Guide to Power System Selective Coordination
Class 0100

Introduction

This paper describes the nature of selective coordination, the NEC requirements pertaining to selective coordination, and approaches for obtaining selective coordination in commonly-encountered scenarios for systems 600 V and below.

Before You Begin

The numbers that appear in brackets throughout this document, [x], refer to the references on page 31.

Background

What is Selective Coordination?

The term **selective coordination** refers to the selection and setting of protective devices in an electric power system in such a manner to ensure the smallest possible portion of the system is de-energized by an abnormal condition. The most commonly encountered abnormal condition is an overcurrent condition, defined by the NEC as “any current in excess of the rated current of equipment or the ampacity of a conductor [1].” The NEC uses a more restricted definition of selective coordination as follows:

> “Localization of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the choice of overcurrent protective devices and their ratings or settings [1].”

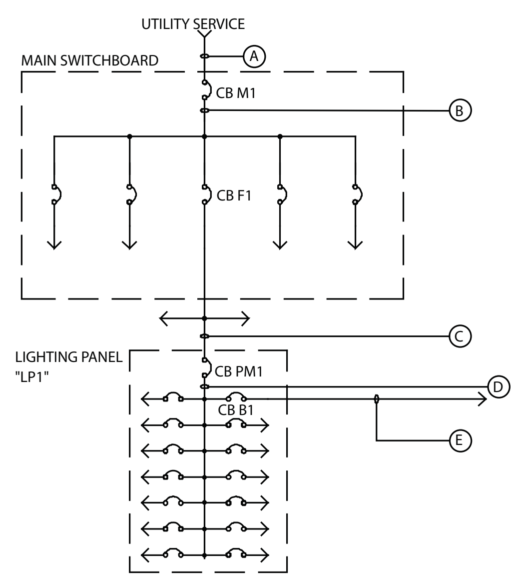
This is the definition that will be used herein.

The concept of selective coordination is best illustrated by example. In the example system of Figure 1, all of the devices shown are overcurrent protective devices, in this case circuit breakers. Five system locations, labeled A-E, have been identified. If selective coordination exists, an overcurrent condition at location E will only cause the lighting panel CB B1 to trip. Similarly, an overcurrent fault at location D should only cause lighting panel CB PM1 to trip. Table 1 shows the protective device that should operate for a fault in each labeled location in Figure 1, assuming selective coordination exists.

Table 1: Protective Device Operation for Example System (see Figure 1)

Fault Location	Device Operating for Selective Coordination
A	Utility protective device
B	CB M1
C	CB F1
D	CB PM1
E	CB B1

Figure 1: Example System



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Nature of Overcurrents

Overcurrent conditions may be divided into two types. An **overload** is defined by the NEC as “operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating [1].”

Similarly, a **fault** is defined as “an unintentional connection of a power system conductor, resulting in an abnormally high flow of current.” Faults typically produce higher overcurrents than do overloads, depending upon the fault impedance. A fault with no impedance in the unintentional connection is referred to as a **short circuit or bolted fault**.

Faults may also be classified by their geometry. A three-phase fault involves all three phases. A line-to-line fault involves only two phases.

A short circuit involving a ground path is referred to as a **ground fault** and may be a three-phase-to-ground fault, two-line-to-ground fault, or single-line-to-ground fault.

NOTE: The typical usage of the term ground-fault usually means a single-line-to-ground fault.

It is commonly believed that ~95% of all system faults are single-line-to-ground faults. A very low percentage of faults are bolted faults. Thus, the occurrence frequency of high-magnitude bolted faults is much lower than that of lower-magnitude faults, such as arcing ground faults. These statistics should be kept in mind when considering the requirements for selective coordination.

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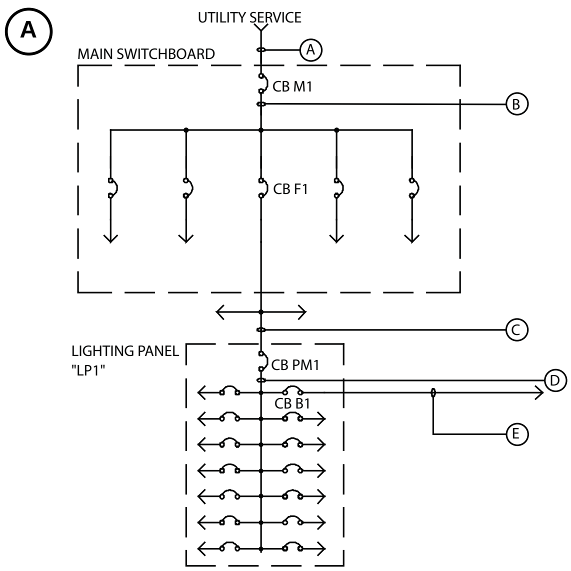
Protective Zone Concept

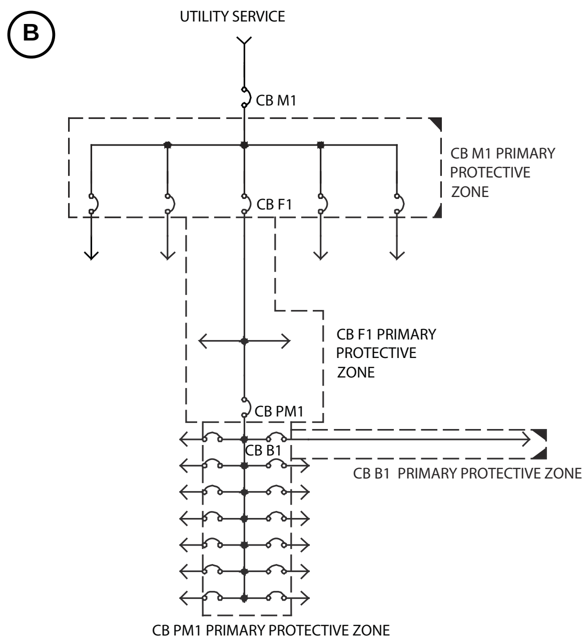
To further visualize the system coordination, the example system (see Figure 2, A below) can be divided into protective zones. A fault in a given protective zone causes a given protective device to operate. The ideal primary protective zones for the system are shown in Figure 2, B. CB B1 should be the only device to operate for a fault in its primary protective zone, and CB PM1 should be the only device to operate for an overcurrent condition in its protective zone, etc. Note that the ideal primary protective zone for a given protective device includes the next level of downstream protective devices since a protective device cannot be assumed to trip for an internal fault in the device itself. In other words, the ideal protective zone boundaries cannot be arbitrarily established, but must take into account which overcurrent conditions each protective device is able to sense and interrupt.

Note that the closer a protective zone is to the source of power, in this case a utility service, the more the system is de-energized for an overcurrent condition in that zone. In fact, in a radial system with only one source of power, an overcurrent condition within a protective zone will affect all downstream protective zones by tripping the overcurrent protective device for that zone.

Figure 2: Ideal Primary Protection Zones for Example System



Example System



Ideal System

Note also that, for an overcurrent condition in the primary protective zone for CB B1, if CB B1 fails to operate, CB PM1 should operate as a backup. Thus, the protective zone for CB B1 may be said to be in the backup protective zone for CB PM1. This same relationship follows to upstream devices as well. Each backup protective zone is limited by the lowest level overcurrent condition the protective device can sense. This limit is referred to as the reach of the device and is dependent upon the size and characteristics of the device, its settings (if applicable), and the available fault currents at various points downstream from the device. In practice, however, the backup protective zones should at least overlap the primary protective zone for the next downstream device, to allow each portion of the system to have backup protection should its primary protective device fail to operate.

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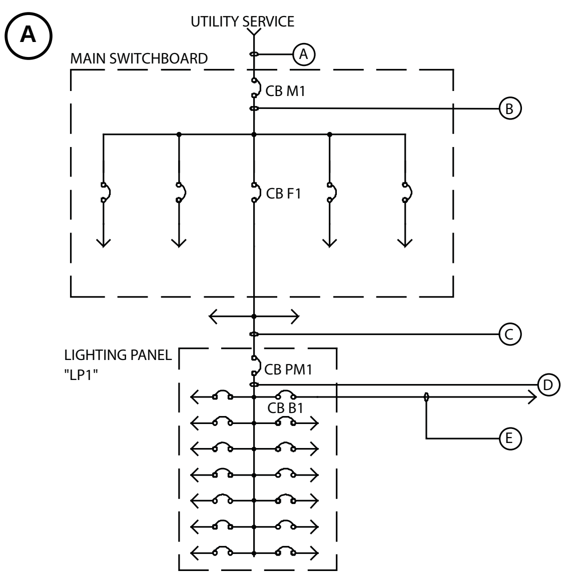
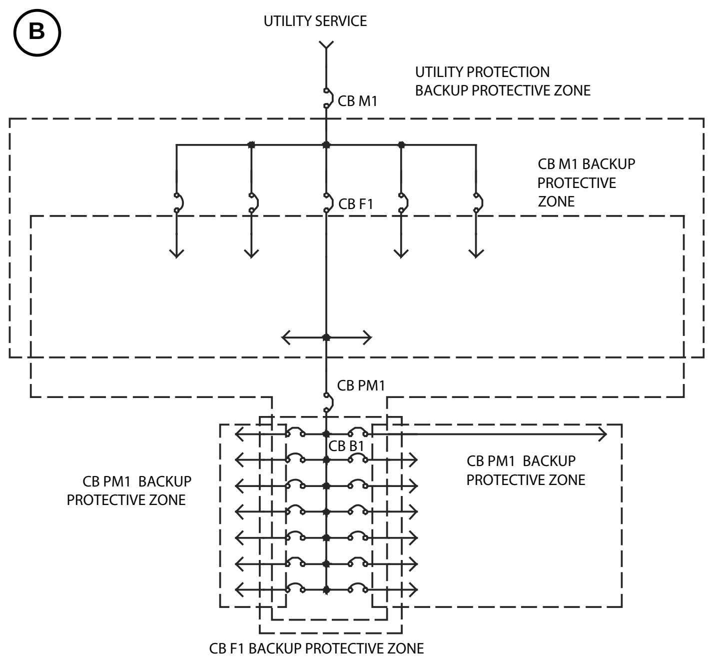
Typical backup protective zones for the example system (shown in Figure 3, B) are based upon the time-current characteristics and available fault currents for this system. Note that although the backup protective zones overlap in a way determined by the reach of the protective devices, the next upstream device should operate upon failure of the primary protective device. For example, for a fault on the branch circuit supplied by CB B1, CB PM1 should operate if CB B1 fails to operate. For a fault on this circuit close to CB B1, the backup protective zones for CB M1 and CB F1 overlap, as dictated by the reach of these circuit breakers. However, if CB PM1, CB F1, and CB M1 are selectively coordinated, even in the region where the backup protective zones overlap, CB PM1 will trip should CB B1 fail to operate. If CB PM1 fails to operate, CB F1 will operate so long as the fault is within its backup protective zone. Should CB F1 fail to operate, then CB M1 will operate, again as long as the fault is within its backup protective zone. In this case a fault on the CB B1 branch circuit, even close to CB B1, is beyond the reach of the utility protective device, so CB M1 is the last line of defense to clear a fault on this circuit close to CB B1. Only CB PM1, however, provides backup protection for the entire circuit since its backup protective zone is the only one that extends around the entire circuit.

Figure 3: Backup Protective Zones for Example System



Example System



Backup Protective Zones

A more specific definition of **selective coordination between two devices in a series** may now be:

> Selective coordination exists between two overcurrent protective devices in a series **if and only if** each device is the only device that operates for faults within its ideal primary protective zone, where the ideal primary protective zone begins at the load terminals of that device and ends at the load terminals of the next level of downstream devices.

Operation of a protective device in its backup zone of protection may indicate a lack of coordination or may indicate that a protective device has failed.

Using this definition, the term **system selective coordination** may be applied to an entire electric power system as follows:

> System selective coordination for an electric power system exists **if and only if** any outage due to an overcurrent condition is restricted to the smallest possible number of loads, as defined by the overcurrent device placement and the ideal protective zone for each device.

While not an official industry term, system selective coordination is an important concept because it is the ideal condition for protective device coordination in the context of the overall system.

How is Selective Coordination Achieved?

In most cases, selective coordination is achieved by the timing characteristics of the devices to be coordinated. For example, each of the circuit breakers for the example system (see Figure 4) has its own time-current characteristic; by coordinating these, selective coordination may be achieved.

This is usually accomplished by comparing the device time-current characteristics graphically. The example shown in Figure 4 illustrates the time-current coordination between circuit breakers CB M1 and CB F1 in the example system. Note that a log-log scale is used to display the device time-current characteristics. The curves for both devices end at the available fault current for their respective busses, in this case 30 kA. Because there is no overlap in the time-current characteristics up to 30 kA, selective coordination exists between these two devices.

NOTE: The time-current characteristic showing border-to-border contact is not considered an overlap.

For example, for the 30 kA available fault, CB F1 will operate in 0.01–0.02s and CB-M1 will operate in 0.22–0.31s. CB F1 will therefore operate more quickly than CB M1 for a fault (up to the 30 kA available fault current) sensed by both devices.

Figure 4: Example System and Typical Time-Current Coordination Plot

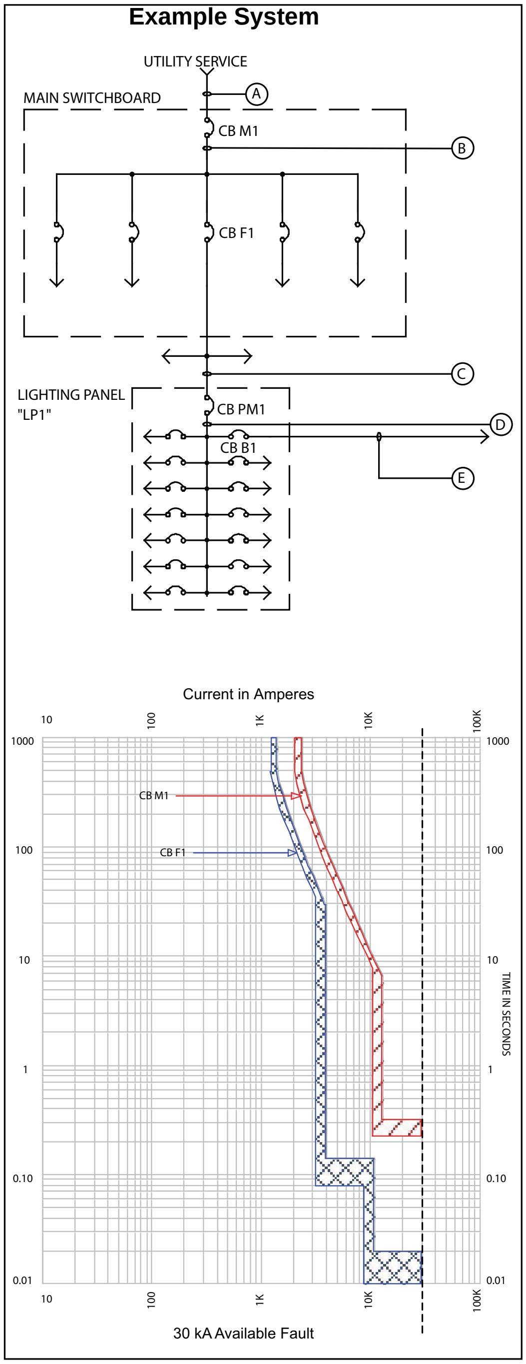
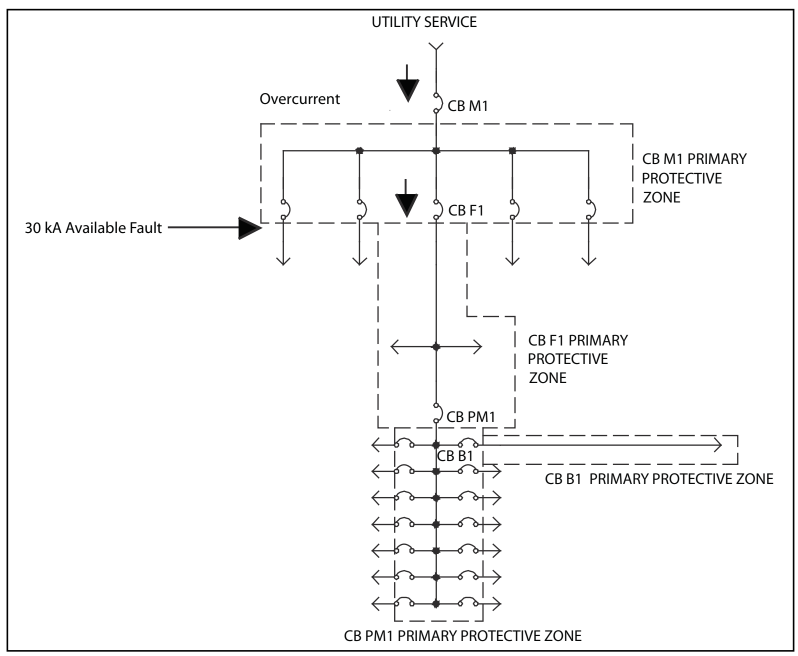


Figure 5: Primary Protective Zones for the Example System Showing the Available Fault Current



Using this graphical method, it may be stated that to achieve selective coordination between two devices, they must have no time-current curve overlap up to the available fault current where their ideal primary protective zones meet. This concept is illustrated in Figure 5 above. The fact that CB M1 and CB F1 will both sense an overcurrent condition at the primary protective zone boundary along with the time-current coordination between the two, it establishes the actual primary protective zone boundary at the location shown, which in this case coincides with the ideal boundary location.

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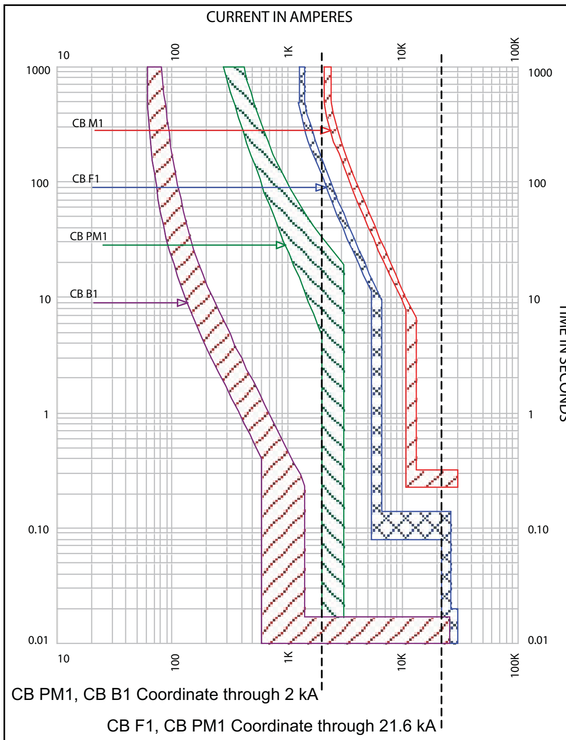
The fact that time is used to coordinate the operation of protective devices in series has an important, and unfortunate, drawback: the closer to the source of power, the slower the protective device must be to coordinate with downstream devices. This means that for faults close to the source of power, fault clearing will be slower than it could be if coordination were not a consideration.

This has important implications for equipment damage and arc-flash hazards, both of which must be taken into consideration in an overall system design.

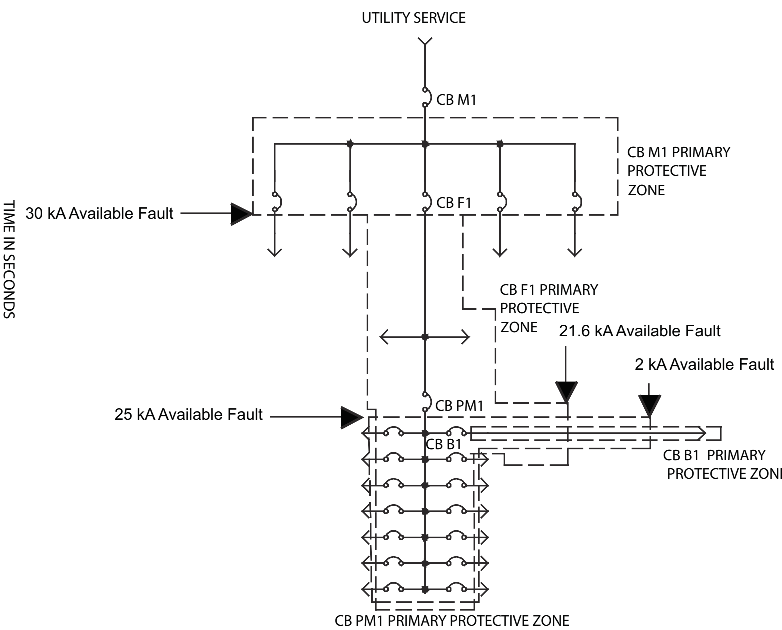
It also has important implications for the backup protection described above, since fault clearing will be slower if the closest upstream device fails to operate or clear the fault. Techniques to mitigate these problems, such as Zone Selective Interlocking (ZSI), are available.

To illustrate how poor coordination of devices affects the protective zones, consider the coordination between CB F1 and CB PM1 in Figure 6. CB F1 and CB PM1 have been deliberately selected to show poor coordination for purposes of illustration. Note that coordination between CB F1 and CB PM1 exists up to 21.6 kA. There is, however, 25 kA available fault current at the line terminals of CB PM1. Because protective devices generally do not present significant impedance in the circuit, the available fault current at either the line or load terminals of a protective device is the same. The line side of the circuit breaker is referenced by convention, although the ideal protective zone boundaries meet at the load terminals). This has the effect of causing the primary protective zones for CB F1 and CB PM1 to overlap to the point in the system where the available fault current is 21.6 kA. This is illustrated in Figure 6, B. Similarly, the primary protective zones for CB PM1 and CB B1 overlap to the point in the system where the available fault current is 2 kA. It can be readily seen that the primary protective zones in Figure 6 are not the ideal primary protective zones in Figure 2, B on page 3.

Figure 6: Time-Current Plot and Ideal Primary Protective Zones Showing Lack of Selective Coordination



Time-Current Plot



Protective Zones

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From the previous discussion, it is apparent that it becomes more difficult to coordinate two overcurrent protective devices as the fault current increases. This is an important concept in light of the common belief presented earlier: **the frequency of occurrence of high-magnitude bolted faults is much less than that of lower-magnitude faults, such as arcing ground faults.**

What about Equipment Protection?

Equipment protection is an important part of the coordination process. Time-current curves such as those shown above may be used to show protection for cables, transformers, and other equipment.

Essentially, the damage curve for the equipment in question is superimposed upon the time-current characteristic curve(s) for the device(s) that protect it. Equipment damage curves that fall to the right and above the protective device curves with sufficient margin are considered to be protected by the device(s). Equipment damage curves that fall on top of or to the left and below the protective device curves are considered not to be protected by the device(s).

Because this paper focuses on protective device coordination, device protection is only addressed where it helps illustrate why a particular protective device is set at a given level. However, it should be understood that device protection is important. “IEEE Recommended Practice for Protection and Coordination of Industrial Power Systems [2]” is an excellent reference both for equipment protection and protective device coordination.

NEC Requirements for Selective Coordination

The NEC requirements for selective coordination are, at present, more stringent than ever before, and (like all code requirements) they are subject to interpretation. These requirements are as follows.

NOTE: Code text is in italics [1]:

Coordinated Short-Circuit Protection/Overload Indication Permitted When Orderly Shutdown is Required (Section 240.12)

240.12 Electrical System Coordination. *Where an orderly shutdown is required to minimize the hazard(s) to personnel and equipment, a system of coordination based on the following two conditions shall be permitted:*

1. *Coordinated short-circuit protection.*
2. *Overload indication based on monitoring systems or devices.*

Where an orderly shutdown is required, short-circuit protection must be present, but overload protection can be indicating only. This is in lieu of full coordinated overload protection and is intended to minimize the risk of unintentionally shutting down part of a system automatically due to an overload condition where a lack of coordination can cause hazards to personnel and equipment. An overload condition can generally be tolerated for a longer period of time than a fault. The overload indication must be acted upon by operating personnel, but the time can be taken for an orderly, rather than an abrupt, shut-down of the affected equipment.

Elevators, Dumbwaiters, Escalators, Moving Walks, Wheelchair Lifts, and Stairway Chair Lifts (Section 620.62)

620.62 Selective Coordination. *Where more than one driving machine disconnecting means is supplied by a single feeder, the overcurrent protective devices in each disconnecting means shall be selectively coordinated with any other supply side overcurrent protective devices.*

This requirement has been in the NEC for some time and is intended to prevent an overcurrent condition in the motor of one elevator, escalator, etc. from de-energizing the entire feeder that supplies other elevator(s), escalator(s), etc. This is important for fire fighter access during a fire.

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Fire Pumps (Section 695.3C3)

NOTE: This is a new section in the 2011 NEC.

695.3 Power Source(s) for Electric Motor-Driven Fire Pumps.

(*C) Multibuilding Campus-Style Complexes.*

(3) Selective Coordination. *The overcurrent protective device(s) in each disconnecting means shall be selectively coordinated with any other supply-side overcurrent protective device(s).*

This requirement has been in the NEC for some time and is intended to prevent an overcurrent condition in the motor of one elevator, escalator, etc. from de-energizing the entire feeder that supplies other elevator(s), escalator(s), etc. This is important for fire-fighting operations in campuses.

Emergency Systems (Section 700.27)

700.27 Coordination. *Emergency system(s) overcurrent devices shall be selectively coordinated with all supply side overcurrent protective devices.*

The definition of an **emergency system** is a system

> "legally required and classed as emergency by municipal, state, federal, or other codes, or by any governmental agency having jurisdiction. These systems are intended to automatically supply illumination, power, or both, to designated areas and equipment in the event of failure of the normal supply or in the event of accident to elements of a system intended to supply, distribute, and control power and illumination essential for safety to human life."

Health Care facilities in Florida have long been subject to the active oversight of the Florida Agency for Health Care Administration (Florida AHCA). Depending upon the jurisdiction, Florida AHCA has required coordination only down to the 0.1s level (i.e., ignoring short-circuit coordination).

Note that selective coordination is referenced in terms of devices rather than as system selective coordination as discussed herein. This can have important consequences for engineers trying to meet the requirements of this code section, as discussed in further detail below.

Legally Required Standby Systems (Section 701.18)

701.18 Coordination. *Legally required standby system(s) overcurrent devices shall be selectively coordinated with all supply side overcurrent protective devices.*

The definition of a **legally required standby system** is a system

> "consisting of circuits and equipment intended to supply, distribute, and control electricity to required facilities for illumination or power, or both, when the normal electrical supply or system is interrupted."

Critical Operations Power Systems (Section 708.54)

NOTE: This was a new section in the 2008 NEC.

708.54 Coordination. *Critical operations power system(s) overcurrent devices shall be selectively coordinated with all supply side overcurrent protective devices.*

The definition of **critical operations power systems** are:

> "those systems so classed by municipal, state, federal, or other codes by any governmental agency having jurisdiction or by facility engineering documentation establishing the necessity for such a system. These systems include but are not limited to power systems, HVAC, fire alarm, security, communications, and signaling for designated critical operations areas."

708.1 Scope. Informational Note No. 1: *Critical operations power systems are generally installed in vital infrastructure facilities that, if destroyed or incapacitated, would disrupt national security, the economy, public health or safety; and where enhanced electrical infrastructure for continuity of operation has been deemed necessary by governmental authority.*

Service Ground-Fault Protection for Equipment (Section 230.95)

230.95 Ground-Fault Protection of Equipment. *Ground-fault protection of equipment shall be provided for solidly grounded wye electrical services of more than 150 volts to ground but not exceeding 600 volts phase-to-phase for each service disconnect rated 1000 amperes or more. The grounded conductor shall be connected directly to ground without inserting any resistor or impedance device. The rating of the service disconnect shall be considered to be the rating of the largest fuse that can be installed or the highest continuous current trip setting for which the actual overcurrent device installed in a circuit breaker is rated or can be adjusted.*

Exception: The ground-fault protection provisions of this section shall not apply to a service disconnect for a continuous industrial process where a nonorderly shutdown will introduce additional or increased hazards.

(A) Setting. *The ground-fault protection system shall operate to cause the service disconnecting means to open all ungrounded conductors of the faulted circuit. The maximum setting of the ground-fault protection shall be 1200 amperes, and the maximum time delay shall be one second for ground-fault currents equal to or greater than 3000 amperes.*

(B) Fuses. *If a switch and fuse combination is used, the fuses employed shall be capable of interrupting any current higher than the interrupting capacity of the switch during a time that the ground-fault protective system will not cause the switch to open.*

(C) Performance Testing. *The ground-fault protection system shall be performance tested when first installed on site. The test shall be conducted in accordance with instructions that shall be provided with the equipment. A written record of this test shall be made and shall be available to the authority having jurisdiction.*

Electrical services of 1000 A or greater, with over 150 V to ground and 600 V or less phase-to-phase (such as 480 Y/277 V systems), require ground-fault protection at the service. This protection must be set to pick up at no more than 1200 A and with a maximum time delay of 1 second at 3000 A or greater.

NOTE: Exceptions apply to continuous industrial processes. This has a direct bearing on coordination with downstream devices, as explained below.

Feeder Ground-Fault Protection for Equipment (Section 215.10)

215.10 Ground-Fault Protection of Equipment. *Each feeder disconnect rated 1000 amperes or more and installed on solidly grounded wye electrical systems of more than 150 volts to ground, but not exceeding 600 V phase-to-phase, shall be provided with ground-fault protection of equipment in accordance with the provisions of 230.95.*

Exception No. 1: The provisions of this section shall not apply to a disconnecting means for a continuous industrial process or where a nonorderly shutdown will introduce additional or increased hazards.

Exception No. 2: The provisions of this section shall not apply if ground-fault protection of equipment is provided on the supply side of the feeder and on the load side of any transformer supplying the feeder.

Feeder disconnects rated 1000 A or more on systems with more than 150 V to ground and 600 V or less phase-to-phase require ground-fault protection with the same requirements for services as stated in NEC 230.95.

NOTE: Exceptions apply to continuous industrial processes, just as for NEC 230.95.

In addition, if ground-fault protection is provided on the supply side of the feeder (such as a feeder supplied from a service with ground-fault protection) the ground-fault protection is not required.

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Ground-Fault Protection in Heath Care Facilities (Section 517.17)

517.17 (B) Feeders. *Where ground-fault protection is provided for operation of the service disconnecting means or feeder disconnecting means as specified by 230.95 or 215.10, an additional step of ground-fault protection shall be provided in all next level feeder disconnecting means downstream toward the load. Such protection shall consist of overcurrent devices and current transformers or other equivalent protective equipment that shall cause the feeder disconnecting means to open.*

The additional levels of ground-fault protection shall not be installed on the load side of an essential electrical system transfer switch.

517.17 (C) Selectivity. *Ground-fault protection for operation of the service and feeder disconnecting means shall be fully selective such that the feeder device, but not the service device, shall open on ground faults on the load side of the feeder device. Separation of ground-fault protection time-current characteristics shall conform to manufacturer's recommendations and shall consider all required tolerances and disconnect operating time to achieve 100 percent selectivity.*

Note that NEC 517.17 applies to hospitals and other buildings with critical care areas or utilizing electrical life support equipment, and buildings that provide the required essential utilities or services for the operation of critical care areas or electrical life support equipment. NEC 517.17 (B) requires an additional level of ground-fault protection for health care facilities where a service or feeder disconnecting means is equipped with ground-fault protection. This additional level of ground-fault protection must be at the next level of protective devices downstream from the service or feeder, but in no case on the load side of an essential electrical system transfer switch.

The elimination of the requirement for six cycles of separation between the two levels of ground-fault protection should enhance the selective coordination of essential electrical systems.

Coordination Study

The only true method for achieving selective coordination and equipment protection, and documenting with certainty the fact that these have been achieved, is by a coordination study. The **coordination study**, also known as a **time-current coordination study**, compares the timing characteristics of the protective devices used with each other and with the damage characteristics of equipment to be protected. For electronic-trip circuit breakers, the appropriate settings for the circuit breaker trip units are developed in the coordination study.

Because the short-circuit currents available at different points in the system are a concern, a coordination study is usually performed in conjunction with a **fault-current study**. The fault-current study evaluates the ability of the equipment to withstand and interrupt the prospective fault currents. The study-calculated fault currents are also used to plot protective device time-current characteristics for the coordination study and evaluate selectivity via manufacturers' published tables.

Note that the previously mentioned stringent 2011 NEC requirements for emergency and standby power systems do not in any way exempt the power system engineer from performing a coordination study. In fact, in order to fit in with the competitive bidding process for equipment, the study may need to be performed sooner in the project timeline than previously in order to avoid costly mistakes in protective device selection. This is discussed in more detail in the following section.

Protective Device Characteristics

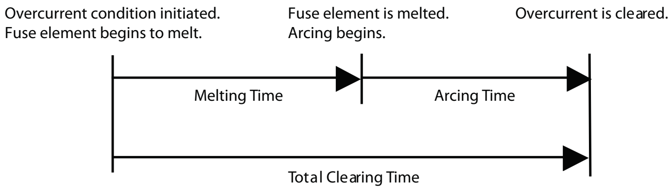
Overcurrent coordination is influenced heavily by the characteristics of the overcurrent protective devices themselves. For systems 600 V and under, the two primary types of overcurrent protective devices are circuit breakers and fuses.

Fuses

Fuses are the simplest of all overcurrent protective devices. As such, they offer the least amount of adjustability of any overcurrent protective device. A fuse consists of an element that melts with a pre-determined time-current characteristic for overcurrents. Low-voltage fuses are divided into classes based upon their characteristics. Some fuses are classified as current-limiting. By strict definition, a current-limiting fuse will interrupt currents in its current limiting range within ½ cycle or less, limiting the current to a value less than that which would be available if the fuse were replaced by a conductor of the same impedance.

Fuse timing response to a given level of overcurrent may be separated into melting time, which is the time required to melt the current-responsive element, and arcing time, which is the time elapsed from the melting of the current-responsive element to the final interruption of the circuit. The arcing time is dependent upon the circuit characteristics, such as the voltage and impedance of the circuit. The total clearing time is the sum of the melting time and the arcing time, as shown in Figure 7.

Figure 7: Fuse Timing Illustration



For all low-voltage fuse classes, the basic timing characteristics can be classified in the same manner. Fuses are typically assigned a minimum melting characteristic and a total clearing characteristic by their manufacturer. These define the boundaries of the fuse time-current characteristic band. For currents with time durations below and to the left of the time-current characteristic band, the fuse will not blow or be damaged. For currents with time durations within the time-current characteristic band, the fuse may or may not blow or be damaged. For currents with time durations above and to the right of the time-current characteristic band, the fuse will blow with a minimum melting time given by the minimum melting time characteristic and a total clearing time given by the total-clearing time characteristic.

Alternatively, the fuse may be assigned an average melting time characteristic. In this case, the total clearing characteristic is considered to be the average melting time characteristic shifted in time by +15%, and the minimum melting characteristic is considered to be the average melting time characteristic shifted in time by -15%.

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A typical fuse time-current characteristic band is shown in Figure 8.

Figure 8: Typical Low-Voltage Fuse Time-Current Characteristic Band

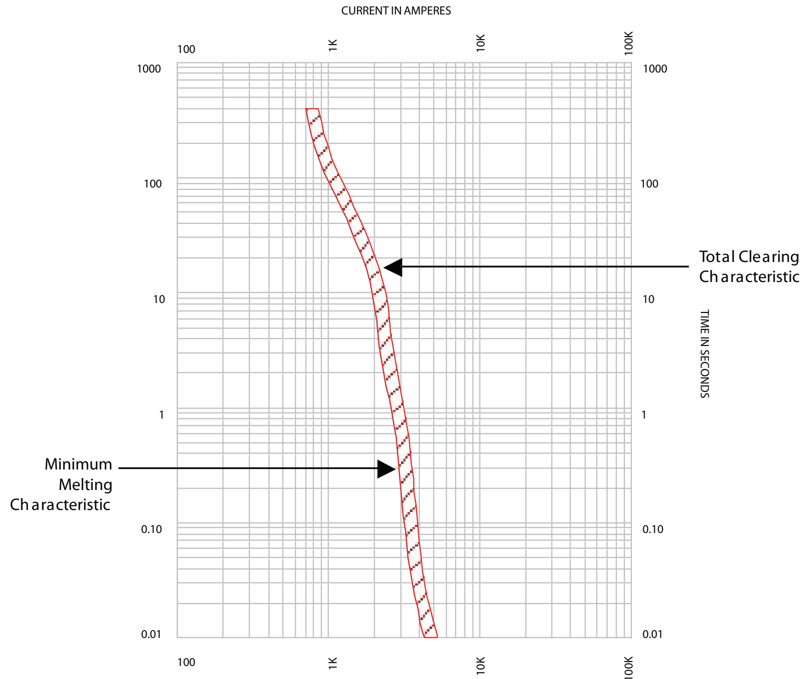
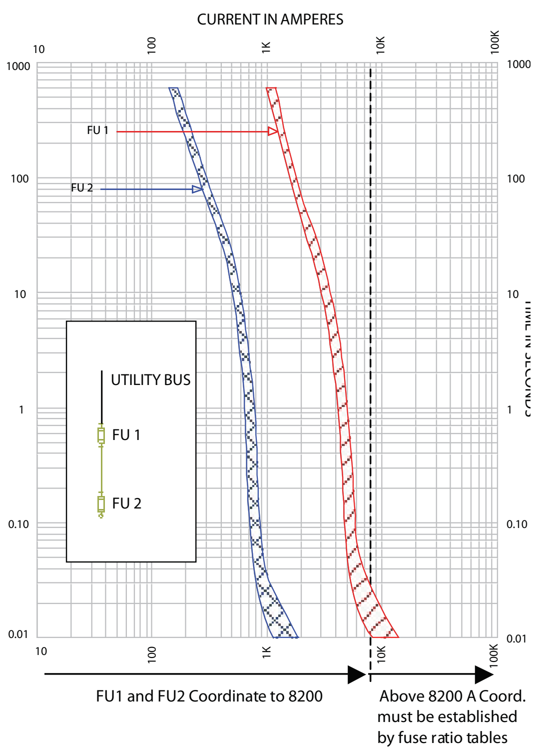


Figure 9: Fuse Coordination Example



Note that in Figure 8, the time-current characteristic is only shown down to 0.01 seconds. Below this level, the arcing time may be equal to or greater than the maximum melting time [2]. The I^2t energy let-through characteristics are used in this case to determine coordination; the minimum melting energy of the upstream fuse must be less than the total clearing energy of the downstream fuse for two fuses to coordinate. Fuse manufacturers publish selectivity ratio tables to document the performance of fuses under these circumstances. Consider two fuses in series, as shown in the one-line diagram/time current plot of Figure 9. It is possible to establish, by means of the time-current plot alone, that fuses FU1 and FU2 coordinate up to 8200 A. Above 8200 A FU1 operates in 0.01s or less and FU2 may operate in 0.01s or less, and coordination must be established by the fuse selectivity ratio tables.

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Circuit Breakers

Circuit breakers offer many advantages over fuses for the protection of low-voltage power systems and are the prevalent form of overcurrent protection for low-voltage power systems. Successful selective coordination with circuit breakers is a vital topic for a successful power system design.

Circuit breakers can be subdivided into two basic categories: molded-case and low-voltage power circuit breakers. Molded-case circuit breakers can be generally divided into thermal-magnetic and electronic tripping types. Molded-case electronic-trip circuit breakers are generally further divided into two categories: those with two-step stored energy mechanisms, often referred to as insulated case circuit breakers, and those without. Insulated case is not a UL term, but does appear in the IEEE Blue Book [5].

From a coordination standpoint, of particular importance is the rated short-time withstand current. This is defined as follows [5]:

> **"Rated Short-Time Withstand Current: (A)** The maximum RMS total current that a circuit breaker can carry momentarily without electrical, thermal, or mechanical damage or permanent deformation. The current shall be the RMS value, including the DC component, at the major peak of the maximum cycle as determined from the envelope of the current wave during a given test time interval. (IEEE C37.100-1992) (B) That value of current assigned by the manufacturer that the device can carry without damage to itself, under prescribed conditions. (NEMA AB1—1993) Syn: **withstand rating; short-time rating**."

All circuit breakers that have inherent time-delay characteristics (essentially every circuit breaker that is not an instantaneous only circuit breaker) have a short-time withstand capability. This capability may or may not be published as a short-time withstand rating. However, it will manifest itself in the time-current characteristics for the circuit breaker since a circuit breaker must be designed so that it will not be damaged for fault currents up to its interrupting rating.

Table 2 summarizes the various low-voltage circuit breaker types with respect to typical levels of short-time withstand capability. Because the information given in Table 2 is general in nature, specific manufacturer's data must be consulted for a given circuit breaker.

Table 2: Low-Voltage Circuit Breaker Types[1]

Circuit Breaker Type	Standard	Tripping Type	Short-Time Withstand Capability[2]
Molded-case	UL 489	Thermal-magnetic	Typically much lower than interrupting rating
		Electronic	Typically lower than interrupting rating
		Electronic (insulated case)[3]	Often comparable to interrupting rating
Low-voltage power	ANSI C37.13 UL 1066	Electronic	Typically comparable to interrupting rating

1 Other circuit breaker types, such as molded-case circuit breakers with instantaneous-only trip units, are available for specific applications, such as short-circuit protection of motor circuits

2 Short-time current is defined by ANSI C37.13 as the designated limit of available (prospective) current at which the circuit breaker is required to perform a duty cycle consisting of two ½-second periods of current flow separated by a 15s interval of zero current. For UL 489-rated circuit breakers, short-time withstand is not defined and the duty cycle may vary.

3 Insulated-case circuit breakers exceed the UL 489 standard. The term "insulated case" is not a UL term.

ENGLISH

Thermal-Magnetic Molded-Case Circuit Breakers

The typical time-current characteristic band of a thermal-magnetic molded-case circuit breaker is shown in Figure 10. The time band is quite large; for example, the UL 489 standard allows the instantaneous trip characteristic for a circuit breaker with an adjustable instantaneous characteristic to vary from -20% to +30% of the marked instantaneous trip current setting. The long-time portion of the trip characteristic is established by a thermal element and is used for overload and low-level fault protection. The instantaneous characteristic is often adjustable, as shown in Figure 11, and is used for short-circuit protection.

Figure 10: Typical Thermal-Magnetic Molded-Case Circuit Breaker Time-Current Characteristic Band

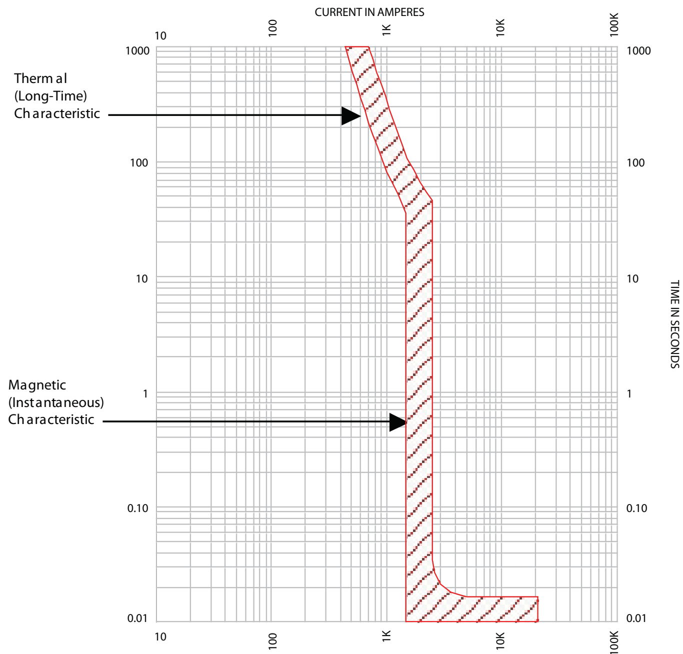
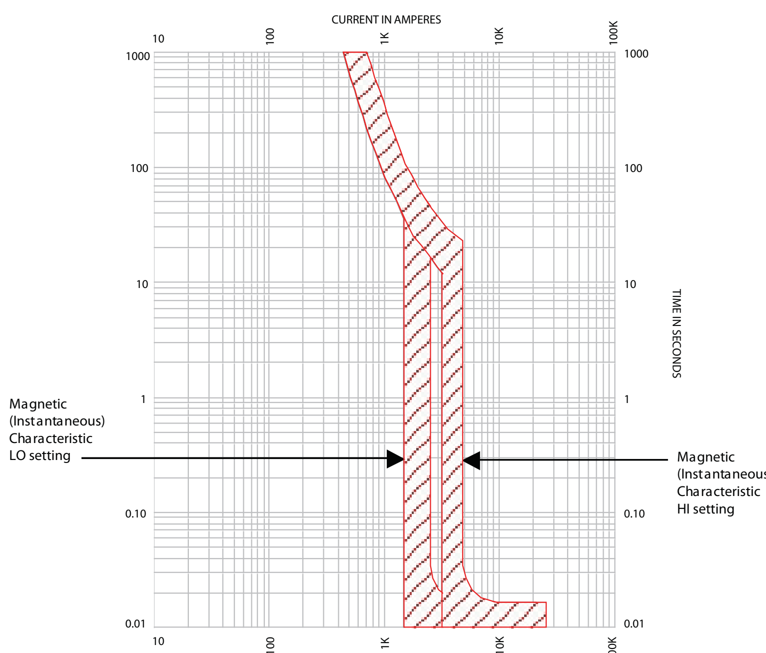


Figure 11: Thermal-Magnetic Circuit Breaker Time-Current Characteristic Showing Adjustable Instantaneous Characteristic



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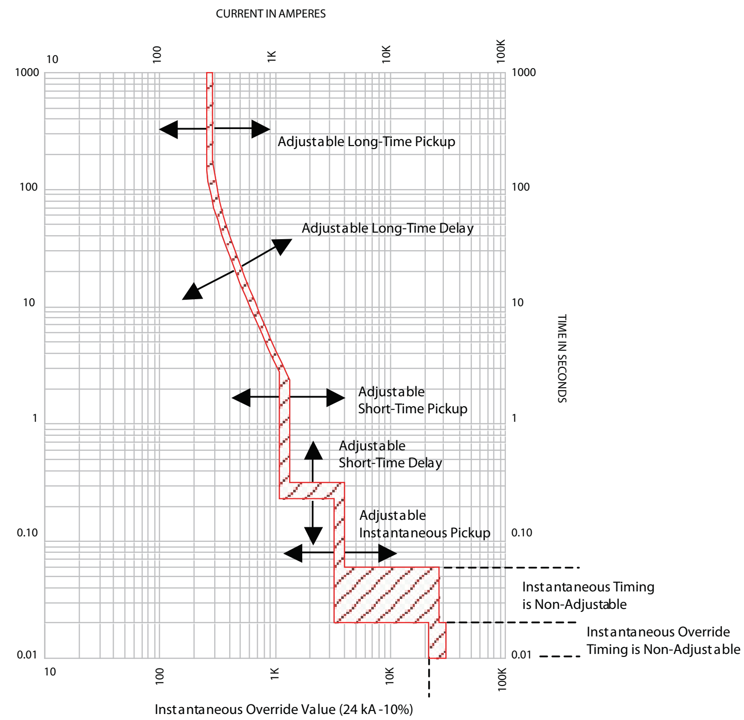
Electronic-Trip Circuit Breakers

Electronic-trip circuit breakers typically are equipped with trip units that give the circuit breakers the general characteristics in Figure 12. The adjustable long-time pickup sets the trip rating of the circuit breaker. The adjustable long-time delay, short-time pickup, short-time delay, and instantaneous pickup allow the circuit breaker's tripping characteristics to be customized to the application. The trip unit represented by Figure 12 is referred to as an **LSI trip unit**, since it is equipped with long-time, short-time, and instantaneous trip characteristics. Trip units without a short-time setting are referred to as **LI trip units**, and units without an instantaneous characteristic are referred to as **LS trip units**. In most cases, the instantaneous characteristic on an LSI trip unit can be turned off if necessary. A trip unit that includes ground fault protection is denoted with a "G," i.e., "LSIG."

Of particular importance to the tripping characteristic is the instantaneous override level. For currents above this override level, even if the instantaneous characteristic is turned off, the circuit breaker will trip instantaneously. The override level is factory-set to protect the circuit breaker according to its short-time withstand capability. Therefore, the higher the withstand level, the higher the override is set. This is an extremely important concept and often determines whether two circuit breakers in series selectively coordinate. Note also that the tripping times for the instantaneous characteristic and for currents above the override level are nonadjustable.

Further, as is the case for the circuit breaker represented in Figure 12, there can be a difference in tripping time when the circuit breaker is operating in the instantaneous region below the override level vs. above the override level.

Figure 12: Typical Time-Current Characteristics for Electronic-Trip Circuit Breaker (Molded-Case Circuit Breaker with "Low" Short-Time Withstand Shown)



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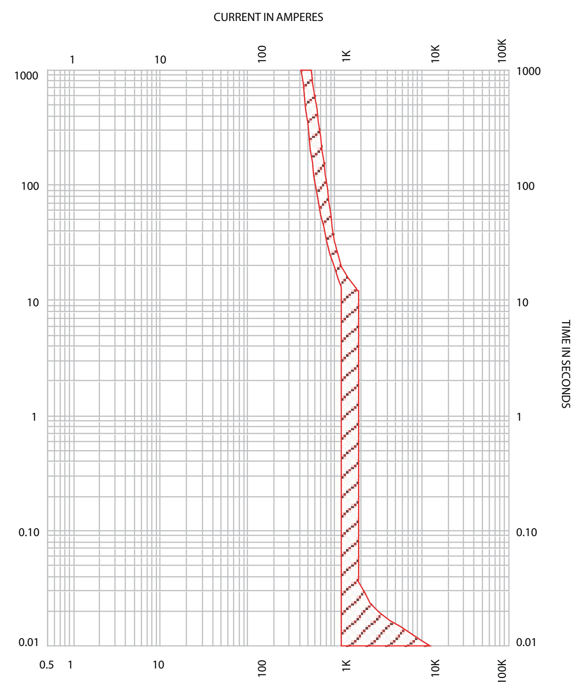
Current-Limiting Circuit Breakers

Like fuses, circuit breakers can be designed to limit the flow of prospective short-circuit current. Similar to a current-limiting fuse, a current-limiting circuit breaker limits the let-through I^2t to a value that is less than its prospective value. Circuit breakers that are current-limiting are typically shown with instantaneous characteristics in that the tripping time decreases with current, as shown in Figure 13.

It is worthy of note that, in some cases, even though the circuit breaker is not officially classified as current-limiting, a degree of current-limitation may exist [3]. This results in the circuit breaker exhibiting time-current characteristics similar to those shown in Figure 13, although the instantaneous characteristic is shown as a horizontal band.

Figure 13: Typical Time-Current Characteristics for Current-Limiting Circuit Breaker



Circuit Breakers in Series: The Dynamic Impedance Concept

An important concept in the coordination of low-voltage circuit breakers is the concept of **dynamic impedance**.

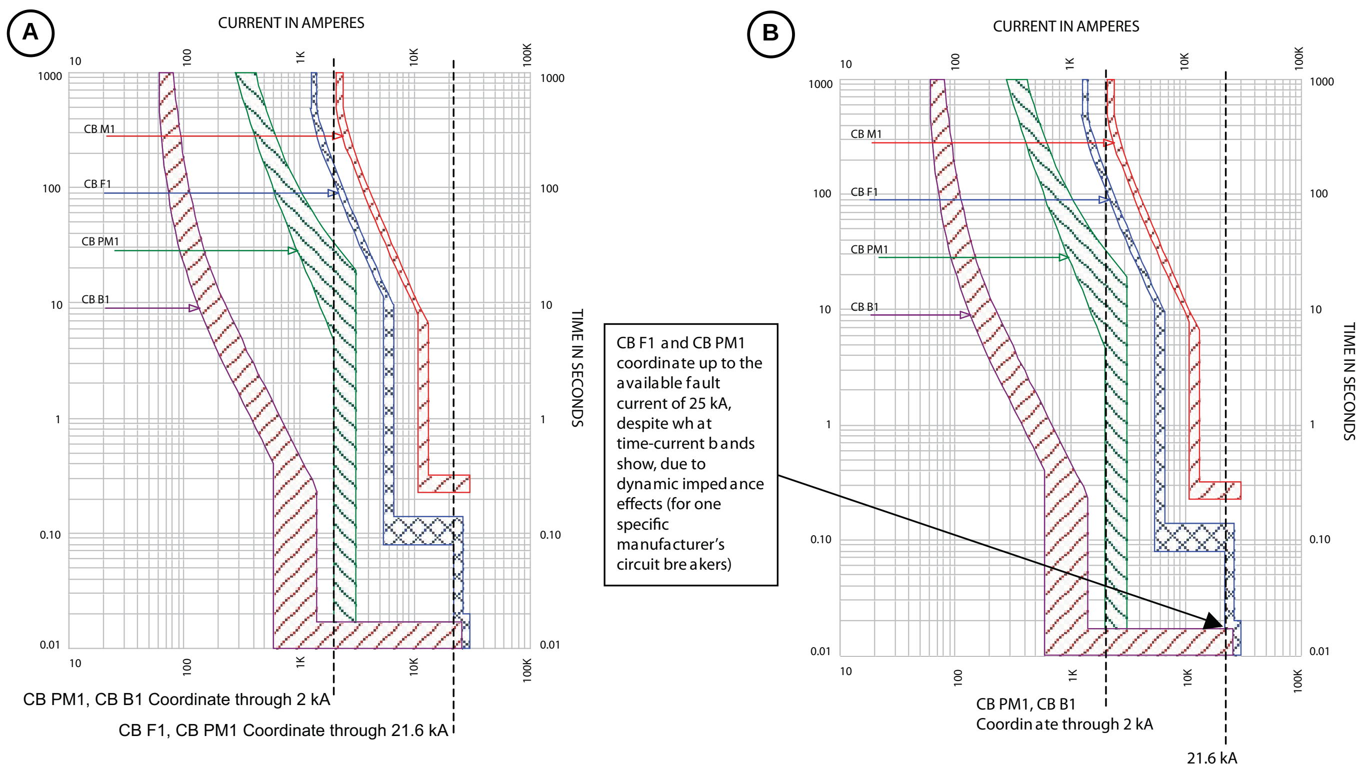
Simply stated, a circuit breaker, when it begins to open, serves to limit the prospective flow of current, even if it is not UL listed as a current-limiting circuit breaker [3]. The impedance presented to the circuit by the circuit breaker during opening changes with time as the circuit breaker opens, hence the term **dynamic**. This impedance can increase the level coordination between two circuit breakers in series by limiting the current that the upstream circuit breaker “sees” for a fault downstream of both circuit breakers when the downstream circuit breaker is opening.

ENGLISH

Short-Circuit Coordination Tables

Taking the dynamic impedance characteristics of circuit breakers into account for selective coordination leads to an important new tool for the coordination of circuit breakers: **short-circuit coordination tables**. Similar to fuse ratio tables, these show the level of coordination between two circuit breakers in a series, as determined by testing Because of the dynamic impedance effects of ordinary circuit breakers, often the level of coordination between two circuit breakers in a series is greater than their time-current characteristic bands would indicate. As an example, the coordination level between CB F1 and CB PM1 was established graphically by the time-current bands as 21.6 kA. However, testing shows that these two circuit breakers in a series, as manufactured by one specific manufacturer, coordinate up to 35 kA. So, even though the time-current bands do not reflect this, CB F1 and CB PM1 **do coordinate up to the available fault current of 25 kA,** as illustrated in Figure 14, B. This level of “extra” time-current coordination can often make a large difference, as in this case.

Figure 14: Time-Current Curve Showing Effects of Dynamic Impedance and Current-Limiting on Level of Selective Coordination Between CB F1 and CB PM1



Time-Current Plot

Time-Current Plot Showing Effects

As with fuse ratio tables, these tables must be developed by the manufacturer. It is extremely important that the levels of short-circuit coordination in the short-circuit coordination tables, if different from the levels determined from the time-current bands, be determined by testing.

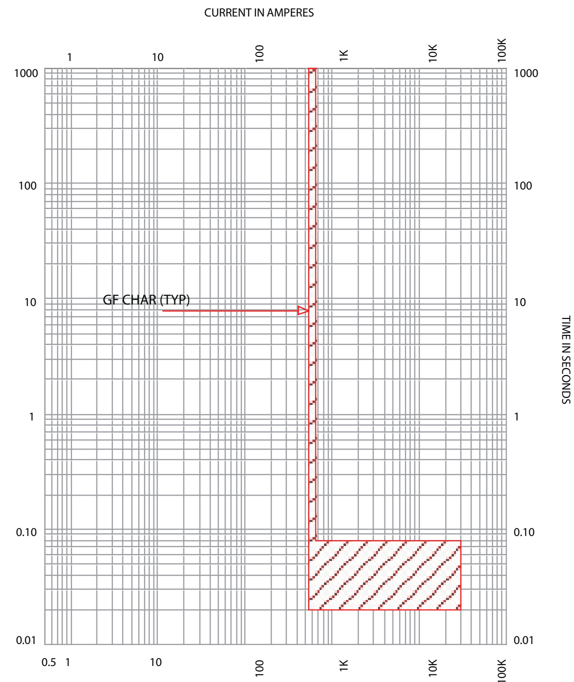
The present state of the art does not lend confidence to calculated values.

ENGLISH

Ground-Fault Protection of Equipment

Ground-fault protection of equipment is designed to provide sensitive protection for ground-faults, typically set below the level of phase overcurrent protection. Typically, ground-fault protection is built into the trip unit of an electronic-trip circuit breaker or, in the case of a thermal-magnetic circuit breaker or fuses, can be supplied by a separate ground relay. Note that if fuses are used a separate disconnecting means with shunt-trip capability is required. A typical time-current characteristic is given in Figure 15.

Figure 15: Typical Ground-Fault Protection Characteristics



The current-sensing arrangement for ground-fault protection may consist of a simple residual connection of current sensors/CTs, a single zero-sequence sensor/CT, or may be a complex affair with differential connections of the sensors/CTs, known as a **modified-differential ground-fault** arrangement. The application of the sensors/CTs is beyond the scope of this paper but the engineer responsible for coordination should be aware of the requirements and potential application issues.

It is important to understand that the multiple levels of ground-fault protection of equipment in a system must not only coordinate with each other but also with the downstream phase overcurrent devices. In other words, a ground fault in a branch circuit should cause the branch circuit overcurrent device to open, not the upstream feeder ground-fault protection.

ENGLISH

Tying It All Together—Design Philosophies and Guidelines

On a practical basis full selective coordination may not always be achievable or desirable. Various industry standards recognize this fact. Compromises may be required between selectivity and equipment protection to achieve the desired results. Further, economic trade-offs are often frequently encountered, as well as code issues. Some examples of wording from various industry standards regarding selective coordination are given in Table 3.

Table 3: Selective Coordination Requirements/Comments per Various Industry Standards

Standard	Requirement/Comment
NFPA 110 Standard for Emergency and Standby Power Systems [6]	**6.5 Protection** **6.5.1 General** The overcurrent protective devices in the EPSS shall be coordinated to optimize selective tripping of the circuit overcurrent protective devices when a short circuit occurs. **Annex A** **A.6.5.1** It is important that the various overcurrent devices be coordinated, as far as practicable, to isolate faulted circuits and to protect against cascading operation on short-circuit faults. In many systems, however, full coordination is not practicable without using equipment that could be prohibitively costly or undesirable for other reasons. Primary consideration also should be given to prevent overloading of equipment by limiting the possibilities of large current inrushes due to instantaneous reestablishment of connections to heavy loads.
IEEE Std. 141 IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (Red Book) [4]	**Chapter 5: Application and Coordination of Protective Devices** **5.1.3 Importance of Responsible Planning** Protection in an electric system is a form of insurance. It pays nothing so long as there is no fault or other emergency, but when a fault occurs it can be credited with reducing the extent and duration of the interruption, the hazards of property damage, and personnel injury. Economically, the premium paid for this insurance should be balanced against the cost of repairs and lost production. Protection, well integrated with the class of service desired, may reduce capital investment by eliminating the need for equipment reserves in the industrial plant or utility supply system. **5.2 Analysis of System Behavior and Protection Needs** **5.2.1 Nature of the Problem** Operating records show that the majority of electric circuit faults begin as phase-to-ground failures . . .
IEEE Std. 241 IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (Gray Book) [9]	**Chapter 9: System Protection and Coordination** **9.7 Selective Coordination** **9.7.1 Coordination of Protective Devices** . . . on all power systems, the protective device should be selected and set to open before the thermal and mechanical limitations of the protected components are exceeded. **9.7.3 Mechanics of Achieving Coordination** . . . quite often, the coordination study will not demonstrate complete selective coordination because a compromise has to be made between the competing objectives of maximum protection and maximum service continuity.
IEEE Std. 242 IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (Buff Book) [2]	**Chapter 1: First Principles** **1.1.2.2 Equipment Damage Versus Service Continuity** Whether minimizing the risk of equipment damage or preserving service continuity is the more important objective depends upon the operating philosophy of the particular industrial plant or commercial business. Some operations can avoid to limited service interruptions to minimize the possibility of equipment repair or replacement costs, while others would regard such an expense as small compared with even a brief interruption of service. In most cases, electrical protection should be designed for the best compromise between equipment damage and service continuity . . . **Chapter 15 Overcurrent Coordination** **15.1 General Discussion** In applying protective devices, it is occasionally necessary to compromise between protection and selectivity. While experience may suggest one alternative over the other, the preferred approach is to favor protection over selectivity. Which choice is made, however, is depended upon the equipment damage and the affect on the process.
IEEE Std. 446 – 1995 IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (Orange Book) [7]	**Chapter 6: Protection** **6.2 Short-Circuit Considerations** . . . careful planning is necessary to design a system that assures optimum selectivity and coordination with both power sources . . .

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Consider Selective Coordination Early in the Design Process

Achieving selective coordination will be less “painful” if selective coordination is considered earlier in the design process. The need for a coordination study, even a preliminary study, early in the design process is increasingly becoming recognized as a need if selective coordination is to be achieved without costly redesigns.

Working with overcurrent protective device manufacturers early in the design process generally makes the effort to achieve selective coordination go much more smoothly. In some cases this will require changes to the way projects are contracted and managed, since working with a particular manufacturer generally means staying with that manufacturer for the protective devices considered.

Good data is essential to the selective coordination effort. The utility available fault current, impedance data for the generator units to be used, motor fault current contribution, and good estimates of cable run lengths are all crucial. The earlier this information is obtained, the easier the coordination effort will be. When obtaining the utility available fault current, avoid **infinite bus calculations**, even on the primary side of a service transformer. “Real world” fault current values will be lower than those that rely on infinite bus assumptions. While infinite bus assumptions have long been recognized as being conservative for short-circuit and coordination studies, coordination per the 2011 NEC requirements and arc-flash concerns both necessitate obtaining actual fault current values from the utility. Typically, obtaining both a **maximum available fault current value** for use with the short-circuit and coordination studies and a **minimum available fault current value** for use with arc-flash studies is preferred (and is an acknowledgement of the electric utility industry’s assertion that available fault current values can change over time due to system changes). This is typically a challenge due to the industry’s reliance on infinite bus calculations.

Recognize NEC Conflicts and Issues

NEC Selective Coordination—Up to Which Source?

Ever since the requirements for selective coordination were added to Sections 700 and 701 in the 2005 NEC, and Section 708 in the 2008 NEC, there has been a question regarding what the word “all” means in the requirements. A statement by Code Making Panel 13 in the 2011 NEC “Report on Proposals” seems to have answered the question.

The selective coordination requirements in Sections 700.27, 701.18, and 708.54 apply to those overcurrent protection devices (OCPDs) on the load side of the automatic transfer switch (ATS) and the OCPDs on the alternate source side of the ATS. This position agrees with the scope of the sections and the definition of an emergency power supply system as illustrated in NFPA 110, Appendix B.1.

Of course it would be prudent for selective coordination to also be evaluated up to the normal sources, attempting to achieve coordination to the extent practicable. NFPA 110 Annex A states:

> “A.6.5.1 It is important that the various overcurrent devices be coordinated, as far as practicable, to isolate faulted circuits and to protect against cascading operation on short-circuit faults. In many systems, however, full coordination is not practicable without using equipment that could be prohibitively costly or undesirable for other reasons.”

For additional information on this topic, see document no. 0600DB0902.

The same is true for the essential electrical system (EES) in hospitals. NEC Sections 517.25 and 517.30 clearly indicate that the EES does not include that portion of the electrical system from the normal source to the line side of the automatic transfer switches. Therefore, selective coordination is required by the NEC up to the alternate power source (see 517.26), and coordination up to the normal source is at the engineer’s discretion.

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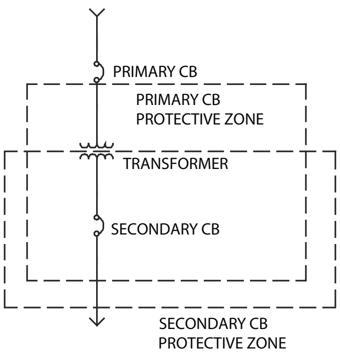
Selective Coordination—What Is It?

The wording of 2011 NEC 700.27, 701.18, and 708.54 leaves an open issue. Although **selective coordination** is defined in NEC 100 as “localization of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the choice of overcurrent protective devices and their ratings or settings,” NEC 700.27, 701.18, and 708.54 contain the wording “shall be selectively coordinated with all supply side overcurrent protective devices.” What about scenarios where two devices that are effectively in a series protect a given piece of equipment?

Figure 16: Typical Low-Voltage Transformer Protection Scenario



Such a scenario is given in Figure 16. The transformer shown is protected for short-circuits by the primary circuit breaker, and for overloads by the secondary circuit breaker. For a fault where the protective zones overlap, it does not matter whether the primary or secondary circuit breaker trips.

Other possible scenarios for this issue are given in Figure 17. In both cases, selective coordination of CB 1 and CB 2 is not required for overall system coordination, since there are no additional devices between the two. Both devices could be the same size device with the same settings.

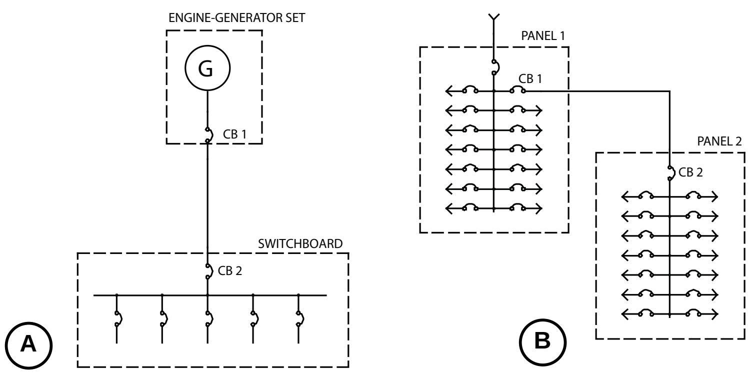
The NEC recognizes this fact in the exception in 700.27 and 701.18:

> *Exception: Selective coordination shall not be required between two overcurrent devices located in series if no loads are connected in parallel with the downstream device.*

While a similar exception has not been included in 708.54, engineers skilled in the practice of selective coordination recognize that coordinating these devices is unnecessary.

Figure 17: Examples of Avoiding Use of Overcurrent Protective Devices

A. Engine-Generator Set with Circuit Breaker Feeding Switchboard with Main Circuit Breaker
B. One Panelboard Feeding another Panelboard with a Main Circuit Breaker



For the short term, the solution is to minimize occurrences of overcurrent protective devices in a series. Long-term actions may include the submission of change proposals for consideration in a future code cycle. The more proposals that are made on this issue, the more likely the issue is to be recognized and corrected.

ENGLISH

Ground-Fault Protection in Health-Care Facilities

Figure 18: Typical Health-Care Facility Electrical System (Source: NEC 2011 FPN Figure 517.30)

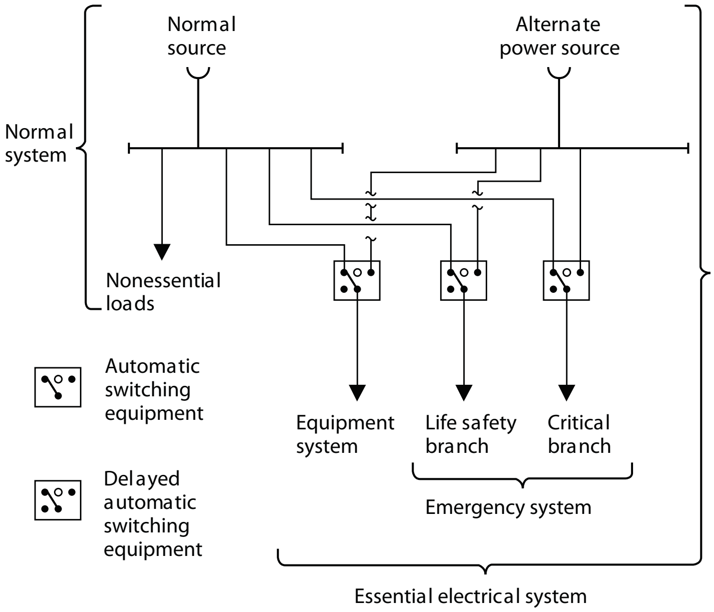


Figure 517.30, No. 1: Greater Than 150 kVA

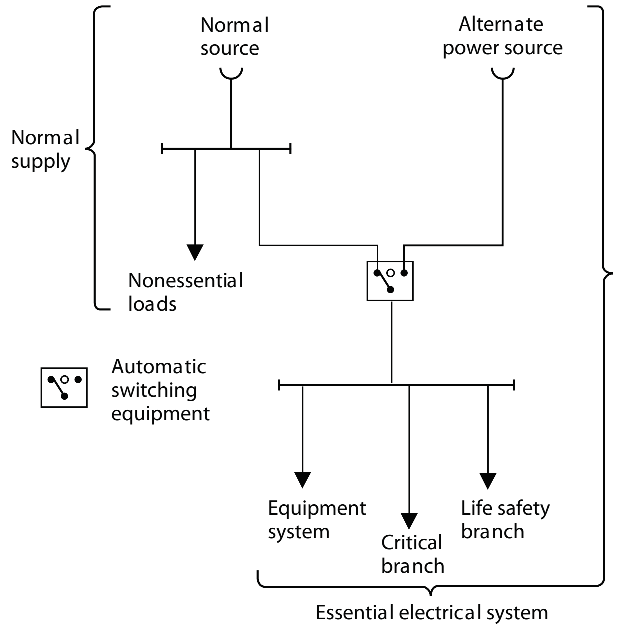


Figure 517.30, No. 2: Less Than 150 kVA

NEC Section 517.17(B) requires an additional level of ground-fault protection in health-care facilities, and 517.17(C) requires the two levels of ground-fault protection to coordinate. Section 517.26 requires the essential electrical system to meet the requirements of 700, which includes 700.27.

To achieve selective coordination for ground-fault protection, the lowest level of ground-fault protection has to coordinate with the phase time-current characteristics of the next lower downstream device. As previously mentioned, **~95% of all system faults are ground faults**, therefore this is very important.

What can be done about this issue? For the short-term, bringing the issue up to the local authority having jurisdiction for resolution is the only recourse. Long-term actions may include the submission of change proposals for consideration in a future code cycle. The more proposals that are made on this issue, the more likely the issue is to be recognized and corrected.

ENGLISH

Is Coordination up to the Available Fault Current Justified on a Practical Basis?

As mentioned in the section “Nature of Overcurrents” on page 2, the frequency of occurrence of high magnitude bolted faults is much lower than that of lower-magnitude faults, such as arcing ground faults. Also, the higher the current level to which two overcurrent protective devices are coordinated, the more difficult the coordination effort becomes. The impact of this fact upon system protection and selective coordination are twofold, namely:

1. It diminishes the practical need for selective coordination up to the available fault current in favor of “practicable” coordination to a lower level of fault current.
2. It reinforces the need for coordinated ground-fault protection.

The wording of the 2011 NEC ignores the statistical evidence of the frequency of occurrence of high-level bolted faults. In reality, these faults are most common during the commissioning phase of the electrical system in a facility, when damage to cable insulation and other application and installation issues are corrected. During the normal lifetime of the system, these types of short-circuits are rare indeed, especially at lower levels in the system. One practical way to address selectivity in emergency and standby systems might be to set an established limit of 50% of the bolted fault current as the level of coordination for overcurrent devices below a given level (for example, 400 A or below). This is an approximate worst-case for the calculated value of the arcing fault current for a 480 V system when calculated using the empirical equations in IEEE-1584 Guide for Performing Arc-Flash Hazard Calculations [8]. Selective coordination up to such a limit would be justifiable on a practical basis. However, no code or standard presently sets this limit.

Arc-flash performance of the system is also a factor. In some cases, arc-flash performance, particularly at the lower levels of the system, may be impaired by forcing selectivity up to the available bolted fault current. The reason for this is that the arc-flash incident energy level is directly proportional to the time duration of an arcing fault, which is the clearing time for the overcurrent protective device that clears the fault.

Also, the NEC effectively prohibits coordinated ground-fault protection in health care facility essential electrical systems, even though ~95% of all system faults are ground faults.

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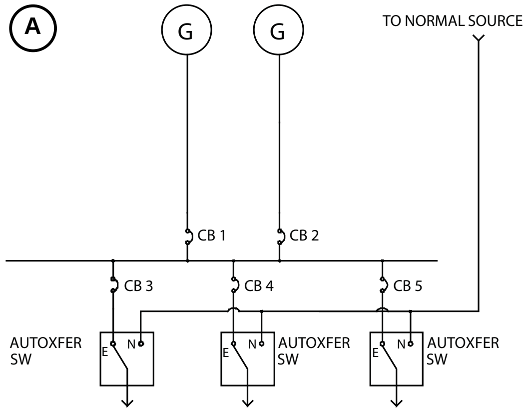
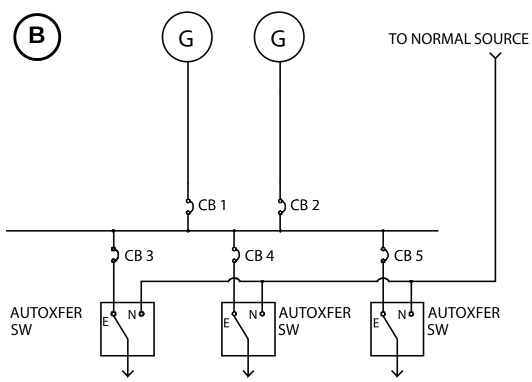
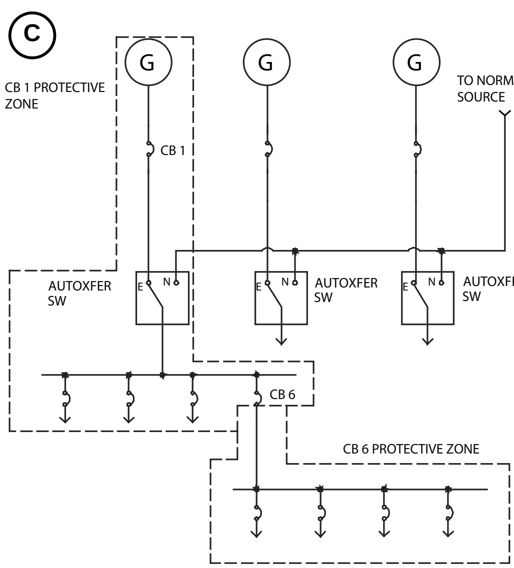
Recognize the Pitfalls of Generator Protection

Figure 19: Application—Paralleled Generators





Expanded to Show Primary Protective Zones



Redesigned for Selective Coordination

Selective coordination of devices is often difficult or impossible while maintaining adequate generator protection.

Consider the system in Figure 19, A. It can be shown that adequate short-circuit protection of the generators and coordination of CB 1 and CB 2 with CB 3, CB 4, and CB 5 are usually mutually exclusive, especially if only one generator is running and when CB 3, CB 4, and CB 5 short-time settings have to be maximized to achieve coordination lower in the system. It is assumed that CB 1–CB 5 are electronic-trip circuit breakers with high short-time withstand ratings, such as ANSI power circuit breakers or insulated-case circuit breakers. This would be the case regardless of the requirements of the NEC for selective coordination or the selectivity of downstream devices.

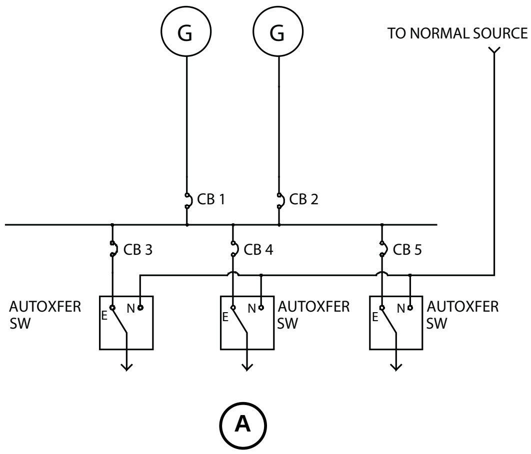
As an illustration of the effects of this lack of selectivity, consider the system of Figure 19, B, which is the same system from Figure 19, A, expanded to show the primary protective zones of the overcurrent protective devices. Note that although CB 3 and CB 6 selectively coordinate, the required settings of CB 1 and CB 2 for generator protection cause their primary protective zones to completely overlap the CB 3 protective zone and extend into the CB 6 protective zone.

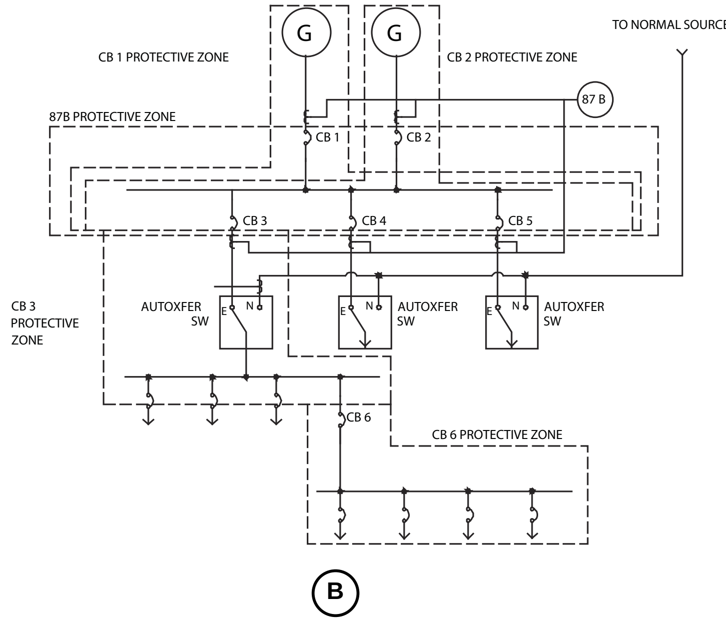
One method to prevent this is to design the system with a larger number of smaller-size generators, as shown in Figure 19, C. This is a gross simplification, but it does illustrate the concept. In reality, reliability concerns will, in many cases, force additional generators to be added for redundancy. This is much more economically feasible for the system of Figure 19, B than for the system of Figure 19, C. The addition of 51 V or 51 C voltage restrained/controlled relays can often improve the generator protection, but will not improve coordination.

ENGLISH

Another approach is to raise the settings of the generator circuit breakers so that they coordinate with the next level downstream. In Figure 20, A, this means that CB 1 and CB 2 would coordinate with CB 3, CB 4, and CB 5. But, CB 1 and CB 2 would no longer protect the generators adequately for short circuits. However, CB 3, CB 4, and CB 5 can typically be set to protect the generators for short circuits. Therefore, only for a fault on the paralleling switchgear bus between CB 1/CB 2 and CB 3/CB 4/CB 5 are the generators unprotected. This can be remedied by adding a bus differential relay for this bus, as shown in Figure 20, B.

Figure 20: Example System Expanded to Show Primary Protective Zones with Higher Settings for CB 1 and Differential Relaying Added



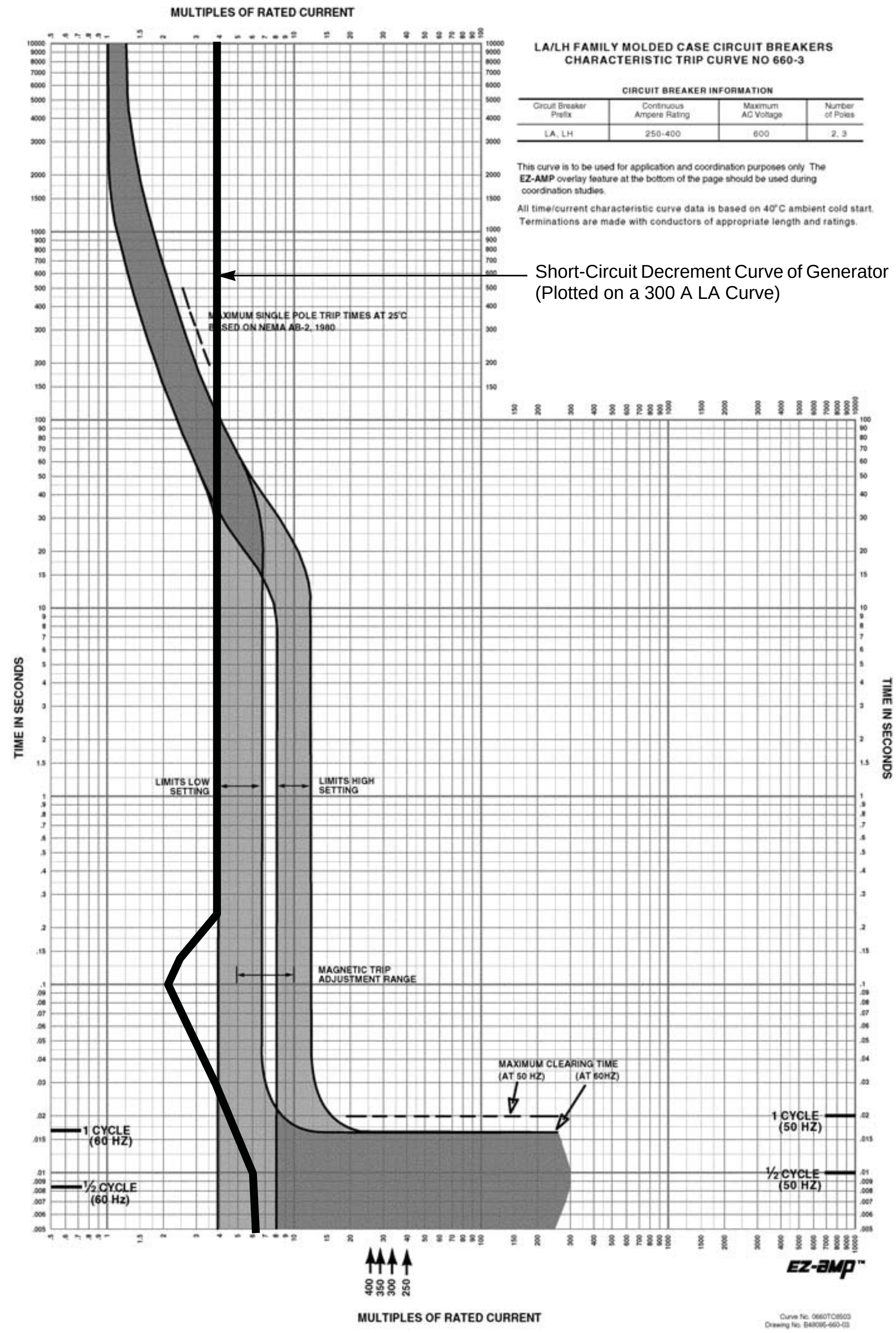


In Figure 20, B, the differential relay 87 B would typically be of the high impedance type and would trip CB 1, CB 2, CB 3, CB 4, and CB 5.

A fault between CB 1/CB 2 and CB 3/CB 4/CB 5 will cause this relay to trip, and, if it is set appropriately, it will operate faster than the trip unit settings of CB 1 or CB 2, providing short-circuit protection for the generators in this protective zone as well as providing short-circuit protection for the paralleling switchgear bus. Generator overload protection would still be provided by CB 1 and CB 2. Note that generator differential protection is not shown; it could be provided for additional protection for the generator, but would not be an aid to selectivity. Generator differential relays, if used, should be of the percentage-differential type rather than impedance type. Note also that lockout relays, while recommended, are not shown. The circuit breakers that must be tripped by the differential relays must be suitable for external relay tripping (suitable insulated case circuit breakers or ANSI power circuit breakers are recommended, but are typically used in this application anyway). Economic concerns (cost of differential relays, CTs, and the extra wiring required) must, of course, be taken into account when considering this approach.

Sometimes selective coordination can be impaired by the self-protection function provided by the gen-set manufacturer (see Figure 21). In this situation, it is suggested that the downstream OCPDs be selected and set to coordinate with the generator protection characteristic rather than to the prospective fault current.

Figure 21: Short-Circuit Decrement Curve of Generator



Utilize Circuit Breakers with Energy-Based Tripping System

Some circuit breakers use an energy-based tripping system to protect the circuit breakers while allowing the maximum selectivity with downstream circuit breakers. The trip units in these circuit breakers have a special selectivity delay to allow downstream circuit breakers to clear. However, on very high faults, or if the downstream circuit breaker does not trip, the circuit breakers employ a tripping system that uses the energy (I^2t) pressure to open the mechanism.

This system maximizes the interaction of the circuit breakers in a series to allow selectivity.

Utilize Circuit Breakers with High Short-Time Withstand Capabilities

Circuit breakers are the de-facto standard for low-voltage overcurrent protection. As previously mentioned, circuit breakers don’t need to be ANSI power circuit breakers to have a short-time withstand capability. Contrary to popular belief, circuit breakers also don’t need to be electronic trip circuit breakers to have a short-time withstand capability. When specifying circuit breakers, however, that the UL 489 standard to which molded-case circuit breakers are designed and tested does not require a short-time withstand capability.

The net effect of a high short-time withstand capability for a circuit breaker is in its tripping performance in the short-circuit region. This can be seen by evaluating the time-current characteristics for a given circuit breaker, although short-circuit coordination tables must be used to gain the full advantage from such circuit breakers due to the dynamic impedance and current-limiting effects described above. In many cases it will be necessary to increase the frame size of the upstream circuit breaker in order obtain short-time withstand levels high enough to achieve total selective coordination. For the service switchgear/switchboards, ANSI power circuit breakers or insulated case circuit breakers are essential, especially for medium to large systems.

A fairly popular misconception is that when using electronic circuit breakers with the instantaneous function turned off, ANSI C37.20.1 low-voltage power switchgear is required. The reason behind this misconception is that UL 891 switchboard through-bus withstand tests are only required to be conducted for three cycles, whereas ANSI low voltage switchgear is required to have a short-time withstand rating of 30 cycles. The exception, of course, would be where a manufacturer tests a switchboard configuration to the full 30-cycle withstand rating.

In reality, the need for a short-time withstand rating for the switchboard bussing is only a concern where ANSI low-voltage power circuit breakers or insulated-case circuit breakers with high (or no) instantaneous override level is provided when the instantaneous function is turned off. In most cases the circuit breakers provided with switchboards have instantaneous overrides that cause the circuit breaker to trip instantaneously above a given level, even if the instantaneous function is turned off, and these are tested with the switchboard to ensure compatibility.

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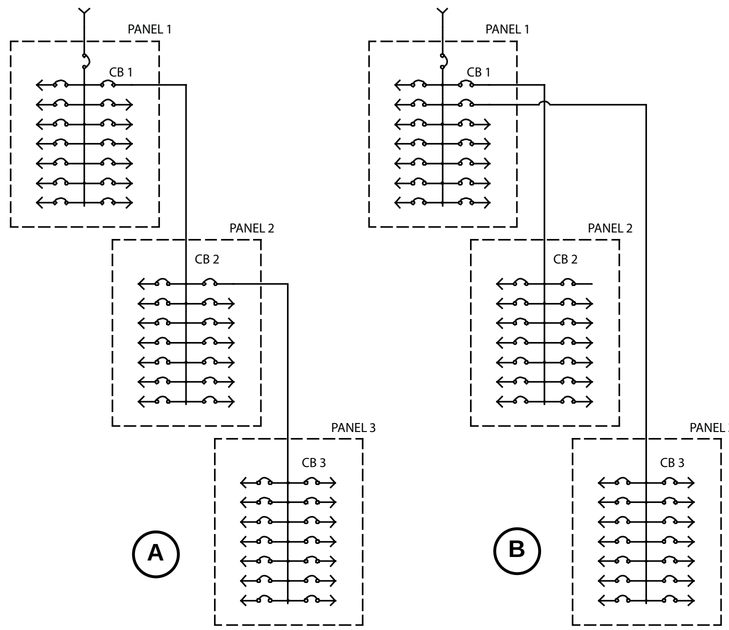
Avoid Multiple Levels of Protective Devices Where Possible

The fewer the number of levels of overcurrent protective devices, the easier coordination becomes. Figure 22 illustrates this point. In Figure 22, A, three panels are arranged so that three levels of selective coordination are required (CB 1 → CB 2 → CB 3). In Figure 22, B, the same number of panels has been rearranged so that only two levels of selective coordination are required (CB 1 → CB 2 and CB 1 → CB 3). Often such an arrangement can be done in an economically feasible manner.

Figure 22: Multiple Levels of Selectivity

A. Three levels of selectivity
B. Same number of panels rearranged with two levels of selectivity



Utilize Step-Down Transformers to Lower Fault Current

Remember that transformer impedance will lower the available fault current, and the smaller the kVA size of the transformer, the more drastic the reduction. Where coordination at the 480 V level, for example, is not possible, coordination from 480 V to 208 V through a step-down transformer may be. If loads can be converted to utilize the lower voltage, this can be a way to achieve selectivity.

NOTE: To reduce the fault current enough to achieve coordination, aluminum-wound transformers can sometimes be used in place of copper.

Increase Transformer Sizes Where Necessary

Although the smaller the transformer, the lower the available fault current is at the secondary, and there may be cases where transformers must be upgraded in order to achieve selective coordination. This is usually due to the frame size of the primary circuit breaker required to coordinate with devices at the next level below the transformer secondary main. A careful balance between the required frame size of the primary circuit breaker and the available fault current at the transformer secondary is usually required.

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Zone-Selective Interlocking—The Facts and the Misconceptions

A popular misconception is that zone-selective interlocking (ZSI) between electronic-trip circuit breakers can force otherwise poorly coordinated systems to coordinate. While it is true that ZSI can reduce the amount of energy let-through during a fault, it cannot be used to force selective coordination. The reason for this is that ZSI typically uses the short-time or ground-fault pickup (or both) on a downstream circuit breaker to identify that the circuit breaker detects a fault. The downstream circuit breaker then sends a signal to “restrain” the next level upstream circuit breaker from tripping instantaneously while at the same time itself tripping instantaneously to clear the fault. However, the upstream circuit breaker will still continue to time out on its time-current band, ultimately tripping if the downstream circuit breaker fails to clear the fault in time. If the two circuit breakers are poorly coordinated, the upstream circuit breaker will trip before the downstream circuit breaker, even with ZSI in place.

Used for the right reasons, ZSI is still a powerful tool for reducing equipment damage and arc-flash incident energy since, on a coordinated system, it forces the device closest to a given fault to open in the minimum amount of time. Typically, this time is somewhat longer than the instantaneous characteristic of the circuit breaker due to the inherent time delay required for the ZSI logic operation.

On-Site Adjustment Requirements

Despite careful planning, selective coordination efforts can quickly come to nothing if the overcurrent protective devices are not properly set onsite. For example, most manufacturers factory-set all but the ampere rating switch for electronic-trip circuit breakers in their lowest positions.

The coordination study should include tabulated settings for each overcurrent protective device that requires adjustment, such as electronic-trip circuit breakers, thermal magnetic circuit breakers with adjustable instantaneous characteristics, ground-fault relays, etc.

References

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[3] “Short Circuit Selective Coordination for Low Voltage Circuit Breakers.” Schneider Electric document no. 0100DB0501, October 2005.

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Related Documents

Document Title	Document Number
Enhancing Short Circuit Selective Coordination with Low Voltage Circuit Breakers	0100DB0403
Short Circuit Selective Coordination for Low Voltage Circuit Breakers	0100DB0501
Selectivity Guidelines For Square D™ Panelboards	0100DB0604
Guide to Low Voltage Transformer Protection and Selective Coordination	0100DB0902
Zone Selective Interlocking (ZSI) Systems and Alternate Maintenance Setting (AMS) Switches in Electrical Distribution Systems	0100DB1017
New 2011 NEC Requirement Regarding Non-Instantaneous Trip Circuit Breakers	0100DB1019
NEC Selective Coordination—Up to Which Source?	0600DB0902
Selective Coordination Streamlining System Design	0100BR0801
Mission Critical Circuit Breakers	0600BR0901
NQ Selectively Coordinated Panelboard	1600BR0902
PowerPact™ D-Frame Mission Critical Circuit Breaker Installation	BBV51100
Selective Coordination—NEMA Low-Voltage Distribution Equipment Section	NEMA ABP 1-2010

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