

Understanding and Reducing Arc Flash Hazards

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WHAT YOU WILL LEARN FROM STUDYING THIS PAPER:

What is Arc Flash
Causes and Effects
Potential Injuries
Safety Standards
How to reduce hazards

WHY YOU NEED TO KNOW ABOUT ARC HAZARDS

Although arc hazards have existed since man began using electricity, increasing deaths, injuries, and property loss from arcing faults have led to increased study into the causes, effects, and methods of protection. The studies are not complete, and the scientific community has not reached complete accord on the methods used to calculate the hazards. However, these studies serve as a starting point for improving worker safety. While much work remains to be done, in the interest of improved safety, several national codes and standards have been revised. These revisions are intended to reduce worker exposure to arc hazards and establish safer work practices when approaching or working on energized equipment. Since the changes affect every person involved in the design, installation, service, and maintenance of electrical systems and all machinery, mechanical equipment, and devices powered or controlled by electricity, applicable codes and standards should always be followed.

While parts of the Standards, Regulations, and Codes especially relating to arc flash hazards are quoted or summarized herein, readers are cautioned that only the complete Standards constitute the law or regulation and all parts must be followed where applicable. In addition, some crit-

ics take the position that calculating methods contained in the standards greatly understate the incident energy for systems under 600 volts. Because the standards and regulations attempt to establish minimum requirements for improving safety, these minimums may not be adequate, and it may be necessary to use an increased level of personal protective equipment.

The principle regulations that address arc hazards are:

National Fire Protection Association (NFPA) Standard 70 “The National Electrical Code” (NEC). By definition the NEC is an installation standard although to some degree its requirements impact on maintenance and repair.

NFPA 70B 2002 “Recommended Practice for Electrical Equipment Maintenance.”

NFPA 70E 2000 “Standard for Electrical Safety Requirements for Employee Workplaces.” NFPA 70E 2000 is referenced by the Occupational Safety and Health Administration (OSHA) and forms part of their “Safety Related Work Practices.”

OSHA Standards 29-CFR, Part 1910. Occupational Safety and Health Standards. 1910 sub part S (electrical) Standard number 1910.333 specifically addresses Standards for Work Practices. OSHA Regulations apply to every worker that may approach or be exposed to electric energy. Failure to conform to these regulations frequently causes serious worker injuries, expensive downtime, and costly lawsuits.

WHAT CAUSES ARCS AND IMMEDIATE CONSEQUENCES.

When electric current flows between two or more separated energized conducting surfaces, an arc occurs. Some arcs may be intentional such as arc welding or they may be accidental caused by a tool slipping or by touching a test probe to the wrong surface. A common cause of an arc is insulation failure. The fault current's magnetic effects causes conductors to separate producing an arc. The results of such arcs are often devastating. Temperatures at the arc terminals can reach or exceed 35,000 degrees Fahrenheit (F) or four times the temperature of the sun's surface. The heat energy and intense light at the point of the arc is termed ARC FLASH. Air surrounding the arc is instantly heated and conductors are vaporized causing a pressure wave termed ARC BLAST. System voltage, arc resistance (impedance) and available short-circuit current determine instantaneous arc energy. Total arc energy (incident energy) is the instantaneous arc energy times the arc duration. Conductive vapors help sustain the arc and the duration of the arc is primarily determined by the time it takes for overcurrent protective devices to open the circuit. Current-limiting fuses for example may open the circuit in 8.3 ms (1/2 cycle) or less while other devices may take 100 ms (6 cycles) or more to open.

WHAT ARE THE HAZARDS

ARC FLASH

Anything that produces electrical current has the potential to produce an arc, even a 12 volt battery. But what industry typically refers to as ARC FLASH, is the SUDDEN release of large amounts of heat and light energy at the point of a fault. Exposure to an arc flash frequently results in a variety of serious injuries and in some cases death. Workers have been injured even when ten feet or more from the arc center. Equipment can be destroyed causing extensive downtime and requiring expensive replacement and repair. Nearby flammable materials may be ignited resulting in

secondary fires that can destroy entire facilities.

ARC BLASTS & EJECTED MATERIAL

An arc flash not only includes intense heat and light but also loud sounds and blast pressures. The arc blast often causes equipment to literally explode ejecting parts, insulating materials, and supporting structures with life threatening force. Heated air and vaporized conducting materials surrounding the arc expand rapidly causing effects comparable to an explosive charge. As conductors vaporize they may project molten particles similar to buckshot. Three inches of vaporized #10 copper wire expands to approximately one cubic foot or 67,000 times its solid state. Tools, loose nuts and bolts, and similar items in the path of an arc blast may become projectiles.

Direct effects of an arc blast are frequently catastrophic. Total force on a worker standing in front of an open enclosure may exceed 1,000 pounds. Such forces may crush a worker's chest breaking bones, puncturing lungs or other organs or even propel workers into equipment, walls, windows, etc. causing additional trauma. Falling from ladders or other insecure positions can also injure workers. Even if the blast is not sufficient to move the worker, arc fault testing indicates that severe head tossing often occurs causing whiplash type injuries with the possibility of brain damage.

LOCATION AFFECTS THE HAZARDS

The immediate surroundings of an arc fault also greatly influence the results to personnel and equipment. Arc Flash effects are more severe in a small enclosed space such as a switchgear room than in open air. When an arcing fault occurs in open air, arc energy spreads in all directions; lessening the effect at any one point. When arcing occurs in a more confined space such as an opened switch box, cabinet or other enclosure, arc energy is concentrated towards the open side. This greatly increases the risk of serious injury to workers that may be standing immediately in front of the opening or reaching in to perform maintenance or testing.

If work is being performed on equipment and an arc occurs, it is not uncommon for a worker to be very close to the arc. Typically, hands may be less than 6", the face 12" and the upper body 18" from the arc. The use of personal protective equipment (PPE) is vital to preventing or minimizing serious injury.

POTENTIAL INJURIES

Direct and Secondary Burns

At some distance from the arc, temperatures are often high enough to instantly destroy skin and tissue. Tissue damage is directly proportional to time and skin temperature. Studies show that skin temperatures above 205° F for 0.1 second result in irreversible tissue damage, defined as an incurable burn. Skin temperature is primarily determined by the intensity of the flash, the distance from the arc, and the exposure time. Table 1 shows effects for other temperatures and duration times.

Skin Temperature	Time Duration	Effect on Skin
110° F	6 hours	Cell breakdown begins
158° F	1 sec.	Complete cell destruction
176° F	0.1 sec.	Curable burn
205° F	0.1 sec.	Incurable burn

Table 1

Heated air and molten materials from arc faults often causes ordinary clothing to burst into flame even if not directly in contact with the arc. Unless the clothing is flame retardant, it may continue to burn increasing the area of injury. Synthetic fibers such as nylon and polyester may melt and adhere to skin resulting in secondary burns.

Vision and Hearing Injuries

Even when regular safety goggles or glasses are worn, arc flash may cause severe damage to vision and or blindness. Intense ultraviolet (UV) light created by arc flash can damage the retina in the eye. Exposure to UV can cause a feeling of

grit in the eye, blurred vision, burning sensations, eye tearing, and even headaches. The pressure created from arc blasts can also compress the eye severely damaging vision. If proper eye protection is not worn, ejected materials and flying particles can come in contact with the eye and cause further damage.

Hearing can also be affected by the loud noises and extreme pressure changes created by arc blasts. Sound and noise levels are commonly measured in decibels (dB). OSHA defines the permissible exposure limit (PEL) at 90 dB and requires workers who are exposed to average levels of 85 dB or higher to use hearing protection. If the sound increases by 3 dB, it is equivalent to the sound level doubling. Published test data has shown arc blasts to exceed 140 dB which is equal to an airplane taking off. Sudden pressure changes exceeding 720 lbs/ft² for 400 milliseconds can also rupture eardrums. Even at lesser pressures, serious or permanent damage to hearing may occur.

WHAT SAFETY STANDARDS ADDRESS ARC FLASH

The principle Standard addressing the **installation** of safe electrical systems is the NEC. Until recently, the NEC has primarily addressed bolted short circuits or faults. When a bolted fault occurs, the **maximum** available short-circuit current will flow through the conductors limited only by the impedance (I^2Z) of the circuit. In order to comply with NEC Sections 110.9 and 110.10, short-circuit calculations are necessary whenever available fault current may exceed equipment interrupting or short-circuit ratings.

Arcing faults present a different problem. NEC section 110.16 helps address this by requiring warning labels on specified equipment. During an arcing fault, arc resistance decreases current flow. Staged tests of arcing faults show that Arc Flash Hazards are often most severe when arc currents are substantially less than available fault current. In order to select PPE, incident energy must be known at every point where workers may

be required to perform work on equipment that is energized.

NEC-2002 addresses Arc Flash Hazards in the new section 110.16:

110.16 Flash Protection. - “Switchboards, panelboards, industrial control panels, and motor control centers that are in other than dwelling occupancies and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.”

While not every type of equipment is expressly named, “industrial control panels” covers every enclosure that may contain exposed energized conductors or components. A typical label is shown in Figure 2. NEC-2002 requires such labels on all new equipment. To achieve maximum safety, these labels should be installed on all existing enclosure doors, removable panels, etc.

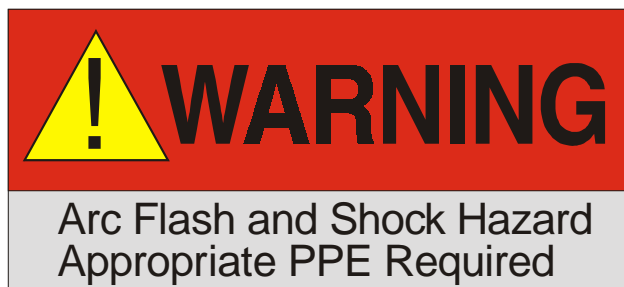


Figure 2

As the number of worker deaths and injuries increased due to electrical hazards, it became apparent that a new National Standard was needed; one that specifically addressed employee safety, and could be used by OSHA. NFPA70E was developed as the result and has become one of the most widely used resources for electrical safety. The purpose of NFPA 70E can be summarized as a standard that “addresses those electrical safety

requirements for employee workplaces that are necessary for the practical safeguarding of employees in the pursuit of gainful employment.”

Below is a brief description of some of the standards that address arc-flash and other electrical hazards:

NFPA 70E Part I contains the General Requirements for Electrical Installations. Part II covers General Requirements for Electrical Work Practices that are required to safeguard employees from injury while they are working on or near exposed electrical conductors or circuit parts that could become energized. In addition to the general rules, it details specific safe work practices to avoid exposure to arc flash, and to reduce the hazard when there is exposure.

OSHA Standards 29-CFR, Part 1910. Occupational Safety and Health Standards. 1910 sub part S (electrical) Standard number 1910.333 specifically addresses Standards for Work Practices and references NFPA 70E.

The Institute of Electronics and Electrical Engineers (IEEE) has published Standard 1584 *IEEE Guide for Performing Arc-Flash Hazard Calculations*. The Guide presents a comprehensive history of Arc-Flash Hazards and contains an arc-flash calculator that is intended to simplify incident energy calculations.

NFPA 70B 2002 “Recommended Practice for Electrical Equipment Maintenance.” This standard is intended to be used to help establish Electrical Preventive Maintenance Programs (EMP). “The purpose of this recommended practice is to reduce hazards to life and property that can result from failure or malfunction of industrial-type electrical systems and equipment.” NFPA 70B also references the NEC and NFPA 70E.

NFPA70. National Electrical Code (NEC) 2002. The NEC is revised every three years. It is important to note that many jurisdictions do not adopt the newest revisions for some time, so the new requirements in Section 110.16 and other provi-

sions relating to arc flash may be unfamiliar, yet it is imperative that the provisions of the 2002 NEC are adopted and enforced. Deaths, injuries, property damage, downtime, insurance claims, and costly lawsuits can be reduced, and OSHA penalties avoided.

The NFPA is in the process of considering numerous proposals for changes in the arc flash requirements for the 2005 NEC. Several proposals have been made that would require the warning labels required in Section 110.16 to indicate the incident energy level or the type of PPE required. Such labels, similar to Figure 3, are already in use by a number of industries.

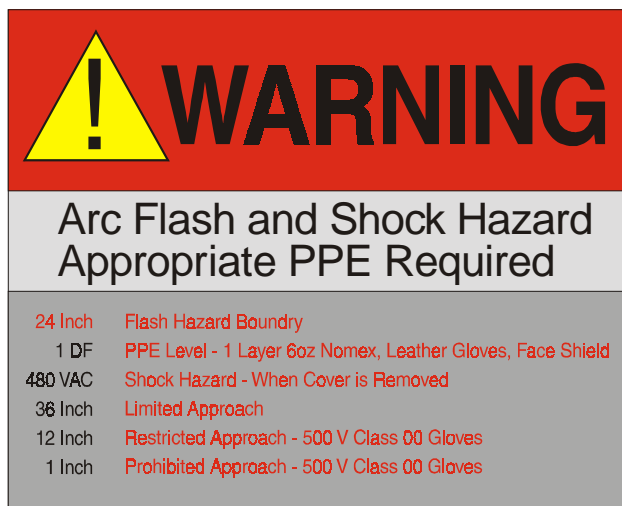


Figure 3

WHAT THE CODES AND STANDARDS REQUIRE

The fundamental rule in all codes and standards is: Before opening any enclosure that may contain exposed energized circuit parts or equipment, or approaching exposed energized conductors or equipment, the equipment shall be **de-energized**. Or, as OSHA states: “. . . be placed in an electrically safe condition.”

While the requirements are very specific and are included in the referenced standards, in general:

1. Before opening any enclosure that may

contain energized circuit parts or equipment, every source of power over 50 volts must be disconnected and appropriate lockout/tagout procedures initiated.

2. After the enclosure is opened, a “qualified” person wearing suitable PPE must use appropriate test equipment to test all exposed parts insuring that the equipment is electrically safe. Special consideration must be given to insure that all capacitors are discharged and that all control power disconnected. Until the testing is completed, OSHA considers the equipment to be electrically **unsafe**.

There are only two exceptions to this requirement:

1. It will create a greater hazard to de-energize the equipment typified by disconnecting ventilation to hazardous areas, or alarm systems.
2. Access to energized equipment is required to perform voltage, current, or other tests.

However, all referenced codes require that the person(s) be specially qualified to work on energized equipment. OSHA, for example, states in 29CFR part **1910.333(c)(2)**:

“Work on energized equipment. Only qualified persons may work on electric circuit parts or equipment that have not been deenergized under the procedures of paragraph (b) of this section. Such persons shall be capable of working safely on energized circuits and shall be familiar with the proper use of special precautionary techniques, personal protective equipment, insulating and shielding materials, and insulated tools.”

Additional material in the NFPA Standards and in OSHA define a qualified person as one who has received documented training in the hazards of working on energized equipment in general, and has been trained in the hazards of the particular equipment to be serviced. Training must include the use and proper application of PPE such as insulating gloves, face shields, fire resistant clothing, insulating blankets, etc.

In those cases where workers must approach energized conductors or equipment, NFPA 70E establishes several boundary limits. These boundaries are determined by the arc-flash energy (incident energy). Incident energy is calculated in calories per square centimeter (cal/cm^2) and is a function of system voltage, available short-circuit current, arc current, and the time required for circuit protective devices to open. Dr. Ralph Lee developed formulas for calculating incident energy and determining approach boundaries. Critics of Dr. Lee's work and IEEE 1584 have stated that some formulas used to calculate incident energy for systems under 600 volts may understate the potential hazard. Caution should be used when applying the formulas and calculation models. NFPA 70E 2000 includes Dr. Lee's calculation formulas, hazards risk assessment, standards for PPE, and similar information. A brief summary is included for protection boundaries but for additional information NFPA 70E and IEEE 1584 should be referenced.

Flash Protection Boundaries: Defined as a safe approach distance from energized equipment or parts. NFPA 70E defines the three shock protection boundaries and establishes the default Flash Protection Boundary at 4.0 ft. for systems from 50 to 600 volts. The boundary must be increased for specific conditions, and higher voltages. NFPA 70E also allows Flash Protection Boundaries (FPB) to be calculated. In some instances, calculations may decrease the boundary distance. Persons crossing into the Flash Protection boundary are required to wear the appropriate PPE as determined by calculating methods contained in NFPA 70E. In addition, a qualified person must accompany unqualified persons.

Limited Approach Boundary: "A shock protection boundary to be crossed by only qualified persons (at a distance from a live part) which is not to be crossed by unqualified persons unless escorted by a qualified person." It includes any conductive tool or item they may be carrying or handling. For example, a painter using a long-handled roller must maintain a distance sufficient that the roller cannot enter the "Limited Space". For a

qualified person to cross the Limited Approach Boundary and enter the "Limited Space", they must use the appropriate PPE and be trained to perform the required work.

Restricted Approach Boundary: "A shock protection boundary to be crossed by only qualified persons (at a distance from a live part) which, due to its proximity to a shock hazard, requires the use of shock protection techniques and equipment when crossed." To cross the Restricted Approach Boundary into the "Restricted Space", in addition to the PPE and required training, a qualified person must have a documented plan approved by management, and plan the work to keep all parts of the body out of the "Prohibited Space".

Prohibited Approach Boundaries: "A shock protection boundary to be crossed by only qualified persons (at a distance from a live part) which, when crossed by a body part or object, requires the same protection as if direct contact is made with a live part." To cross the boundary and enter the "Prohibited Space", the qualified worker must have specified training to work on energized conductors or components, and a documented plan justifying the need to perform this work.

As noted, the electrical safety standards contained in NFPA 70E and OSHA apply to all workers, not just those performing electrical work. For example, cleaning personnel or painters working near exposed energized equipment or conductors must not approach closer than the limited approach boundary. In addition, any tools they may use must not be capable of entering the boundary.

REDUCING ARC-FLASH HAZARDS

Studies and tests referenced in NFPA70E and IEEE 1584 show that opening time of the overcurrent protective devices directly affects total arc-flash intensity. Protective devices (primarily fuses and circuit breakers) intended to interrupt fault currents operate fastest at higher values of overcurrent (See Table 2).

Typical Opening Times of Overcurrent Protective Devices

Overcurrent Device	Opening time at 8 x rating	Opening time at 20 x rating
Current-limiting fuses ^A	0.1 to 1 sec	8.3 ms or less
Molded case circuit breakers under 600 amps	5-8 seconds	<10 ms ^B
Molded case circuits breaker over 600 amps	Depends on trip settings: over 5 to 20 sec.	<25 ms ^B
Large air power breakers	Depends on trip settings: over 5 to 20 sec.	<50 ms=3 cycles ^B
Medium voltage breakers ^C	Depends on trip settings: over 5 to 20 sec.	<100 ms=6 cycles

Table 2

^ACurrent-limiting fuses also reduce the fault current.

^BWhen equipped with instantaneous trip units.

If short delay trips are used for coordination, time may exceed 0.2 seconds

^CPlus relay time

When the arc current exceeds the current-limiting threshold of the fuse, the amount of arc current is greatly reduced, and the circuit is opened in less than ½ cycle (0.0083 seconds) In many cases, opening time may be ¼ cycle (0.004 seconds) or less. When arc resistance decreases, current below the current limiting range of the protective device may allow the arcing to continue for an extended time. This in turn will increase the arcing hazard. Protecting each circuit with carefully applied current-limiting fuses will significantly reduce arc-flash hazards. The use of Littelfuse Class RK1, J and CC fuses provide unsurpassed protection to circuits 600A and below. While no protective device can totally eliminate the hazards, proper fuse application will reduce the hazard, and help simplify the selection of PPE.

In order to properly apply fuses or circuit breakers, the available fault current must be determined at each point where workers may be exposed to energized circuits, the arc energy must be calculated, and the opening time of the protective device determined.

Littelfuse POWR-GARD Products has a continuing commitment to improved safety and system protection. For additional application information or answers to your questions, call the Littelfuse Technical Hot line at 1-800-TEC-FUSE (832-3873).

REFERENCES

NFPA publishes over 300 codes and standards; many that impact employee safety and which may also apply to arc flash protection. Full access to NFPA web site (www.nfpa.org) is restricted to members of NFPA or those subscribing to their services, lists of publications and standards are accessible by all and may be purchased through the web.

NFPA 70 2002- National Electrical Code®

NFPA 70B 2002 - Recommended Practice for Electrical Equipment Maintenance

NFPA 70E 2000- Standard for Electrical Safety Requirements for Employee Workplaces

NFPA 79 2002- Electrical Standard for Industrial Machinery

NFPA 101 2003- Life Safety Code

OSHA Standards 29-CFR, Part 1910. Occupational Safety and Health Standards. 1910 sub part S (electrical). OSHA Regulations may be accessed at www.OSHA.GOV.

IEEE standard No. 1584-2002: *IEEE Guide for Performing Arc-Flash Hazard Calculations* Information on obtaining copies of the Guide as well as other information may be found at the IEEE website: www.ieee.org.

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