Thought leadership
White paper

Eliminate risk by design

How compartmentalized safety switches advance safety through the isolation of line-side power

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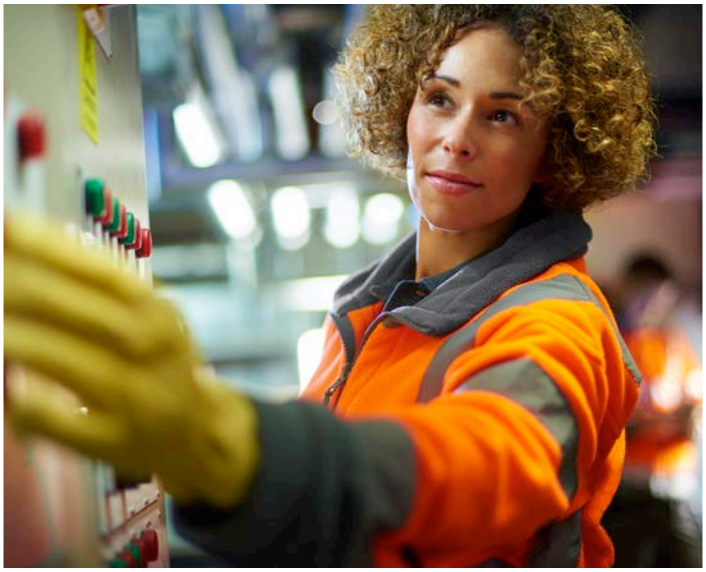


Introduction

Today's zero incident safety culture, especially when it comes to arc flash, demands emphasis on prevention, protection and preparation. As modern industrial environments have become more and more safety conscious, it is a higher priority than ever before to create a safer environment for everyone close to, and working on, equipment.

Although the industry has made great strides in developing codes, standards and solutions to better protect workers and equipment, there continues to be opportunities to enhance workplace safety beyond the existing codes and standards.

Powering Business Worldwide

An enhanced safety switch design to increase protection and decrease risk

According to the most recent Electrical Safety Foundation International (EFSI) data available, there was a 35 percent increase in workplace electrical injuries between 2016 and 2017.

With 2,210 workplace electrical injuries registered in 2017 alone, the industry can do better to minimize personnel exposure to electric current—especially considering contact with, and exposure to, electric voltage maintained its position as the sixth most common type of workplace fatality in the EFSI survey.

The injuries and fatalities caused by inadvertent contact and exposure to electric current are preventable through the following:

- Proper use of personal protective equipment (PPE)
- Training of personnel
- Procedures and instructions
- Visual awareness
- Engineering controls

In an ideal world, people would only work on deenergized equipment. However, that's not always possible, and sometimes powering equipment down causes problems for critical operations.

Delivering safe electrical power has always been a core initiative. Eaton is applying expertise to help customers enhance electrical safety through:

- Education and training programs that demystify codes and standards
- Innovative and expansive portfolio of electrical solutions

This document demonstrates how one of Eaton's most recent innovations—an enhanced safety switch design with engineering controls—can help reduce risk by using National Fire Protection Association® (NFPA) 70E Standard Annex F (Risk Assessment Procedure) to evaluate the inherent danger of common maintenance practices, specifically arc flash.

Safety switches provide vital functionality

Creating a safe environment for personnel close to, operating and working on equipment is essential.

On the most basic level, safety switches are used to open and close a circuit, whether as a disconnecting means for a service entrance or to facilitate lock-out/tag-out procedures for motors and other critical power system equipment.

These solutions have been around for nearly 100 years, but have evolved to provide more robust protection for personnel and equipment.

What the electrical standards say

A disconnecting means (i.e., safety switch) is a necessity in all commercial and industrial applications, per the National Electrical Code® (NEC®), established by the NFPA.

According to NEC article 430.102(B), a disconnecting means must be in sight from all motors and manufacturing equipment. The NEC defines "in sight" as visible and not more than 50 feet from the equipment it controls.

Safety switches (enclosed switches) are required to be tested and meet specific design requirements when listed to the UL® 98 standard and CSA® C22.2 No. 4-40.

Adding a level of protection

Additional levels of protection are designed to prevent injuries and include: PPE, system controls, procedures, training, lock-out/tag-out, etc. Eaton's field experience shows that several layers of protection are not completely sufficient in preventing accidents. It is equally important that new and seasoned workers alike are well versed in proper safety practices and the risk levels associated with different workplace tasks. When a level of safety is compromised, the risk for injury increases. Examples of compromised safety include locking out the wrong breaker, operator inexperience or insulating electrical glove damage such as a pinhole.

The traditional single-door safety switch design includes an interlock that prevents the door from opening when the handle is switched to the ON position. On an energized circuit, throwing the handle to the OFF position removes power from the load side of the switch and allows the door to be opened. When the door is opened, exposed live voltage is still present on the line-side of the switch, even when the handle is in the OFF position. This leaves the operator exposed to live voltage and is an arc flash hazard.

A recent safety switch innovation is the double-door safety switch, which adds an extra level of protection by providing an internal barrier between upper and lower compartments, therefore advancing safety by isolation of line-side power. This revolutionary design protects personnel from line-side power and enhances safety while performing maintenance or testing within the load-side fuse compartment.

New designs also include a viewing window that provides positive visual indication of the position of the switch blades, allowing personnel to clearly see that blades are disengaged from stationary contacts when the switch is in the OFF position. Mechanical interlocks prevent the doors from being opened when the handle is in the ON position and a built-in defeater mechanism allows for user access when the switch is closed.

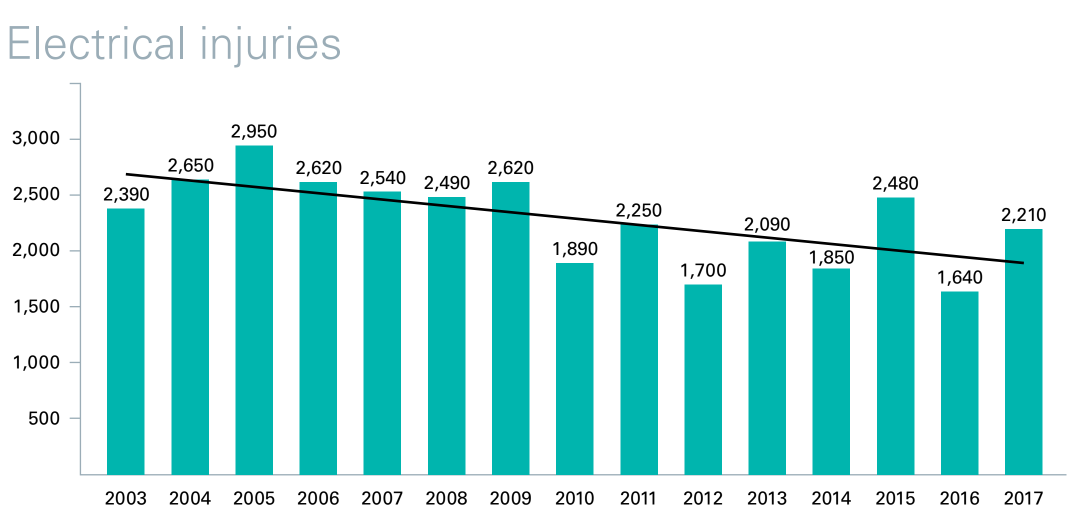
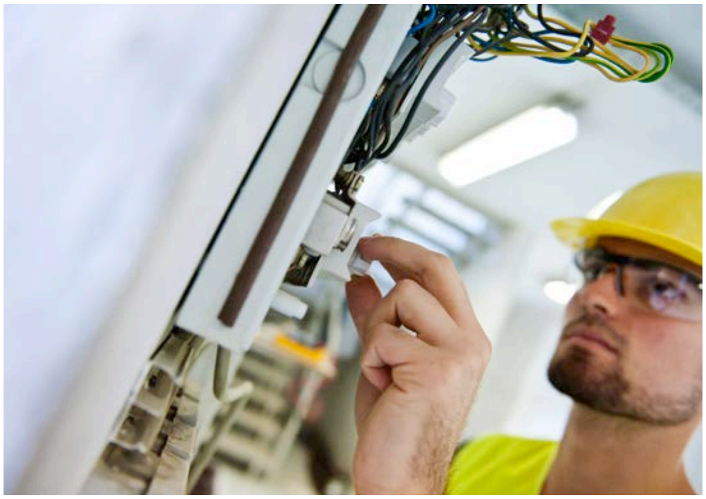


Figure 1. Workplace electrical injuries 2003–2018 (EFSI)

How a compartmentalized safety switch reduces risk by design

The following three scenarios are examples of typical injuries that could be experienced when performing maintenance within the standard enclosure of a safety switch. Risk evaluations for each scenario are completed following the Risk Assessment Procedure as detailed in NFPA Standard 70E Annex F. The risk evaluation totals the frequency, probability and likelihood of avoiding injury as the probability of occurrence. The probability of occurrence is multiplied by the severity to develop a risk score.



Scenario 1

A circuit is showing a fault and a technician is sent to investigate the circuit. The circuit electric power is fed from a fused, single-door safety switch. The technician turns the safety switch OFF, which opens the blades and the door is opened, as shown in **Figure 2**. Although the switch is in the OFF position and the circuit is open, exposed live voltage is present on the line-side of the switch. The technician then determines a fuse has cleared and proceeds to replace it. While removing the fuse, the technician puts his/her hand at the top of switch to gain leverage while pulling out the fuse and the technician inadvertently contacts the line-side power of the switch.

Result: In this scenario, the frequency of a fuse clearing would be between once every two weeks to a year in a large facility. The severity of the technician's actions in this instance is estimated as having substantial risk as shown in **Table 1**.

Scenario 2

In this example, an HVAC unit unexpectedly stops operating and a night maintenance manager, untrained in electrical safety, attempts to troubleshoot. The electric service for the HVAC unit is fed from a safety switch mounted on the unit. The manager turns the switch off, opens the safety switch door and examines using a flashlight—seeing that one fuse is discolored, indicating a blown fuse. The manager then retrieves a spare fuse along with tools and proceeds to replace the fuse. During this process, one of the tools accidentally comes in contact with line-side power of the switch.

Result: In this scenario, the number of times a fuse clears a fault and needs replacement in a commercial building is estimated to be more than once per year. The severity of the technician's actions in this instance is estimated as having substantial risk as shown in **Table 1**.

Figure 2. Safety switch with door open
With a traditional safety switch design, the enclosure door can be opened once a technician turns the safety switch to OFF. Although the switch is in the OFF position and the circuit is open, exposed live voltage is still present on the line-side of the switch.

Scenario 3

An experienced electrician is working late or in a hurry to complete a project. The safety switch is serviced because a fuse needs to be replaced, phase rotation is being switched or load cables are changed. The switch is turned off and the switch door is opened. A minor barrier is in place over the line-side contacts and line-side power is still present. The electrician pushes against the switch and barrier to gain leverage, which breaks the switch or barrier and an electrocution results.

Result: In this scenario, the frequency of an electrician hurrying the work on equipment and inadvertently contacting a switch or barrier is estimated to be greater than once per year. The severity of the electrician's actions in this scenario is estimated as having substantial risk as shown in **Table 1**.

Table 1: Risk evaluation

		Probability of harmful occurrence—Factors					
Scenario #	Hazard	Severity (Se)	Frequency (Fe)	Probability (Pr)	Avoiding (Av)	Total	Risk score
1	Electrical	8	3	3	5	11	88
2	Electrical	8	2	3	5	10	80
3	Electrical	8	2	3	5	10	80

Analyzing the results: How we evaluate risk

When evaluating the risk of events, such as the scenarios described, the most dominant factor is the Severity of the Possible Injury (Se). The more severe the possible injury, the more likely the motivation to modify behavior, change procedures or redesign equipment. It is well understood that electrical energy can cause severe injuries, which leads to the highest Se value of 8.

The Avoiding or Limiting Injury and Damage to Health factor (Av) also had a high impact on the analysis of risk. Contacting energized conductors resulting in shock or initiating an arc event results in a sudden appearance of the hazardous event. Muscle contraction from shock or the rapid expansion of an arc blast makes avoiding injury or possible death impossible if a hazardous event is initiated, which led to the highest Av value of 5 in each scenario.

The other two factors, Likelihood of a Hazardous Event (Pr) and Frequency and Duration of Exposure (Fe), were not given as much weight as the Se and Av parameters. Frequency and Probability are also more subjective measures, which also led to choosing lower values so as not to overstate the impact of the extra level of protection that a safety switch with a double-door design will provide.

The risk scores indicate a substantial risk for each scenario, which warrant establishing safe work procedures and policies, the use of PPE, site restrictions and the application of manufacturer design enhancements that control or reduce the risk.

Now, let’s take another look at each scenario to determine how a safety switch with a double-door design and line-side isolation helps eliminate exposure to live voltages when accessing the fuse compartment.

Figure 3. Double-door safety switch
Double-door line isolation switches are designed with separate interlocked compartments. When the handle is in the OFF position, the bottom door can be opened independently to prevent accidental exposure to line-side voltage.

Revised risk scenarios

The following three examples mirror the same scenarios above, except with the use of the double-door safety switch that separates the line-side power from the fuse connection. The double-door safety switch is shown in **Figure 3**. In these scenarios, the users perform his/her function in the same manner. Both compartments are interlocked so they both may only be opened when the switch is in the OFF position. The line-side power compartment is locked, and the users are only able to access the bottom compartment.

Revised scenario 1

A circuit is showing a fault and a technician is sent to investigate the circuit. The technician turns the safety switch feeding the circuit OFF and opens the lower door, providing access to the fuses. The upper door, which houses the switch mechanism, remains closed, therefore all live conductors are barricaded from the fuse compartment. The technician then determines a fuse has cleared a fault and proceeds to replace it. While removing the fuse, the technician puts their hand at the top of the switch in order to gain leverage while pulling out the fuse. A second door covering the line-side of the switch prevents incidental contact with live conductors or parts.

Result: In this scenario, the frequency of a fuse clearing statistically is between once every two weeks to a year. However, because the safety switch incorporates a design that shields the technician from line-side power, this reduces the severity level by orders of magnitude. As shown in **Table 2**, the severity level was reduced from a significant irreversible injury to a maximum of a minor injury (8 to 1).

Revised scenario 2

In this example, a HVAC unit unexpectedly stops operating and a night maintenance manager, untrained in electrical safety, attempts to troubleshoot by checking for a blown fuse. The manager turns off the switch, opens the lower door and examines using a flashlight—seeing that one fuse is discolored, indicating a blown fuse. The manager then retrieves a spare fuse and tools and proceeds to replace the fuse. During this process, line-side power is shielded by the double-door design and it is impossible for a tool to come into accidental contact with live currents.

Result: In this scenario, the frequency of a fuse clearing in a commercial building is estimated to be greater than once per year. As shown in **Table 2**, risk was drastically mitigated due to line-side isolation.

Revised scenario 3

An experienced electrician is working late or in a hurry to complete a project. The safety switch is serviced because a fuse needs to be replaced, phase rotation is switched or load cables are changed. The switch is turned off and the switch’s lower door is opened while the upper door remains closed. Line-side power is still live, but shielded by the upper door. When the electrician pushes the door to gain leverage, the electrician is protected by a grounded metal enclosure.

Result: In this scenario, the frequency of an electrician in a hurry while working on equipment in a facility and putting a hand on a switch or barrier is estimated to be greater than once per year. As shown in **Table 2**, risk was drastically mitigated due to line-ide isolation.

Table 2: Risk evaluation—Factors revised

		Probability of harmful occurrence—Factors					
Scenario #	**Hazard**	**Severity (Se)**	**Frequency (Fe)**	**Probability (Pr)**	**Avoiding (Av)**	**Total**	**Risk score**
1	Electrical	1	3	1	1	5	5
2	Electrical	1	2	1	1	4	4
3	Electrical	1	2	1	1	4	4

Hierarchy of safety controls

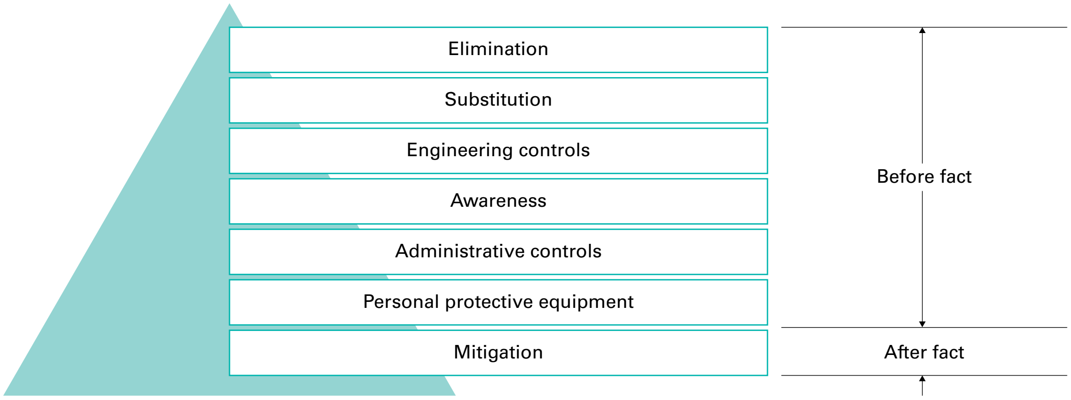


Figure 4. Safety controls
This diagram, taken from NFPA 70E, Annex P, Exhibit P.2 illustrates an existing hierarchy of safety controls.

Analyzing the revised results: How a compartmentalized safety switch design reduces risk

The Severity of the Possible Injury (Se) factor in the risk assessment was reduced from the highest value with the original scenarios to the lowest value in the revised double- door scenarios. Removing exposure to live electrical parts from the fuse compartment reduces the severity risk to 1, meaning only the possibility of minor lacerations and bruises.

The Avoiding or Limiting Injury and Damage to Health factor (Av) also reduced from the highest value with the original scenarios to the lowest value in the revised double-door scenarios by removing possible contact with live electrical parts in the fuse compartment. When accessing the fuse compartment, the likelihood of eliminating or limiting Injury or damage to health is probable.

The other two factors, Likelihood of a Hazardous Event (Pr) and Frequency and Duration of Exposure (Fe), were not given as much weight as the Se and Av parameters. As such, these metrics did not change in the double-door design evaluation.

Frequency and Probability are also more subjective measures, which also led to choosing lower values so as to not overstate the impact of the extra level of protection that the double-door safety switch provides.

As demonstrated through a comparison of **Table 1** and **Table 2**, the scores indicate a substantial risk reduction through the use of a safety switch with a double-door design that isolates line-side power.

A zero-incident culture demands emphasis on prevention, protection and preparation.

Reducing risk through design

Risk mitigation plans should be both comprehensive and easy to understand. One specific feature of the risk mitigation plan should include basic instructions such as work authorization, but any system that can be bypassed should have contingencies for such processes not being followed.

Training personnel can ensure the authorized workers have the skills necessary to understand the danger. However, training can only be as comprehensive as time allows, and not every danger can be conceived and conveyed. An electrical room that has access control is a good example of an engineering control that ensures only authorized personnel may access the equipment. The door may be inadvertently left unlocked and access control to electrical equipment therefore may not always be viable.

Figure 4, taken from NFPA 70E, Annex P, Exhibit P.2, illustrates an existing hierarchy of safety controls. There is a hierarchy of safety controls ranging from the simple to complex. A good mitigation plan should include multiple levels on control and all plans should work toward risk elimination. As shown, elimination of risk by design is often the most difficult level of risk to achieve. Changes in product design include tooling modifications and certification testing that could take several years to implement. As a result of this thorough process, elimination of risk by design can be the most complete method to risk mitigation.

Adding a simple door to cover open circuits within an enclosure seems trivial today, but placing an electrical circuit inside a metal enclosure was an extraordinary step forward when safety switches were first introduced.

Conclusion

A zero-incident culture demands emphasis on prevention, protection and preparation. Though a commonly overlooked element of plant architecture, safety switches will continue to play a pivotal role in protecting equipment and personnel.

Next generation solutions provide a wide range of design innovations that were not always available—creating greater peace of mind and productivity when working on heavy industrial equipment or performing routine plant maintenance.

Following the Risk Assessment Procedure in NFPA Standard 70E Annex F is an industry-accepted method for determining risk, however, the entire hierarchy of risk controls must be implemented to minimize the hazard or risk of injury. Often, a combination of engineered controls is necessary to achieve the desired result.

Eaton's double-door line isolation switch was the industry's first compartmentalized fusible safety switch design. The internal barrier that separates the upper switching compartment from the lower fuse compartment allows operators to access the fuse compartment without exposure to line-side power, providing enhanced safety during fuse replacement.

Additionally, personnel can directly observe the position of the movable blades within the switch base. An external window and enhanced visible blades enable confirmation of whether the circuit is open or closed. Personnel can also clearly see that the blades are disengaged from the stationary contacts when the switch is OFF. Further, an interlocking mechanism keeps the door closed when the handle is in the ON position and the defeat mechanism enables user access when necessary.

The elimination of risk through design and layers of engineered controls can directly create a safer work environment or at least minimize the risk or severity of an injury—which is critical considering the frequency of routine maintenance carried out on live equipment in today's "always-on" environments.

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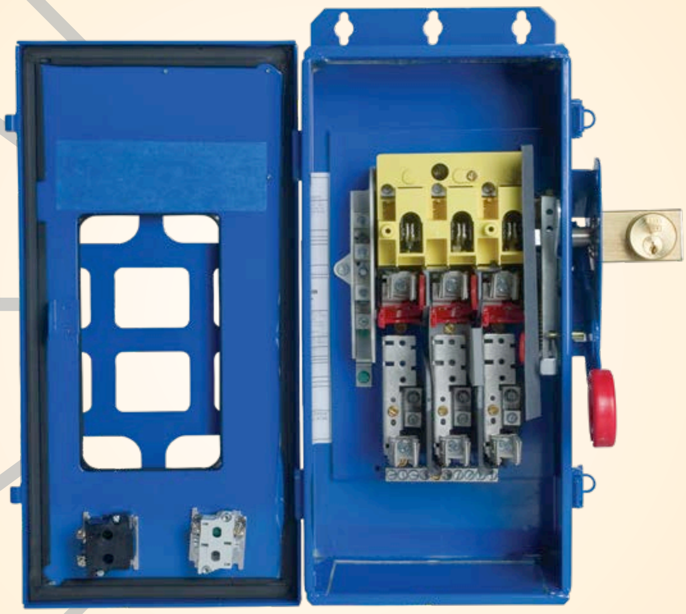

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