

The Three A's of Arc Flash

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In 2007 GE conducted a survey of industry professionals working in facilities related to the oil and gas industry, pulp and paper industry, and power generation. We asked questions that identified:

- Whether or not they knew the current hazard risk categories in their facilities
- Whether or not they had conducted a hazard risk analysis in their facility
- What actions, if any they had taken as a result of the hazard risk analysis
- What were the most important benefits they would expect from reducing the hazard risk category of equipment
- Identify the solutions currently in place to reduce the risk of arc flash injury.

The study results revealed what we called the problematic three A's of arc flash. Before we get into the study and it's results, let's review the basics about arc flash.

In very simple terms, an arc flash is an extremely violent event. An arc occurs when the electric current uses a path through air rather than through conductive material. Where there is no firm connection between shorted conductors there is usually an arc. Arc flash is a separate hazard from electric shock, which you must also guard against when performing work associated with live equipment. The arc releases energy in the form of thermal energy and also mechanical energy. There are two basic characteristics that drive this energy release.

- The arc is hotter than the temperature at the sun's surface
- When solid copper is vaporized, its volume expands 67,000 times...and that can create an immense pressure wave

While these are the two biggest effects, there are many more caustic byproducts of an arc flash. These include deafening sound, blinding light, toxic gases, molten metal, and pieces of metal or other material explosively thrown off. Nothing about an arc flash is pleasant.

According to statistics published by NFPA and IEEE, the arc flash injury rate during the years 1992 through 2002 was about 2,000 per year. At this rate about five people per day

suffered from arc flash injury. Furthermore, the statistics indicated that the rate of all electrical injuries requiring hospitalization was an average of about 13 cases per day.

An arc flash can be started by several causes. Some of these, like accidental contact and dropping tools are avoided by just not opening up energized equipment. Arcs can initiate from tracking across insulators, most commonly seen in high voltage equipment and caused by surface contamination on the insulators. Corrosion can increase the resistance of connections and cause extreme heating or lead to mechanical failure. Unsafe work practices is one of the more significant causes because they are avoidable. Many times this is caused by just trying to do things too quickly or without thinking things through; "cutting corners"; or not following proper lock-out/tag-out procedures.

Arc flash injury is best avoided by not working on energized electrical equipment. Sometimes this is not possible. In those cases the work must be performed by trained qualified workers and following the completion of a hazard risk analysis.

A hazard risk analysis will help identify the appropriate personal protective clothing or PPE for the task. The required quality of the selected PPE depends on the estimated amount of heat released by an arc flash. This thermal energy is dependent on a number of factors but the three most significant are.

- How much current is in the arc
- The time to clear the fault and totally stop the current
- The distance from the person to the arc

The PPE does not guarantee you will walk away unscathed from an arc flash. It merely makes the incident survivable by limiting injuries to second degree burns. Permissible forms of PPE vary from common cotton clothing to highly insulated heavy clothing combined with hoods and face shields. Note that polyester and other similar synthetic fiber clothing is not allowed.

When the arc energy exceeds Category 4 capabilities the blast effect injuries are of more concern than the burns caused by thermal effects. There are no PPE designed to withstand the blast effects of an arc flash. That's why there is no category beyond class 4.

The flash protection boundary is another important concept. This is the minimum distance from exposed live parts where the heat released from an arc flash would cause a second degree burn on unprotected skin. Besides the flash protection boundary are other limits and clearances related to avoiding electric shock that need to be observed.

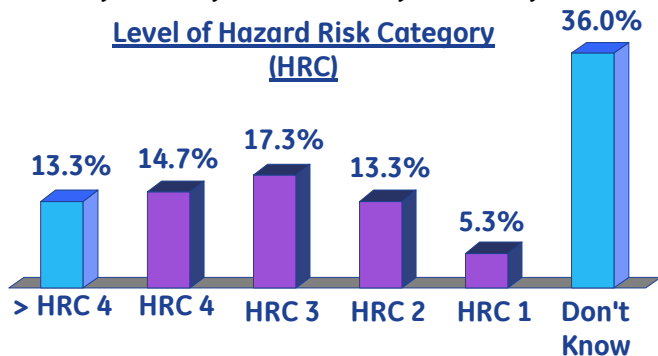
There are two equations available for establishing the flash protection boundary. One in NFPA 70E and the other in IEEE 1584. In the case of a 100A lighting panel with 10,000A short circuit available, the flash protection boundary determined from these equations could be six to twelve inches from the live parts. In 4000A low voltage switchgear with 42,000A available, the flash protection boundary may be on the order of 49 to 166 inches. These figures are provided to provide the reader with an idea of the distances that might be expected and to show the dissimilarity in results obtained from the two equations. Do not assume these figures apply to any given situation.

Now that we have laid the groundwork of a basic knowledge of arc flash, let's look at the survey results in detail. As we mentioned before, the results identified the "three A's of arc flash":

- **Awareness** - 36% of end users and 38% of specifiers did not know the HRC of their facility or their electrical system design.
- **Analysis** - 50% of end users said no arc flash hazard study had been performed in their facility.
- **Action** - 35% end users said no changes were made despite conducting analysis

For those who did know the HRC in their facility, the survey asked them to identify what HRC levels were present. Those results are illustrated in the following graph (Figure 1). Note that for those that knew the category, the results were evenly split among categories 2 and higher. You

Figure 1: Responses to "What level of HRC do you currently have in your electrical system today?"



should especially take notice of the data for sites that reported that they were "above category 4". Remember that there is no PPE that can protect against the blast effects associated with energy levels greater than HRC 4. This data seems to indicate that having a locations that exceed HRC-4 is just about as likely as any other category except for category 1 which doesn't appear to be all that common. So it is just as likely to have a location where the incident energy exceeds the capabilities of any PPE as it is to have a location where there is PPE available to protect the worker. This shows what a dangerous misconception it would be to think that using HRC-4 PPE will protect the worker where the hazard risk category is not known. This data shows that such an assumption could result in deadly consequences on an average of about one in four cases.

With regards to questions asked about performing arc flash studies, the results showed an almost even split between facilities where studies were performed versus those that have not. This suggests that the level of awareness is not where it should be.

Of those facilities where arc flash studies were performed, some owners adopted multiple changes as a result of the arc flash study. Most of them purchased new equipment or controls or other devices to make the facility safer. In many cases overcurrent device ratings or settings were changed to reduce the arc flash energy. Usually, this was possible without sacrificing the selective operation of the devices, which would reduce overall system reliability and uptime.

Unfortunately more than one third of respondents indicated that no action was taken following the arc flash analysis. Those who felt that no action was possible accounted for only 12% of those who conducted arc flash studies, which suggests that some improvement may be possible in most cases where a study is being done for the first time.

Reducing the hazard risk category can result in several advantages. These include

- Lower insurance costs
- Lower workers compensation costs
- Lower maintenance labor costs
- Reducing the PPE needs of the workforce

Reducing the PPE needs goes beyond just the cost involved in obtaining and caring for category 4 protective equipment. The insulation and materials required to withstand the intense heat of the arc at the highest category results in protective clothing that is heavy, cumbersome and hot. The protective gloves reduce dexterity and make handling tools more difficult which could increase the risk of a dropped tool. The clothing keeps body heat in and can cause the worker to be uncomfortable or unable to work for long periods. Face

shields can obscure vision. So it's not surprising that lowering the PPE requirements for a task is the most popular benefit of reducing the hazard risk level.

There are many options available on electrical distribution equipment that will make working around the gear safer and possibly result in being able to use a lower category PPE. These include not only options that are available when you order new equipment but also options that can be added to existing equipment.

Racking drawout breakers in and out is one of those activities that carries some increased risk to failure when care is not exercised. Consider how easy it is to leave a tool across the stabs of a circuit breaker and rack the breaker onto an energized bus without removing the tool first. Remote racking devices are available that allow the worker to stand outside the flash protection boundary while racking the circuit breaker in or out. The motor operator attaches to the front of the breaker and engages the racking mechanism drive shaft. The worker uses a push button control at the end of a long control cable to operate the racking motor. The control cable allows the worker to stand outside the flash protection boundary, including well to the side of the breaker being racked out, which would keep him out of the path of thermal and blast effects. These operators are available on both low voltage switchgear and medium voltage (5kV and 15kV) switchgear.

Opening and closing circuit breakers may also involve some risk and is an task that is commonly performed manually. Let's say that tool we mentioned previously was left on the load stabs of the breaker. So nothing would happen while the breaker is being racked in, but a dead short could exist across the phases upon closing that breaker. Or you may be trying to open a breaker that has not been properly

Figure 2: Using a remote racking device on Wavepro low voltage power circuit breakers in AKD-10 switchgear.



maintained or is so old that it is reaching the end of its useful life.

The ability to remotely open and close circuit breakers makes this task safer by moving the breaker controls to outside the flash protection boundary and away from the thermal and blast effects of arcs. Remote operation is possible in existing equipment where the breaker is already electrically operated. Electrically operated breakers are standard in medium voltage switchgear and is optional in low voltage switchgear and switchboards. In low voltage equipment, it may be possible to convert a manually operated circuit breaker to electrical operation. This needs to be reviewed on a case by case basis.

Remote operation can be carried out through a number of methods today. If the breaker open and close coils can be wired to an input/output device that is connected to some form of broadband network or programmable logic controller, the circuit breakers could be operated via a touchscreen panel or from a remote computer via a supervisory control and data acquisition (SCADA) system. At the simplest level, the circuit breaker open/close coils could be direct wired to control switches or pushbuttons that are mounted on a panel outside the flash protection boundary.

Infrared scanning ports allow thermographic evaluation of connections without opening covers. When connections loosen up the resistance of the connection increases. The result is that the temperature of a loose connection is much hotter than adjacent connections or conductors. If the connection overheats, a dangerous failure could result. Thermographic scanning allows you to spot loose connections while the equipment is operating under load. The thermographic cameras cannot detect the heat very well through metal covers, so this task is usually done by

Figure 3: An example of an Entellisys switchgear touchscreen used for remote circuit breaker operation.



There are two options for low voltage equipment that will provide better protection to live parts in cable compartments of rear access equipment such as low voltage switchgear. These are section barriers and insulated/isolated bus. It should be realized that the standards for low voltage switchgear allow the rear area behind the circuit breaker cubicles to be wide open from one end to the other inside the enclosure. Furthermore the standards allow bare main bus to be applied, posing an obvious shock hazard to those that need to open the cable compartment covers while the equipment is energized.

Section barriers separate and guard adjacent sections using a combination of grounded metal and polyester glass. The section barrier provides effective protection from exposed live parts in adjacent sections. Section barriers will also impede the propagation of an arc through equipment. When a short circuit occurs the arc will want to move along the conductors in a direction away from the source. This is the "Jacob's ladder" effect that you've seen in those old movies with the mad scientists' lab. The section barrier can help keep this moving arc from traveling beyond the faulted section. It also keeps arc byproducts such as ionized gases, vaporized metals, and carbon from spreading and contaminating other sections.

The second option that may be available in rear-access type switchboards or switchgear is insulated/isolated bus. When this option is specified, the main bus is insulated with epoxy and each phase of the vertical riser bus is isolated from each other using polyester-glass barriers. The bus joints have removable/ replaceable covers to allow easy access to the joints to check bolt tightness when de-energized. When this option is provided, the only possible exposed live parts are the load side cable lugs. By reducing the amount of exposed live parts, the cable compartment

Figure 4: Low voltage insulated/isolated bus in a rear access Powerbreak II switchboard or AKD-10 or Entellisys switchgear.



area is much safer to work around with the covers open. This option also drastically reduces the probability that a bus fault can happen.

What about simply keeping people out of places where they don't belong? The following options follow this strategy.

Just the act of opening or closing equipment doors on live equipment can trigger an arc flash. Padlock devices can be used for securing the hinged door that covers a circuit breaker. Padlocking doors can prevent injuries caused by the casual opening of doors and can keep unqualified persons out of dangerous spaces. Provisions for padlocking on hinged rear doors of rear access equipment is also available.

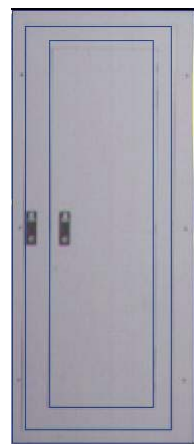
Opening the door of a live closed breaker carries some risk. A short circuit can occur at any time and may be located well away from the breaker, so you may have no warning when a circuit breaker is about to trip on a short circuit. It's best not to be immediately in front of a tripping breaker when it's enclosure cover is open. Interlocks are available that prevent operators from opening breaker compartments while the breaker is closed. Drawout breaker interlocks may require the breaker to be opened, and then disconnected from it's primary stabs before allowing the door to be opened. Many years ago there were also interlocks installed that did not prevent the breaker door from opening but tripped the breaker as the door was being opened. Today such interlocks are not commonly available nor are they recommended.

Hinged covers and fronts keep the metal cover in better control and less likely to fall into energized parts when it is necessary to get inside the enclosure. There are two common ways that the fronts of lighting or distribution panels can be hinged to expose the wiring gutters inside, while the deadfront trim in front of the breakers remains in

Figure 5: Hinged fronts on panelboards.

Door-in-Door

Hinged Door to Box



place, so the main bus stays guarded. The “door-in-door” style can be distinguished by the “picture frame” design of the sheet metal. The inner door exposes the deadfront trim and breaker operating handles. The outer door allows access to the wireways. The “hinged door to box” style has a full-height piano-style hinge along one side which remains bolted to the panel box. The door that swings out is also bolted to the box. Removing just the bolts on the swing-out piece allows the wiring gutters to be exposed.

The safest work practice of all for electrical equipment is to turn off the power and make the equipment electrically safe before you open the covers and commence work. The Standard For Electrical Safety in the Workplace, NFPA 70E, lists the following as its definition of an “electrically safe work condition.”

1. De-energize the equipment to be worked on
2. *VERIFY* that the equipment has been truly de-energized prior to commencing work.
3. Formal lock-out and tag-out procedures should be part of any work plan.
4. Installation of grounding cables, where practical and/or feasible is recommended, depending on the equipment or nature of the work.

The importance of having accurate single line diagrams cannot be overstated. They are invaluable in their use as a reference in assessing the hazards of work about to be done and to allow the worker to identify all potential sources of power to the work area so that all can be placed in an electrically safe condition.

The most basic dictate of NFPA 70E is that the equipment must be placed in an electrically safe condition before anyone, especially unqualified employees, can be allowed to work on or near exposed parts. The standard only allows qualified persons to work on energized live parts that have not be placed into an electrically safe condition. Work on energized equipment is done all too often because of a rationale that the load must keep operating for one reason or another. NFPA 70E Section 130.1 recognizes only two conditions as justification for working on energized equipment:

- De-energizing introduces additional or increased hazards to the workplace. For example emergency alarm systems, hazardous location ventilation, and life support equipment may need to stay energized at all times to keep a workplace safe.
- De-energizing is infeasible due to equipment design or operational limitations. Examples: start-up/trouble shooting, or circuits form an integral part of a continuous process that would otherwise

need to be completely shut down in order to work on that circuit or process component.

Designing for maintainability allows parts of the system to be shut down and made electrically safe while keeping the load operating and is a prime consideration when designing for reliability. Such designs have redundant paths to feed the load. The alternate path can keep the load operating while the normal path can be de-energized for whatever work needs to be performed. If an electrical system cannot be maintained properly then its reliability cannot be assured. Responsible owners who want a high degree of uptime from their equipment realize that reliability is dependent on properly maintained equipment and that planned orderly shutdowns are preferred over unplanned unscheduled outages due to failures. Nonetheless first-cost pressures and or space limitations can take priority over life cycle cost justification for redundant systems and maintainable systems are simply not designed.

Lets turn our attention now to reducing arc affects. Remember that the three significant factors previously mentioned were distance, time, and current magnitude. Let’s look at the last two beginning with current.

How much current should you expect from an arc? The arc itself adds resistance to the short circuit path and can reduce the current significantly. At low voltage, the current of arcing faults is expected to be between 43% to 57% of the available three phase bolted fault for bolted fault currents between 20,000A and 100,000A. This ratio starts out high for the smaller currents and gets lower as the bolted fault current increases. But the actual arcing current might be even lower than what the standard calculations predict, and lower arcing current isn’t always a good thing.

Short circuit calculations are estimates and carry some assumptions with them. The assumptions for bolted fault current are meant to drive a high number since they were primarily intended to determine the short circuit ratings of equipment. If anything, we want the equipment to have a short circuit rating higher than the available current and assumptions that raise the calculated current level tend toward a safer installation. But this means that the arcing current estimate may be much higher than an actual figure. IEEE 1584 recommends making a second calculation at 85% of the bolted fault current to make up for this. But this may not make up for everything.

For example, the utility data could be overstated, using data based on future maximum possible capacity rather than data based on the actual equipment installed. In addition, ground fault currents may be much lower on cable runs where the impedance of the ground return path decreases the current dramatically.

To further make the point that lower currents can be problematic, refer to Figure 6. This shows how a lower current can make things worse when applying circuit breakers and the impact of the overcurrent settings on the required PPE. This is an example of a large circuit breaker applied as a main in a unit substation. The calculated bolted fault current is shown by where the curve ends to the right, near the bottom of the graph. The yellow region shows the area which the equations indicate are the value of arcing faults corresponding to this bolted fault current. As you go from the minimum of the range to the highest calculated value, the current may be acted on by either the short time function or the long time function. In this example, the arcing current is never in the instantaneous trip portion of the device. Notice how much time effects the category of PPE that should be worn. The clearing time for the breaker to trip could result in a requirement for HRC-3, or HRC-4, or beyond the capacity of any PPE.

Again, remember that data or assumptions that over-inflated the short circuit calculations could deceive us into thinking that the current is higher than it really is. The current might be lower than that indicated here, making it more likely that the long-time setting would have to trip out the arcing fault.

To ensure that arcing faults can be cleared in the lowest time possible, consider temporarily reducing the settings on devices which supply areas where work is about to occur. Breakers with fully adjustable trips may have a "reduced energy let-through" or "maintenance switch" feature that sets the instantaneous setting to a pre-set lower pickup value when this feature is enabled. However, reducing these settings can compromise the system selectivity for the purposes of safety.

Selectivity is a system characteristic whereby the protective device ratings and settings are designed to minimize the

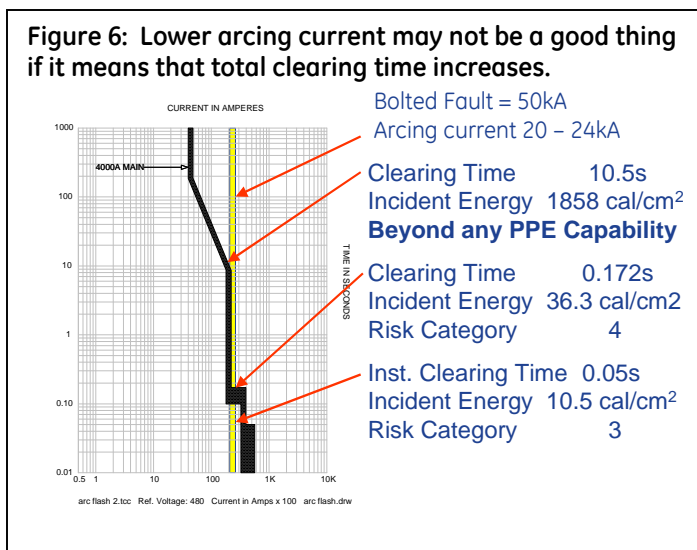
amount of the facility that is shut down when a short circuit occurs. If the protection is not selective, short circuits will result in equipment outages affecting much more of the facility than necessary. Reducing the settings and causing loss of selectivity may not be an allowable option for devices applied on standby systems where the National Electric Code requires selective coordination. Care must also be exercised on feeders that supply loads that draw high inrush currents upon starting, such as motors. Settings arbitrarily reduced too low could nuisance trip on these inrush currents, and may cause an accident if the tripping device is in close proximity to the work area and startles a worker when it trips. Fuse selectivity can be compromised if reducing the fuse rating to achieve lower arc flash heat release results in compromising the ratio of fuse ratings that assure selectivity.

If we want to have both high speed protection and selectivity, we may need to employ advanced protective devices. Selective coordination may require settings with high time delays that would allow high arc flash energies. What's needed is equipment that reacts to short circuits faster than a completely selective system using conventional trip devices and maintains selectivity. This kind of protection has been available on equipment rated above 600V and has recently become available on low voltage equipment. Advanced protection includes such things as dynamic zone interlocking and/or bus differential protection.

Bus differential protection is inherently selective. A properly designed system will not react to any short circuit outside its zone of protection. But it can be very sensitive to short circuits inside the protective zone. The sensitivity setting can be lower than the full load current rating of the equipment. With such a wide range of sensitivity, the likelihood of an internal fault escaping detection by the bus differential system is extremely remote. And since the time delay is virtually the same throughout the range of currents that it detects, it makes determining PPE requirements easier.

Dynamic zone selective interlocking adapts to the switching configuration of the equipment. It is especially useful on main-tie-main designs. It allows the short time and ground fault functions to react to a short circuit as quickly as possible when the short circuit is located in the feeder's zone of protection. It also assures that mains or ties that supply the feeder react as quickly as possible to bus faults and can provide the best possible backup protection should a feeder fail to isolate the short circuit.

Enhanced protection is now possible in low voltage systems using Entellisys low voltage switchgear. The central processor concept of Entellisys allows it to monitor all the breakers simultaneously. It can act selectively upon a short circuit based on fault location, not just fault current



magnitude and time delay settings. The Entellisys HMI touchscreen panel provides full access to all settings, controls, and event logs, and can be located outside the flash protection boundary. The optional remote racking operator allows racking the breaker outside the flash protection boundary. Through Entellisys, cost-effective bus differential protection is now available. The bus differential protection provides fast selective protection from internal faults. It ensures that arcing currents cannot be too low that the protection cannot detect and isolate them rapidly. The reduced energy let-through mode places protective settings at minimum values to limit the arc flash energy while workers are near or in the equipment. The reduced energy let-through mode can be enabled either through the HMI or through discrete switches located at access points to the electrical room.

Circuit breaker trips for insulated case and low voltage power circuit breakers have improved zone selective interlocking that helps achieve lower arc incident energy levels on the main bus. Through the ability to set both the “unrestrained” and “restrained” settings, the feeder breakers can be adjusted to be selective with downstream feeders and branch devices while allowing the possibility for the main settings to clear faster than the feeder settings. On equipment employing low voltage power circuit breakers, the instantaneous trips can be zone interlocked to reduce the time delays even more while assuring selective operation. The GE Entelliguard TU trip device can provide the protective features described.

It is our hope that this article has given you some useful information concerning the Three A's of Arc Flash and you will no longer be at risk due to a lack of **awareness** about arc flash. And that this awareness will prompt you to perform the required **analysis** to determine the hazards that may be involved in working in or around electrical equipment. And that you always promote safety in your workplace through your own **actions**, both on and off the job; and promote improving the workplace and its equipment to make a safer work environment. Please visit www.geelectrical.com on the web if you'd like more information.