Introduction to Arc Flash Safety

nVent HOFFMAN

WHAT IS ARC FLASH?

Although not a new phenomenon, awareness of arc flash and protecting against it has become a growing concern in the electrical industry. Often, an arc flash event is triggered by operator movement or contact with the energized equipment. This is a particular threat when faults occur within an enclosure. A phase-to-ground or phase-to-phase fault that results in an explosion can cause fatal injuries, severe burns and produce considerable property damage.

When an uncontrolled arc forms at high voltages, arc flashes can produce deafening noises, supersonic concussive-forces, super-heated shrapnel, temperatures far greater than the sun's surface, and intense, high-energy radiation capable of vaporizing nearby materials.

STANDARDS FOR SAFE ELECTRICAL PRACTICE

LAWS AND GUIDELINES

The National Fire Protection Association (NFPA) 70E Standard for Electrical Safety in the Workplace was written to protect personnel by reducing exposure to major electrical hazards. Originally developed at the request of the Occupational Safety and Health Administration (OSHA), NFPA 70E helps companies and employees avoid workplace injuries and fatalities due to shock, electrocution, arc flash, and arc blast.

The NFPA 70E standard provides the prescriptive work practice to comply with OSHA 29 Code of Federal Regulations (CFR), 1910 Subpart S. To protect operators, the standards require an "arc flash boundary" and recommend that electrical work should only take place on de-energized equipment. The "arc flash boundary" is the distance where the incident energy is equal to 5 J/cm2 (1.2 cal/cm^2), which is the energy level that unprotected skin will sustain a second degree burn. Unqualified personnel must be continuously escorted by qualified workers and Personal Protective Equipment (PPE) is required within the "arc flash boundary." In other words, access to potentially energized equipment capable of generating an arc flash must be limited to qualified personnel with extensive PPE, including arc-rated suits and hoods along with insulated tools and equipment. Arc flash PPE category is selected from either Incident Energy Analysis Method or the Arc Flash PPE Categories Method using tables 130.7(C)(15) and 130.7(C)(16) found in the NFPA 70E standard.

In addition to selecting the appropriate PPE, NFPA 70E describes risk assessments and enclosure labeling. It also covers safety-related work practices, maintenance of electrical equipment/installations, the requirements of special equipment for electrical installation, and employee training.

FINES

When safety guidelines are ignored or not enforced and a worker is injured or killed, companies face fines from OSHA.

In one instance cited in the OSHA Regional News Release in October 2014, an electric technician at a steel manufacturer in New York was struck by an arc flash when removing wiring from a fan motor in an overhead crane which caused an ungrounded electrical conductor to touch a grounded surface. The technician sustained third-degree burns on her hand and first-degree burns on her face, which could have been avoided had she worn rubber insulating gloves and a face shield. OSHA cited the company with proposed penalties totaling $147,000.

In another instance over the same time period, a maintenance worker at a furniture upholstery manufacturer in Mississippi was fatally electrocuted while disconnecting wiring on a saw. Due to the company's failure to provide electrical safety training, the worker was unaware that the equipment he was working on was still "live" and had enough electricity to kill him. OSHA found the manufacturer to be in violation of nine safety standards, resulting in $55,100 of proposed penalties.

In addition to fines, companies can also face other costs due to destroyed equipment, operation disruptions, litigation, higher insurance costs, and worker compensation claims.

RESPONSIBILITY

Facility managers, electricians, and control panel engineers have the responsibility to ensure a safe workplace environment to protect employees and businesses from harm.

Even the best-designed safety program will not guarantee that it will be consistently implemented and adopted across all workplaces. Implementation of a safety compliance program requires the support of management and the marshaling of many resources. Without this support, many safety programs often fail due to urgent priorities, inconsistent training of the workforce and delayed implementation.

The right project management and training support can help you:

- ensure compliance with relevant hazardous energy standards
- reduce time to compliance
- improve workplace safety
- provide high-quality, cost-effective implementation and training services, and
- limit exposure to regulatory fines.

PREVENTING ARC FLASH

AWARENESS OF THE HAZARDS

As automation and control systems continue to expand and become increasingly complex, the more crucial it is to take necessary safety precautions. Balancing productivity and system optimization with worker safety is a challenging act that requires a disciplined approach. Because of the fatal nature of the injuries and the cost implications to the business, the risks are too high to leave things to chance. It takes just one incident to change the life of a worker. The damages created by an arc flash incident are preventable if safety precautions are implemented and followed.

STATISTICS ON FATALITIES AND INJURIES DUE TO ARC FLASH

The statistics on arc flash accidents, ranging from death to severe injuries, shed light onto the prevalence of such incidents.

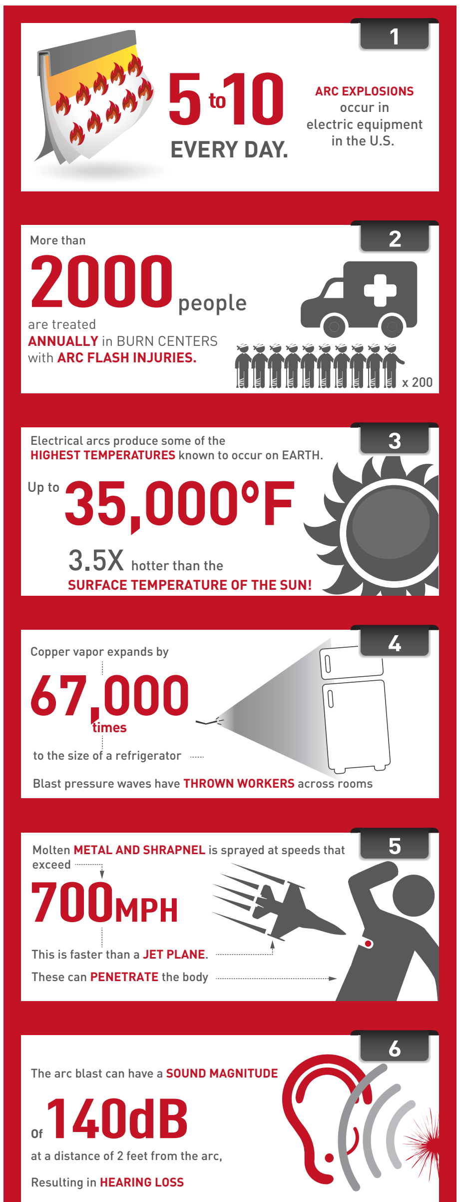
There are 5-10 arc explosions every day in the U.S., resulting in numerous deaths each year. Electrical arcs produce some of the highest temperatures known to occur on earth. Up to 35,000°F, which is 3.5X the surface temperature of the sun. Even when several feet from the arc, fatal burns can occur, as clothing can be ignited from 10 feet away.

When victims do survive, estimates indicate that more than 30,000 non-fatal electrical shock accidents occur each year. According to NFPA 70E, typically, as much as 80 percent of hospital admissions from electrical incidents are a result of burns from an arc flash and ignition of flammable clothing, rather than electrical shock. Over 2,000 people are admitted to burn centers for severe arc flash burns each year.

At these high temperatures, all known materials are vaporized causing a sudden expansion of air. These blast pressure waves have thrown workers across rooms. Additionally, the blast heat and pressure causes droplets of molten metal to spray at speeds that exceed 700 mph, faster than a jet plane. Blast shrapnel can penetrate the body from 10 feet away.

To add to the list of injuries, the arc blast can have a sound magnitude of 140dB at a distance of 2 feet from the arc, similar to the sound of military jet afterburners. This results in hearing loss.

The numbers of deaths and injuries resulting from arc flash may actually be higher than reported. Burns caused by arc flash may not be classified as an electrical burn or arc flash burn, dwindling the perception of the occurrence of arc flash incidents.



Source: NFPA 70E - 2015 Edition, Creative Safety Supply (www.creativesafetysupply.com)

PROCEDURES

Best practices in meeting the OSHA, NFPA 70E, and Canadian Standards Association (CSA) safety standard requirements to establish a workplace free of unknown hazards in relation to the electrical system include risk assessments, training programs, lockout-tagout procedures, and marking and identification systems.

Risk Assessments

Mitigating the risk of electrical hazards begins with a shock risk assessment and an arc-flash risk assessment. The shock risk assessment determines the voltage personnel could be exposed to, the shock protection boundary, and the appropriate PPE for shock protection. The arc-flash risk assessment determines if an arc-flash hazard exists. If so, it further determines the appropriate safety related work practices, the arc-flash boundary, and appropriate PPE for arc-flash protection. The arc flash boundary is relevant to systems 50 volts and greater.

The risk assessments must be updated when a significant modification or renovation involving the electrical distribution system occurs or it must be reviewed at least every five years.

Training Programs

Training is critical for all workers who are exposed to risk hazards. These workers must thoroughly understand the requirements of the electrical safety program, which is required by NFPA 70E and OSHA 29 CFR 1910.147 for all industrial locations and must include safety principles, controls used to measure and monitor, and specific procedures regarding how to work within the safety boundaries.

NFPA 70 requires training which is divided into two groups: Qualified and Unqualified employees. A qualified person has demonstrated skills and knowledge relating to the construction and operation of electrical equipment and installations. This person is typically the electrician who is working on energized conductors. Unqualified personnel are neither trained nor familiar with determining exposed energized conductors or how to determine nominal system voltage and the apparent hazard.

The content of the qualified personnel training includes the identification of specific electrical hazards and the potential risk for injury. It also discusses emergency procedures needed in the event of an incident and first aid care, including resuscitation.

Unqualified employee training only includes training on electrical safety practices necessary to avoid injury.

Retraining or additional training is required when new technology or job roles change or on an interval NOT to exceed three years. It is important that the employer documents employee training, which should include the content of the training, employee's name and dates of training.

Lockout/Tagout

Lockout/Tagout (LOTO) procedures are established to protect employees from accidental start-up of equipment or accidental release of hazardous energy.

NFPA 70E specifies that LOTO procedures be implemented as part of establishing an electrically safe working condition—see related specification OSHA 29 CFR 1910.147, The Control of Hazardous Energy. Annex G of NFPA 70E Handbook has a sample LOTO program that may be used as a template. A key principle of the LOTO procedure is that a circuit or panel is considered to be "live" until a test instrument is used by a qualified employee wearing required PPE to verify the source(s) of energy are removed. Test instruments are to be verified that they are working properly by checking with a reference voltage source before and after an absence of voltage test is performed. Wherever possible, verification includes visual inspection of the blades of disconnecting devices to insure they are in the fully disconnected position.

Other key principles of a robust LOTO program include:

- **Employee Involvement**—each person who could be exposed to hazardous energy on a specific job is included in the LOTO process, otherwise referred to as Group Lockout. Personnel shift changes should also be monitored.
- **Training**—employees are trained on the site specific LOTO/Energy Control Procedure.
- **Procedures**—specific procedures are required for complex LOTO instances where there are multiple energy sources and/or multiple crews, locations, employers, specific sequences, etc. See NFPA 70E Article 120 (D) (2) for more information. OSHA 29 CFR 1910.147 (c) (4) (i) requires machine-specific procedures in complex lockout conditions including equipment with more than one energy source.

LOTO procedures need to contain instructions to include:

- **De-Energize Equipment**—where and how to de-energize the equipment
- **Stored Energy**—how to release hazardous electrical, mechanical, or other stored energy (for example capacitors are discharged, springs unloaded, pneumatic/hydraulic pressure released, etc.)
- **Verification**—how to verify the equipment is de-energized and cannot restart in the locked out condition
- **Easy to Understand Procedures**—for securing equipment and electrical access points start with a floor plan layout that provides a bird's eye view or easy-to-understand photographs of equipment.

Marking and Labeling

Signage, labeling and identification systems form the backbone for safety information. They also help with routine tasks that mark, for example, the location for parking a fork lift truck. Safety identification systems can include:

- Signs and labels that indicate hazardous conditions
- Voltage markers, pipe markers, tapes and letters/numbers and
- Custom markers.

Labeling equipment plays a critical role to warn, remind, and alert people of possible harm. NFPA 70 requires the labeling of switchboards, panel boards, and industrial control panels, meter socket enclosures and motor control centers to warn the qualified person of the potential for arc flash. All power sources for machines are potential sources of danger and are required to be appropriately labeled with information to perform shock risk and arc flash hazard risk assessments. Figure 1 is an example of an arc flash warning label.

The label must include:

1. Nominal system voltage
2. Arc flash boundary
3. At least one of the following
    a. Available incident energy and the corresponding working distance OR the arc flash PPE category, but not both
    b. Minimum arc rating of clothing
    c. Site-specific level of PPE

Other alerting techniques such as safety signs, symbols, or prevention tags are recommended to warn employees of potential workplace hazards. As an example of facility signage specified by the National Electric Code according to 490.53 for equipment operating over 1000V, all energized switching and control equipment shall be enclosed in grounded metal cabinets and marked "DANGER - HIGH VOLTAGE - KEEP OUT."

PERSONAL PROTECTIVE EQUIPMENT

The purpose of personal protective equipment (PPE) is to reduce employee exposure to hazards when engineering and administrative controls are not feasible or effective to reduce these risks to acceptable levels.

PPE includes specialized clothing or equipment worn by employees to protect the body including the head, face, eyes, ears and hands. The level of PPE is determined by the degree of the shock and arc flash hazard. The arc flash PPE category determined by the NFPA 70E tables 130.7(C)(15) and 130.7(C)(16) or the Incident Energy Analysis Method is then used to decide the required PPE for the task. For example, according to Table 130.7(C)(15)(A)(a), PPE is required for toggling a circuit breaker with the enclosure doors open for a 600V class motor control center (MCC) with a maximum 65kA short circuit current available and maximum clearing time of 0.03 seconds. According to Table 130.7(C)(15)(A)(b), category 2 PPE is required, which consists of 8 cal/cm2 arc-rated clothing covering the entire body and head, a hard hat, safety goggles, hearing protection, leather gloves, and leather footwear. Additionally, insulated tools and equipment (and/or handling equipment) are used when working within the restricted approach boundary or arc flash boundary.

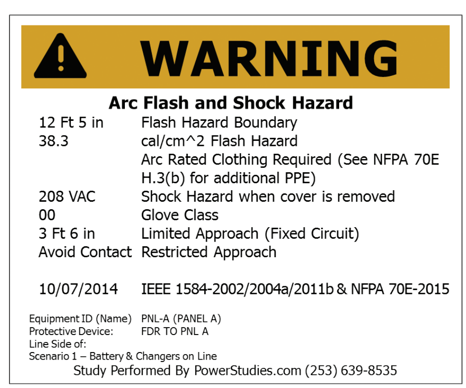


Figure 1. Example of Arc Flash Warning Label

The PPE is listed in Table 130.7(C)(16) and is arranged into Categories 1 through 4. Forty cal/cm2 is considered the upper boundary for the maximum anticipated exposure level because PPE is not able to sufficiently protect employees, which means energized work is prohibited. NFPA 70E Table 130.7(C)(14) lists the standards relevant to protective equipment.

ENCLOSURE DESIGN

While PPE is essential to the workplace in protecting against injury from arc flash, it does not eliminate the likelihood of an incident occurring. In other words, wearing the appropriate PPE reduces the severity of the injuries sustained, making the incident survivable. To reduce the likelihood of an arc flash event from happening in the first place, modifying the design and configuration of electrical equipment is essential.

DESIGNS THAT KEEP WORKERS SAFE FROM POWERED ELECTRICAL ENCLOSURE

The design and configuration of electrical equipment can be constructed in such a way as to create physical obstructions intended to prevent contact with equipment or live electrical components. Examples of designs and configurations that can help achieve that include:

- **Interlock mechanisms**—When the power source is on, this mechanism prevents personnel from getting inside the enclosure. These mechanisms, which can be either mechanical or electrical, assure that power is physically turned off to allow the enclosure door to open. Once the enclosure door is closed, power can then be restored. (See Appendix solution #1 and #2.)
- **External disconnect enclosures**—An external disconnect enclosure attaches to the side of the control enclosure and houses only the disconnect switch or circuit breaker, physically removing it from the control enclosure. Power passes to the control enclosure via a terminal block mounted on the shared enclosure walls. When the disconnect switch is off, the line side of the disconnect switch, which is still hot, is isolated in the external disconnect enclosure and there is no power coming into the control enclosure. Work can be done on the interior components of the control enclosure without exposure to those live parts. (See Appendix solution #3.)
- **Infrared (IR) windows**—Windows that can be installed on the enclosure to provide a view or inspect internal equipment. These allow technicians or thermographers to conduct maintenance tasks or thermal surveys without the need to open the enclosure or de-energize the equipment. (See Appendix solution #4.)
- **Data ports**—These are used to allow programming access as well as conduct diagnostics to devices inside an enclosure without opening the enclosure. These ports can be mounted on the outside of the enclosure door or enclosure wall, allowing personnel to program the device inside the enclosure. (See Appendix solution #5.)
- **External data pockets**—A data pocket that mounts on the outside of the enclosure to keep manuals and various worksheets outside the enclosure. It keeps these materials nearby for convenience and prevents the need to open the enclosure to access them. (See Appendix solution #6.)
- **Lockouts**—These are used when more than one person is servicing an enclosure and needs to secure the power source. Safety lockouts ensure that before any work on a machine or equipment is started, all applicable energy sources have been rendered safe. Personnel can apply individual padlocks to secure the power source when servicing the enclosure and remove their own lock once completed. This ensures that the power source cannot be turned on by one person when another person is servicing the enclosure. The last person to complete the project removes the lock and restores the equipment to operation. (See Appendix solution #6.)

BENEFITS OF DESIGNING TO MITIGATE ARC FLASH INCIDENTS

The major benefit of designing to mitigate arc flash incidents is that it is a more effective approach to increase worker safety. When thought is put behind the system design, the factors that can cause an arc flash to occur are reduced or eliminated.

Generally, there are three main causes of arc flash incidents:

- **Human error**—naive or arrogant attitude on work procedures, amateur maintenance mistakes, and mishandling tools, wires, and metal covers
- **Negligent preventive maintenance**—not checking for loose terminals, allowing dust and debris build-up (critical in medium and high voltages), and not testing stored energy (e.g., spring-operated bolted pressure switches)
- **Inadequate electrical equipment/system design**—incorrect configurations or using legacy equipment that doesn't take risk hazards into account

Unfortunately, human error is hard to eliminate and negligent preventative maintenance can only be improved to the extent that companies enforce safety programs. However, designing or configuring equipment and systems reduce the probability of arc flash incidents is very possible, if not a more reliable way to achieve that.

Maintenance is a key factor that should be considered in the system design phase. In high volume production facilities in particular, downtime is an expensive endeavor and should be avoided at all possible. Designing a system to avoid downtime includes integrating methods of operational verification. Infrared thermography is a widely common routine in the electrical maintenance procedures. "Hot spots" caused by defective electrical equipment can give an early indication of looming failure which can be easily identified utilizing infrared camera technology. The detection of these "hot spots" is dependent on the heat generated by the equipment when running or shortly thereafter, either exposing a worker to energized equipment or pressuring the worker into a rushed lockout-tagout procedure to gain accurate data. Both of these scenarios increase the chance of an arc flash incident. Infrared windows, for these reasons, eliminate the exposure to energized equipment yet allow transmission of infrared radiation.
They not only help reduce the likelihood of an arc flash incident but also reduce the time invested in performing routine inspections by eliminating the need for PPE and the removal of enclosure covers in order to perform such analysis.

Often, work must be done on an open enclosure. In these instances, external disconnect enclosures effectively mitigates arc flash incidents in two ways. One is through its interlocking mechanism which ensures that the control enclosure door cannot be opened when the disconnect is in the on position. This protects workers from exposure to energized components and complies with interlocking requirements of UL 508A, NFPA 79, IEC 60204 and HS 1738 – the most common electrical standards for industrial machinery. The human error of opening the control enclosure before turning the power off or forgetting to close the doors before turning power on is eliminated.

The second reason this system design is effective in mitigating arc flash incidents is because it moves the disconnect switch to an external enclosure. The line side of the switch is live even after the power has been turned off, which is an area with a potential for an arc flash. By physically isolating the risk area to an external location, technicians are able to work on the control enclosure without exposing themselves to live electrical components. As a result, this enables technicians to remove PPE, once a panel is verified power free, while working in the control enclosure.

The mindset of seeing an enclosure based arc flash mitigation solutions as an avoidable expense, unfortunately many do not consider the cost of the alternative result.

Although developing electrical equipment and system designs that reduce arc flash incidents present an added initial cost in the design phase, it can almost certainly be deemed a worthwhile investment when fully understanding the implications of not implementing this technology. If a single serious arc flash incident occurs, aside from the physical and emotional damage to the employee, it could cost and employer over $1,000,000 in fines, workers compensation claims, legal fees and equipment downtime. Arc flash is preventable if all safety avenues are considered as a whole.

APPENDIX

SOLUTIONS FROM NVENT HOFFMAN TO MITIGATE ARC FLASH INCIDENTS

#1

DISCONNECT ENCLOSURES

Disconnect enclosures, designed with mechanically interlocked latching, prevent exposure to components when the power is on.

#2

ELECTRICAL INTERLOCKS

Electrical interlocks provide internal safety lockout while the equipment is energized. When energized, interlocks prevent the enclosure door from being opened.

#3

SEQUESTR EXTERNAL DISCONNECT ENCLOSURE

External disconnect enclosures help mitigate arc flash occurrences when working on interior components by isolating incoming power from the control enclosure.

#4

IR WINDOWS

IR windows provide a safe, efficient, and accurate way to perform electrical inspections or predictive maintenance without removing the panels or disturbing the electrical equipment.

#5

INTERSAFE DATA INTERFACE PORTS

Data ports allow technicians to conduct diagnostics and provide access to programming devices inside an enclosure without opening the enclosure door.

#6

EXTERNAL DATA POCKETS

Data pockets mounted on the exterior of an enclosure provide access to system documentation without opening the enclosure door.

#7

SAFETY LOCKOUTS

Safety lockouts provide a means of using multiple padlocks on a secured power source. Includes a 10.00-in. (254-mm) plated steel chain. Manufactured from 10- gauge steel with six station holes

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