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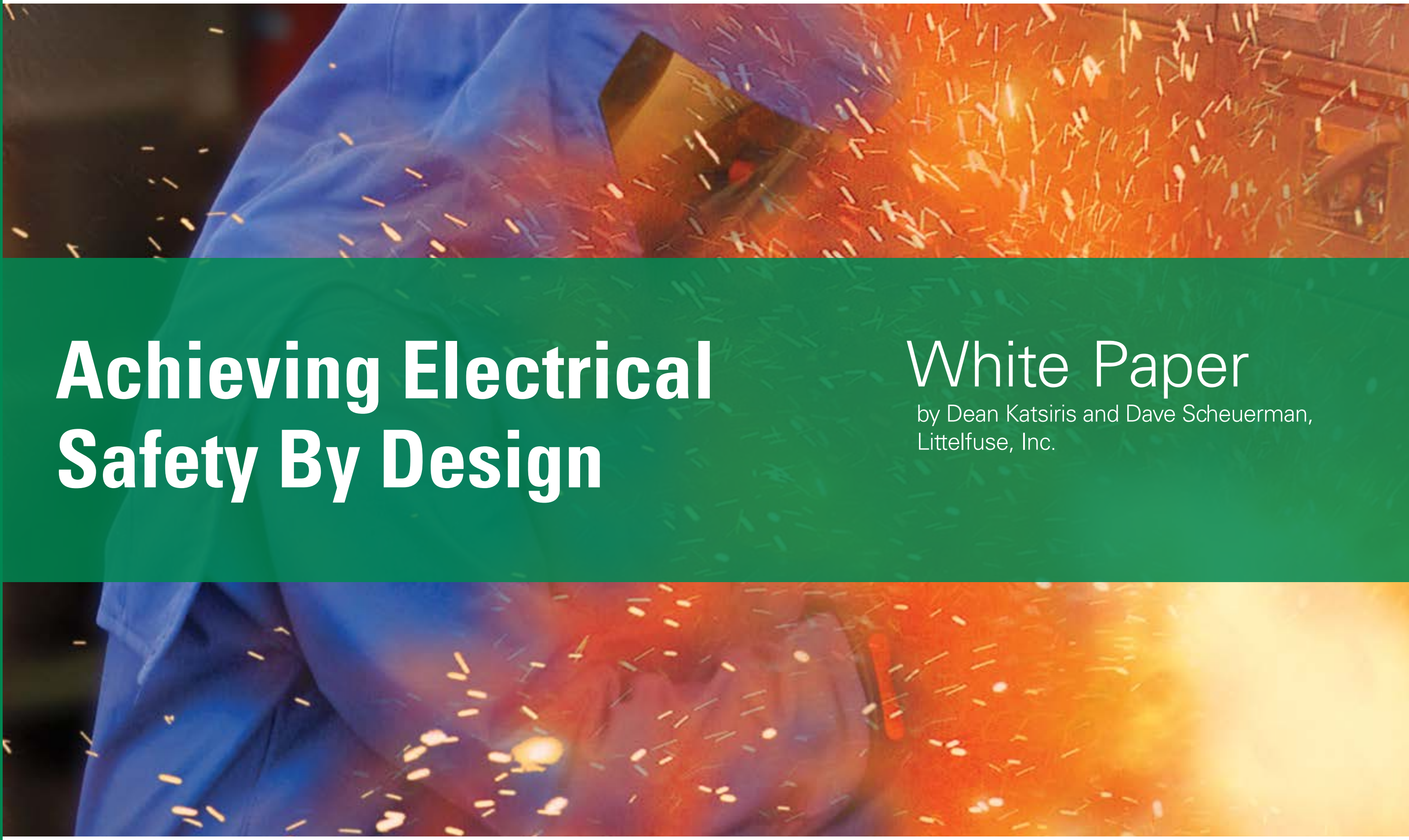

Achieving Electrical Safety By Design

White Paper

by Dean Katsiris and Dave Scheuerman,
Littelfuse, Inc.

Introduction

According to the U.S. Bureau of Labor Statistics, the two most common electrical hazards in industrial environments are electric shock and arc flash. The Electrical Safety Foundation International (ESFI) reports that there were 2,480 non-fatal electrical injuries and 134 electrical fatalities in the United States in 2015. The statistics are especially troubling looking forward. As baby boomers retire and younger workers are hired to learn from and eventually replace them, it's likely that the number of fatalities and injuries will increase without additional mitigation effort. Between 2011 and 2015, the rate of electrical fatalities for workers between the ages of 18 and 34 was roughly twice that for workers 45 to 54 years old and three times that for workers between 55 and 64 years old.

All workers, regardless of age, need to be reminded that while Personal Protective Equipment (PPE) is essential, it is the last line of defense in an electrical hazard. The ANSI Z10/CSA Z1000 Occupational Health and Safety risk control hierarchy lists PPE as the least effective safeguard for arc-flash risk. By far the best approach is to design safety into the plant's electrical system from the start. Cost is often an obstacle to implementing engineering controls to mitigate risk, but electrical incidents have a huge impact on a plant's bottom line both directly and indirectly. OSHA estimates the average electric shock injury costs an employer over $180,000. Furthermore, the American Society of Safety Engineers (ASSE) reports that Liberty Mutual polled executives and learned that for every $1.00 spent on workplace safety, they saw a return of $3.00. Safety is a good investment.

Know the Points in Your Electrical System Where Safety Can Be Designed-In

This white paper discusses implementing the higher levels of the hierarchy of controls, moving beyond PPE and reducing both the risk and incidence of electrical hazards and components that can be designed into an electrical system to make it safer. The Hierarchy of Controls *(Figure 1)* is an accepted evaluation of risk mitigation and we will reference it throughout this paper to understand the components that are effective at each level to design in electrical safety.

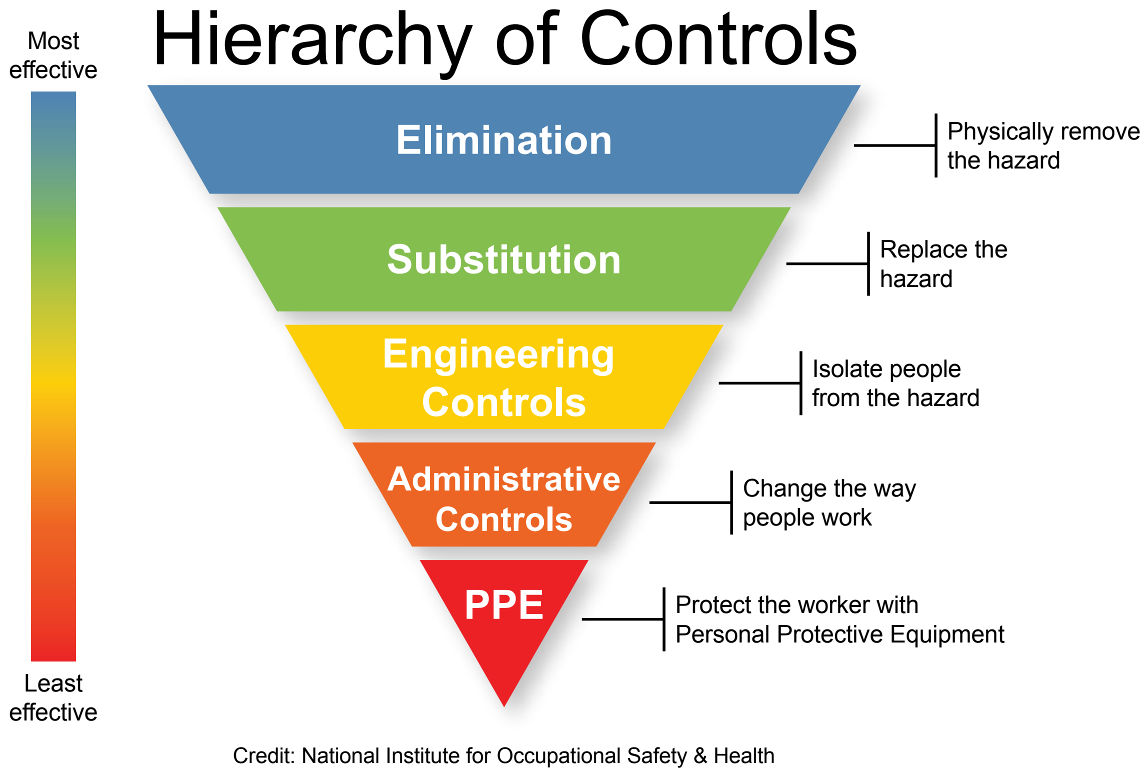

Figure 1: ANSI Z10/CSA Z1000 Hierarchy of Controls

Consider a maintenance worker diagnosing a motor stoppage. They may need to enter an energized panel to determine the cause of the motor trip, exposing them to risk of shock or even arc flash. One way of mitigating that risk is PPE: the worker could wear gloves and arc-resistant clothing. However, as we move up the hierarchy, it is important to note that without Administrative Controls requiring the PPE, ensuring the PPE is in good condition, and detailing the PPE category for the arc hazard, the worker may not use PPE at all or would be at risk of inadequate PPE for the situation. Further Administrative Controls might prohibit working while energized and utilize lock-out, tag-out (LOTO) to prevent re-energizing during maintenance.

Unfortunately, this is where many facilities stop. Administrative Controls and PPE help reduce the risk of injury or death but not the hazard itself. Even the use of adequate PPE only reduces the probability of second-degree burns to 50% in an arc flash. And this assumes the correct working distance, burn time, well-maintained clothing, and no recent material changes that could modify the energy exposure. To use a different analogy of a vehicle, Administrative Controls and PPE are the traffic laws and seat belt, respectively. Yet even when traffic laws are followed and seat belts are used, accidents can still happen and injuries and death, though reduced, can still occur. Vehicle manufacturers are now focused on designing in safety controls to prevent accidents altogether. Seat belts are still important, but are the last level of protection. Risk reduction, incident prevention, and hazard elimination are becoming more important.

Let's take a closer look at the safety control points in the risk hierarchy and what components can be used to design in safety focused on reducing risk, preventing accidents, and eliminating hazards.

Safety Control Points

These safety control points are spread out across a plant's electrical infrastructure, from switchgear to motor control centers and even to specific pieces of equipment such as submersible pumps. While younger workers are at higher risk of electrical injury, older facilities have more potential to have dated electrical equipment in place that may be grandfathered in but is no longer compliant with best safety practices. It may not be practical or affordable to replace whole parts of the system. Fortunately, upgrading key safety components need not be difficult or expensive, and adds significantly to plant safety. Table 1 shows what components can be designed into a electrical system to address the safety control points associated with the Hierarchy of Control.

Table 1: Risk Hierarchy and Components to Design in Safety

RISK HIERARCHY	SAFETY CONTROL POINT BENEFIT	DESIGN IN COMPONENT(S)
Engineering Controls	Reduce Risk of Electrical Shock	Industrial GFCIs
	Limit Arc-Flash Incident Energy	Arc-Flash Relays Current-Limiting Fuses
Substitution	Updating Older Equipment	Current-Limiting Fuses Replace Renewable Fuses Indicating Fuses Electromechanical Relays
	Update Grounding Method	High-Resistance Grounding NGR Monitors
Elimination	Remote Diagnostics to Avoid Electrical Exposure	Bluetooth® Enabled Overload Relays

Risk Hierarchy: Engineering Controls

Reduce the Risk of Electrical Shock

While arc-flash incidents are dramatic and have arguably been the focus of electrical safety in recent years, far more workers are killed each year by electric shock. Arguably one of the most effective ways to protect against electric shock is to utilize a Ground-Fault Circuit Interrupter (GFCI) designed towards the UL 943 Standard. The benefit of GFCIs in improving safety is why GFCIs have been required by Code in every US dwelling built since 1973. Since then, the number of Americans electrocuted in their homes has tracked steadily downward as the number of installed GFCIs has tracked upward at an inverse rate.

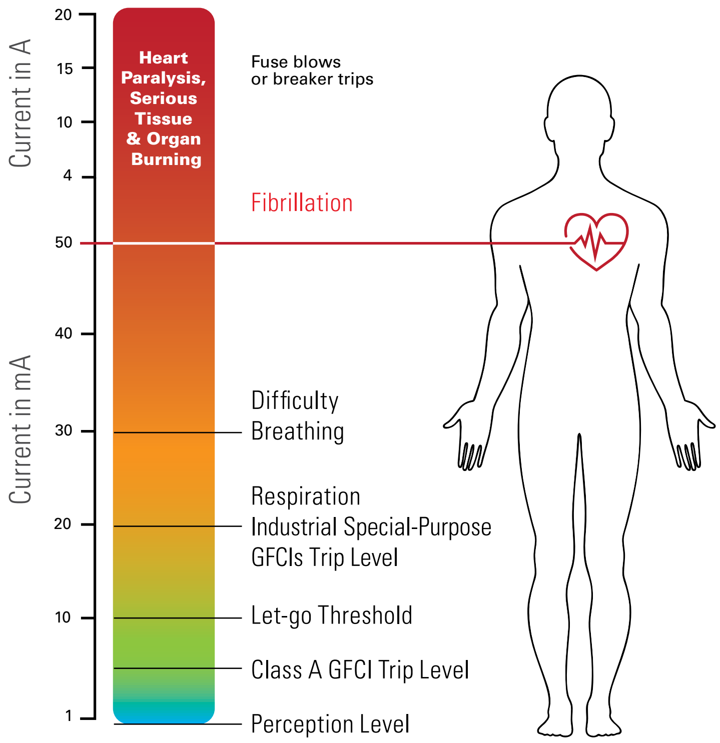

Figure 2: Source: Littelfuse

As shown above, it can take as little as 50 mA of current to put an adult human heart into fibrillation, with potentially fatal results. Even as low as 10 mA, muscle clamping can prevent a person being shocked from letting go of the conductor, trapping them without external intervention to break the circuit. UL 943 Class A GFCIs trip between 4-6 mA (typically 5 mA) in part to remain below this threshold, and this has saved many lives. Unfortunately, industrial leakage currents under normal operating conditions can be near or exceed 6 mA, making Class A GFCI impractical for many industrial applications. Best practices have focused on wearing properly maintained and tested insulated gloves, establishing policies to not work energized (with LOTO), and the use of sensitive ground-fault relays to achieve the lowest ground-fault trip level possible within the limitations of the application.

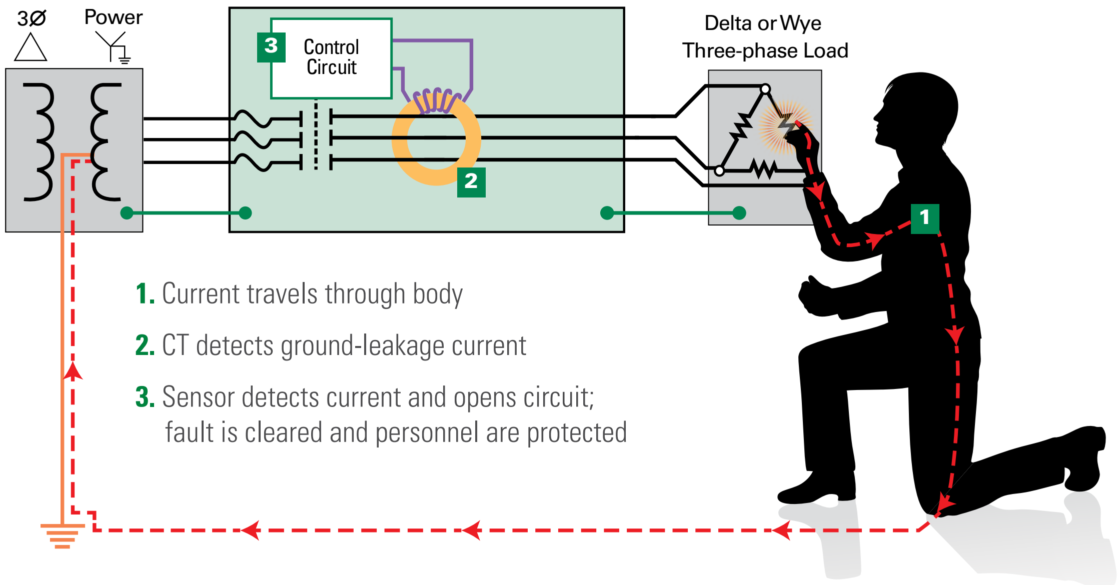

Figure 3: Source: Littelfuse

A GFCI monitors the difference between current in the phase conductors going out to the load and returning through those conductors. Any difference indicates that current is returning through an unintended path (usually through ground and potentially through a person), and when such a current is detected, the GFCI rapidly shuts off the power. A GFCI differs from a ground-fault relay in one vital aspect: a ground-fault relay does not open the circuit directly, but triggers an upstream circuit breaker or contactor to open. As a result, even the fastest and most sensitive ground-fault relays are not classified as people protection because the total interruption time is not tested by the manufacturer to conform to UL 943.

It is important to note that not all GFCIs are personnel protection. The use of the term GFCI isn't regulated and while it implies personnel protection, be careful to check the product is actually tested for that. There are products on the market today that identify themselves as GFCI but have not been tested to or do not meet the applicable standard for personnel protection. Some even refer to the standard in their marketing, implying that they meet or exceed the requirements when they do not. For industrial personnel protection, look for UL 943C listing and/or CSA C22.2 No. 144-M91 Ground Fault Circuit Interrupters, Class 1451-01 (GFCI).

Recently, UL 943C has been developed in recognition of the need to offer a means of protecting industrial personnel from shock while acknowledging that industrial applications have unique challenges and risks. UL 943C creates two new classes of what are now called Special-Purpose GFCIs (SPGFCI), Classes C and D. SPGFCIs differ from household (Class A) units in a number of ways. Aside from the obvious — industrial packaging, operating voltage and availability in three-phase models — the trip level has been moved from 6 mA to 20 mA, providing more flexibility to industrial applications while still operating in the time required by the UL 943 trip curve and protecting personnel. Another key difference for SPGFCIs is that they monitor the ground conductor, and will trip if the ground conductor is discontinuous (i.e. the load loses the low-resistance path to ground provided in the electrical cable). This protects personnel from an ungrounded chassis which could potentially be at full phase voltage as a result of a ground fault.

It is worth noting that for some applications, 20 mA still may be too sensitive (particularly where variable frequency drives are employed). A device similar to a SPGFCI that is not intended for personnel safety but for equipment protection, is called an Equipment Ground-Fault Protection Device or EGFPD. EGFPDs operate on the same UL 943 curve as other GFCIs but have adjustable sensitivity, typically as low as Class A (6 mA) but all the way up to 100 mA. This can allow for sensitivity to be adjusted to the next highest sensitivity above the base leakage current, providing the safest possible environment for personnel in cases where personnel protection at 20 mA is not achievable. Typically, EGFPDs also monitor the ground conductor, but such monitoring is not required.

For more information visit **Littelfuse.com/ShockProtection**

Limit Arc-Flash Incident Energy Levels

It is no surprise that there has been such considerable focus on PPE and Administrative Controls. NFPA 70E (Standard for Electrical Safety in the Workplace), the leading standard dealing with arc-flash risk mitigation, places a lot of emphasis on PPE and labeling, even opting to rename the former "Hazard Risk Categories" to "PPE Categories". Today, there are many options available in both new design and retrofits to reduce arc-flash energy. From designing in a more distributed power system with smaller transformers (thus limiting available energy) to arc-resistant switchgear, to insulated bus bars, arc-flash relays, high-resistance grounding, current-limiting fuses, and instantaneous trips, there are no shortage of options for engineering controls that provide a higher level of safety.

Arc-Flash Relays

A relatively inexpensive and simple way to limit arc-flash incident energy at either the design phase or in retrofit applications is through the use of arc-flash relays. An arc-flash relay (for example, the Littelfuse AF0500 Arc-Flash relay shown below) detects the high-intensity light an arc-flash gives off and rapidly initiates a trip at the circuit breaker. The fastest arc-flash relays available today can initiate a trip in less than 1 ms. As with arc-flash relays, circuit breaker operating times will vary based on model and maintenance, but will typically open in 30-50 ms, fast enough to prevent significant damage and to dramatically reduce the amount of energy, explosive force, shrapnel, fire, and other associated arc-flash hazards.

Figure 4: Littelfuse AF0500

Arc-flash relays are typically used in switchgear, motor control centers, generators (between the generator breaker and the generator), and panels where voltages are greater than 300 V. Optical sensors are mounted in or pass through each cubicle to cover all horizontal and vertical bus bars, breaker compartments, drawers, and anywhere that there is potential for an arc fault. Threading a fiber-optic sensor through the cabinets and in areas where point-sensor coverage is uncertain results in complete coverage and an added level of redundancy. Even if policy is to work on de-energized systems only, all maintenance areas should be monitored to prevent potential damage and additional cost.

An arc-flash relay can be set up as part of a zone-selective interlocking system in which downstream overcurrent protective devices, when tripped, signal those upstream to go into delay mode to prevent power outages from spreading. An arc-flash relay in a cabinet will be connected to the breaker that feeds that cabinet, but it can also be connected to the arc-flash relay in the next cabinet or panel upstream. If the closest breaker fails to trip when signaled, then the arc-flash relay will signal its counterpart upstream to trip its breaker.

As arc-flash relays are increasingly microprocessor-based to add new features and configuration options, a key safety feature is that arc-flash relays have a solid-state redundant trip circuit. This not only provides a measure of fail-safe operation, but provides fast response time on power up in the event that an arc flash is initiated when power is applied to the equipment and arc-flash relay simultaneously. Any device, whether it is a computer, camera, phone, or protection relay, with a microprocessor requires time to boot and initialize the system, and this time can be far too long to effectively trip on power up. A solid state redundant trip circuit provides fast response times even while the microprocessor is initializing.

Many people think of arc-flash relays as suitable for only large electrical cabinets, but this is no longer the case. An arc-flash relay such as the Littelfuse AF0100 makes it easier and more affordable than ever before to put arc-flash protection anywhere. Unlike competing models that can take many hours to install, the AF0100 can be installed in less than 30 minutes, further making it cost-effective for OEMs to design-in safety into their equipment. The wiring ports are clearly marked, allowing contract electricians and less experienced technicians to see quickly how to wire the system. The point sensors will blink to indicate that they are operating. If they are not blinking, the electrical worker can immediately close the cabinet.

For more information see **Littelfuse.com/ArcFlash**

The Danger of Arc Flash

Arc flash is one of the main sources of hazard to electrical maintenance workers. Caused by shorting an energized conductor to ground or another conductor, an arc flash produces a searing burst of visible and invisible light that can cause burns (as well as blindness) in a fraction of a second; a blast wave that can smash equipment, crush a worker's chest or throw him/her across a room; and a burst of solid and molten shrapnel moving at ballistic speed. An arc flash that lasts for ten AC cycles (167 ms) on a 480 V system with 25 kA available fault current releases as much energy as detonating two pounds of TNT.

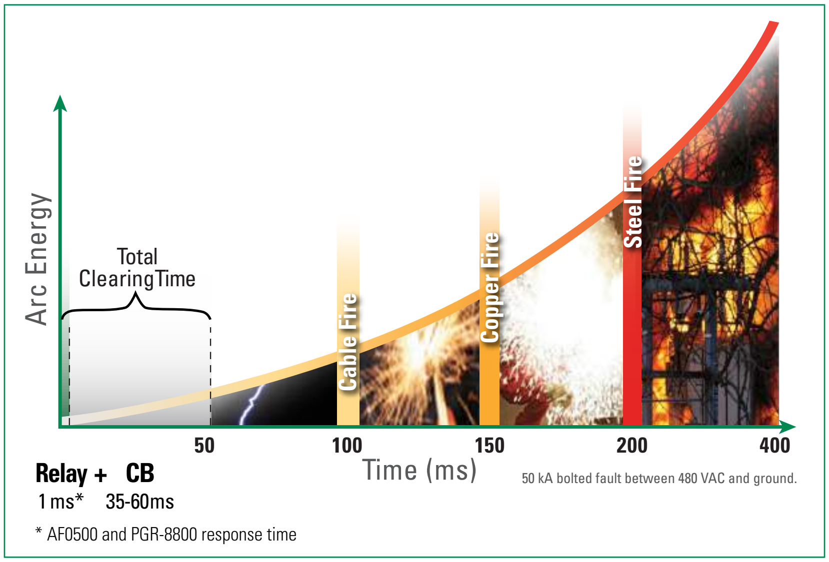

Figure 5: Lifespan of an Arc Flash

The amount of energy released during an arc-flash is a function of time and current. The diagram above plots the energy released during a 50 kA bolted fault on a 480 Volt system. Faster than the blink of an eye (typically 300 ms), copper, cable, and steel catch fire. A low-impedance plasma cloud forms, spreading and engulfing other phases and increasing the total energy of the arc.

Current-Limiting Fuses

Another inexpensive way to limit the current or energy available to a panel during a short circuit is to install a more current-limiting fuse. Because the amount of thermal energy released in an arc-flash is dependent on both the current available and the time during which the arc continues (expressed as I^2t), any reduction to the duration of the fuse's arcing will help in establishing a safer working environment. Consider Table 2 below:

Table 2: Typical Opening Times of Overcurrent Protective Devices

OVERCURRENT DEVICE	OPENING TIME AT 8X RATING	OPENING TIME AT 20X RATING
Current-limiting fuses A	0.1 to 1 sec	8.3 ms or less
Molded case circuit breakers under 600 amps	5-8 seconds	<10 ms B
Molded case circuit breakers over 600 amps	Depends on trip settings: over 5 to 20 sec.	<25 ms B
Large air power breakers	Depends on trip settings: over 5 to 20 sec.	<50 ms=3 cycles B
Medium voltage breakers C	Depends on trip settings: over 5 to 20 sec	<100 ms=6 cycles

A Current-limiting fuses also reduce the fault current.

B When equipped with instantaneous trip units.
If short delay trips are used for coordination, time may exceed 0.2 seconds

C Plus relay time

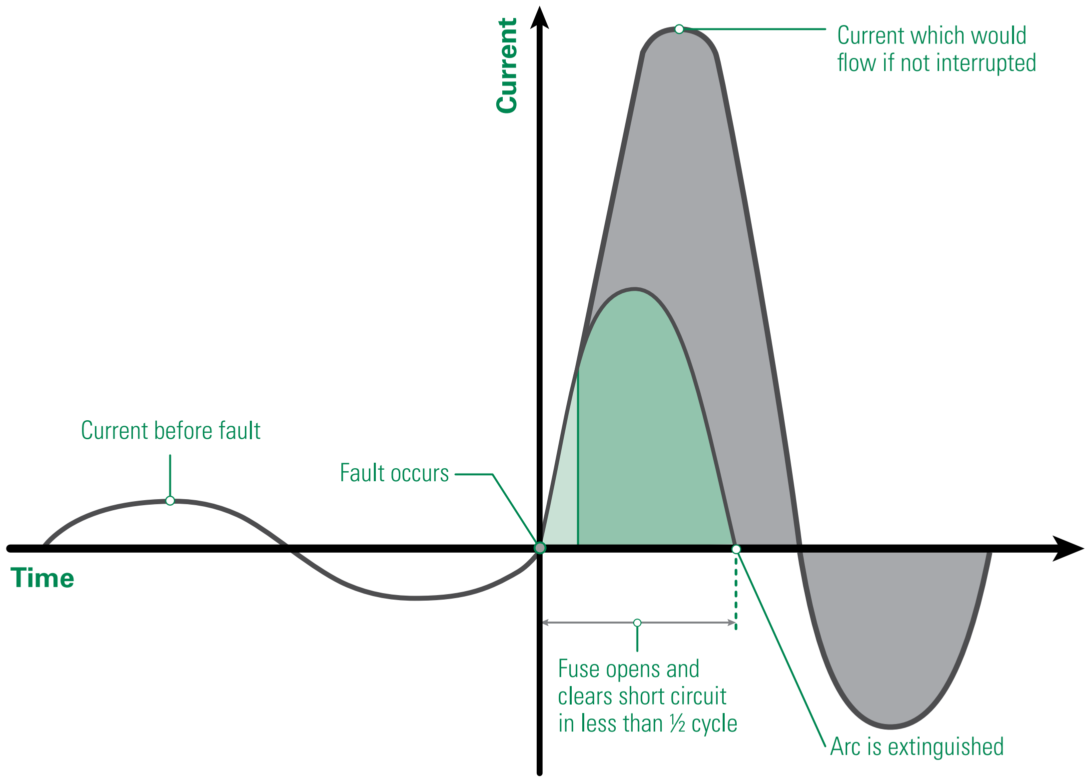

Figure 6: Current Limitation with a Current-Limiting Fuse (Source: Littelfuse)

As shown above, at sufficient current (20x rating), a current-limiting fuse will open in less than 8.3 ms (1/2 of an electrical cycle at 60Hz) which prevents the current from reaching its potential peak. Yet this is not the whole story. An arc capable of doing considerable damage may not draw enough current to cause an instantaneous trip. While it takes 20 times an overcurrent device's normal rating to cause it to open in 10 milliseconds or less, an arc — especially when it first starts — will typically draw much less, yet can still do considerable damage even before growing into a full-blown arc-flash event. Consider that an arc welder delivering just 125 amperes will easily weld together 1/8 inch thick steel. Many overcurrent devices will not open at this level of current – or at least take several seconds to do so – so the solution is to consider installing arc-flash relays. (See *Perform an Arc-Flash Risk Assessment* section.)

Using current-limiting fuses is also a simple way to increase the short circuit current rating (SCCR) of a panel. In most cases, a panel's SCCR is less than the interrupting rating of the panel's overcurrent devices. It is commonly determined by the SCCR of the "weakest link" or lowest-rated device within the panel. But if the panel uses current-limiting fuses in the feeder circuit, its SCCR may be greater than that of the lowest-rated component, which means it's often possible to increase the SCCR of a panel by replacing non-current-limiting overcurrent protective devices with current-limiting fuses. The method of calculating the SCCR when current-limiting fuses are used is discussed in the Littelfuse White Paper *"Using Current-Limiting Fuses to Increase Short Circuit Current Ratings of Industrial Control Panels",* available on the Littelfuse website at **www.littelfuse.com/sccr.**

A further, slightly less simple step is to replace a molded-case circuit breaker with a fusible disconnect switch equipped with current-limiting fuses. Not only can this increase the SCCR of the panel at little cost, but workers will appreciate not having to open the panel to turn off the power. Thinking back to the Hierarchy of Controls, this is an example of using current-limiting fuses not only as an engineering control but as a substitution of one control for a safer and more effective one.

Perform an Arc-Flash Risk Assessment

NFPA 70E *(Standard for Electrical Safety in the Workplace)* states that every workplace should perform an arc-flash risk assessment. This can help to identify the arc-flash hazard at each electrical panel or piece of equipment. An arc-flash hazard study may have been done in the past, but if it is more than a couple of years old it is probably out of date, both because the standards have changed and because the facility itself has probably changed. Note that the hazard level for each cabinet or panel will change with revisions to the electrical system.

After the assessment, equipment with arc-flash hazards may be mitigated by adding an arc-flash relay, current-limiting fuses, and/or with a maintenance mode setting on a motor or feeder protection relay. These are easily and affordably retrofitted into existing panels, avoiding the cost of replacing major equipment, such as new arc-flash resistant switchgear. Moreover, they provide Engineering Controls that, when combined with appropriate PPE and Administrative Controls, result in much more effective risk mitigation and a safer work environment.

Know your risk. The recent *Occupational Injuries from Electric Shock and Arc Flash Events* report prepared by NFPA and UL estimates 5 to 10 arc-flash explosions occur in electrical equipment every day, just in the US alone.

Risk Hierarchy: Substitution

Replace Renewable Fuses

Renewable fuses such as the ones shown on the right have not been permitted for new applications since 2005, yet they can still be found on the storeroom shelves in many facilities. For those unfamiliar with this antique technology, a renewable (or UL Class H) fuse consisted of a fiber tube with metal end caps that unscrewed to reveal a metal element (usually made of zinc). When the element opened due to an overcurrent event an electrician was supposed to replace it with another of the same kind. Of course, there was no way to keep the person doing the work from installing the wrong element, or installing two elements instead of one to keep the fuse from opening again, or even installing a piece of heavy wire because no replacement element was on hand. Also, repeated blowing caused metal vapor to condense on the inside of the tube, which could eventually result in a flashover and fire when the fuse opened again. In addition, the connections between the end caps and the element tended to deteriorate with time, which could lead to localized heating and cause nearby insulation to deteriorate. Finally, renewable fuses have limited interrupting ratings of just 10,000A and are not considered current-limiting per UL Standard 246-7 (4).

Renewable fuses should be replaced with modern fuses wherever they are found. Current-limiting fuses, discussed in the previous section, are the appropriate replacement choice. As with replacing a molded-case circuit breaker, we move further up the Hierarchy of Controls into Substitution, replacing a poor form of engineering control with a more effective and safe one.

Littelfuse Renewable Fuses
Courtesy Littelfuse Archives

Install Indicating Fuses

Conventional fuses have a significant drawback: a blown fuse looks just like a good one. If a fuse blows, a worker must get into the panel and use a voltmeter to determine which fuse is open. This troubleshooting often takes place while the power is on, exposing the worker to the risk of shock and arc flash. Resolving this issue requires taking the time necessary to select the appropriate PPE for that panel before then metering all the fuses to identify which fuse has opened. A better solution is to substitute older fuse designs with newer indicating fuse designs or indicating fuse holders to take advantage of all the safety advantages that both products offer.

Littelfuse Indicating Fuse Holders

Littelfuse Class J Indicating Fuses

One commonly-used type of indicating fuse has a window in the side that turns dark when it clears the circuit or blows. Others have a pin that extends from the end of the fuse when the internal element opens; the pin can trip a switch to provide a remote indication. Note that this type of fuse (with pin indication) cannot be used in a UL Listed branch circuit, but can only be a supplementary fuse with branch circuit protection provided upstream.

Indicating fuse holders, such as the Littelfuse LF Series shown above, typically have lamps or LEDs that glow when the corresponding fuse(s) open. Other fuse types with blown fuse pin indication will often be installed in a way to send a signal to a control system once the fuse blows. That signal can notify a PLC or relay to open switches on other phases to increase safety and to prevent motor burnout.

For more information see **Littelfuse.com/Fuses**

Substitute High-Resistance Grounding: Eliminate Arc Flash on the First Ground Fault

For both older facilities and for newer ones, an excellent way to reduce arc-flash hazard and prevent unnecessary downtime is to install a high-resistance grounding system. The majority (95%) of electrical faults begin as ground faults, and so improving the safety of the electrical system when a ground fault occurs has a significant effect on the overall system safety.

Three-phase power systems for distribution in an industrial facility will either have the transformer secondary wye-connected, with a central neutral often connected to ground, or ungrounded (delta connected), with no connection to ground.

Delta-Connected System

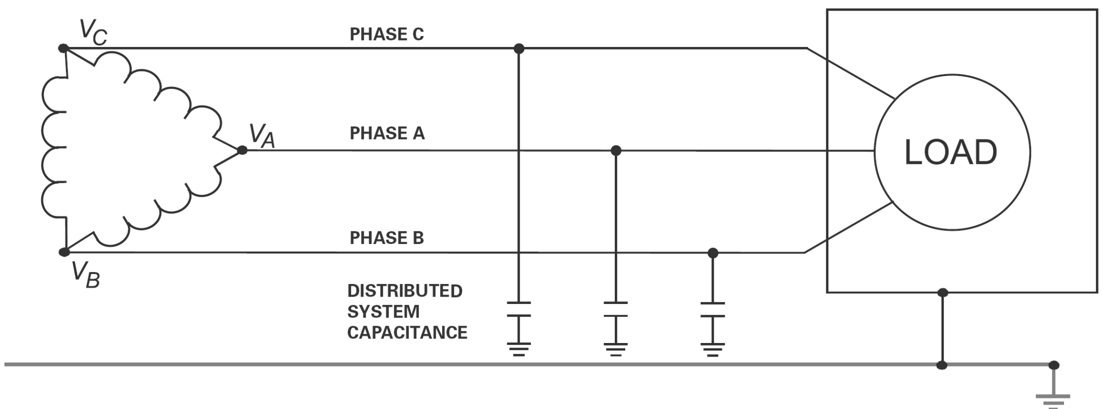

Figure 7: Ungrounded Electrical System

Wye-Connected System

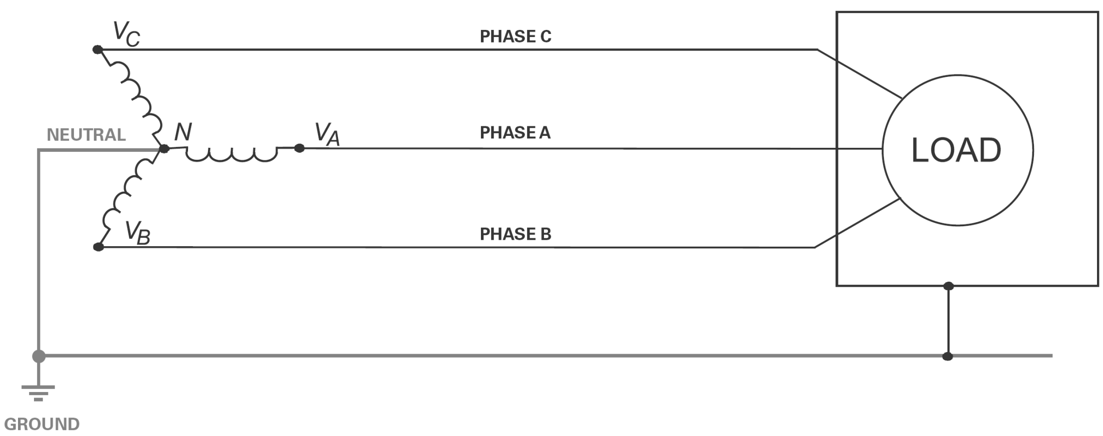

Figure 8: Solidly Grounded Electrical System

If one of the phase conductors in a wye-connected system shorts solidly to ground or to another phase it will draw a very large current and activate the overcurrent protection device upstream, shutting down all the loads on the system. If the fault is higher impedance, such as an arc flash, the overcurrent protection device may trip in its long or short time, or in some cases not at all, resulting in very high arc-flash incident energy.

High-Resistance Grounded System

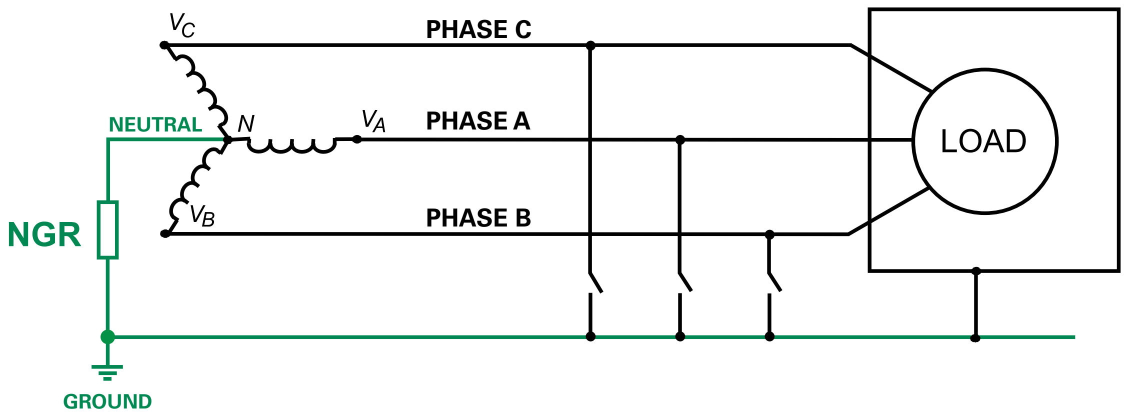

Figure 9: High-Resistance Grounded System

An increasingly popular way to boost both uptime and safety is to convert either system to a high-resistance grounded (HRG) system, in which the neutral is connected to ground through a resistor, as shown in *Figure 9.* The value of the neutral-grounding resistor (NGR) is chosen so that if one phase shorts to ground the fault current will be limited to a low amperage (typically 5 or 10 amps), which will not trip the overcurrent protective device and allow the system to remain in operation. Moreover, it has already been stated that the majority of electrical faults begin as ground faults. Considering the Hierarchy of Controls, at such low fault currents, HRG systems bring us to the most effective means of risk mitigation by eliminating the risk of an arc flash on ground faults. It must be remembered that phase-to-phase faults (or a second ground fault on a different phase, which is effectively a phase-to-phase fault) can still result in an arc flash. For this reason, all the preceding arc-flash mitigation techniques are still recommended but when used in combination with high-resistance grounding provide a safer system design.

Ungrounded Systems

If one phase of an ungrounded (delta-connected) system shorts to ground, no ground-fault current will flow, and the system will continue to operate *(see Figure 7).* For this reason, many process industries such as textile factories, oil refineries, steel mills, etc. have historically used ungrounded systems.

This big advantage comes at a price with a list of serious disadvantages that affect both safety and productivity. Plants that do not need to shut down on a ground fault may be tempted to continue operating longer than needed with the ground fault present on the system. During a ground fault, the voltage on the unfaulted phases rises relative to ground, adding stress to the system insulation, degrading it and leading to more and more faults over time. A second ground fault on a different phase is effectively a phase-to-phase fault, which could result in an arc flash. If one of these faults is intermittent or arcing, that can lead to a hazardous condition known as transient overvoltage where the system's inherent distributed capacitance charges and builds voltage that may be six times the nominal system voltage before a catastrophic breakdown.

Finally, locating a ground fault in an ungrounded system can be quite difficult due to the lack of ground-fault current. Typically, operators must shut down individual sections of the plant until clearing the fault in order to narrow down the location, consuming valuable time and stopping production repeatedly.

Ungrounded AC systems are required to have ground fault detectors installed by the National Electrical Code® (NEC®) Article 250.21(B) and the Canadian Electrical Code® Part 1, Section 10-106 (2). It is still common to use three lights to indicate voltage on each phase. A ground fault on one phase turns that phase light out and because of the increased voltage on the other two phases, brightens those lights. This system is heavily dependent on personnel being proactive when spotting a dark light. An improvement to this system, the EL3100, is available from Littelfuse and provides the phase lights, but also has a contact to connect to an alarm or SCADA system and alert operators to the problem.

Resistance grounding protects a system against transient overvoltages caused by arcing ground faults and it provides adequate fault current for selective ground-fault detection and coordination. If permitted by code, a high-resistance grounded system can maintain continuity of service for process industries. Practical considerations (and in some jurisdictions, code requirements) limit these “alarm only” systems to HRG systems below 5 kV and with a limit of 10 A or less on ground-fault current.

Delta-connected supplies and wye-connected supplies with inaccessible neutrals cannot have neutral grounding resistors (NGR’s) directly connected to them; however, resistance grounding can be achieved on an ungrounded system by establishing an artificial neutral with a zigzag transformer.

A zigzag transformer is a six-winding, three-phase transformer that is wye-connected with a pair of series connected, phase-displaced windings symmetrically connected to each phase. It can be used to establish an artificial neutral for a three-phase system by connecting its neutral point to ground through a NGR. During normal operation, the only current that flows in the zigzag transformer is an extremely small magnetizing current. When one phase is grounded, the NGR and the zigzag transformer provide a path for ground-fault current to flow.

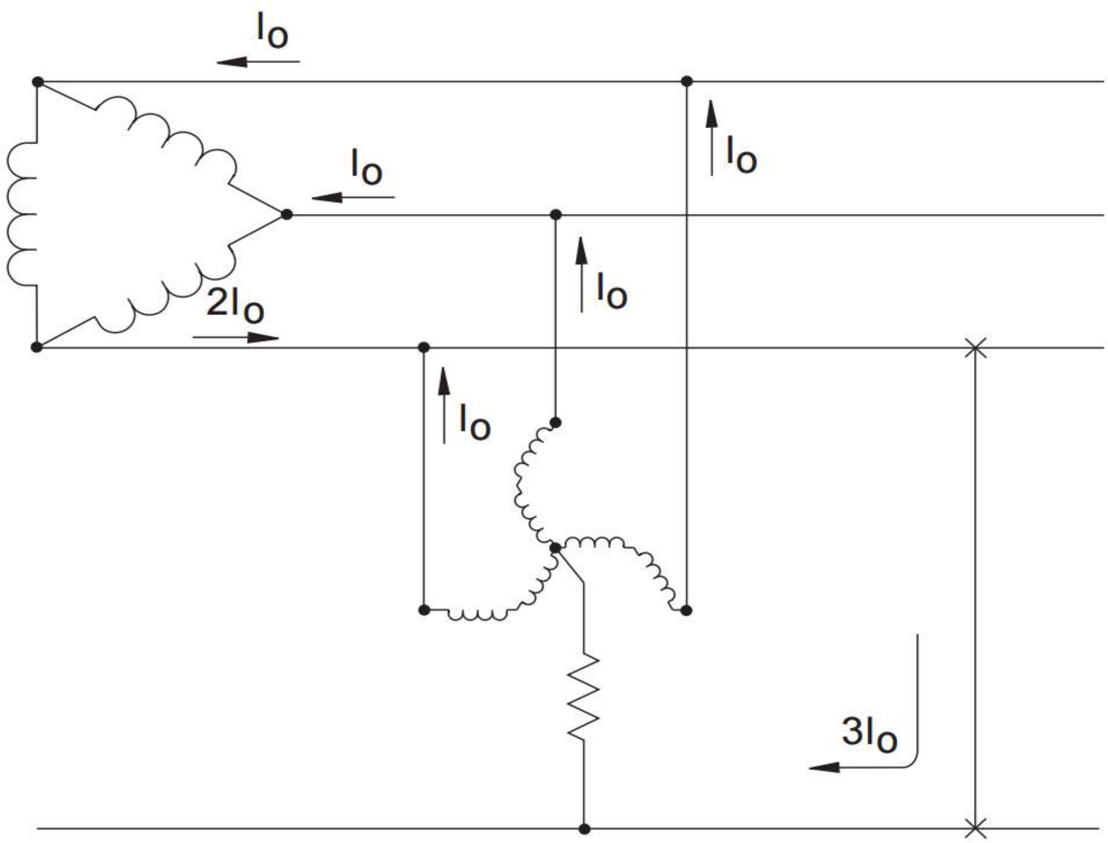

Figure 10: Creating a neutral using a zigzag transformer *(taken from Tech Note RG-12)*

Solidly Grounded Systems

Today, the most common system grounding method is directly grounding the secondary neutral on a wye-delta transformer. Unlike ungrounded systems, substantial ground-fault current will flow on the first ground fault. This eliminates the risk of transient overvoltage on the system and allows for quick location of ground faults, two of the principal disadvantages of an ungrounded system.

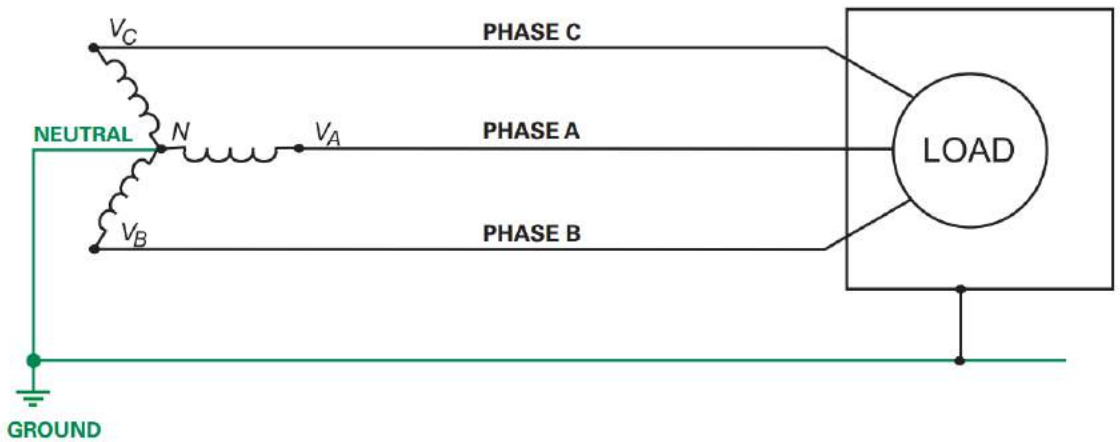

Figure 11: Solidly Grounded Transformer

On the other hand, when a ground fault occurs, high point-of-fault damage and an arc flash can result because power available to the fault is limited only by the system and fault impedance. In some generator applications, the potential ground-fault current is greater than the short-circuit current. Given that ground faults are the most common electrical fault, the high fault current of a solidly grounded system is a significant disadvantage and safety concern. Also, ground-fault voltage, which is equal to the product of the fault current and the ground impedance, can exceed 100 V when a high fault current is available.

The greatly reduced ground-fault current of a resistance-grounded system does not require rapid ground-fault trip times. In tripping systems, the ground-fault relay furthest downstream can be set to operate quickly, on a definite-time basis, and moving closer to the source (upstream), additional delays can be added. The relay closest to a fault will trip first, providing the ability to quickly locate or remove a ground-fault and keep the rest of the system running until the faulted equipment is repaired.

Resistance grounding is typically applied to three-wire systems. If a four-wire system is resistance grounded, the distributed neutral conductor, which is always at zero potential on a solidly grounded system, will rise to line-neutral voltage during a ground fault. To resistance ground a four-wire system, either use a 1:1 isolation transformer where line-neutral loads are used, or convert line-neutral loads to line-line loads. In Canada, the Electrical Code CEC Part 1, 10-1102, allows the use of NGRs on four-wire systems, provided that the neutral conductor is insulated to the system voltage, and a shorted phase-to-ground, a shorted neutral-to-ground, or an open NGR causes the system to de-energize.

In industrial facilities with three-phase three-wire resistance-grounded systems, equipment such as variable frequency drives and UPSs may have filters at their inputs. These filters must be rated to withstand the elevated line-to-ground voltage that occurs during a ground fault. The filters on many modern VFDs are rated to handle this voltage; however, verification of this is recommended. If transient voltage surge suppressors (TVSS) are used, they must be rated for line-to-line voltage to ground.

High-Resistance Grounded Systems

In a resistance-grounded system, the neutral point is connected to ground through a neutral-grounding resistor (NGR) used to limit current. The NGR resistance is small enough to provide the stability of a solidly grounded system and large enough to limit ground-fault current. Since the NGR limits current available to the fault, point-of-fault damage is minimized, ground-fault voltage is controlled, and the risk of an arc flash caused by a ground fault is eliminated. In some applications, electrical codes allow a resistance-grounded system to continue to operate with a ground fault until critical processes or batches are completed and maintenance can be scheduled at a convenient time.

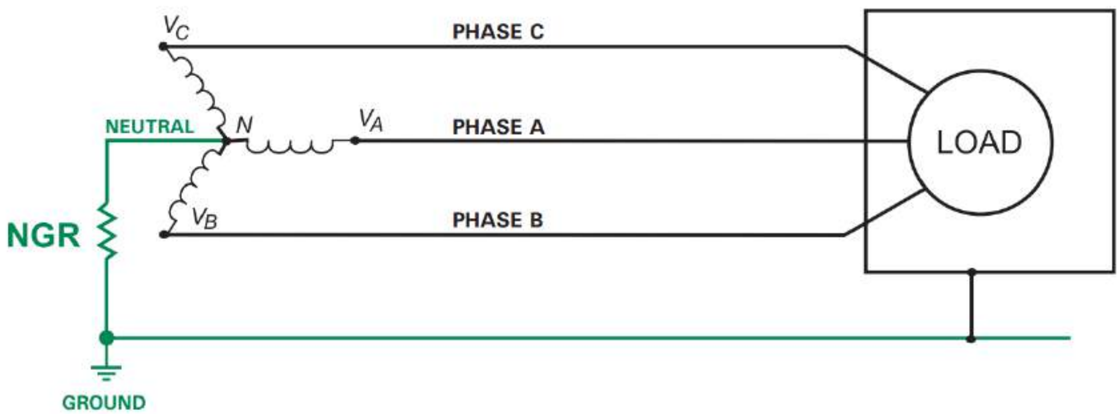

Figure 12: Resistance-Grounded Transformer

Fault Monitoring in an HRG System

An HRG system may remain online when a ground fault occurs, so how do you find out when it happens? While there are several manual methods, the simplest answer is to use a current-sensing ground-fault relay just as would be used on a solidly grounded system. However, it's important that the ground-fault relay used on a HRG system is sensitive enough to detect faults as low as 10% of the NGR let-through fault current. The use of ground-fault relays also make it possible to utilize selective coordination.

The main disadvantage of resistance grounding is that the resistor does, like an incandescent light bulb, have the potential to fail over time. Just like a light bulb, neutral-grounding resistors fail open, resulting in the entire system becoming ungrounded.

One could schedule periodic inspections and other checks to make sure all the NGRs in a facility are working properly, but these are labor-intensive, require shut down, and may result in a long time where the system is unknowingly floating. Inspections also introduce further electrical exposure to personnel and the potential for the inspector to forget to reconnect an NGR after testing it.

Littelfuse NGR Monitors

Once again, a dedicated instrument solves the problem — in this case a continuous NGR monitor, which will alert immediately any time an NGR opens.

For additional information about monitoring neutral grounding resistors, read our whitepaper, *Monitoring Neutral-Grounding Resistors - An Update*. Go to Littelfuse.com/Technical Resources and look in the Relays and Controls Technical Center.

Risk Hierarchy: Elimination

Use Remote Diagnostics to Avoid Opening Panels

It may not be obvious, but the Industrial Internet of Things (IIoT) holds promise for electrical safety. As experienced maintenance professionals and electrical technicians retire from the workforce, the younger workers who replace them have less skill with hand tools and wires, and less familiarity with safe work practices. If electrical equipment can communicate its status to workers via the IIoT or wirelessly, then there will be less need for workers to enter electrical panels and be exposed to arc flash and shock hazards.

Bluetooth®-enabled devices, such as a Littelfuse® MP8000 motor protection relay, allow workers to interact with electrical equipment using a smartphone or tablet. This technology replaces the need to probe around a live cabinet with an amperage meter or voltage meter. Rather than open the panel door, a worker need only to open the app, select the piece of equipment that is of interest, and all the fault history and set points are available at the touch of a finger.

The range of Bluetooth® allows for interaction at a safe distance. For outdoor panels, the technician can remain sitting in his truck instead of having to get out to open a panel. In rain, snow and other inclement weather, this can also help him avoid shock hazards. The Bluetooth® interactivity can also aid troubleshooting as a technician can stand by the motor to troubleshoot or monitor its status instead of having to be all the way over at the panel. This is especially of benefit when trying to obtain real-time feedback during a motor restart.

Bluetooth®-enabled relays increase safety in another way. The worker does not need to read the hazard label on the electrical panel, see what PPE is required, walk to the locker, put on the PPE, and walk back to the panel. When the panel door stays closed, it doesn't matter if hurried workers are tempted to skip these steps, or skip some of the bulkier PPE, because no PPE is required.

Workers find that controlling an electrical device via a smartphone app is more intuitive than scrolling through a display on the device, navigating step-down menus and cryptic fault codes, reducing the risk of incorrect configuration or misunderstanding of the system status. Also, a Bluetooth®connection—with its one-to-one device pairing—may be more secure than a wi-fi network or the cloud.

Remote communication has long been available with some motor-protection relays, ground-fault relays and arc-flash relays. By communicating to the network, these devices enable a technician to remotely monitor the health of connected motors, pumps and other devices for worn insulation, ground faults, leakage current and excessive heat. The challenge is that it is inconvenient for the worker to walk to a terminal connected to the factory network to access the device's information. Ideally the information is available on the worker's tablet or smartphone.

An example is the Littelfuse MP8000 smart motor protection relay (below), which can communicate to a technician's smart phone via a Bluetooth® connection. The worker can see important fault information and troubleshoot energized equipment while remaining safely outside the electrical enclosure.

For more information about the Littelfuse MP8000 go to **Littelfuse.com/BluetoothRelay**.

Littelfuse MP8000

Summary

This paper used the Hierarchy of Controls to walk through some of the safety control points where components can be used to control, substitute, and even eliminate electrical risk in a facility. Upgrading components such as current-limiting fuses, arc-flash relays, industrial GFCI, and Bluetooth® enabled relays to design in safety need not be expensive and the return on safety investment is well worth it. Workers and business owners need to be reminded that while PPE is essential, it is the last line of defense in an electrical hazard. Even one incident can cost more than the price of the component upgrade, so there is no excuse for not considering it. Working together we can make electric shock and arc-flash injuries in industrial environments, much less common. The best way to reduce risk of injury from electrical hazards is to design in safety from the start.

Dean Katsiris
Product Manager, Protection Relays
Industrial Business Unit, Littelfuse, Inc.

Dean Katsiris is Product Manager for Protection Relays at Littelfuse and holds bachelors' degrees in Electrical Engineering and Computer Science from the University of Saskatchewan. Over the past decade, he has worked in a variety of roles at Littelfuse including research & development and sales. Dean is an IEEE member.

Dave Scheuerman
Technical Training Manager
Industrial Business Unit, Littelfuse, Inc.

Dave Scheuerman is the Technical Training Manager at Littelfuse, responsible for Littelfuse University and all aspects of training in the Industrial Business Unit. He holds a Bachelor of Science in Electrical Engineering from Purdue University, and for more than 26 years has worked in a variety of sales and marketing roles at Littelfuse. Dave is a member of IEEE, NFPA and IAEI.

For more information, visit
Littelfuse.com/safetybydesign

Additional technical information and application data for Littelfuse protection relays, generator and engine controls, fuses and other circuit protection and safety products can be found on **www.littelfuse.com**. For questions, contact our Technical Support Group **(800-832-3873)**. Specifications, descriptions and illustrative material in this literature are as accurate as known at the time of publication, but are subject to changes without notice. All data was compiled from public information available from manufacturers' manuals and datasheets.

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