contacts, both moving and stationary, and ensure proper contact penetration.
e) Check the latch mechanisms and their engagements, both open and closed.
f) Check the lubrication and lubricate as necessary per the manufacturer's instructions.
g) Check the operation of manual tripping devices.
h) Test the LVPCB to ascertain that it performs on the representative time-current coordination curves.

These tests and testing methods are described in the manufacturers' inspection and maintenance instructions. Just as in testing the MCCBs, the availability of a high current test set is necessary to completely test the LVPCB. The following tests should be performed on each pole of the LVPCB:

- Long-time delay overcurrent that protects against a circuit overload condition.
- Short-time delay overcurrent that protects for lower order fault-current conditions.
- Instantaneous-trip operation that provides circuit protection for short-circuit or higher order fault-current conditions.
- Ground-fault protection that provides circuit protection for a ground-fault condition. (Ground-fault protection is usually found only on LVPCBs equipped with an ETD. The ground-fault unit will function during single-pole high-current testing of the breaker, and it must be disabled per the manufacturers' instructions to verify the phase-trip unit.)

Many LVPCBs of modern manufacture are equipped with ETDs. Most manufacturers provide test units for use on their ETDs. The same performance verification testing should be performed on ETDs as those outlined above. Use of the high-current test set will test the current sensing devices on the LVPCB at the same time as the ETD if verification is desired. Generally the high-current test is not necessary for routine field maintenance checks of the ETD unless there is some question as to the sensor's operation. The test units for the manufacturer's ETDs will verify the trip characteristics of the selected settings.

## 7.5 Maintenance and testing of ICCBs

ICCBs are typically rated and constructed as MCCBs. Some ICCBs are rated as LVPCBs. Maintenance and testing of ICCBs should follow the same guidelines as presented for the appropriate type of MCCBs or LVPCBs. However, if ICCBs are rated as LVPCBs, some aspects of maintenance may be limited due to construction differences between traditional LVPCBs. For instance, with ICCBs, inspection and cleaning of contacts and arc chutes typically cannot be completed.

## 7.6 Maintenance and testing of molded-case switches

Molded-case switches have construction features that are similar to those of MCCBs; therefore, their maintenance should parallel that of the MCCBs. As they do not provide overcurrent protection, tests for operation tripping (thermal or instantaneous) are typically not required. Although some molded-case switches contain a high-level instantaneous trip feature to protect their contacts, this feature is not calibrated as an overcurrent protective feature and does not require testing.

Additional information on molded-case switches can be found in UL 489-2002.

## 7.7 Maintenance of ground-fault circuit interrupters (GFCIs)

There are four types of GFCIs, as follows:

a) Circuit-breaker type
b) Receptacle type
c) Portable type

d) Permanently mounted type

Each type is equipped with a test unit that is an integral part of the GFCI. Because the GFCIs are sealed at the factory, maintenance activities on these devices should be limited to those recommended by the manufacturer.

Additional general information on GFCI maintenance can be found in NFPA 70B-2002 and NEMA 280-1990.

## 7.8 Documenting maintenance results

Keeping records of maintenance work and troubleshooting can seem like an unnecessary burden. However, good maintenance records, when properly documented and analyzed, will save you time, money, and aggravation.

For example, unexpected breaker trips can result in lost production for the user, causing frustration. The user may want to know why the malfunction occurred, how long repairs will take, and what will be done to prevent the breaker trip from happening again. Keeping proper records can help to address these concerns more efficiently.

In another example, a particular breaker may trip under test at a higher current or longer time than it did when initially installed. After repeating the test a second time, the breaker performs closer to its setting. This breaker may either need to be exercised more frequently, or there may be a problem with the breaker. This condition would probably need to be discussed with the manufacturer. If this condition was not noticed, the wire or equipment that the breaker was intended to protect could be seriously damaged if the breaker did not trip correctly the first time as expected.

If records show that nothing is ever found wrong with a particular circuit breaker or set of breakers, this might indicate that the length of time between inspections and maintenance can be safely increased, thus saving time and money.

To take full advantage of documentation, records need to be taken properly. Documentation should be made not only during scheduled maintenance, but also every time it is necessary to inspect or investigate a problem on a particular piece of equipment. The information documented should be reasonably detailed. A statement such as checked breaker does not provide enough detail. A better record would state “checked breaker because of reported overheating” or “overheating when I arrived found no problem.” Proper documentation will help analyze and correct the equipment problem more efficiently.

## 7.9 Testing program

The purpose of a test procedure is to provide instructions for performing and documenting the results of tests on LVCBs. The acceptance criteria and the source of those criteria are entered on the test data record sheets immediately after the specification criteria.

### 7.9.1 Testing prerequisites

(Record on data record sheet. See Annex 7A and Annex 7B.)

a) Review the past data record sheet and verify that previous deficiencies (if any) will not affect the test.

b) Verify that the component(s) to be tested has been released to the testing organization by the operations organization.

c) Record the current revision numbers and/or dates of implementing references used on the test data cover sheet.

d) Verify that the test procedure and the official test data recording sheet contain the latest revisions.

e) Verify that no temporary modifications will affect the performance of this procedure.

f) Notify the shift supervisor before commencement, stopping, or restarting this test.

g) Notify QA/QC (if so organized) of the intention to commence testing, as applicable.

### 7.9.2 Initial conditions

(Record on data record sheet. See Annex 7A and Annex 7B.)

a) Verify that work clearance tags, permits, and/or lockout/tagout devices are applied on equipment to be tested, as well as on any related equipment or devices, as required to support this test.

b) Place warning signs and barriers around equipment to be tested.

c) Ensure that the test equipment in 7A.4 has a valid calibration status (if applicable). Record test equipment description, control number, and calibration due date on test data cover sheet.

d) Determine proper protection to be used to preclude injury as a result of an arc flash.

### 7.9.3 Precautions

(Record on data record sheet. See Annex 7A and Annex 7B.)

a) Carefully store all equipment parts removed during the performance of this test so that they can be easily found.

b) Avoid exposing equipment to moisture, dust, dirt, or other hazardous conditions.

c) Use caution when working in or around the circuit-breaker cubicles and be aware of energized terminals and space heaters.

d) All tests shall be made only on circuit breakers that are de-energized and isolated, so that no accidental contact is made with any live parts.

e) During testing, keep hands and fingers clear of moving parts. Serious injury could result from the crushing forces that are present during power circuit-breaker operation.

f) Use only manufacturers' recommended lubricants on breakers. Do not use lubricants on contact faces or on ETDs.

g) Before removing breakers or performing work on breakers verify proper isolation is achieved (i.e., lockout/tagout implementation) and proper installation of maintenance grounds as required by company procedure.

h) As required by company procedures, protective clothing and personal protective equipment shall be required when work is performed within a flash protection boundary.

### 7.9.4 Test equipment

(Record on data record sheet. See Annex 7A and Annex 7B.)

a) Megohmmeter

b) Digital multimeter

c) Digital low-resistance ohmmeter

d) Circuit-breaker test set

e) Psychrometer

f) Variable voltage source, ac or dc, as required

g) Appropriate gauges and tools per manufacturer's maintenance manual

### 7.9.5 Personnel orientation

(Record on data record sheet. See Annex 7A and Annex 7B.)

The lead test engineer shall ensure that personnel performing this test have been trained with respect to the operation of the electrical system, operation of the test equipment, and the electrical equipment to be tested. The lead test engineer shall also ensure that the personnel have been trained in safety precautions, data collecting techniques, and actions to be taken in the event that abnormal or unexpected conditions occur.

### 7.9.6 Test instructions

#### 7.9.6.1 MCCBs and MCPs (see Annex 7A)

##### 7.9.6.1.1 7Visual inspection

a) Determine ambient temperature. Record on data record sheet.

b) Check that the MCCB or MCP is free of visual defects, chipping, cracks, breaks, burns, signs of overheating, and deterioration. Record this on the data record sheet.

c) Mount MCCB or MCP onto a surface that is or can be grounded (grounded plate). Record on data record sheet.

d) Perform several mechanical ON-OFF operations.

e) Make a circuit continuity check with a digital low-resistance ohmmeter on each pole with the circuit breaker in the closed position.

#### 7.9.6.1.2 Primary circuit insulation resistance

NOTE—Apply megohmmeter voltage for a period of 1 min or until reading is stable for test voltage selection. (Use Table 1 in 7A.6.2.) Acceptance criteria for insulation resistance should be obtained from the manufacturer's instruction book. Typical minimum criteria are 50 MΩ to 100 MΩ or greater. Record test voltage and acceptance criteria on data record sheet.[2]

a) Short all auxiliary leads on the MCCB or MCP together and connect to cubicle frame. This would include leads from auxiliary contacts or from the shunt trip coil. Record on data record sheet.

b) With the MCCB or MCP open, jumper the line-side terminals together. Jumper the load-side terminals together. Ground load-side terminals to cubicle. Record on data record sheet.

c) Connect the megohmmeter to the line-side terminals and the cubicle. Record on data record sheet.

d) Apply the test voltage to the line-side terminals, and record the megohmmeter reading on the data record sheet.

e) Remove the ground from the load-side terminals, and put it on the line-side terminals. Record on data record sheet.

f) Connect the megohmmeter to the load-side terminals and the cubicle. Record on data record sheet.

g) Apply the test voltage to the load-side terminals, and record the megohmmeter reading on the data record sheet.

h) Remove the line- and load-side jumpers and ground. Record on data record sheet.

i) Operate the MCCB or MCP to the CLOSED position.

j) Apply megohmmeter phase-to-phase. Record on data record sheet.

k) Apply megohmmeter phase-to-ground. Record on data record sheet.

l) Remove test equipment, shorts, and ground installed for 7A.6.2 from cubicle. Record on data record sheet.

#### 7.9.6.1.3 MCCB overcurrent trip test

**CAUTION**

Care should be taken to limit the maximum trip time to prevent damage to the MCCB.

a) Obtain the desired time range for the type and rating of the circuit breaker being tested, from the applicable breaker setting sheet. If a breaker setting sheet is not

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

available, use the manufacturer's curve to obtain the correct time range at 300% of the breakers rated circuit. Record on data record sheet.

b) Make certain that the time delay tests are made in open air at an ambient temperature of 25 °C (if possible) with breakers allowed to adjust to that temperature before starting overcurrent tests.

c) Conductor leads should be of the same size as specified in UL 489-2002, and properly secured.

d) The test equipment must be capable of holding the current constant over the entire test time with as little variation as possible.

e) Close the breaker, and apply 300% of breaker-rated continuous current to each pole of the circuit breaker. Repeated tests on any pole should be spaced by at least 20 min; tests on adjacent poles must be spaced by at least 5 min. Record test current on data record sheet.

f) Record the breaker trip time for each pole on data record sheet.

#### 7.9.6.1.4 MCCB shunt-trip device (if used)

a) Obtain the percentage shunt-trip coil voltage (%TCV) and the minimum trip voltage (MTV) from the MCCB manufacturer. Calculate the MTV if only %TCV is obtained. Enter on data record sheet.

b) Apply the MTV to the shunt-trip coil and observe the MCCB trips, and record on data record sheet.

#### 7.9.6.1.5 Instantaneous overcurrent trip test

There are two common methods for this test, one being the run-up method, in which the test set current control is set at a point equal to 60–70% of the expected tripping current when energized. After power is turned ON, the current can then be increased from this value to a tripping current without excessive delay, which could cause the thermal unit to trip. The second method, considered preferred, is called the pulse method and requires that the test set be equipped with a pointer stop ammeter. The current is applied in short pulses of 5–10 cycles duration. [Some manufacturers recommended that the pulsed overcurrent be first applied in excess of the instantaneous trip (IT) range, prior to adjusting for calculated ranges.] The current is increased on each succeeding step until the MCCB or MCP trips. If this meets the criteria, no further tests are required. However, it is often desirable to pulse check the tripping bandwidth. The current is then reduced to just below that band, and by repeated pulses, the pointer stop on the ammeter is adjusted until the pointer movement is barely perceptible when the current is pulsed. The current can then be raised slightly to recheck the trip point.

**CAUTION**

Do not exceed the maximum current values of the manufacturer's time-current curve for the MCCB's or MCP's magnetic coil.

a) When the MCCB or MCP to be tested has an adjustable instantaneous trip, adjust to MAX setting. Pulse the test setting to obtain desired magnetic overcurrent (MOC). Record MOC from breaker setting sheet on data record sheet.

b) Obtain the MCCB or MCP maximum (PLUS TOLERANCE) and minimum (MINUS TOLERANCE) tolerances from the MCCB/MCP manufacturer. Typical values are shown in 7A.6.5. Enter on data record sheet. Calculate the normal tolerance values for the MOC setting of the MCCB or MCP.

c) Alternately decrease magnetic-trip adjustment and pulse test set to obtain MOC. Record the actual MOC trip obtained on the data record sheet.

d) Perform step a) through step c) for each pole to be tested.

e) Indicate on the data record sheet the final setting for each pole adjustment of the instantaneous trip device.

f) Remove MCCB or MCP from grounding plate installed in step 7A.6.1, and record on data record sheet.

g) Enter on data record sheet the completion of step 7A.6.5.

#### 7.9.6.1.6 Installation of draw-out MCCB or MCP cubicle

a) Ensure that the MCCB or MCP is in the OPEN position. Record on data record sheet.

CAUTION

Before installing MCCB or MCP cubicles into their respective compartments, ensure that there are no protruding metal screws or sharp edges that would damage adjacent cable insulation and that the terminations on the MCCB have the correct bolts and washers properly installed.

b) Align properly and install the draw-out MCCB or MCP cubicle in appropriate compartment. Record on data record sheet.

c) Install control transformer fuses.

d) Reterminate wires that have been lifted. Record on data record sheet.

e) Verify cubicle ground continuity to ground bus. Record on data record sheet.

### 7.9.6.2 LVPCB (see Annex 7B)

WARNING

Due to extreme crushing forces present during the open and close cycles of the LVPCB, care must be taken to keep hands and fingers away from the moving parts of the breaker.

#### 7.9.6.2.1 Visual inspection

a) Record the ambient temperature on the data record sheet.
b) Remove LVPCB from its compartment. Record on data record sheet.
c) Ensure the breaker to be tested is in the OPEN and SPRINGS DISCHARGED position. Record on data record sheet.
d) If required by the manufacturer, remove the ETD from the breaker. Record on data record sheet.
e) Mark the phase identification on each of the arc chutes, and remove from the breaker. Record on data record sheet.
f) Inspect wiring terminations for tightness. Record on data record sheet.
g) Measure resistance of trip coil (TC), close coil (52X), and control relay (52Y) using a digital multimeter. Record on data record sheet.

#### 7.9.6.2.2 Breaker mechanical operation

Perform the following steps in accordance with the manufacturer's instruction manual:

a) Contact adjustment (for butt-type contacts only). Record on data record sheet.
b) Manual slow close. Record on data record sheet.
c) Primary trip latch adjustment. Record on data record sheet.
d) Tripper bar adjustment. Record on data record sheet.
e) Primary close latch adjustment. Record on data record sheet.
f) Shunt-trip device adjustment. Record on data record sheet.
g) Magnetic latch device trip adjustment. Record on data record sheet.

#### 7.9.6.2.3 Insulation resistance

NOTE—Apply megohmmeter voltage for a period of 1 min or until reading is stable. Acceptance criteria for insulation resistance should be obtained from the manufacturer's instruction book. Typical minimum criteria are 50 MΩ to 100 MΩ greater. Record test voltage and acceptance criteria on data record sheet.

a) Connect all wires of the ETD wiring harness together and to ground.
b) Place the charging motor disconnect switch in the OFF position to isolate the charging motor.
c) Close the LVPCB; perform an insulation resistance test at 1000 V dc for 1 min or until stable reading is observed. Test each pole phase-to-ground and phase-to-phase. Record the data record sheet.
d) Remove the shorting connections from the ETD wiring. Record on data record sheet.

#### 7.9.6.2.4 Main contact continuity test

a) With breaker closed, using a digital low-resistance ohmmeter, read the resistance across the main contacts (line-to-load) on each phase. Record on data record sheet.

b) Open the breaker.

#### 7.9.6.2.5 Close coil and trip coil minimum voltage operation test

NOTE—DC control voltages for the LVPCB below are assumed to be 125 V dc. Adjust dc power supply output voltage to LVPCB specified control voltage and minimum trip voltages if using other than 125 V dc.

a) Slowly adjust the dc power supply output voltage to 100 V dc. Record on data record sheet.
b) Close the breaker using the close push button. Record on data record sheet.
c) Adjust the dc power supply output voltage to 70 V dc. Record on data record sheet.
d) With charging motor switch in the OFF position, trip the breaker. Record on data record sheet.
e) Adjust the dc power supply output voltage to 125 V dc.

#### 7.9.6.2.6 Time delay trip test

WARNING

If a test has to be terminated in an emergency situation, depress the output switch and then move the test set incoming circuit breaker to OFF position.

NOTE—Use the breaker setting sheet to set the test set points on the ETD for long-time delay, short-time delay, and instantaneous and ground-fault trips.

a) Replace the arc chutes and the ETD, if previously removed, in the breaker. Record on data record sheet.
b) Perform the following steps in accordance with breaker test set manual and verify that the trip times are in accordance with the manufacturer's instruction manual. Record each step on data record sheet.
    1) Long-time delay trip test
    2) Short-time delay trip test
    3) Instantaneous trip test
    4) Ground-fault trip test
c) Verify that the ETD for the breaker has been tested and the final settings have been made in accordance with the breaker setting sheet. Record on data record sheet.

### 7.9.7 Restoration

(Record on data record sheet. See Annex 7A and Annex 7B.)

a) Remove test cable and modifications, as necessary. Record on data record sheet.

b) Ensure that all equipment used during the performance of this test has been disconnected and removed, and that the surrounding area has been cleaned. Record on data record sheet.

c) Ensure that all data record sheets and tables are complete. Each data blank shall be filled out or marked N/A when not applicable. Record on data record sheet.

d) Record and identify any attachment used for the conduct of this test on page 1 of the data record sheet. Record on data record sheet.

e) Ensure that work clearances are released, as necessary. Record on data record sheet.

f) On the data record sheet, enter the initials, signature, and printed name of the individuals signing or initialing steps in the performance of this test. Record on data record sheet.

g) Verify electronic-trip setting is as per low-voltage circuit-breaker setting sheet and is sealed with lead seal (if available). Record on data record sheet.

h) Verify that calculations, if any, are entered in the test data record sheet with the acceptance criteria. Record on data record sheet.

i) Ensure LVCB is completely reassembled. Record on data record sheet.

j) Make sure LVCB is left in the OPEN position with closing springs discharged. Record on data record sheet.

#### 7.9.7.1 Breaker primary circuit to bus connections

a) With the LVPCB control power circuit de-energized, rack the LVPCB into the CONNECT position. Record on data record sheet.

b) Rack the LVPCB out to the DISCONNECT position. Record on data record sheet.

c) Verify the primary circuit connections make up evenly observing the tracks in the lubrication. Record on data record sheet.

NOTE—If an uneven primary contact makeup is displayed, adjust the contact fingers to achieve a satisfactory contact mating.

### 7.10 Failures detected

Should the LVCB fail any of the tests in the sequence, the tests should be stopped at that point, and the failure should be noted on the data record sheet. Similarly, tests should not be performed in any other sequence, because the order of testing is to protect all concerned. The insulation test is a definite first for many reasons for both the equipment and the personnel performing the test work.

### 7.11 Normative references

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

ANSI Std C37.16™-2000, American National Standard for Switchgear Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors—Preferred Ratings, Related Requirements, and Application Recommendations.[3]

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

ANSI Std C37.50™-1989 (Reaff 2000), American National Standard for Switchgear—Low-Voltage AC Power Circuit Breakers Used in Enclosures—Test Procedures.

IEEE Std 4™-1995, IEEE Standard Techniques for High-Voltage Testing.[4, 5]

IEEE Std 43™-2000, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

IEEE Std 62™-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus Part 1: Oil Filled Power Transformers, Regulators, and Reactors.

IEEE Std 141™-1993 (Reaff 1999), IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*™).

IEEE Std 241™-1990 (Reaff 1997), IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (*IEEE Gray Book*™).

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

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

IEEE Std C37.20.1™-2002, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

IEEE C37.100™-1992 (Reaff 2001), IEEE Standard Definitions for Power Switchgear.

NEMA AB 4-2003, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers used in Commercial and Industrial Applications.[6]

NEMA 280-1990, Application Guide for Ground Fault Circuit Interrupters.

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

[4] The IEEE standards or products referred to in this chapter are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

[5] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

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

NETA, Acceptance Testing Specifications—2003.[7]

NETA, Maintenance Testing Specifications—2001.

NFPA 70B-2002, Recommended Practice for Electrical Equipment Maintenance[8].

NFPA 70E-2004, Standard for Electrical Safety in the Workplace.

UL 489-2002, Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures.[9]

29 CFR 1910.147, The Control of Hazardous Energy (lockout/tagout).[10]

## 7.12 Bibliography

[B1] Square D publication SD363-88-1987, Field Testing Industrial Molded-Case Circuit Breakers.

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[7] NETA publications are available from the National Electrical Testing Association, P.O. Box 687, 106 Stone St., Morrison, CO 80465.

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

[9] UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (http:// global.ihs.com/).

[10] The Code of Federal Regulations is available from the Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20037, USA.

# Annex 7A

(informative)

## MCCB or MCP data record

(SHEET 1 OF 6)

PERFORMED BY:
INITIAL_____DATE_____

1. UNIT _________________2. EQUIPMENT TAG NO.__________3. ITEM NO.________

EQUIPMENT UNDER TEST

4. EQUIPMENT NAME/DESCRIPTION______________________________________

5. MODEL/TYPE______________ 6. MANUFACTURER________________
7. SERIAL NO. _______________ 8. SPEC. NUMBER__________________
9. LOOP__________________10. CLASS ____________11. SCHEME____________
12. FEEDER BREAKER__________________

13. IMPLEMENTING REFERENCES

P&ID: ______________________________ REV: ________________________
ELEM: ______________________________REV: _______________________
SINGLE LINE: _______________________REV: ________________________
OTHER: ______________________ REV: ________________________
OTHER: ______________________ REV: ________________________
OTHER: ______________________ REV: ________________________

14. TEST EQUIPMENT

DESCRIPTION CONTROL NUMBER CALIBRATION DUE
DATE

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
__________________________________________________________________

15. ATTACHMENTS

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
____________________________________________________________________

(SHEET 2 OF 6) PERFORMED BY:
INITIAL_____DATE_____

**7A.1 PREREQUISITES**

a) REVIEW PAST DATA RECORDS____________________________
b) COMPONENT RELEASED BY OPERATIONS FOR TESTING_____________
c) VERIFY REFERENCES ARE LATEST REVISION_____________
d) OFFICIAL TEST COPY VERIFIED_____________
e) TEMPORARY MODIFICATION EVALUATED (IF APPLICABLE)____________
f) SHIFT SUPERVISOR NOTIFIED_____________
g) QA/QC NOTIFIED_____________

**7A.2 INITIAL CONDITIONS**

a) WORK CLEARANCE TAGS HUNG (LOCKOUT/TAGOUT) _____________
b) MAINTENANCE GROUNDS INSTALLED _____________
c) WARNING SIGNS AND BARRIERS ERECTED_____________
d) TEST EQUIPMENT CALIBRATION STATUS VALID_____________
e) PROPER PROTECTIVE CLOTHING/PERSONAL PROTECTIVE EQUIPMENT REQUIRED FOR ARC FLASH PROTECTION DETERMINED _______________

**7A.3 PRECAUTIONS UNDERSTOOD_____________**
**7A.4 TEST EQUIPMENT ACQUIRED_____________**
**7A.5 PERSONNEL ORIENTATION CONDUCTED_____________**
**7A.6 TEST INSTRUCTIONS**
**7A.6.1 VISUAL INSPECTION**

a) AMBIENT TEMPERATURE___________°F
b) MCCB or MCP FREE OF VISUAL DEFECTS_______________
c) MCCB or MCP MOUNTED ON GROUNDED PLATE_____________
d) MECHANICAL ON-OFF OPERATIONS PERFORMED___________
e) CONTINUITY CHECK EACH POLE______________________

**7A.6.2 PRIMARY CIRCUIT INSULATION RESISTANCE**

TABLE 1

APPLIED VOLTAGE________________________VDC
ACCEPTANCE CRITERIA
SOURCE_____________ MΩ____________

PROCEDURE

a) AUX LEADS CONNECTED TO CUBICLE FRAME____________
b) LINE-SIDE TERMINALS JUMPERED____________
LOAD-SIDE TERMINALS JUMPERED____________
LOAD-SIDE TERMINALS GROUNDED____________
c MEGOHMMETER CONNECTED LINE-SIDE TO CUBICLE FRAME___
d LINE-SIDE TERMINALS TO CUBICLE ____________ MΩ

ACCEPTANCE CRITERIA MET____________________________________/_______
SIGNATURE DATE

(SHEET 3 OF 6) PERFORMED BY:

INITIAL_____DATE_____

e) JUMPER FROM LOAD-SIDE TO GROUND REMOVED
LINE-SIDE TERMINALS GROUNDED__________________

f) MEGOHMMETER CONNECTED LOAD-SIDE TO CUBICLE
FRAME___________

g) LOAD-SIDE TERMINALS TO CUBICLE____________MΩ

ACCEPTANCE CRITERIA MET____________________________________/_______
SIGNATURE DATE

h) LINE-SIDE, LOAD-SIDE, AND GROUND JUMPERS REMOVED_____

i) OPERATE THE MCCB TO CLOSED POSITION________________

j) INSULATION RESISTANCE PHASE-TO-PHASE

PHASE A Aθ _____________MΩ
PHASE B Bθ _____________MΩ
PHASE C Cθ _____________MΩ

ACCEPTANCE CRITERIA MET____________________________________/_______
SIGNATURE DATE

k) INSULATION RESISTANCE PHASE-TO-GROUND

PHASE Aθ-GROUND _____________MΩ
PHASE Bθ-GROUND _____________MΩ
PHASE Cθ-GROUND _____________MΩ

ACCEPTANCE CRITERIA MET____________________________________/_______
SIGNATURE DATE

l) TEST EQUIPMENT, SHORTS, AND GROUNDS
REMOVED______________

(SHEET 4 OF 6)

PERFORMED BY:
INITIAL_____DATE_____

### 7A.6.3 MCCB OVERCURRENT TRIP TEST (Not Used for an MCP)

a) BREAKER TRIP TIME_________s _________s (ACCEPTANCE CRITERIA)
MAX MIN

SOURCE: BREAKER SETTING SHEET NO._______ CURVE NO.___________

b) BREAKER TEST CURRENT

PHASE A __________ PHASE B ________ PHASE C _______

c) BREAKER TRIP TIME (in seconds)

PHASE A __________ PHASE B ________ PHASE C _______

ACCEPTANCE CRITERIA MET____________________________________/_______
SIGNATURE DATE

### 7A.6.4 MCCB SHUNT-TRIP DEVICE (Not Used for an MCP)

a) SHUNT-TRIP COIL VOLTAGE (TCV)_____________ V

PERCENTAGES SHUNT-TRIP COIL VOLTAGE (%TCV)________%
MINIMUM TRIP VOLTAGE (MTV)_____________ V
MTV = %TCV/100 × TCV
MTV = __________%/100 × _________ V =__________ V

b) MCCB TRIPPED____________________

(SHEET 5 OF 6)

PERFORMED BY:
INITIAL_____DATE_____

### 7A.6.5 INSTANTANEOUS OVERCURRENT TRIP TEST

a) MOC: FROM BREAKER SETTING SHEET_______________

b) MCCB or MCP MAX TRIP TOLERANCE (PLUS TOL)_____________

Adjustable +40%
Non-adjustable +25%

MCCB or MCP MIN TRIP TOLERANCE (MINUS TOL)_____________

Adjustable –30%
Non-Adjustable –25%

CALCULATE THE MAX AND MIN FOR THE FINAL MAGNETIC ADJUSTMENT SETTING.

RECORD THE FOLLOWING DATA:

MAX = MOC + (MOC × PLUS TOL)

MAX = _______ + (_______ ×________) = _______ A

RECORD MAX FINAL MAGNETIC ADJUSTMENT SETTING IN THE “FINAL INSTANTANEOUS OVERCURRENT TRIP DATA BLOCK ACCEPTANCE CRITERIA.”

MIN = MOC – (MOC × MINUS TOL)

MIN = _______ – (_______ ×__________) = _______ A

RECORD MIN FINAL MAG ADJ SETTING IN THE “FINAL INSTANTANEOUS OVERCURRENT TRIP DATA BLOCK ACCEPTANCE CRITERIA.”

c) FINAL INSTANTANEOUS OVERCURRENT TRIP DATA:

ACCEPTANCE CRITERIA MET____________________________________/_______
SIGNATURE DATE

| | | | |
|---|---|---|---|
| d) FINAL AS LEFT SETTING | PHASE A | PHASE B | PHASE C |
| | _______ A | _______ A | _______ A |

e) GROUNDING PLATE REMOVED________________

f) SECTION COMPLETE _________________________/___________
SIGNATURE DATE

(SHEET 6 OF 6)

PERFORMED BY:
INITIAL_____DATE_____

**7A.6.6 INSTALLATION OF CUBICLE**

a) BREAKER OPEN________________
b) CUBICLE IS INSTALLED________________
c) CONTROL FUSES INSTALLED________________
d) LIFTED WIRES RETERMINATED________________
e) GROUND CONTINUITY VERIFIED________________

**7A.7 RESTORATION**

a) TEST MODIFICATION REMOVED________________
b) TEST EQUIPMENT DISCONNECTED________________
c) DATA RECORD SHEETS COMPLETE________________
d) RECORD ATTACHMENTS USED________________
e) MAINTENANCE GROUNDS REMOVED________________
f) WORK CLEARANCES (LOCKOUT/TAGOUT) RELEASED________________
g) INDIVIDUALS SIGNING OR INITIALING STEPS________________
h) SETTING PER RELAY SETTING SHEET SEALED________________
i) CALCULATIONS ENTERED________________
j) BREAKER COMPLETELY REASSEMBLED________________
k) BREAKER IN THE OPEN POSITION________________

SIGNATURE PRINTED NAME INITIAL DATE

PERFORMED BY:________________________________________________________

REVIEWED BY:________________________________________________________

APPROVED BY: ________________________________________________________

QA/QC REVIEW: ________________________________________________________

# Annex 7B

(informative)

# LVPCB data record

(SHEET 1 OF 5)

PERFORMED BY:
INITIAL_____DATE_____

1. UNIT __________________2. EQUIPMENT TAG NO.__________3. ITEM NO._____

EQUIPMENT UNDER TEST

4. EQUIPMENT NAME/DESCRIPTION______________________________________

5. MODEL/TYPE______________ 6. MANUFACTURER________________
7. SERIAL NO. _______________ 8. SPEC. NUMBER____________________
9. LOOP________________ 10. CLASS ______________ 11. SCHEME__________
12. FEEDER BREAKER__________________

13. IMPLEMENTING REFERENCES

P&ID: ______________________________________ REV: __________________
ELEM: _____________________________________ REV: __________________
SINGLE LINE: _______________________________ REV: __________________
OTHER: ______________________ REV: ________________________
OTHER: ______________________ REV: ________________________
OTHER: ______________________ REV: ________________________

14. TEST EQUIPMENT

| DESCRIPTION | CONTROL NUMBER | CALIBRATION DUE DATE |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

15. ATTACHMENTS

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
____________________________________________________________________

(SHEET 2 OF 5)

PERFORMED BY:
INITIAL_____DATE_____

**7B.1 PREREQUISITES**

a) REVIEW PAST DATA RECORDS____________________________
b) COMPONENT RELEASED BY OPERATIONS FOR TESTING_____________
c) VERIFY REFERENCES ARE LATEST REVISION_____________
d) OFFICIAL TEST COPY VERIFIED_____________
e) TEMPORARY MODIFICATION EVALUATED (IF APPLICABLE)____________
f) SHIFT SUPERVISOR NOTIFIED_____________
g) QA/QC NOTIFIED_____________

**7B.2 INITIAL CONDITIONS**

a) WORK CLEARANCE TAGS HUNG (LOCKOUT/TAGOUT) _____________
b) MAINTENANCE GROUNDS INSTALLED
c) WARNING SIGNS AND BARRIERS ERECTED________________
d) TEST EQUIPMENT CALIBRATION STATUS VALID_____________
e) PROPER PROTECTIVE CLOTHING/PERSONAL PROTECTIVE EQUIPMENT REQUIRED FOR ARC FLASH PROTECTION DETERMINED _______________

**7B.3 PRECAUTIONS UNDERSTOOD**_____________

**7B.4 TEST EQUIPMENT ACQUIRED**_____________

**7B.5 PERSONNEL ORIENTATION CONDUCTED**_____________

**7B.6 TEST INSTRUCTIONS**

**7B.6.1 VISUAL INSPECTION**

a) AMBIENT TEMPERATURE_____________°F
b) REMOVE BREAKER FROM COMPARTMENT_____________
c) ENSURE BREAKER OPEN, SPRINGS DISCHARGED_____________
d) REMOVE ETD FROM BREAKER (IF REQUIRED)_____________
e) MARK AND REMOVE ARC CHUTES_____________
f) WIRING TERMINATIONS TIGHT_____________
g) TRIP COIL (TC), CLOSE COIL (52X), AND CONTROL RELAY (52Y) RESISTANCE

| RESISTANCE | NOMINAL VALUE |
|---|---|
| TC ___________Ω | 98 ± 10% (88–108) |
| 52X __________Ω | 180 ± 10% (162–198) |
| 52Y __________Ω | 2310 ± 10% (2079–2541) |

SOURCE:_________________________________

ACCEPTANCE CRITERIA MET____________________________________/_______
SIGNATURE DATE

(SHEET 3 OF 5)

PERFORMED BY:
INITIAL_____DATE_____

**7B.6.2 BREAKER MECHANICAL OPERATION**

a) CONTACT ADJUSTMENT______________________
b) MANUAL SLOW CLOSE______________________
c) PRIMARY TRIP LATCH ADJUSTMENT______________________
d) TRIPPER BAR ADJUSTMENT______________________
e) PRIMARY CLOSE LATCH ADJUSTMENT______________________
f) SHUNT-TRIP DEVICE ADJUSTMENT______________________
g) MAGNETIC LATCH DEVICE TRIP ADJUSTMENT______________________

**7B.6.3 INSULATION RESISTANCE**

a) SHORT ALL ETD WIRES TOGETHER AND GROUND (IF APPLICABLE)_______
b) ISOLATE CHARGING MOTOR______________________
c) INSULATION RESISTANCE
    APPLIED VOLTAGE______________________ VDC
    ACCEPTANCE CRITERIA
    SOURCE__________________MΩ ___________________

ACCEPTANCE CRITERIA MET_____________________________________/_______
SIGNATURE DATE

APPLIED VOLTAGE

| FROM | TO | MΩ |
|---|---|---|
| Phase A | Phase B | ________________ |
| Phase B | Phase C | ________________ |
| Phase C | Phase A | ________________ |
| Phase A | GRD | ________________ |
| Phase B | GRD | ________________ |
| Phase C | GRD | ________________ |

ACCEPTANCE CRITERIA MET_____________________________________/_______
SIGNATURE DATE

d) SHORTING CONNECTION REMOVED FROM ETD WIRING_______________

**7B.6.4 MAIN CONTACT CONTINUITY TEST**

a) MAIN CONTACT CONTINUITY
    PHASE A _____________Micro-ohms
    PHASE B _____________Micro-ohms
    PHASE C _____________Micro-ohms
b) BREAKER OPEN________________

**7B.6.5 CLOSE AND TRIP COILS MINIMUM VOLTAGE OPERATION TEST**

(SEE NOTE IN 7.9.6.2.5)

a) 125 VDC SUPPLY ADJUSTED TO 100 VDC____________
b) BREAKER CLOSES USING CLOSE PUSHBUTTON____________
c) VDC SUPPLY ADJUSTED TO 70 VDC____________
d) BREAKER OPENS____________
e) 125 VDC SUPPLY ADJUSTED TO 125 VDC____________

(SHEET 4 OF 5)

PERFORMED BY:
INITIAL_____DATE_____

**7B.6.6 TIME DELAY TRIP TEST**

a) ARC CHUTES AND ETD IF PREVIOUSLY REMOVED REPLACED_____________

b) BREAKER TRIP TEST

1) LONG-TIME DELAY TRIP TEST

PHASE A ___________ A ___________ sec.
PHASE B ___________ A ___________ sec.
PHASE C ___________ A ___________ sec.
ACCEPTANCE TOLERANCE (__________ sec. TO__________ sec.)
ACCEPTANCE CRITERIA: TIME CURRENT CURVE___________
SOURCE:______________
ACCEPTANCE CRITERIA MET__________________________/_______
SIGNATURE DATE

2) SHORT-TIME DELAY TRIP TEST

PHASE A ___________ A ___________ sec.
PHASE B ___________ A ___________ sec.
PHASE C ___________ A ___________ sec.
ACCEPTANCE TOLERANCE (__________ sec. TO__________ sec.)
ACCEPTANCE CRITERIA: TIME CURRENT CURVE___________
SOURCE:______________
ACCEPTANCE CRITERIA MET__________________________/_______
SIGNATURE DATE

3) INSTANTANEOUS TRIP TEST

PHASE A ___________ A ___________ sec.
PHASE B ___________ A ___________ sec.
PHASE C ___________ A ___________ sec.
ACCEPTANCE TOLERANCE (__________ sec. TO__________ sec.)
ACCEPTANCE CRITERIA: TIME CURRENT CURVE___________
SOURCE:______________
ACCEPTANCE CRITERIA MET__________________________/_______
SIGNATURE DATE

4) GROUND FAULT TRIP TEST

PHASE A ___________ A ___________ sec.
PHASE B ___________ A ___________ sec.
PHASE C ___________ A ___________ sec.
ACCEPTANCE TOLERANCE (__________ sec. TO__________ sec.)
ACCEPTANCE CRITERIA: TIME CURRENT CURVE___________
SOURCE:______________
ACCEPTANCE CRITERIA MET__________________________/_______
SIGNATURE DATE

c) VERIFY ETD DEVICE TESTED AND FINAL SETTINGS MADE_____________

((SHEET 5 OF 5)

PERFORMED BY:
INITIAL_____DATE_____

### 7B.7 RESTORATION

a) TEST MODIFICATION REMOVED____________________
b) TEST EQUIPMENT DISCONNECTED____________________
c) DATA RECORD SHEETS COMPLETE____________________
d) RECORD ATTACHMENTS USED____________________
e) MAINTENANCE GROUNDS REMOVED ____
f) WORK CLEARANCES RELEASED____________________
g) INDIVIDUALS SIGNING OF INITIALING STEPS_________________
h) ETD SETTING PER RELAY SETTING SHEET SEALED_________________
i) CALCULATIONS ENTERED____________________
j) BREAKER COMPLETELY REASSEMBLED____________________
k) BREAKER IN THE OPEN POSITION WITH CLOSING SPRINGS DISCHARGED____________________

### 7B.7.1 BREAKER PRIMARY CIRCUIT TO BUS CONNECTIONS

a) CONTROL POWER DEENERGIZED____________________
RACK BREAKER INTO CONNECT POSITION____________________
b) BREAKER RACKED OUT TO DISCONNECT POSITION___________
c) PRIMARY CIRCUIT CONNECTION MAKE UP EVENLY___________

| | SIGNATURE | PRINTED NAME | INITIAL | DATE |
|---|---|---|---|---|
| PERFORMED BY: | | | | |
| REVIEWED BY: | | | | |
| APPROVED BY: | | | | |
| QA/QC REVIEW: | | | | |