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What you need to know about arc flash

Adam Reeves, P.E., Senior Power Systems Engineer, Eaton, USA

David G. Loucks, Ph.D., P.E., CEM, Manager, Application & Advanced System Engineering, Eaton, USA

Understanding and mitigating the dangers of electrical explosions.

Executive summary

Arc flash—a fiery explosion that can result from short circuits in high-power electrical devices—kills workers in the U.S. every year and permanently injures many more. An arc flash can also wreak financial havoc in the form of fines, lawsuits and damage to expensive equipment. Yet, many equipment operators are perilously unfamiliar with both the causes of arc flash events and the serious dangers they pose.

This white paper aims to fill that knowledge gap by providing introductory-level information about what an arc flash is, why it's so hazardous and what steps managers should take to safeguard their employees, infrastructure and productivity.

What is an arc flash?

In the simplest terms, an arc flash is the energy release that occurs during an electrical fault when current flows through the air between two live conductors, causing a short circuit. In a residential setting, an arc flash usually produces little more than a brief flash of light before extinguishing itself harmlessly. In a commercial or industrial setting, however, voltages and currents are significantly higher, so electrical faults typically release far more energy. As a result, an arc flash routinely produces a powerful explosion marked by searing heat, toxic fumes, blinding light, deafening noise and massive pressure waves.

Figure 1. An arc flash can ignite large and dangerous explosions.

Needless to say, the human and financial repercussions of such blasts can be devastating, some are stated below:

- **Injuries to employees.** Without adequate protection, workers exposed to arc flash events can suffer third-degree burns, collapsed lungs, vision loss, eardrum ruptures, puncture wounds, and even death. In fact, electrical contact results in 3,600 disabling injuries annually and one workplace death every day in the U.S., according to statistics from the National Institute for Occupational Safety and Health.
- **Steep medical and insurance bills.** Covering the cost of an injured employee's medical leave after an arc flash incident can be expensive. In addition, businesses that have experienced an arc flash may have difficulty obtaining insurance and will probably pay higher rates for any coverage they do acquire until they can prove appropriate safety measures have been taken.

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- **Exposure to fines and lawsuits.** Any time employees die or are injured on the job, costly lawsuits are almost sure to follow. So, too, are fines from the Occupational Safety and Health Administration (OSHA). In fact, OSHA has been known to impose fines totaling millions of dollars after arc flash events, and has even fined companies that have yet to suffer an event for failure to comply with arc flash safety standards. New compliance safety standards were set by OSHA January 1, 2015, and put into effect April 1, 2015. In addition to observing revised minimum approach distances, employers now must estimate the incident heat energy of any electric-arc hazard to which a worker would be exposed, and must provide workers exposed to hazards from electric arcs with protective clothing and other protective equipment with an arc rating greater than or equal to the estimated heat energy. Through the OSHA general duty clause, companies can also be fined for not complying with the requirements of NFPA-70E.
- **Damage to equipment.** Arc flash events are likely to severely damage or permanently destroy any industrial, commercial and electrical equipment in their immediate vicinity. Smoke condensation can cause further harm to sensitive electrical equipment at greater distances. Additionally, should an arc flash trigger the fire suppression system, valuable equipment will likely be covered in water or thick flame-retardant foam.
- **Delays and downtime.** Companies sometimes must wait for OSHA to complete an investigation before repairing arc flash-related damage. That means organizations with insufficiently redundant equipment can suffer hours, days or even weeks of downtime after an arc flash event.
- **Impact on morale.** Attracting and retaining qualified technicians can be difficult if an arc flash incident causes current and prospective employees to view the facility as an unsafe place to work.

Arc flash mitigation strategies

Given the significant dangers they pose, arc flash safety merits serious attention. Here are some of the most effective strategies for reducing the frequency, severity and destruction of arc flash incidents.

1. Perform an incident energy analysis

Per NFPA-70E 130.5(G) an arc flash mitigation program must be updated every 5 years with an incident energy analysis aimed at calculating how much energy an arc flash could release at various points along the power system. Incident energy is defined as the amount of energy, at a prescribed distance from the equipment, generated during an electrical arc event. It increases as the magnitude of current flowing in the fault and clearing time increase. Incident energy from an arc flash event destroys electrical equipment, injures personnel and contributes to extended periods of downtime.

Accuracy is essential with such measurements, so managers who lack direct and extensive experience with arc flash incident energy assessment should always seek assistance from a qualified power systems engineer. The following standard assists with performing an incident energy analysis:

- **IEEE 1584:** Created by the Institute of Electrical and Electronics Engineers (IEEE), one of the world's most respected technical professional associations, IEEE 1584 offers guidance on quantifying potential arc flash incident energy levels.

Upon completion of an arc flash incident energy analysis, companies should take the following steps:

2. Equip staff with appropriate personal protective equipment.

Technicians should never come within range of a potential arc-flash hazard without wearing appropriate personal protective equipment (PPE), such as flame-resistant clothing, eye protection and gloves. PPE is available in varying degrees of strength, with varying degrees of protection. Electrical engineers and fire safety professionals developed a standard to help organizations determine how much protection their employees require:

- **NFPA 70E:** Produced by the National Fire Protection Association, a non-profit organization dedicated to fire, electrical, building and life safety, NFPA 70E defines thresholds for appropriate PPE based on the severity of potential arc flash hazards.

Drawing on the two standards above, as well as data collected during an arc flash incident energy analysis, organizations can accurately determine their incident energy value at each location in their system. Based on that value, organizations can choose the type of PPE their employees should wear when working in arc flash danger zones. Managers should also ensure that personnel from any vendors or third-party service providers who perform maintenance procedures on their infrastructure wear appropriate PPE at all times.

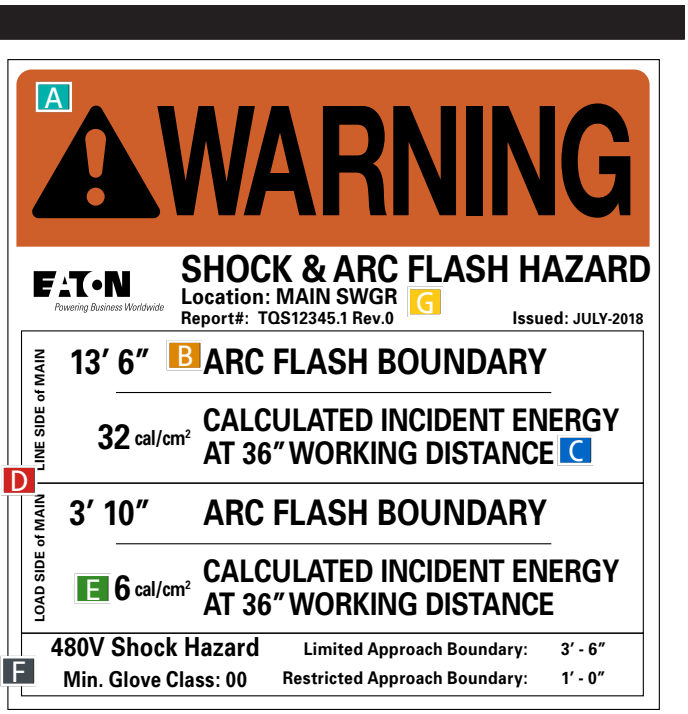
While arc flash safety standards such as IEEE 1584-2002 are extremely helpful tools, they contain an important gap at present: single-phase-to-ground faults. Though IEEE 1584-2002 provides energy calculations for three-phase arcing faults, it offers no guidance on single-phase-to-ground faults, which according to IEEE 493-2007 Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems, are between 7.8 (for junctions) and 73 times (for cable) more likely to occur than three-phase faults. Instead, the standard assumes that ground faults will either self-extinguish or escalate into a three-phase fault.

In truth, however, the additional energy released by single-phase ground faults before they become three-phase faults can be substantial. This is because ground faults tend to be lower current faults that require more time for upstream protective devices to clear, while higher current three-phase faults are cleared quickly. Since current IEEE 1584-2002 guidelines fail to take that additional energy into account, they may significantly underestimate the amount of protection exposed workers require. As previously mentioned, on January 1, 2015, OSHA implemented a new safety standard that states employers generally must provide workers exposed to hazards from electric arcs with protective clothing and other protective equipment with an arc rating greater than or equal to the estimated heat energy.

3. Post warning labels

To ensure a facility's employees are always aware of potential arc flash hazards, companies should place warning labels on any piece of electrical equipment that poses an arc flash risk. They should also mark arc flash hazard zones on the floor so workers not wearing PPE can clearly see how far away from electrical equipment they must stand to avoid serious injury.

Note that the NFPA 70E standard explicitly requires employers to post signage notifying employees of potential arc flash dangers. Organizations that ignore this directive dramatically increase their chances of paying serious fines and losing expensive lawsuits after arc flash incidents.



Callouts for label:

A The owner of the electrical equipment is responsible for providing arc flash warning labels which are required on electrical equipment over 50V that could be accessed while energized.

B An arc flash boundary is the distance at which the incident energy equals 1.2 cal/cm2, and arc-rated PPE is required for any employee within the arc flash boundary.

C The working distance is the distance from a person's face and chest to the prospective arc source. Typical working distances, primarily based on equipment type, are published in IEEE standard 1584 and used in studies to perform the incident energy calculations.

D While performing two sets of calculations for the load side and the line side of the main breaker on specific equipment is not specified in NFPA 70E, Eaton recommends making this a standard practice to enhance productivity and safety for equipment that has adequate isolation of the main protective device.

- If the calculation is performed on the line side only, the entire switchgear lineup may be incorrectly thought to have incident energy above 40 cal/cm2 and not able to be worked on while energized.

- If the calculation is performed on the load side only, the calculated incident energy value will be relatively low, putting workers on the line side in danger.

E Calculated incident energy is the amount of thermal energy (cal/cm2) at a distance from an electrical arc event and indicates the level of PPE required to protect workers

F Nominal voltage, limited and restricted approach boundaries, and PPE glove rating are also displayed on the label to help protect workers from electric shock.

G Eaton's labels display the arc flash study report number for reference.

4. Implement an employee training program

To ensure personnel understand arc flash dangers and know how to avoid them, be sure every existing and newly hired employee receives thorough arc flash safety training.

5. Reduce available fault current

Though not applicable to environments protected by fuses and current-limiting breakers, commercial, industrial and electrical equipment that use non-current limiting breakers (NCLBs) can reduce the amount of incident energy released during an arc flash by reducing the amount of available fault current. The following four strategies can help with NCLBs that significantly reduce available fault current.

Please note that reducing arc current can result in your devices taking longer to trip, and therefore, have a higher incident energy. It's important to implement the right solutions to help shorten fault clearing time.

a. **Operate with an open tie during maintenance.** Maintaining dual electrical feeds helps increase the redundancy of their power supply, and hence the availability of their systems. The downside of this power architecture, however, is that it can double the amount of current available when faults occur. In most cases, opening the tie between dual power feeds during maintenance procedures reduces arc flash dangers by cutting available fault current in half.

   Of course, opening ties during maintenance also temporarily renders your power scheme less redundant, exposing equipment to heightened risk of failure. Given the devastating human and financial toll an arc flash can take, most organizations consider that a tradeoff well worth making.

b. **Switch to smaller kVA and/or higher impedance transformers.** Consider using smaller continuously rated transformers and supporting infrequent overloads through temperature controlled fans. These fans can be ordered as optional equipment on both dry-type and liquid-filled transformers. Another solution is to specify high temperature liquid dielectric that supports higher continuous operating temperatures (75°C) and therefore can be safely loaded to a higher level. In addition, or separately, higher impedance (Z) on the transformer can be specified. Note that in both cases (smaller transformer and/or higher impedance) load flow studies should be performed to ensure that voltage regulation limits are maintained during load switching events, especially motor starting.

c. **Employ high-resistance grounding.** During ground faults, high-resistance grounding (HRG) systems provide a path for ground current via a resistance that limits current magnitude. This dramatically reduces the size of line-to-ground faults and associated arc flashes. HRG can be used on systems that service only three-phase loads. The U.S. National Electrical Code prohibits using HRG on distribution systems serving loads that are connected line-to-neutral, as are most servers. This limits the practicality of an HRG system to the portion of a facility's distribution system that typically only supplies motor loads.

d. **Current limiting devices.** Connected in series and used to reduce fault currents and to match impedance of parallel feeders. For example, current limiting reactors can be used to reduce available short-circuit current, providing a reduction in the bolted and arcing fault current at downstream equipment.

Figure 2. A typical low-voltage motor control center shown above.

6. Shorten clearing time

Just as a smaller arc flash releases less energy, so, too, does a shorter one. Here are five techniques for shortening arc flash events by decreasing fault clearance times:

a. **Utilize zone selective interlocking. Zone selective interlocking** (ZSI) is a protection scheme that uses an "inhibit" signal transmitted from downstream breakers that see a fault to the next breaker upstream. The upstream breaker sees both the fault current and the inhibit signal, and therefore delays tripping, allowing the downstream breaker to clear the fault. Should a fault occur between the downstream and upstream breaker, however, the downstream feeder doesn't see the fault and will not, therefore, send an inhibit signal to the upstream breaker. That causes the upstream breaker to bypass any intentional time delay settings, significantly reducing arc flash incident energy.

b. **Implement a bus differential scheme.** These are coordinated zones of protection within an electrical system. When a fault occurs within a given zone of protection (i.e., between the main and feeder breakers), protective devices trip instantaneously, limiting arc flash durations while also confining arc flash damage to specific portions of your infrastructure. Bus differential systems are typically faster and more sensitive than ZSI but require additional current transformers and relaying equipment. This generally makes them harder to implement and more expensive.

c. **Deploy an Arc Flash Reduction Maintenance System.** An Arc Flash Reduction Maintenance System shortens faults by bypassing all time delays in the trip circuit any time current exceeds a preset maximum. That enables faults to clear even faster than a circuit breaker's "instantaneous" function makes possible. Technicians must manually enable circuits before doing maintenance work and then disable them when that work is complete, employing familiar lockout/tagout procedures.

d. **Implement an Arc Flash Relay system.** Arc faults are the most dangerous type of fault in low-voltage (LV) and medium-voltage (MV) switchgear. An Arc Flash Relay system helps improve worker safety and maximize electrical assembly uptime by combining current sensing with fiber optic light sensing to quickly detect and clear arc flash events. The system is designed to rapidly detect and clear even the most difficult forms of arc flash events in LV and MV electrical assemblies. For more information, refer to Eaton.com/EAFR

e. **Utilize Arc Quenching Switchgear.** The total clearing time of the aforementioned systems includes the clearing time of the upstream circuit breaker. Low voltage power circuit breakers, often found in switchgear, can take up to 4 cycles or 67 ms to clear a fault. Since incident energy is related to the magnitude of current flowing in the fault and clearing time, the main circuit breaker creates an impediment to achieve further reductions in incident energy. Arc quenching switchgear, however, is able to detect and contain an arc fault in less than 4 milliseconds, and can distinguish an arc fault from arcing that occurs during normal breaker operation. This is over 10 times faster than systems that rely on a circuit breaker to clear a fault and yields a corresponding reduction in incident energy. The system works by detecting the ignition of an arc inside the switchgear using Eaton's arc flash relay and transferring it to the arc quenching device where it is extinguished. Arc quenching switchgear has such a fast clearing time that it not only provides excellent personnel protection, but it also provides advanced equipment protection and it minimizes downtime due to arc flash events.

Note: When performing an incident energy analysis and implementing mitigation solutions, care must be taken to ensure the qualified worker understands the equipment and zone of protection. For example, a switchboard main breaker equipped with maintenance mode may not be suitable to reduce the arc flash hazard if there is not adequate separation or barriers to prevent a load side fault from propagating to the line side of the main breaker.

Figure 3. An Arc Flash Reduction Maintenance System shortens fault clearing times by bypassing time delays in the trip circuit.

Actions to reduce arc flash risk

Although the following actions will not reduce the calculated incident energy at a given location, these best practices will improve safety by removing personnel from the arc flash hazard and reduce the risk of an arc flash event occurring in the first place.

1. Adopt remote operation

Executing potentially dangerous procedures remotely can shield personnel from injuries. Here are two ways to limit the number of maintenance operations technicians must perform while in range of arc flash blasts:

a. **Install remote monitoring, control and diagnostics software.** Today's sophisticated power management systems equip administrators to perform many administrative tasks remotely. They also equip companies to remotely de-energize electrical equipment before staff approach it.

b. **Employ remote racking devices.** Traditionally, technicians have had to stand close to equipment with live, electrical connections when racking and un-racking breakers. Remote racking devices enable operators to perform these extremely dangerous tasks from a safe distance

2. Predict and prevent faults

One of the most effective ways to prevent an arc flash event is to anticipate and eliminate the conditions that cause it. The following are three possible solutions that can enable organizations to spot potential arc flash dangers before they have a chance to do harm and to keep personnel safely away from live connections.

a. **Monitor insulation integrity.** Deteriorating insulation is the leading cause of arc-producing electrical failures. Identifying and repairing compromised insulation before it fails can help avert arc flash explosions. Predictive maintenance systems provide early warning of insulation failure in medium-voltage switchgear, substations, generators, transformers and motors.

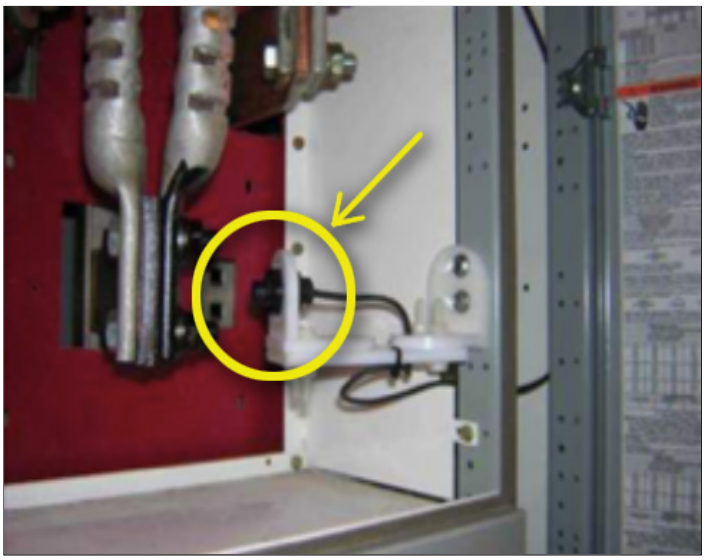


Figure 4. Pyrometers, like the one shown here, continuously monitor pressure junctions for signs of loosening.

b. **Use infrared (IR) windows.** Using contactless IR thermography technology, IR windows enable technicians to perform IR scans without removing switchgear side panels, lessening the likelihood of arc flash events caused by accidental contact with live bus.

3. Redirect blast energy

Equipment that directs arc flash energy away from personnel is called "arc resistant." Arc-resistant switchgear, for example, utilizes sealed joints, top-mounted pressure relief vents, and reinforced hinges to contain the energy and heat released by arc flashes and channel them via ducts to an unoccupied area inside or outside.

When all else fails, arc-resistant switchgear offers vulnerable employees a critical last line of defense from the explosive power of arc flash incidents. However, its protective qualities are effective only when equipment doors are closed, so companies should train their technicians to fasten doors securely during normal operation.

Conclusion

Arc flash events can do significant harm, ranging from disabling or fatal injuries to heavy fines and financially ruinous lawsuits. Yet, far too few equipment operators fully appreciate either the hazards arc flashes pose or the frequency with which they occur.

Fortunately, arc flash dangers can be dramatically mitigated with the help of a wide range of proven technologies and techniques. Remember, the first step is to perform an incident energy analysis to quantify arc flash hazards and to determine the best way to help mitigate risk. Though no combination of counter measures can totally eliminate arc flash hazards, utilizing the solutions and strategies discussed in this white paper can help organizations make arc flash incidents both significantly less likely to happen and drastically less harmful when they do.

About Eaton

Eaton is a power management company with 2017 sales of $20.4 billion. We provide energy-efficient solutions that help our customers effectively manage electrical, hydraulic and mechanical power more efficiently, safely and sustainably. Eaton is dedicated to improving the quality of life and the environment through the use of power management technologies and services. Eaton has approximately 96,000 employees and sells products to customers in more than 175 countries.

About the authors

David Loucks received a BSEE from the University of Kentucky and a MSEE and Ph.D. from the University of Pittsburgh and has served the electrical industry for 39 years. He's a 24-year Eaton veteran and currently researches and deploys novel solutions to a variety of power systems problems. Dave has been awarded 12 patents with several additional pending and is a senior member of the IEEE. Besides being licensed as a Certified Energy Manager through the Association of Energy Engineers he is also a registered Professional Engineer in the Commonwealth of Pennsylvania.

Adam Reeves joined Eaton in 2012 and holds the position of Senior Power Systems Engineer where he is responsible for performing power systems studies such as Short Circuit, Protective Device Coordination Arc Flash Analysis, Selective Coordination, and Load Flow studies. In addition, Adam is responsible for performing Onsite Metering, Power Quality Investigations and Harmonic Analysis Studies. Adam is Chairman of Eaton/PSE's Arc Flash Committee and has instructed arc flash training classes for commercial and industrial clients. He is also an IEEE member and is a Registered Professional Engineer in the State of Maryland. Adam received his bachelor of science in electrical engineering from the University of Maryland, College Park, MD.

Eaton
1000 Eaton Boulevard
Cleveland, OH 44122
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Eaton.com

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