

Arc Flash Mitigation

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Executive summary

Arc flash events can result in significant injury to workers, including severe burn injuries. The most effective arc flash safety programs are not those that rely on worker training, warning signs, and Personal Protective Equipment (PPE) but those that look to incorporate “safety by design” or other mitigation techniques. This paper reviews those design choices and engineering controls which help to minimize the arc flash hazard.

Introduction

An *arc flash hazard* is defined as “A dangerous condition associated with the possible release of energy caused by an electric arc.”¹ An *arcing fault* (or short-circuit) is one where short-circuit current flows through air rather than on a solid connection between phases or from phase to ground. Because of the high levels of fault current and relatively high voltages typically associated with electric power distribution systems, these arcing faults carry high levels of energy, releasing a great deal of heat and pressure into the environment – one can think of the resulting arc flash as an electrical explosion.

Arc flash events can result from inadvertent contact with energized parts, contamination, equipment failure, or a number of other causes. The resulting heat and pressure wave can cause significant injury to workers, including severe burn injuries. In the worst cases, the injuries are fatal. The heat and pressure can also cause significant damage to the equipment within which arcing faults occur. Dense power infrastructures with high levels of potential energy, such as those found in data centers and electrical substations, present prime conditions for arc flash. The industry’s increasing awareness of the dangers of arc flash has brought more attention to safety standards.

NFPA 70E-2012, the *Standard for Electrical Safety in the Workplace*, is the primary industry consensus standard in the US that addresses arc flash safety. It contains extensive information on safe work practices, analysis procedures, requirements for documentation and equipment labeling, and PPE selection principles intended to allow for workers to be appropriately protected against arc flash hazards. IEEE Standard 1584-2002, *IEEE Guide for Performing Arc flash Hazard Calculations*,² contains an empirical calculation model that can be used to quantify arc flash hazard levels on power systems operating from 208V – 15kV. NFPA 70E does not necessarily require that a customer perform arc flash calculations using the IEEE 1584-2002 calculation methods, but since doing such a study is the only way that the potential impact of arc flash mitigation solutions can be evaluated, it is the recommended option.

Increased awareness of arc flash hazards and years of research into the phenomenon led to increasingly stringent regulations in the late 1990s and early 2000s. In the decade or so since, the understanding and awareness of arc flash and related hazards has increased greatly among electrical workers, engineers, and safety personnel. But while much attention has focused on the need for system analysis and the selection of appropriate Personal Protective Equipment (PPE), the application of product or design solutions intended to reduce the hazard levels or mitigate the risk of arc flash events has received relatively little attention.

The most effective arc flash safety programs are those that do not rely on worker training, warning signs, and PPE but also look to incorporate “safety by design” or other mitigation techniques. This paper will provide information on a number of methods that have been successfully applied in arc flash mitigation projects.

Analysis and labeling

Section 130.3 of NFPA 70E-2012 requires that a customer perform an Electrical Hazard Analysis, including an evaluation of both shock and arc flash hazards, when workers are going to be exposed to energized equipment operating at 50V or more. Section 130.5 allows for arc flash PPE to be selected based on either an incident energy analysis (e.g., a study done according to IEEE 1584-2002), or through use of tables in NFPA 70E that define PPE requirements based on specific work tasks being performed for various classes of equipment.

¹ NFPA 70E-2012, Standard for Electrical Safety in the Workplace, National Fire Protection Association.

² IEEE 1584-2002, IEEE Guide for Performing Arc Flash Hazard Calculations, Institute of Electrical and Electronics Engineers, Inc.

While the use of the tables appears to be simple, the computational requirements are almost as lengthy as a full incident energy analysis. Footnotes defining the applicable ranges for fault current and arcing fault clearing time must be evaluated at each piece of equipment to ensure it falls within the table's maximums. Further, the PPE requirements defined in the NFPA 70E tables are fixed. Once they are determined, they may not be reduced even if steps are taken to reduce the level of hazard at that point in the system.

The incident energy analysis calculates the severity of the arc flash hazard at various locations in the system based on the available fault current and the arcing fault clearing time. Determining these parameters requires collection of a great deal of information on the system, including cable sizes and lengths, transformer and motor nameplate data, etc. Even for facilities with up-to-date one-line diagrams, this can be a time-consuming task. But once the data is gathered and a model of the power system is constructed, it can be used to calculate accurate arc flash hazard levels at various points in the system and also to evaluate the impact of potential system changes (e.g., upgrading of protective relaying) on the calculated hazard levels.

Arc flash incident energy levels are generally measured in terms of calories per square centimeter (cal/cm^2), and are calculated at a certain distance (such as the typical "working distance") from a piece of equipment, as the hazard level varies with distance. Incident energy levels above $1.2 \text{ cal}/\text{cm}^2$ are considered to be sufficient to cause 2nd-degree burns on exposed skin, so arc-rated PPE is required above this level. Arc-rated PPE is commercially available up to $140 \text{ cal}/\text{cm}^2$, though many facilities or employers restrict work at locations with more than $40 \text{ cal}/\text{cm}^2$ available. Available arc-rated clothing includes shirts, pants, coveralls, flash suits, face shields, arc hoods, etc. The clothing is typically either treated cotton (more common for lower ratings) or arc-rated synthetic fabrics (e.g., Nomex). For more details on selecting PPE, see NFPA 70E³.

Regardless of the analysis method chosen, NFPA 70E-2012 130.5(C) requires that equipment be labeled to advise personnel of information sufficient to select PPE appropriate for the location, including either the required PPE level or available incident energy level. The labels required by NFPA 70E provide more information than those required by Section 110.16 of the National Electrical Code⁴, which simply require that equipment be marked to warn of the presence of a hazard. An example of a Schneider Electric arc flash information label meeting the requirements of NFPA 70E is shown in **Figure 1**.

Figure 1
Sample arc flash
information label

Arc Flash Information	
Category	Use this information in accordance with applicable OSHA standards, NFPA 70E, and other required safe electrical work practices.
0	
18 inches Flash Protection Boundary 1.2 cal/cm² Max Incident Energy at 18" Working Distance Category 0 PPE Category (Per NFPA 70E-2012)	
480 V Shock hazard when cover is open 42 inches Limited Approach 12 inches Restricted Approach 1 inch Prohibited Approach	
} Per NFPA 70E-2012	
Eqpt Name: LP8	Q2C: 12345678 Date: 10/26/11
Values produced by a Schneider Electric engineering analysis. Any system modification, adjustment of protective device settings, or failure to properly maintain equipment will invalidate this label. For more information, contact Schneider Electric at 1-888-778-2733. <small>Copyright © 2011 Schneider Electric All Rights Reserved</small>	

³ IEEE 1584-2002, IEEE Guide for Performing Arc Flash Hazard Calculations, Institute of Electrical and Electronics Engineers, Inc.

⁴ NFPA 70-2011, National Electrical Code, National Fire Protection Association

Mitigation strategies

Arc flash mitigation involves taking steps to minimize the level of hazard (i.e., the potential severity of an incident) and/or the risk (i.e., the probability that an incident will occur) associated with an arc flash event. ANSI Z10-2012, *Occupational Health and Safety Management Systems*⁵, defines a hierarchy of mitigation controls as follows, listed from least- to most-effective:

- Personal Protective Equipment (PPE)
- Administrative Controls (work policies & procedures)
- Warnings (including awareness training)
- Engineering Controls
- Substitution (of less hazard materials, processes, etc.)
- Elimination

While PPE, administrative controls, and warnings are required for every facility and make up essential parts of electrical safety policies and practices, they are the least effective mitigation techniques. PPE, in particular, is often mistakenly viewed as the “solution” to arc flash hazards – the belief sometimes being that if a worker is wearing a flash suit (adequately-rated or not), then they are equipped to work anywhere, anytime. The reality is that even when PPE is properly selected, it does not guarantee freedom from injury – NFPA 70E only makes the claim that injuries sustained during an arc flash event would be “reduced” and “survivable” due to mitigating effects of arc-rated PPE. Most electrical workers would hope to do better than to sustain a “survivable” injury!

Using the other techniques is may be much more effective. Completely eliminating a hazard (e.g., banning asbestos in new construction) is most effective, but may not always be possible. In facilities where electrical loads are present, electricity cannot be eliminated nor can an alternative energy source be used as a substitute. Engineering controls, which involve application of devices or design techniques to mitigate the arc flash hazard, may not be as effective as substitution or elimination, but they are considered more effective than PPE because they seek to reduce the degree of hazard, and are considered to be more effective than administrative controls and warnings because they often do not rely solely on workers following proper procedures and safe work practices. Engineering controls occupy the “sweet spot” for arc flash mitigation and will be our area of main focus in the remainder of the paper.

Engineering controls

Device selection and settings

Per the equations in IEEE Std. 1584-2002, arc flash incident energy varies linearly with time - i.e., double the duration of the arcing fault and the available energy doubles; halve the duration and you cut the energy in half. As a result, proper selection of overcurrent protective devices - in particular, selecting devices that will quickly clear arcing faults from the power system - is a powerful mitigation strategy. Since incident energy is proportional to arcing time, the use of faster-acting devices is key.

Current-limiting fuses act very quickly when the fault current levels are high enough to cause the fuse to act in its current-limiting region, but application of fuses for arc flash reduction requires some careful consideration. First of all, not all current-limiting fuses are created equal. Both class RK-1 and RK-5 low-voltage fuses are current-limiting. RK-1 fuses are the more current limiting of the two, so arc flash levels downstream of RK-1 fuses can be

⁵ ANSI Z10-2012, *Occupational Health and Safety Management Systems*, American National Standards Institute

significantly lower than those downstream of RK-5 fuses. For larger fuses (e.g., mains, larger feeders, or "limiter" fuses that may be applied with certain types of circuit breakers), current limitation (and the corresponding arc flash reduction) may only occur at very high fault current levels. An arc flash study can help determine not only arc flash levels downstream of existing fuses, but also locations where replacing existing devices with those of a different type may reduce available incident energy levels.

Circuit breakers, particularly those with adjustable trip settings that allow for shaping of the device tripping curves, may allow for better performance across a broad range of available fault current levels. To provide the maximum benefit, though, the breaker settings must be chosen with arc flash levels in mind, and instantaneous tripping must be employed. Selection of breaker settings that strikes an optimal balance between arc flash reduction and maximizing selectivity requires that arc flash be considered as part of the device coordination study. Since the settings do affect the incident energy levels, care must be taken to ensure that settings are not adjusted from the values specified in the study (e.g., by turning them up to "maximum" after a breaker trips). The study may also help identify areas in an existing facility where replacing thermal-magnetic breakers with devices having an electronic trip unit, or upgrading older trip units with modern trip unit retrofit kits (e.g., to add instantaneous protection, to add setting flexibility, or to increase reliability), or whether using features such as zone-selective interlocking (ZSI) would help to reduce incident energy levels.

Proper device selection is not only an issue for low-voltage fuses or breakers - it is important for protective relays as well. Older-style electromechanical overcurrent relays typically have an adjustable pickup level, an adjustable time delay based on a fixed curve shape (moderately-inverse, highly-inverse, etc.), and may or may not have an instantaneous element. The relatively limited adjustability of the relay characteristics for these devices may make it difficult for them to provide good arc flash protection in some circumstances. Newer, digital relays typically allow for more flexibility in developing settings, and through features such as selectable curve shapes and multiple instantaneous elements with adjustable delays, it may be possible to "custom-fit" a time-current curve that allows for faster clearing of an arcing fault while still maintaining selective coordination.

Maintenance switches

As noted in the "Device selection and settings" section, while the selection of protective device types is important, so is the selection of settings for adjustable devices. Settings must be chosen to properly protect equipment while still allowing for normal load currents and routine temporary overcurrents (e.g., motor starting current) to flow without causing a trip. Settings also ideally result in coordination between different levels of devices - i.e., the overcurrent protective device closest to the fault or overload is the only one that trips, so service is interrupted to a minimal portion of the system. This need for coordination between various levels of devices typically means that overcurrent protective devices closer to the source are set with higher pickup levels and/or with longer time delays than devices farther downstream. This gives the downstream devices time to react and clear an abnormal condition before a large feeder or main device operates, perhaps interrupting power to a large portion of the facility. Of course, since clearing faults quickly is one of the keys to arc flash reduction, this philosophy may not always lend itself to arc flash mitigation.

One way to provide protection while minimizing the impact of miscoordination is the use of so-called "maintenance" switches. These are external switches that are wired into a circuit breaker or relay to allow an operator to select between "normal" and "maintenance" settings. In "normal" mode, the breaker or relay is typically set for normal selective coordination, which may result in a high incident energy level downstream. As long as no workers are present, this may be acceptable. When work is being performed, the switch is turned to the "maintenance" setting, which modifies the trip settings of the device (making them lower

and/or faster), which is intended to reduce the incident energy levels downstream. This may also result in a sacrifice of selective coordination, but the idea is that the "maintenance" setting is to be used only when workers are actually present, when protection of personnel takes priority. When work is complete, the system is then returned to "normal" mode.

Since maintenance switches result in locations where arc flash levels vary (depending on the position of the switch), they require some additional consideration, including determining how the equipment should be labeled, modification of work procedures, and worker training curriculum, etc.

Relay system design

In addition to selection of proper device types and settings, the basic design of a protective relaying scheme can help reduce arc flash levels in a system. For example, bus or transformer differential protection typically allows for faults inside the zone of protection to be cleared quickly without creating concerns over coordination issues. Since they typically operate quickly, they are also effective at reducing arc flash levels, so their use may be considered for locations where differential protection might not have been used in the past. Two examples of relay design specifically being used for arc flash protection are the *virtual main* configuration and *optical relaying*, and these will be discussed in more detail below.

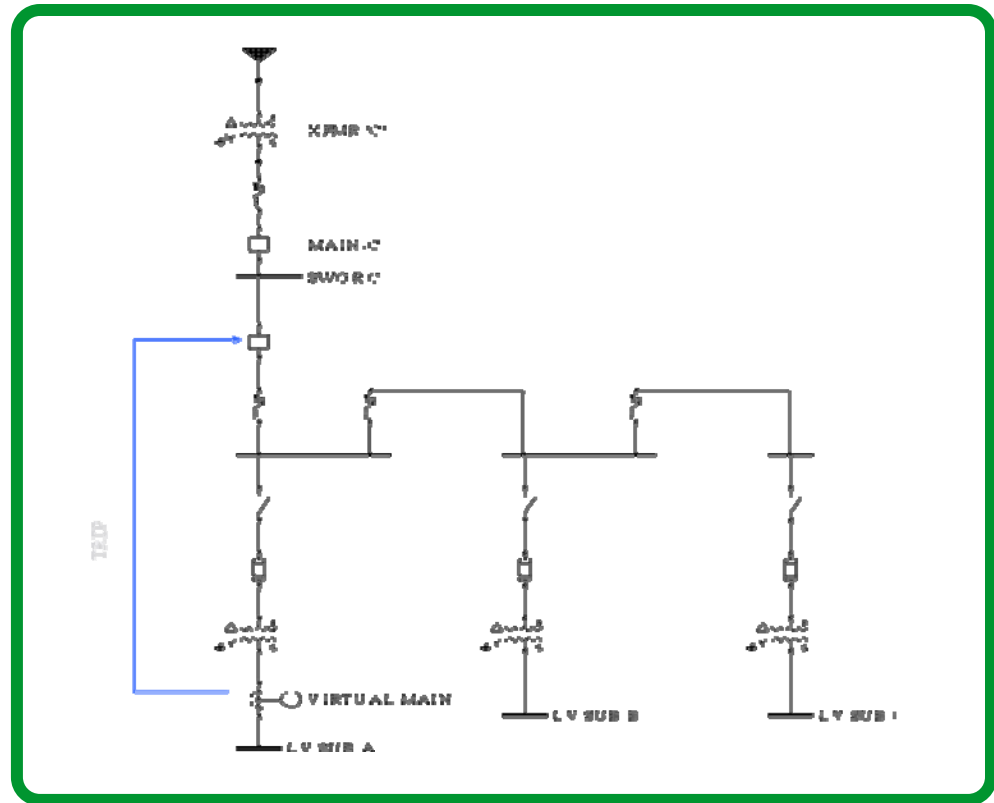
Virtual main

A virtual main system seeks to solve a typical arc flash issue - the high incident energy typically present at the low-voltage side of a substation transformer - which would affect at a minimum the low-voltage transformer compartment and the main section of the downstream switchgear, and at worst the entire low-voltage switchgear/switchboard. At such locations, the overcurrent protection for an arcing fault is provided by a relay or fuse on the high-voltage side of the transformer. It is certainly no stretch to imagine that a 35kV transformer primary fuse might not react quickly to an arcing fault on the 480V side of a transformer.

If CTs were installed on the transformer secondary bushings and run to a relay set to quickly detect and send a trip signal for a low-voltage arcing fault, the problem of detecting the fault is solved. But what should the relay trip? Even if there is a low-voltage main breaker present, it cannot protect for arcing faults on its line side, so at best there would still be a high level of incident energy available in the main section of the equipment. But if the relay could be wired to trip an overcurrent protective device - such as a feeder breaker - on the high-voltage side of the transformer, then the entire circuit is protected. **Figure 2** shows a typical configuration - the relay at Sub 'A' sends its trip signal upstream to the medium-voltage feeder breaker.

There are two potentially significant issues that must be overcome before a virtual main system can be successfully applied. First, there must be something upstream for the relay to trip! When dealing with a large system with medium-voltage circuit breaker switchgear, this may not be a problem. But medium-voltage disconnect switches cannot interrupt fault currents, and if the utility owns the medium-voltage equipment, they may not allow a customer relay to control its operation. The second is coordination - consider **Figure 2**, where a fault at Sub 'A' that tripped the medium-voltage breaker would also interrupt power to Subs 'B' and 'C'. Application of a maintenance switch at the virtual main relay can help minimize potential exposure to miscoordination.

Figure 2
Virtual main configuration



Optical relaying

As previously discussed, fast fault clearing is a key to arc flash mitigation, but breaker or relay settings near the source of power may have to have significant time delays to allow for coordination of devices farther downstream. One novel and relatively new way to deal with this conflict is to use relays that detect the presence of arcing faults by looking not only for the characteristic current flow but also for the flash of light associated with the arcing fault. Typically, both quantities must be present before an arcing fault is detected - either high current or a burst of light alone will not cause one of these relays to operate. But when both conditions are present, the relay can operate very quickly to clear the fault, typically through operation of an overcurrent protective device, but sometimes through activation of a shorting switch that creates a bolted fault that clears the arc even more quickly than a circuit breaker could operate. Optical relays could also be used as the protective relay in a virtual main configuration.

System grounding

The method of system grounding can have an impact on arc flash hazards. The majority of facilities today are *solidly-grounded*, which means that there is an intentional, low-impedance connection between the system neutral and ground. Solidly-grounded systems are required by code in many instances. Some systems (these days, often legacy systems) may be ungrounded, which means there is no intentional connection to ground. Each type of grounding has its pros and cons - for a single ground fault in an ungrounded system, no ground fault current flows, so the system can continue to operate. However, an arcing ground fault can produce high transient overvoltages. Solidly-grounded systems very effectively limit overvoltages during fault conditions but may allow a great deal of fault current (and energy) to flow, which can result in significant damage to equipment or personnel.

An *impedance-grounded system*, where the neutral point is connected to ground through an impedance (typically a resistor) is a hybrid of the grounded and ungrounded systems, and as such shares some of the characteristics of both. *High-resistance grounded systems*, which have the resistor selected to limit ground fault current to less than 10A and are most often used at 480V (though sometimes used at 5kV), greatly reduce the available ground-fault current and therefore let the system continue to operate during a ground fault condition, at least for some period of time until the fault escalates. They are also fairly effective at limiting transient overvoltages.

More recently, some have promoted HRG systems as an arc flash mitigation means. But how can system grounding affect the hazard or risk related to arc flash incidents when the calculation methods in IEEE 1584 are based on three-phase faults? The idea is that since the majority of faults in power systems are either single-phase-to-ground faults (or they begin that way and then escalate), the fact that HRG systems inherently limit the energy delivered to a ground fault by limiting the available current can provide a great deal of protection.

Ground faults with such low current levels are unlikely to produce the explosion and intense heat characteristic of a typical arc flash event, and they are also less likely to quickly escalate to multi-phase faults. While this is certainly a positive, HRG systems do not eliminate the possibility of a multi-phase arc flash occurring, and they do nothing to reduce the energy delivered to phase-to-phase or three-phase faults that do occur. In fact, per IEEE 1584-2002, the incident energy from three-phase arcing faults is actually slightly higher on impedance-grounded or ungrounded systems than for an otherwise identical solidly-grounded system.

One way to understand the mitigating effect of an HRG system is to reconsider the definitions of hazard and risk given in the “Mitigation strategies” section. An HRG system would make it less likely that a ground-fault in a system would escalate into a damaging three-phase arcing fault, so the risk is reduced - though the actual degree of risk reduction is difficult to quantify. What about the hazard? As long as only single-phase faults are considered, the hazard is also significantly reduced due to the reduction in available fault current. As discussed above, an HRG system does not guarantee that three-phase faults will not occur, and does not do anything to mitigate their effect when they do, so neither the hazard nor the risk is eliminated. The incident energy calculations and equipment labels would still show the incident energy levels calculated based on the three-phase fault, and worker PPE would not be reduced.

This is not to say that high-resistance grounded systems do not provide any benefit where arc flash safety is concerned; only that a user must be aware of what it will and will not do where arc flash mitigation is concerned.

Arc-resistant switchgear

The solutions mentioned so far are concerned with limiting the duration or frequency of high-energy arcing faults. Worker safety can also be increased by containing and redirecting the effects of an arcing fault that occurs in a piece of electrical equipment. In this section, we will provide a brief introduction to *Arc-resistant switchgear*, both passive and active.

Arc-resistant switchgear is switchgear designed to meet performance requirements set forth in IEEE Standard C37.20.7-2007, *IEEE Guide for Testing Metal-Enclosed Switchgear Rated Up to 38kV for Internal Arcing Faults*. Arc-resistant equipment provides protection from internal arcing faults to workers standing in front of (Type 1) or anywhere around the perimeter (Type 2) of the equipment, provided that the equipment is in its **normal operating condition**.

Equipment qualified to this IEEE guide has been lab-tested to show that an internal arcing fault will not:

- Cause doors or covers to open or blow off during the event
- Fragment and eject parts within the protected area
- Allow the arcing fault to burn through the enclosure
- Allow cotton indicators spaced about the gear to ignite
- Have any of its grounding connections become ineffective

The **normal operating conditions** are defined by the manufacturer but typically include operation (opening and closing) of circuit breakers or switches, and inserting or removing withdrawable components. Table 130.7(C)(15)(a) in NFPA 70E-2012 shows that Category 0 PPE is appropriate when performing such activities on arc-resistant Switchgear. Normal operating conditions do not typically include operations with outer covers or doors open, or maintenance activities that involve replacement of primary active components (e.g., fuses).

Passive arc-resistant switchgear

Passive arc-resistant equipment typically provides the increased protection through strengthened enclosures, venting of pressurized hot gases and other arc products, etc.

Active arc-resistant switchgear

One drawback of traditional passive arc-resistant switchgear is that while it may provide a significant degree of protection to workers, it may not do anything to reduce the intensity or duration of the internal arcing fault itself. The equipment may be designed to contain the "blast" but the internal damage may be significant, requiring either significant re-work or even replacement of the switchgear before it can be returned to service. Conversely, active arc-resistant switchgear works to limit the arc energy.

For example, Schneider Electric's medium-voltage switchgear with the active Arc Terminator shorting-switch system is considered arc-resistant per C37.20.7, due to the fast action of the switch, which can extinguish an arcing fault in as little as $\frac{1}{4}$ cycle. In addition to providing protection for workers, this kind of active solution can reduce the amount of damage that the equipment itself sustains during the arcing fault event. Note that placing a device that limits arc energy, in non-arc-resistant switchgear can meet the performance requirements of IEEE C37.20.7.

There are several application issues that must be considered when using arc-resistant switchgear, including ensuring that available fault current and fault clearing times are within the values defined for the equipment, ensuring that access is limited above and below the gear as protection is not provided in the vertical plane, observing required room dimensions, and if/how to vent hot gases and other byproducts of the arcing fault. These and other specific application issues are beyond the scope of this paper. A good deal of discussion is provided in IEEE C37.20.7, and equipment manufacturers should also be consulted regarding special requirements that may apply based on their specific design.

Although the C37.20.7 guide only explicitly covers low- and medium-voltage switchgear, manufacturers are beginning to offer "arc-resistant" versions of other products, such as low-voltage motor control centers. This is indicative of the performance requirements in C37.20.7 becoming a "de-facto" standard for arc-resistant equipment in general, and equipment meeting the performance requirements in the guide would be expected to deliver a similar level of protection as arc-resistant switchgear. Future revisions of IEEE C37.20.7 may provide additional guidance on testing and application of these other products.

Remote operations

As discussed previously, reducing the duration of the arcing fault can be a very effective means to mitigate arc flash hazards. Increasing the effective working distance - that is, the distance between a worker and the location of the arc - is also a very effective mitigation strategy, as energy levels drop off exponentially as the working distance is increased. See **Figure 3**, which shows the decrease in incident energy as a worker moves away from a low-voltage switchboard.

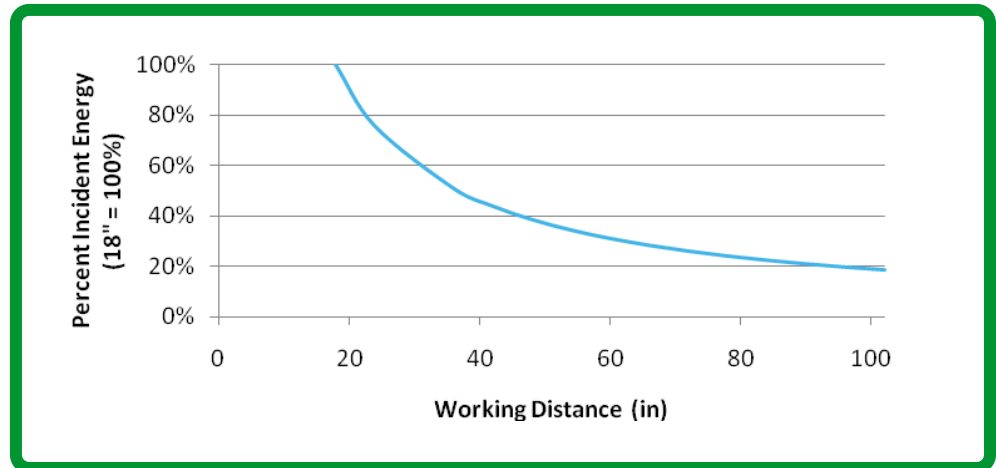


Figure 3

Incident energy vs. working distance for a low-voltage switchboard

Based on **Figure 3**, if the standard working distance of 18" (per IEEE 1584-2002) is the reference point, then doubling the distance to 36" means the available incident energy will drop to 32% of the reference value. Though the drop in energy is not as dramatic for other equipment classes (e.g., doubling the working distance in front of medium-voltage switchgear will reduce the incident energy by about 50%), it is still significant, so looking for ways to remotely operate or interact with equipment is a powerful mitigation strategy.

Remote operation of circuit breakers or switches is an established technology, and can be accomplished in a number of ways. While it does require the breakers to be electrically-operated and capable of being shunt-closed and shunt-tripped, these features are available on a wide range of devices. Remote switching of devices may be done from remotely-mounted operating switches, pushbuttons, HMI screens, and even over networking through SCADA systems, network-connected relays, or other devices. There are even portable devices that can be temporarily mounted to control switches or other operating mechanisms. In all cases, the ideal situation is for the remote operating point to be located outside the arc flash boundary of the equipment being controlled.

Anecdotally, many arc flash incidents occur when withdrawable components (e.g., circuit breakers, starter buckets, etc.) are inserted or withdrawn from equipment – i.e., they are “racked” in or out. There are an increasing number of remote racking options now available (**Figure 4**) for both low-voltage and medium-voltage equipment, both from OEMs and third-party vendors. The principle is much the same as with remote operation – the remote racking device allows the operator to significantly increase the working distance during these operations, ideally to a point outside the arc flash boundary.

Figure 4

Example of remote racking system with remote operating station



Design choices

Technically speaking, all of the engineering controls discussed in this section—from the system ground method, to relay/breaker/fuse type, to the nature of the control system, are part of the choices made when designing a power system. But there are also more fundamental design choices that can impact the ultimate levels of hazard and risk that workers will have to deal with when the system is in operation. Awareness of and consideration of these issues in the initial design stage can help engineers more effectively design safety into a system rather than trying to develop patchwork solutions after-the-fact.

The ideal way to proceed is to explicitly consider arc flash hazards and other potential safety concerns in the design of a facility. An initial arc flash analysis can identify potential areas of concern before the design is substantially complete and can lead to better choices of network topology and equipment specifications. Discussions with the facility owner regarding safety policies and practices may help to define performance requirements (e.g., are energy levels over 40 cal/cm² acceptable to the owner?) that also drive engineering decisions. Waiting to perform an arc flash analysis until after the design is complete and equipment is being manufactured (or worse, when it is already on-site and in service) has the potential to either handicap mitigation efforts or at least, make them much more expensive, as it may be difficult to implement some solutions due to equipment construction, available space in electrical rooms, or other factors.

This is not to say that arc flash mitigation is not possible for existing facilities, but there may be additional challenges that have to be overcome in order to reduce hazard levels in all areas. The so-called "80/20 rule" comes to mind - the idea that 80% of the effort will be required to solve the last 20% of the problem. The flip side of that rule, though, indicates that arc flash levels can be mitigated in many locations with relatively little effort (e.g., adjusting existing circuit breaker trip settings). Mitigation efforts in existing facilities should include careful prioritization of efforts, including identification of locations where mitigation can be easily implemented as well as locations where implementing solutions may be more difficult but where high energy levels and/or frequent worker exposure justify the efforts.

Maintenance

NFPA 70E-2012 recognizes the relationship between maintenance practices and safety in Section 205.3, which states that "Electrical equipment shall be maintained in accordance with manufacturers' instructions or industry consensus standards to reduce the risk of failure and the subsequent exposure of employees to electrical hazards." Of course, total failure is not required to increase the level of hazards to which employees may be exposed.

Informational Note #1 to NFPA 70E-2012 130.5 states that "Improper or inadequate maintenance can result in increased operating time of the overcurrent protective device, thus increasing the incident energy." Clearly, proper maintenance techniques and practices are an important part of an electrical safety program and must be employed along with other

mitigation techniques. For specific recommendations on maintenance workscopes and frequency, consult equipment manufacturers or NFPA 70B-2013, *Recommended Practice for Electrical Equipment Maintenance*⁶. For facilities with existing maintenance programs in place, installation of engineering controls such as maintenance switches or optical relaying may require that such procedures be updated to include the new equipment.

Maintenance is another factor that should be considered in the system design phase. In facilities such as data centers, where uptime is critical and business conditions do not allow for extended facility shutdowns for maintenance, "run to failure" should not be the response. Instead, redundancy should be designed into the system such that individual pieces of equipment can be taken completely out of service without interrupting power to critical loads. If redundancy is designed into a system, that redundancy must be actively maintained as well. Continued load additions without regard to location or amount may eventually create situations where the load level has grown to the point that taking one transformer, UPS, switchgear, etc. out of service will overload the remaining equipment. At that point, to restore the capability to effectively maintain the system, either load must be shifted to new services or more efficient equipment must be installed. In most cases though, this simply means an end to many maintenance activities, which is far from ideal.

The design considerations for maintenance can also include application of devices intended to simplify and extend maintenance activities beyond the more "traditional" methods. Infrared Thermography is a routine part of the electrical maintenance program in many facilities. Loose connections or other defects in electrical equipment may create "hot spots" that give early warning of impending failure and that are readily visible to infrared cameras. Since the goal of this type of inspection is to detect heat created by current flowing through problem areas, the inspections are typically either done with the equipment energized or they are done within the first few minutes after a shutdown before equipment has had time to cool. Neither is ideal - the former exposes workers to energized equipment, while the latter could require a rushed lockout-tagout procedure which increases the probability that something goes wrong in the process.

Fortunately, there are relatively straightforward solutions available - such as installation of infrared viewing windows in equipment that allow for infrared scans to be performed without exposure to hazardous energy (**Figure 5**). The windows, which are intended to allow for transmission of infrared radiation, are installed in the equipment covers at strategic locations such that key joints/locations within the equipment can be seen by the camera. Not only is hazard exposure reduced because covers do not have to be removed, but the entire process is made faster (rather than removing/reinstalling a cover held on by several bolts, only a protective cover over the window may need to be removed) and therefore less expensive, making it easier and more cost effective to perform periodic inspections.

Figure 5

Example of remote racking system with remote operating station



Newer continuous monitoring technology has the potential to allow for earlier detection of potential issues as well as to allow for development of maintenance programs based on the

⁶ NFPA 70B-2013, Recommended Practice for Electrical Equipment Maintenance, National Fire Protection Association

actual equipment condition. Properly-placed thermal sensors can perform essentially the same diagnostics as thermographic scanning, but on a continuous basis. Partial-discharge monitors can detect degradation of insulation systems before they actually break down and cause a fault. Advanced trip units and relays monitor or predict breaker contact wear. These and other monitoring solutions can be wired to local alarming, facility-wide SCADA systems, or could potentially even connect to the internet and set to automatically alert operators of potential issues.

Conclusion

Application of engineering controls to help mitigate arc flash hazards can be a very effective way to enhance safety for electrical workers. Ideally, arc flash safety is taken into consideration when a facility's electrical distribution system is designed, but many of the techniques discussed in this paper are equally applicable as retrofits to existing systems. Devices such as specialty relaying, remote operating mechanisms, etc. intended to specifically address arc flash are still relatively new, and future developments may add additional "tools" to the mitigation toolbox. Advances in related fields, such as those discussed related to maintenance of electrical equipment, should not be overlooked either. Though application of some of the product-based solutions result in increased electrical equipment costs, the alternative is not acceptable. A single serious injury, besides being a tragic human event, can result in costs to employers of \$1 million or more. Arc flash mitigation in almost all situations is deemed a wise investment.



About the author

Antony Parsons is a Technical Consultant in Schneider Electric's Power Systems Engineering group. He is responsible for providing power system analysis, troubleshooting, and design consulting services for Schneider Electric's customers, as well as engineering support for Schneider Electric's field services operations. He is proficient in computer modeling of electric power systems, system protection, power quality and harmonics, and electrical safety. Antony received the BSEE degree from the University of Houston in 1995, then received the MSE and Ph.D. degrees from the University of Texas at Austin in 1996 and 1999, respectively, all in electrical engineering. He is a member of the Institute of Electrical and Electronics Engineers (IEEE) and the IEEE Industry Applications Society. He is a licensed engineer in the states of Texas, Arkansas, Oklahoma, and Louisiana.

Antony has authored several technical papers, both in IEEE Transactions publications and IEEE conference proceedings, and has made technical presentations at conferences in the US and abroad. He has also helped to develop extensive training material for both Schneider Electric employees and clients, and has served as an instructor for Schneider Electric's "Power Quality and Disturbance Monitoring" and "Understanding Arc Flash" short courses. He is a member of the IEEE P1584 working group on Arc Flash Calculations, and represents Schneider Electric as a member of the Technical Advisory Committee to the IEEE/NFPA Arc Flash Collaborative Research Project.