Providing circuit protection for safety

When correctly selected and applied, circuit breakers, fuses, and other protection components can help keep workers safe from injuries and machines from damage.

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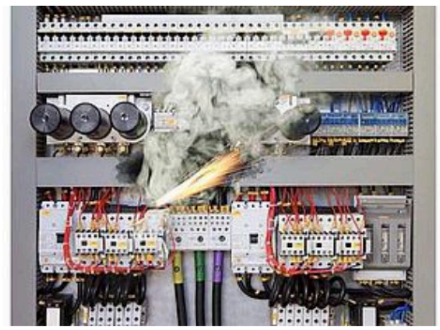

Most engineers, technicians, and factory workers have a story about industrial injuries, such as shock or burns, that occurred on the manufacturing floor. While most incidents happen during construction, maintenance, or testing, they can occur during normal operations as well. There are a variety of scenarios where shock or burn injuries can occur, but most can be prevented by using best design practices and following safe operating procedures.

There are many causes for electrical fires and other incidents, with various prevention methods for each type of problem found in the National Fire Protection Association (NFPA) document, NFPA 70-2017: National Electrical Code (NEC). A big part of electrical safety involves proper circuit protection, which can mitigate problems and reduce their impact.

Electrical protection in all forms is critical for the protection of personnel, but it's often overlooked. Properly protecting a system or equipment is a key step in reducing costly downtime and equipment damages. This article examines common electrical safety scenarios, along with ways to protect personnel and machines (see Figure 1).

Problem scenarios

Proper short-circuit current and overload protection is required to protect against electrical system damages. During construction, an overload could shut down power. During maintenance, incorrect wiring or a misplaced tool could cause these current-limiting devices to activate.

For example, during a construction project, a large circuit breaker in a plant tripped during operation. The breaker did its job, quickly ending a short-circuit condition, but it cut off power completely to an entire building. At the time, it was not known which of the many building loads caused the breaker to trip, so it was difficult to find the source of the problem.

Eventually, the root cause was found to be a shorted brake on a large motor. What made the problem difficult to locate was the load-shedding breakers used to safely limit generator loads by dropping some of the load. These load shedding breakers re-close with a delay, complicating troubleshooting the issue.

While it contributed to the outage, this breaker continued to operate and protected the people and equipment during the troubleshooting and diagnostics process. After the shorted brake was found and repaired, the long-term solution was to coordinate operation of all the breakers so that downstream breakers operate prior to upstream breakers during low-level faults.

Another incident occurred near the end of a week-long, plant-wide outage to perform preventive maintenance on switchgear. As part of the re-energization procedure, final safety testing was done to confirm all the busses and feeder lines were electrically isolated, and not grounded or shorted together. The breakers also needed to be tested to confirm proper insulation integrity.

Even with all this testing, when the main site breaker was closed, it shorted out the switchgear. Later testing revealed someone inadvertently had left a tool in a spot where it vibrated down onto the main breaker and was not visible. Fortunately, a fast, current-limiting breaker activated and contained the incident with only minor damage. Without the current-limiting breaker, the short likely would have resulted in an explosive arc within the switchgear, and possibly personnel injuries from fire or arc flash.

Safeguards from shock and fire

To mitigate incidents like the two described above and others, NFPA 70E-2018: Standard for Electrical Safety in the Workplace provides detailed information regarding electrical safety and many other regulations for electrical wiring and overcurrent protection. In addition, NFPA 79-2018: Electrical Standard for Industrial Machinery, discusses protection of equipment as well.

There are many requirements and guidelines to follow to protect personnel and machines from shock, fire, and other damaging events due to the presence of electrical energy or electrical failures. An overview of some of the many electrical safeguards include:

- Provide a lockable disconnect means
- Interlock doors to disconnect power
- Include safety signs
- Provide overcurrent protection
- Provide surge protection.

This article is a general safety discussion, and it's important to note that there are exceptions to many requirements, with some important details not covered due to space constraints.

Though often overlooked, disconnects on industrial control systems perform the important function of ensuring the electrical feed circuit to a machine or system is completely de-energized to protect maintenance and operations personnel from electrical shock. Regulations require all power to the equipment must be shut off, locked out, and tagged out before servicing. Disconnects provide this functionality.

NFPA 79 requires a disconnecting means for isolating the supply of power to a machine. While this can be as simple as a plug and a safety sign, most machines use other methods. Typical disconnect methods are UL 98-rated fused/non-fused switches or a UL 489 circuit breaker. Usually there is just one machine electrical supply circuit and all power should be switched off by opening the disconnect for this supply. This should be labeled as the "Machine Power Supply Disconnect." If multiple sources of power are present, signs must clearly state the exceptions and the proper procedure to remove power from a machine.

This disconnect should be mounted in or next to the main control system enclosure. If the main control system enclosure contains common ac voltages such as 120 Vac or 480 Vac, or if any voltage greater than or equal to 50 Vac or 60 Vdc is present, the door should be interlocked to the disconnect. To reduce the risk of electrical shock, the door shouldn't open if the disconnect is on unless it is defeated by qualified personnel using a specialized tool.

While a disconnect with a door interlock is the best-practice way to remove the electrical feed from a control panel, other methods such as door locks and keys, and guards protecting personnel from direct contact with hazardous voltages, are allowed. Regardless of the method used to disconnect power or protect personnel, safety signs on the enclosure should define proper procedures for removing power.

Branch circuit versus supplementary protection

Circuit protection is critical to protect a machine from currents greater than the machine's or device's current-carrying capacity. Proper electrical protection is the key to safely removing the effects of dangerous overcurrent due to short circuit, overloads, ground faults, voltage transients from switching surges, and other abnormal conditions (see Figure 2).

To provide this protection, it's important to understand branch circuit protection versus supplementary protection. In general, branch circuit-rated devices protect the wires, and supplementary devices provide additional protection, but they are not sufficient to protect the equipment or load exclusively. Supplementary devices often are used for lower load equipment, internal loads, or as a simple additional disconnecting means.

There are many general requirements, wiring practices, and grounding and bonding techniques to protect machines and personnel. To provide overcurrent protection, branch-circuit short-circuit, and ground-fault protective devices, supplemental overcurrent protective devices are needed.

In general, UL 489-labeled devices provide branch circuit protection, and UL 1077-labeled devices provide supplementary protection, with NEC Sections 100, 430, and 409 providing detailed definitions (see Figure 3). Outside the U.S., there are different, but related, standards.

Most electrical circuits start with branch circuit devices, such as an appropriately labeled circuit breaker or fuse. These devices protect against fire and electrical shock by limiting current flowing through wires and provide a means to remove electrical power during equipment service.

Branch circuit protection does not necessarily protect a load such as a power supply, a PC, or a programmable logic controller (PLC). To provide this protection, supplementary protection fuses and circuit breakers are used. Supplementary protection provides additional equipment protection where branch circuit protection is already provided or not required.

Breakers and fuses

UL 489-rated miniature circuit breakers and molded case circuit breakers often are used for branch circuit protection of feeder circuits downstream from a main disconnect, or for motor circuits. They are available in sizes ranging from fractional amps to about 800 amps, often with miniature form factors, and come in a variety of frame sizes, with 1- to 3-pole configurations.

These devices use thermal and magnetic trip units to trip/open the breaker when either an overload or a short circuit is detected. Overloads are caused by excess current slowly heating wires and equipment. Breakers protect circuits from these dangerous events by sensing the heating effects of an overload condition using the thermal elements of the trip unit. On the flip side, massive damage of a short-circuit fault will occur in a fraction of a second. In this instance, the breaker's trip unit senses this fast change in current via magnetic field sensors and initiates the protective function.

Some breakers include current-limiting designs to provide fast operation during short circuit events. This reduces the let-through energy, which can damage the equipment or wiring. They can have fault current interrupt ratings in the 10 to 100 kA range. Different trip curve characteristics also are available for low inrush circuits such as resistive loads, and for high inrush inductive and other loads. Breakers with these special curve characteristics provide the best protection, and also reduce nuance tripping.

Fuses usually are a more cost-effective method of overcurrent protection. They work well in applications where high fault current exists, and are commonly used to protect transformers, power supplies, and motors. Many branch circuit protection fuses are current-limiting and available with high interrupting ratings up to 200 kA. Fuses are available to meet UL and NEC code requirements and include time-delay and fast acting types. These fuses don't wear out as there are no moving parts as with a circuit breaker, and contamination by dust or oil is unlikely.

A fuse's biggest disadvantage is the need for replacement after operation, unlike a circuit breaker, which can typically be reset. Also, fuses inherently increase the chance of single phasing. Thus, while a fuse protects the system from a fault, equipment can be damaged by a single-phase condition, so key equipment should be equipped with blown-fuse detection phase monitoring devices.

While breakers are becoming more economical and their protection technologies are improving, fuses always have been the gold standard for fast interruption of very large amounts of current. However, many users are willing to pay more for the capabilities breakers provide, especially electronic trip and current limiting, because of the downtime required to replace fuses. The logistics of stocking, finding, and replacing a blown fuse weigh heavily in these cases.

Supplementary protectors comply with UL 1077. They are not built, tested, or certified for branch circuit protection. These devices supplement the branch circuit protection that must already be in place. These supplementary protective devices are specified to protect control circuits, PLC input/output (I/O), contactor coils, relays internal to a panel or piece of equipment, etc. They have much tighter spacing than UL 489 devices, and they also have lower interrupt ratings, usually less than or equal to 10 kA.

Whether it's a circuit breaker or fuse, or branch circuit or supplemental protection, users must pay attention to operating conditions, such as high inrush current, maximum amperage and voltage, maximum short circuit currents, and other factors. Fuses usually offer better protection due to superior current limiting, but they must be replaced after operation, which can increase downtime. Circuit breakers are quick and easy to reset, but even a current-limiting circuit breaker will not operate as fast as a properly sized and selected fuse.

Providing safety from surges

When it comes to shock or fire safety, surge suppression often is overlooked, but power surges cost U.S. companies more than $80 billion a year. Surge protection devices (SPDs) can help prevent these losses by shielding against small power spikes that damage equipment over time and also can provide defense against less frequent but more serious major power surges.

Approximately 20% of power surges come from lightning strikes, while the other 80% typically originate from within a plant or facility from motors starting and stopping, and from other high inductive loads.

While it always has been good design practice to include surge protection, the NEC has been adding areas where surge protection is required. SPDs have been increasingly seen as crucial for protecting emergency systems and equipment. A partial list of areas when surge protectors are now required by NEC 2017 includes:

- **Article 670.6:** Industrial machinery with safety interlock circuits shall have surge protection installed
- **Article 695.15:** A listed surge protection device shall be installed in or on the fire pump controller
- **Article 700.8:** A listed SPD shall be installed in or on all emergency systems switchboards and panelboards
- **Article 708.20:** Surge protection devices shall be provided at all facility voltage distribution levels.

Type 1 surge suppression typically is installed on the line side of a disconnect, protecting equipment from lightning, but can be used anywhere in an electrical circuit. Type 2 surge suppression is installed on the load side, protecting from motor starts and stops, and similar surges. Type 3 surge suppression is installed at the device level, such as in power strips.

These surge devices are selected based on the supply voltage, expected magnitude and rate of occurrence of power surges, and the number of phases in the power circuit. They provide inexpensive insurance from equipment damage.

PLC outputs also should be protected from surges and overloads. Some outputs may have surge suppression built in, which protects the output from inductive loads, but these are not always adequate for many loads, such as solenoids or contactors, so it's good design practice to add suppression at the load as this will lengthen the life of the PLC outputs.

Inductive loads can cause a spike of hundreds of volts, and these high voltages can damage or destroy PLC relay and transistor outputs. To provide protection, a diode can be installed across the output coil to provide a path for the current to flow back through the coil while the magnetic field is collapsing, eliminating the voltage surge. While a simple diode probably is the best option for surge suppression across a dc coil, a variety of surge suppression devices are available to protect against surges from ac/dc loads including varistors, resistor/capacitor (R/C) combos, and specialized transient voltage suppression diodes.

There are more than 800 pages in the NEC, so this article only provides an overview of requirements to keep personnel safe from electrical shock and to prevent electrical fires. Using this information as a starting point and a blueprint, additional details can be filled in from the NEC and other sources to provide the circuit protection needed to ensure safety in an industrial plant or facility. [onlinebyline]

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