Selective coordination studies for mission critical environments

Isolating an electrical fault condition to the smallest area possible is essential in providing the most reliable electrical distribution system with maximum uptime for your facility.

BY KEITH LANE, PE, RCDD, LEED AP BD+C, *Lane Coburn & Assocs. LLC, Bothell, Wash.*

Learning objectives

- Learn the basics of protective device coordination studies.
- Know the proper sizing of the transformer primary breaker.
- Understand selective coordination impacts on arc fault.

An unexpected loss of power can have a significant effect on business, especially in a mission critical environment. Isolating an electrical fault condition to the smallest area possible is essential in providing the most reliable electrical distribution system with maximum uptime for your facility. Expensive electronic distribution protection equipment is not worth the extra cost unless a proper protective device coordination study is provided by an experienced electrical engineer.

A properly coordinated system will limit an electrical fault to the nearest upstream protective device. After a one-line diagram of an electrical distribution system is completed and the brand and model of the protective devices are selected, an overcurrent protective coordination study can be completed. Protective devices can consist of both fuses and breakers. Evaluating the merits of choosing to use fuses or circuit breakers is beyond the scope of this article. The primary focus of this article is adjustable trip circuit breakers as the protective device.

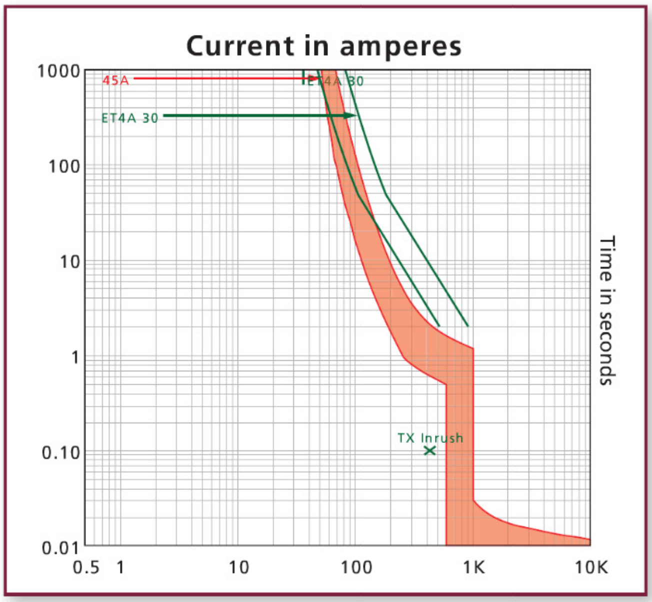

Figure 1: This indicates a 30 kVA transformer protected by a 45 amp circuit breaker. The "Tx" refers to the transformer inrush. The 45 amp breaker curve is represented by the red hash marks. This breaker curve is to the right of the "Tx" ensuring that the transformer inrush will not trip the breaker during system startup. The green curves at the top of the graph represent the transformer damage curves. The breaker should be as far to the left of the damage curves as possible. All graphics courtesy: Lane Coburn & Assocs.

Several parameters can be selected for each protective device. The total number, type, and sensitivity of the settings will depend on the specific device. Adjustment of these parameters allows for what is referred to as "curve shaping." Curve shaping allows for better coordination between upstream and downstream overcurrent protection devices. Below is a list of the common possible parameters.

Continuous current rating

Continuous current rating is often called the current sensor or plug. There are several possibilities:

- **Long-time pickup (long time per unit):** This is the long-time trip setting of the overcurrent protective device. This parameter, also known as continuous amps, is a percentage of the breaker's nominal rating and can typically be set at 20% to 100%. This setting is usually achieved with a thermal overload in a molded case circuit breaker.
- **Long-time delay:** This setting allows for inrush from motors to pass without tripping the breaker. This setting effects the position of the I squared T slope just below the continuous current setting.

■ **Short-time pickup:** This is typically provided with an adjustment of 5 to 10 times. This setting allows downstream overcurrent protection devices to clear faults without tripping upstream devices. It can also be adjusted to allow for transformer inrush current.

■ **Short-time delay and instantaneous override:** This setting postpones the short-time pickup. It can be a fixed setting or an I squared T ramp setting. This allows for better coordination between upstream and downstream devices. An instantaneous override can be set at high current to override this function and protect electrical equipment. The I square T function of the short-time delay can provide better coordination when coordinating a breaker with a fuse.

■ **Instantaneous:** This setting will trip the overcurrent protective device with no intentional delay.

■ **Ground fault setting (ground fault per unit):** This is the percentage of the rating of the breaker for the ground fault setting. Per the NFPA 70: National Electrical Code, ground fault cannot exceed 1,200 amps, regardless of the size of the breaker.

■ **Ground fault delay:** This setting allows for a time delay before ground fault pickup, which allows for better selective coordination between multiple levels of ground fault protection. In addition, the time delay cannot exceed 1 second (60 cycles) for ground fault currents of 3,000 amps or more.

Before beginning a coordination study, the electrical engineer should design a one-line diagram and coordinate with the electrical contractor and/or the equipment provider to determine the actual equipment to be installed. The following are required to provide an accurate protective coordination study:

■ Description, make, and catalog numbers of protective devices

■ Full load current at the protective device

■ Transformer kVA, impedance, and inrush data

■ Available fault current at the protective device

■ Conductor cable information including current carrying capacity and insulation type

■ Protective device design requirements from the serving utility.

It is common to perform complicated electrical protection coordination studies with computer software. These software platforms typically contain libraries that include most of the common overcurrent protective device required settings. Sometimes new device settings have to be developed by the electrical engineer in the software program.

As noted above, with the review of protective coordination study basics, an electrical system's reliability can be assured only if proper coordination is implemented between protective devices. The next portion of this article will review instances where the National Electrical Code requires a protective coordination study and where K-rated transformers are employed to deal with electronics and nonlinear loads can reduce reliability if not properly coordinated.

Using K-rated transformers

On a typical transformer, the current and associated magnetic field is 90 deg out of phase with the voltage. When you close a breaker and turn on a transformer, the instantaneous magnetic field can be twice as high as normal. In an "ideal" transformer, the current required to supply this magnetic field would also be twice as high. However, in a real transformer, the core is saturated and the actual current required to create the field can be 12 times as high as normal. Factors such as the size of the transformers' cores and the time the voltage is applied play roles in determining the amount of inrush current.

The actual inrush current mentioned above is different depending on the actual transformer manufacturer. It is critical to contact the specific manufacturer of the transformer supplied in the field.

Selective coordination in elevators

Selective coordination is required when more than one elevator is supplied by a common feeder, per NEC Article 620-62. Figure 2 shows an example of a coordination study illustrating the feeder breaker overcurrent protection, the elevator fuse overcurrent protection, and the elevator motor start-up curves.

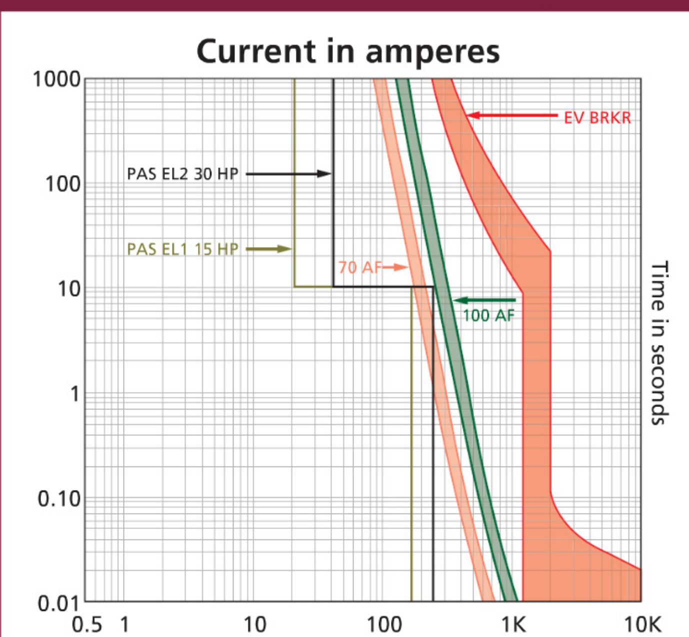

Figure 2: The graph indicates a 200 amp breaker in the main distribution gear feeding an elevator control panel with a 100 amp and a 70 amp fuse. The study must ensure that the two fuses will trip in a fault condition in any one of the separate elevator feeders and will not trip the 200 amp main breaker. A fault in one of the elevator feeders that took out the main breaker would essentially take out both elevators.

If actual transformer inrush data is not known, common industry standard is to assume the inrush is 12 times for 0.1 seconds and 25 times for 0.01 seconds. Figure 1 illustrates the transformer inrush at 12 times for 0.1 seconds.

Electrical engineers were running into trouble some years back when the K13-rated transformer was becoming more prolific in regular office and mission critical facilities. A K13-rated transformer is often just a larger transformer with a smaller rating to compensate for harmonics. The same 110 amp breaker typically on the primary side of a regular 75 kVA transformer may trip when protecting a 75 kVA, K13 transformer. For sizing of the primary side overcurrent protective device for K13 or higher rated transformers, I recommend multiplying the input full load amps of a transformer by 125% and going to the next common size up. In addition, a breaker with the instantaneous setting is often required to allow for the transformer current inrush. As a final step, I recommend a coordination study to ensure the system will work before it is too late, after construction is complete and the engineer is stuck with an angry owner.

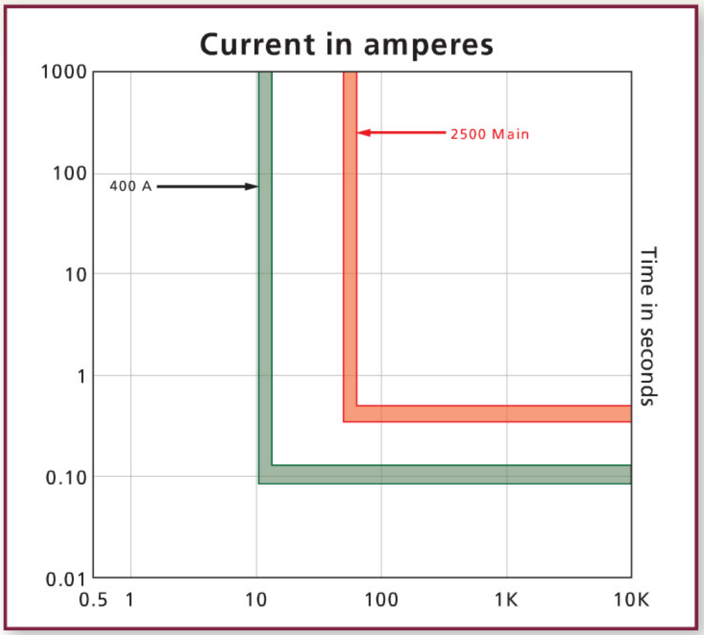

Figure 3: This graph illustrates the ground fault setting for a 2,500 amp main breaker and the ground fault setting for a 400 amp sub breaker. There is clear separation between the ground fault curves. A ground fault on the 400 amp feeder would trip the 400 amp breaker before tripping the 2,500 amp main breaker. If the 2,500 amp main breaker tripped, the entire system would go down, not just the 400 amp feeder.

Understanding the code

To understand the full potential impacts of recent changes to the NEC, it is important to quote the new definition of "selective coordination" and the new codes in sections 100, 517, 700, and 701 as they apply to emergency and standby systems, which are a part of mission critical systems:

NEC 100 definitions – coordination (selective): Localization of an overcurrent condition to restrict outages to the circuit or equipment effected, accomplished by the choice of overcurrent protective devices and their ratings and settings.

NEC 517.26 - application of other articles: The essential electrical system shall meet the requirements of Article 700, except as amended by Article 517.

NEC 700.27 - coordination: Emergency system(s) overcurrent devices shall be selectively coordinated with all supply side overcurrent protective devices.

NEC 701.18 - coordination: Legally required standby system(s) overcurrent devices shall be selectively coordinated with all supply side overcurrent protective devices.

For clarity, it is important to include the NEC definition (Section 100) of overcurrent and the fine-print notes defining emergency systems and legally required standby loads in Sections 700 and 701:

Overcurrent: Any current in excess of the rated current of the equipment or ampacity of the conductor. It may result from overload, short circuit, or ground fault.

A "short circuit" is noted as one of the items that can cause an overcurrent. The typical molded case circuit breaker combination with the upstream breaker somewhat larger than the downstream breaker does not have a problem coordinating in the overload area of the time current curve, but a high level of current in the short circuit area of the time current curve can represent significant problems to selective coordination.

NEC Section 700.1 "fine-print note" (FPN) No. 3: Emergency systems are generally installed in places of assembly where artificial illumination is required for safe exit and panic control … Emergency systems may also provide power for such functions as ventilation, fire detection and alarm systems, elevators, fire pumps, public safety communication, and industrial processes.

NEC Section 701.2 FPN: Legally required standby systems are typically installed to serve loads, such as heating and refrigeration systems, communication systems, sewage disposal, lighting systems, and industrial processes, that, when stopped during any interruption of normal electrical supply, could create hazard or hamper rescue or fire fighter operations.

Arc flash studies

We are seeing more requirements for arc flash studies for critical infrastructure. The amount of arc flash energy levels that can be produced at any point in an electrical distribution system depends on the amount of fault current that is available and the speed at which the overcurrent protective device operates.

The arc flash calculation will determine the amount of thermal incident energy to which an electrician's chest and face can be exposed to at working distances. This energy level is measured in Joules/cm^2 or calories/cm^2.

These calculations are provided to determine the amount of personal protective equipment (PPE) that is required to operate or maintain the equipment with exposed live parts. The flash boundary is the approach distance limit to the exposed live parts during maintenance, operation, or testing. If the electrician is not appropriately protected in this flash boundary, he could receive second-degree burns.

Typically, a fault current study is first performed on a project. The second step is to perform a coordination study to determine the optimum settings of the overcurrent protective devices and protective relays to provide for as much selective coordination as possible. Then as a third step, after the settings of the breakers and relays are determined, the arc flash study is performed. Therefore, settings that provide the optimum separation between the time current curves and isolate a fault to the smallest area possible may actually cause higher levels of arc flash energy.

NEC 517-17 requires that if ground fault protection is provided for the service disconnecting means, then an additional step of ground fault protection shall be provided in the next level of feeder disconnecting means downstream toward the load. Figure 3 is an example of a properly coordinated ground fault study.

Figure 4: This is an aerial shot of the construction of the SABEY Intergate Quincy Data Center Facility. Lane Coburn & Assocs. worked closely with the owner, electrical contractor, and switchgear vendors to ensure proper coordination between all overcurrent protective devices for optimum protection and uptime of the facility.

Ground fault settings

NEC 230-95 indicates that all 480 V, 3-phase services 1,000 amps and over must be installed with a ground fault relay. The setting of the ground fault relay cannot exceed 1,200 amps, regardless of the size of the overcurrent protection device. In addition, the time delay cannot exceed 1 second (60 cycles) for ground fault currents of 3,000 amps or more. There shall be a minimum of 6 cycles (0.1 second) ground fault delay between ground fault devices in health care facilities.

Ground fault settings for main breakers serving downstream motors that are set too low or too fast may trip a main overcurrent protection device before tripping the local thermal magnetic overcurrent protection device during motor starting ground faults. On the other hand, ground fault settings that are too high can cause undue damage before a ground fault is interrupted. It is important to provide the ground fault setting that will not permit nuisance tripping, but will protect the electrical equipment from excessive damage during an event.

It has been my experience that sometimes perfect coordination between a set of devices cannot be obtained. Certain settings may be required on a breaker that could affect the settings of many breakers. In some cases, there may be many levels of breakers that cause overlap of the breaker curves within the tolerance of the curves. In these cases experience will help the engineer make judgment calls as to compromises in coordination between devices. The engineering behind providing protective coordination studies is not a perfect science.

Often, completed projects have no protective device study. In such cases the breaker manufacturer will ship the breakers with all settings set to the most sensitive. This will ensure the most protection but will increase false trips and is typically not good for the reliability and uptime of the systems. As soon as the owner complains of a false trip, the facility personnel will probably set all of the dials to least sensitive. This will reduce false trips, but may not adequately protect the electrical system and reduce selective coordination of the system.

A coordination study is typically required to ensure that the most reliable electrical system has been installed. In addition, there are instances where NEC requires that a study be performed. In either case, the cost of a coordination study is pretty cheap insurance for most installations that would be adversely affected by an extensive power outage. |cse|

Keith Lane is president and CEO of Lane Coburn & Assocs. He is a member of the Consulting-Specifying Engineer *editorial advisory board, and was a 2008 40 Under 40 award winner. Lane has more than 20 years of experience designing, commissioning, and optimizing mission critical facilities.*