

Breaker coordination: What you really need to know



Selective coordination is an electrical system design practice that improves reliability. The methodology increases uptime by limiting power outages to the branch of an electrical system where a problem occurs without knocking out other areas of the system. When a fault happens, the closest overcurrent protective device opens, either a breaker or a fuse, ensuring that any faults don't cascade upstream.

Breaker coordination refers to the use of breakers specifically—including the latest electronic trip breakers—to isolate electrical problems, stop nuisance tripping and avoid system-wide blackouts. In addition to limiting an outage to the shorted or overloaded branch circuit, breaker coordination makes it easier for electricians to investigate causes of faults, identify underrated or overloaded equipment, and make corrections. Power can typically be restored faster than when upstream breakers are tripped, especially if a panel board has been taken down.

This ABB Management Technology Briefing reviews the regulatory issues and technical challenges related to breaker coordination to help designers understand how system engineers take operational needs, functional requirements (current and future), and safety into consideration.

When critical power fails:

Lost of business, lost of customers

It's difficult to put an exact dollar figure on the impact of unexpected power losses. Most organizations are extremely reluctant to share any information about such failures, but they still sometimes make the news. In recent years data center power failures have temporarily knocked out a number of well-known Internet-based businesses, disabling operations and halting business transactions. Ranging from less than an hour to more than 24 hours, major sites that have gone down include Amazon, Craigslist, Technorati, and Intuit.

A 2011 study by the Ponemon Institute, an independent research organization, found that data center downtime costs over \$500,000 per incident on average, or \$5,600 per minute. Of the 41 data centers that participated in the study, 95% had experienced one or more unplanned outages over the past two years. Downtime costs increase dramatically for enterprises that depend on IT and those that provide online services to customers, such as telecommunication and e-commerce companies. For these companies the cost for a power outage averages \$11,000 or more per minute. Primary failure causes cited in the study were uninterruptible power supply battery failure, accidents/human error, and water, heat or cooling system failures.

In other sectors power failures have disrupted surgical operations in hospitals, stranded rail transit passengers, and even disabled oxygen and water systems on the international space station. In most of these cases backup power systems existed. Those systems simply didn't function properly. Generators failed to kick in. UPS systems failed to operate. Switches faulted. Such incidences, often predictable in retrospect, emphasize the need for frequent system testing and maintenance, especially when facilities or equipment are added or upgraded. Properly configured, breaker coordination provides one more line of defense against unplanned power outages.

Vital load applications

Driving the world's online economy, today's massive data centers often house thousands of servers. These computer systems have zero tolerance for power loss, which is why data centers have some of the world's most technologically sophisticated standby power systems. These systems typically include backup generators, uninterruptible power supplies, and distribution systems that respond instantly if the primary source of power is interrupted.

For these data centers and many financial, government and military applications, as well as chemical and food processing plants, the risks and potential losses that could result from a system failure easily justify any incremental design and construction costs required for selectively coordinating the electrical system. In some applications selective coordination is required by the electrical code.

The National Fire Protection Association's (NFPA) National Electrical Code (NEC®) requires selective coordination where the improved system reliability protects public safety and for emergency management and national security operations. Examples include patient-care areas of hospitals, emergency services, security operations, and water and gas distribution facilities.

From design note to regulatory requirement

As a regulatory requirement, selective coordination has evolved over the past 20 years, most significantly over the past decade. Selective coordination was first required for elevator circuits in the 1993 edition of the NEC. During the 2005 NEC revision cycle, the Code Making Panel elevated selective coordination from a design consideration to a mandatory requirement in Articles 700.27 and 701.18 for emergency and legally required standby systems (see Selective Coordination in the 2011 NEC section). These sections of the code state a number of requirements that are intended to ensure that electrical systems remain operational during catastrophic events, as well as unexpected power losses. The selective coordination requirements apply to both normal sources of power and standby sources.



Prompted in part by the system failures during the 9/11 attacks and hurricane Katrina, the U.S. Department of Homeland Security asked NFPA to add new requirements related to national security, which became a new section in the 2008 NEC edition: Article 708, Critical Operations Power Systems (COPS). Critical operations power systems are defined as those in "vital infrastructure facilities that, if destroyed or incapacitated, would disrupt national security, the economy, public health or safety." It requires selective coordination for these critical loads.

Selective coordination in the 2011 NEC

The National Fire Protection Association has sponsored the National Electrical Code since 1911. The original code was developed in 1897 as a result of efforts by insurance, electrical, architectural, and allied interests. The code requirements are interpreted and enforced by local electrical inspectors as designated by the relevant governing bodies. Inspectors typically are not experts in selective coordination. The electrical system engineer will provide documentation about overcurrent device type, ampere ratings, and equipment settings that bears his or her professional seal verifying that the system is selectively coordinated.

The primary goal of the selective coordination requirements in the NEC is to protect health and safety and maintain operations during national security events and natural catastrophes. Article 517 Health Care Facilities incorporates the requirements of Section 700.27 for hospitals, doctor examination rooms, nursing homes and similar facilities. The specific requirements are: 700.27 Coordination. Emergency system(s) overcurrent devices shall be selectively coordinated with all supply side overcurrent protective devices.

Lacking Breaker Coordination

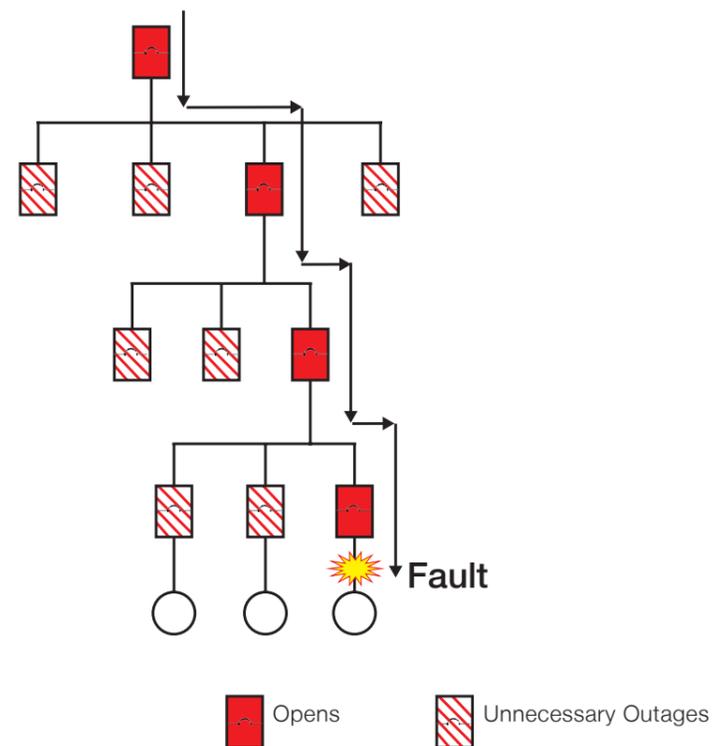


Figure 1. Systems lacking breaker coordination

The example on the left lacks breaker coordination. When a short circuit or overload occurs, upstream breakers are tripped, unnecessarily knocking out circuits and equipment, which also makes it more difficult for maintenance personnel to locate the source of the fault. In the example on the right with breaker coordination, the breaker isolates the fault to the branch circuit where it occurred.

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.

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

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.

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

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With Breaker Coordination

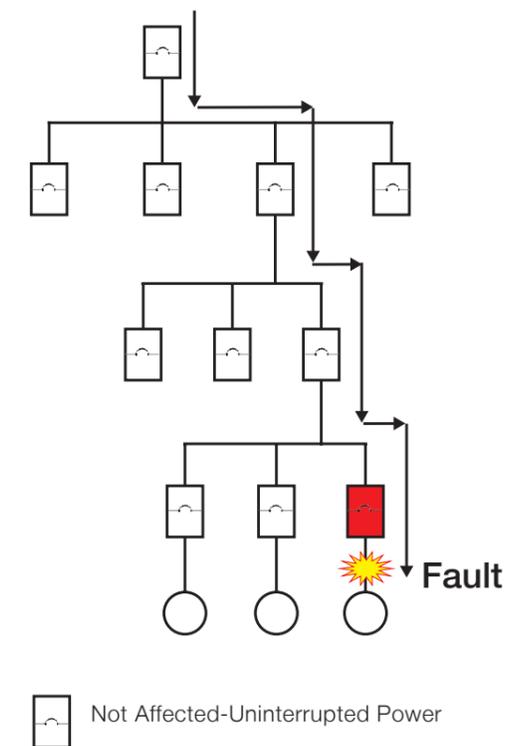


Figure 2. Systems providing breaker coordination

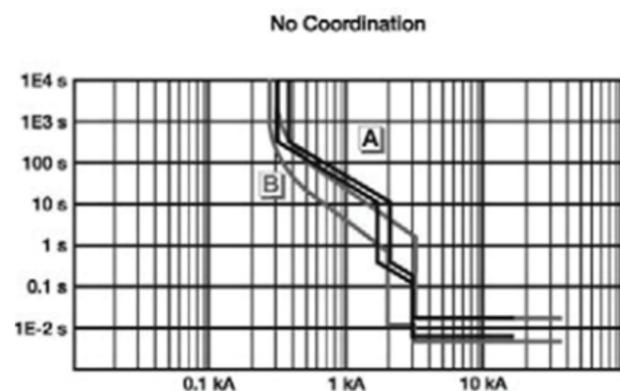
Design guidelines and challenges

Electrical system design requires attention to many details, including the selection of the right circuit breakers to protect people, equipment and conductors. For a selectively coordinated system, when an over-current event occurs at the branch breaker level (CB1), and the event is within the operating characteristics of the breaker, then the branch breaker should interrupt the circuit (open) and the main breaker should remain closed and energized.

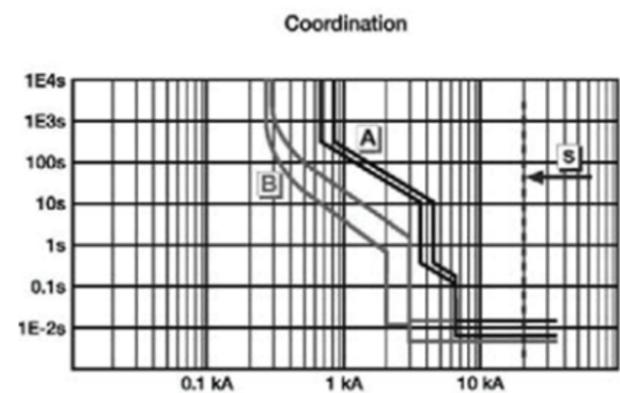
Time current curves aid breaker selection and coordination. The curves show circuit breaker performance characteristics on a logarithmic scale. The time current curve below shows a downstream branch breaker (B curve) and a main breaker (A curve) without coordination. Note that there is no separation between the curves. The branch breaker will react to a fault and the main breaker will also open and de-energize all other downstream circuits.

The chart below is a graphical representation of a downstream branch breaker (B curve) and a main breaker (A curve) with selective coordination. The separation between the curves means that the branch breaker will react to a fault faster while the main breaker remains closed and energized.

For optimum reliability, today's electrical systems require multiple levels of protection. It's not uncommon for selective



coordination to be overlooked during system design and equipment selection. A selective coordination study conducted before equipment installation will determine the proper configuration and show the impact of short circuits and overloads on facility operation. Retrofitting an electrical system to make it selectively coordinated—in response to



changing system and tenant requirements for example—will typically require additional costs and new electrical system components.

Electrical engineers perform selective coordination studies by manually overlaying the breaker curves provided by manufacturers, or by using computer software that helps analyze breaker performance characteristics. Key priorities when making equipment selection decisions include:

- Personnel safety
- Equipment protection

- Rapid problem identification
- Backup protection if any device malfunctions
- Balance between system reliability and cost effectiveness.

If the analysis is focused on device protection because of overcurrent releases, the strategy used to coordinate the devices depends on the rated current and short-circuit current values. The types of breaker specified will vary depending on the application. Options include molded-case circuit breakers, insulated-case circuit breakers with short time-delay options, low-voltage breakers, thermal magnetic breakers, and high performance electronic trip circuit breakers, which can be set so the trip curves don't overlap. The system designer must also consider ground fault protection systems, which can introduce coordination issues.

Generally speaking, there are four types of selectivity: current selectivity, time selectivity, zone selectivity, and energy selectivity.

Current selectivity is based on the observation that the closer the fault is to the power supply, the higher the short circuit current will be. A fault can therefore be discriminated simply by setting a protection device to a limit value that does not generate unwarranted trips. Total discrimination can only be obtained this way in cases where the fault current is not very high or where a component with high impedance is placed between the two protection devices, such as a transformer or a very long cable.

This type of coordination is intrinsically rapid (instantaneous), easy to implement and relatively inexpensive. But, the selectivity limit current is normally low so discrimination is only partial, the threshold setting of the overcurrent protection devices limits the ability to reduce damage caused by short-circuits, and it's impossible to provide redundant protection that provides protection if a device fails.

Time selectivity offers another level of protection. Using this type of coordination, a given current value will trip the protection devices after an established time delay that allows breakers closer to the fault to trip first. The strategy is to progressively increase the current thresholds and the trip time delays the closer one gets to the power supply source. Selective circuit-breakers, often of the open type, must be used to guarantee a sufficiently high short-time withstand current. As with current type selectivity, the study is carried out by comparing the time-current protection device trip curves.

This type of coordination is generally easy to study and implement, and fairly inexpensive. It allows even high limit discrimination levels to be obtained, depending on the short time withstand current of the supply side device and allows redundant protection functions. Drawbacks include the

potential for high levels of energy to pass through, creating the potential for equipment damage. The other circuit-breakers must also be capable of withstanding the thermal and electro-dynamic stresses related to the passage of the fault current for the intentional time delay. The duration of the disturbance induced by the short-circuit current on the power supply voltages can also pose some problems for electromechanical and electronic devices.

Zone selectivity is a further evolution of time coordination. Generally speaking, it is implemented by linking current measuring devices. When these devices detect that the setting threshold has been exceeded, a central supervision system cuts the power supply to the zone affected by the fault. Or, when current values exceed the set threshold, each protection device sends a blocking signal to the protection device higher on the supply side (in relation to the direction of the power flow) and, before it trips, makes sure that a similar blocking signal has not arrived from the protection device on the load side. This way, only the protection device immediately to the supply side of the fault is tripped.

Compared to time-based coordination, zone selectivity reduces trip times and increases safety levels. It reduces the potential for damage caused by the fault and the disturbance to the power supply network. It also reduces the thermal and dynamic stresses on the circuit-breakers and can allow a very high number of discrimination levels. It is, however, more burdensome in terms of costs and in the complexity of system installation. Zone selectivity is therefore used mainly in systems with high rated current and short-circuit current values that require optimum safety and service continuity.

Energy-based selectivity exploits the current limiting characteristics of molded-case circuit-breakers. In this case the energy associated with the load side circuit-breaker trip is lower than the energy value needed to complete the opening of the supply side circuit-breaker. To ensure acceptable reliability, energy-based coordination calculations should be integrated with the current limiting curves and other breaker information. The discrimination level is not limited by the value of the short-time current withstood by the devices.

This type of selectivity is more difficult to implement than the previous options because it depends largely on the interaction between the two devices placed in series (wave forms, etc.) and requires access to data often unavailable to the end user. The advantages of using this type of coordination include fast trip times that become shorter as the short-circuit current increases. This reduces the potential damage caused by the fault (thermal and dynamic stresses) and the disturbance to the power supply system. This approach also allows different current-limiting devices (fuses, circuit-breakers, etc.) to be coordinated, even when located in intermediate positions along the chain.

Equipment selection and final testing

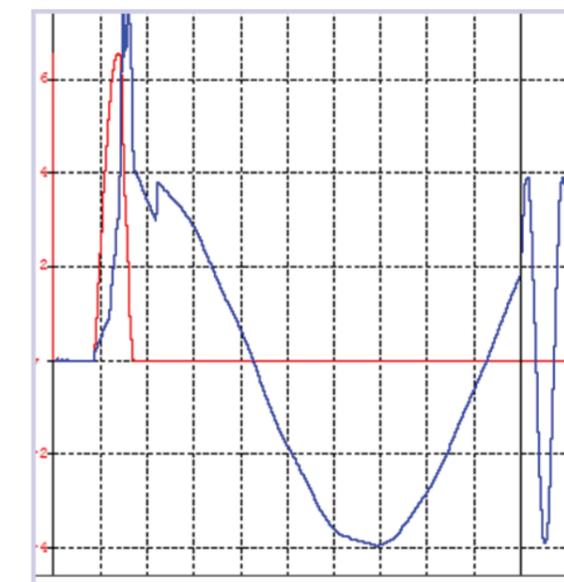
UL defines breaker current limitation as a breaker that interrupts and isolates a fault in less than one-half of an AC cycle, which takes 8.3 milliseconds. A typical zero point extinguishing breaker will interrupt a fault, but it will not isolate the energy. The breaker allows an arc to be present between the open contacts until the AC wave form crosses zero (as long as 8.3 seconds). When the wave form crosses zero, the potential energy is zero and the arc (fault) naturally extinguishes.



Recent improvements in circuit breaker technology has pushed the response time and tripping characteristics of electronic trip breakers to the same level as fuses. With these microcomputer-equipped breakers, a microcomputer is able to take many samples of the current's waveform. The microcomputer then uses these samples to calculate the value of the load current. This allows the breaker to react faster. By design electronic breakers offer increased trip repeatability and accuracy that does not vary depending on the weather or environmental conditions.

Coordination using a current limiting breaker

It should be noted that series ratings are different from coordination ratings. Unlike coordination ratings where the



In this example of selective coordination the graph shows the response to short circuit of 26.8 kA (almost 3X the rated capacity) of an ABB S200 current-limiting breaker (red line). Compared to a zero-crossing breaker, which could require as long as 8.3 milliseconds, the current limiting breaker tripped in 1.7 milliseconds, one-quarter of an AC cycle. The upstream breaker (blue line) never saw enough energy to trip, remaining closed and operational.

branch opens and the main remains closed, a series rated combination is one where both the branch and main breakers open and work together to isolate the fault. The series rating combination of two breakers is equal to the "stand alone" interrupting value of the main breaker. During a short circuit the main breaker will limit the energy to a level that is below the "stand alone" value of the branch breaker.

Competent system designers know that arc flash hazards increase with the current magnitude and the time that current is permitted to flow. Short-time delay settings on circuit breakers can therefore increase arc flash incident energy and potential equipment damage. To prevent this some short-time delay breakers have a maintenance option that can be switched to an instantaneous trip setting when necessary to protect worker safety. In the event of a fault, having a current-limiting touchsafe panelboard, such as the ProLine Panelboard by ABB, also allows technicians to safely perform maintenance on each branch.

Before startup, testing and commissioning of the electrical system verifies that all backup equipment and breaker coordination is operating and has been setup properly. This final step, which should involve in-house maintenance personnel, is essential to make sure that the system provides the anticipated reliability.

Because of the specialized components, analysis requirements and additional installation time, it requires a greater investment to install a breaker coordinated electrical system. Based on the cost impact of unexpected downtime, it's a business management decision to factor the risks and determine whether the incremental expense is worth the enhanced reliability.

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