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Electrical Safety Requirements

By Dennis K. Neitzel, CPE

The three major hazards of electricity are electrical shock, electrical arc flash and electrical arc blast. These electrical hazards in the workplace pose a significant risk of injury or death to any employee who may be in the vicinity of electrical equipment when energized parts are exposed or when a failure occurs.

OSHA develops and issues the principal legal requirements for electrical safety in the U.S. The OSH Act was signed into law on December 29, 1970, with the first electrical safety standard becoming final rule on January 16, 1981. OSHA has provided the industry with several performance-oriented regulations that address the minimum requirements for safe work practices necessary to protect employees from these hazards. These regulations include:

- Design Safety Standards for Electrical Systems;
- Electrical Safety-Related Work Practices;
- Control of Hazardous Energy Source (Lockout/Tagout);
- Electrical Power Generation, Transmission and Distribution;
- Personal Protective Equipment (PPE);
- Permit-Required Confined Spaces.

This article addresses electrical hazards along with these OSHA regulations, as well as a corresponding consensus standard published by the National Fire Protection Association (NFPA), Standard for Electrical Safety in the Workplace (NFPA 70E), that reinforces OSHA's requirements. Additional regulations concerning energy control (lockout/tagout) and confined space work that apply to electrical safety are also addressed.

Compliance with these regulations and standards is intended to protect employees who work on or near exposed energized and deenergized parts of electric equipment by providing the requirements for various hazards analysis and safe work practice procedures, as well as the required PPE. Compliance will also help reduce the number of electrical accidents that result from the use of unsafe work practices and equipment by employees.

Electrical Hazards

Statistics show that several hundred deaths occur annually as a result of electrical shock. NIOSH statistics show that electrical contact results in 4,000 nondisabling and 3,600 disabling injuries annually, plus one death in the workplace every day in the U.S. alone. Other studies show that 10-15 employees are hospitalized every day with electrical arc flash-related burns.

Electricity is no respecter of persons; it will injure or kill a contractor, custodian, manager or office worker just as fast as it will injure or kill an electrician. The laws of physics for electricity apply to everyone. Some employees have a higher risk because they work with electricity directly as part of their everyday jobs, while others work with it indirectly, primarily by the use of cord- and plug-connected equipment and portable tools, but they also face risks from electrical hazards.

Over half of those killed in electrical accidents are contractors, outside service personnel, painters, laborers and drivers. [Detailed surveillance data and investigative reports of fatal incidents involving workers who contacted energized electrical conductors or equipment are derived from the National Traumatic Occupational Fatalities surveillance system maintained by NIOSH]. The U.S. Bureau of Labor Statistics provides information on nonfatal electrical incidents for electrical shock and burns for various industries (Figure 1).

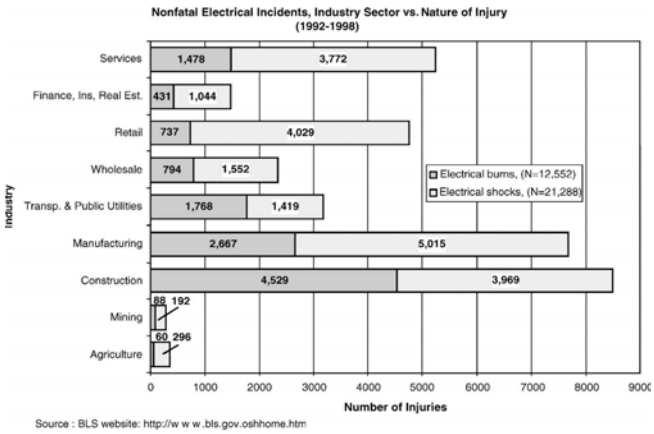

Figure 1. Nonfatal electrical incidents in various industry sectors. (U.S. Bureau of Labor Statistics)

Electrical Shock

Electrical shock occurs when a person's body completes the current path between two energized conductors of an electrical circuit or between an energized conductor and a grounded surface or object. Essentially, when there is a difference in potential from one part of the body to another, current will flow. The effects of an electrical shock can vary from a slight tingle to immediate cardiac arrest. The severity depends on several factors:

- Body resistance (wet or dry skin are major factors of resistance);
- Circuit voltage;
- Amount of current flowing through the body;
- Current path through the body;
- Area of contact;
- Duration of contact.

It takes a very low value of current flowing through the human body to cause death or serious physical harm. Many studies have been performed in this area with different values of current causing each effect. Table 1 illustrates average values of current and the effects as taken from published studies:

Current	Effect
1 mA	Barely perceptible
1-3 mA	Perception threshold (most cases)
3-9 mA	Painful sensations
9-25 mA	Muscular contractions (cannot let go)
25-60 mA	Respiratory paralysis (may be fatal)
60 mA or more	Ventricular fibrillation (probably fatal)
4 A or more	Heart paralysis (fatal)
5 A or more	Tissue burning (fatal if vital organ)

Table 1. Average values of current and effects on the human body.

Shock hazard analysis required by NFPA 70E provides the guidance needed to determine the level of shock hazard. This analysis also determines shock protection boundaries, approach limits for qualified and unqualified employees and required PPE.

Electrical Arc Flash

Various studies on the causes of electrical injuries show that a large number of serious electrical injuries involve burns from electrical arcs.

Three different issues in arc-flash hazard include arc temperature, incident energy and pressure developed by the arc. The main concern with arc temperature is the flash flame and ignition of clothing. At approximately 203°F (96°C) for one-tenth of a second (6 cycles), the skin is rendered incurable and suffers a third-degree burn. The incident energy threshold for the onset of a second-degree burn is 1.2 cal/cm^2, and the onset of a third-degree burn is 10.7 cal/cm^2. It does not take a very high temperature or very much incident energy to cause severe injury, which may result in extreme pain and discomfort or death to the worker. The American Burn Association provides statistics concerning the survivability of electrical burns based on the age of the worker and the percentage of body burn (Figure 2).

Flash hazard analysis required by NFPA 70E is used to determine the incident energy of an electrical arc, establish the flash protection boundary and identify required PPE. This standard also requires that a flash hazard analysis be performed “in order to protect personnel from the possibility of being injured by an arc flash.”

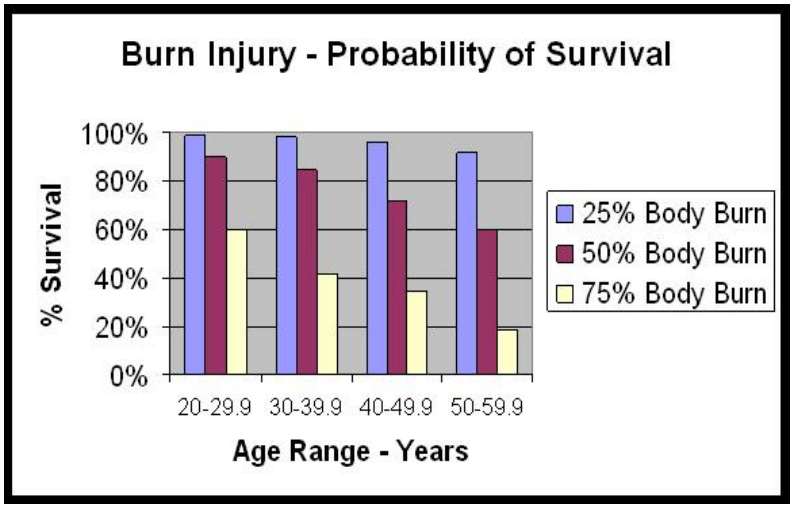

Figure 2. Survivability of electrical burns based on the age of the worker and the percentage of body burn. (American Burn Association)

The best way to avoid this hazard is to stay away from energized electrical equipment, especially when disconnecting devices are operated. Electrical equipment rooms should never be used for storage, break rooms, offices, shops or anything else other than electrical equipment. If an equipment failure occurred and the room was occupied, injuries or fatalities could occur.

Electrical Arc Blast

The third major hazard of electricity is the rapid expansion of air caused by an electrical arc. This occurrence is referred to as an electrical arc blast or explosion.

According to studies on the subject, pressures from an arc are developed from two sources: 1) the expansion of the metal in boiling and vaporizing and 2) the heating of air by passage of the arc through it. For example, copper expands by a factor of 67,000 times when it vaporizes. As a result, one inch^3 of copper vaporizes into 1.44 yards^3 of vapor.

OSHA states, “The pressures developed by high-energy arcs can damage equipment causing fragmented metal to fly in all directions. In atmospheres which contain explosive gases or vapors or combustible dusts, even low-energy arcs can cause violent explosions.”

Ralph Lee’s paper, “Pressures Developed by Arcs” (IEEE 1987), discusses methods that can be used to determine the amount of damage that a short circuit can cause in switchgear and in the buildings where the gear is located.

Overview of Regulations & Standards

OSHA operates under the direction of the Assistant Secretary of Labor. The OSH Act, enacted by Congress on December 29, 1970, states, “An Act: To assure safe and healthful working conditions for working men and women by authorizing enforcement of the standards under the Act; by assisting and encouraging the States in their efforts to assure safe and healthful working conditions; by providing for research, information, education, and training in the field of occupational safety and health; and for other purposes.”

The General Duty Clause, Section 5(a) and (b) of the OSHA Act states the responsibilities of both the employer and the employee as follows:

“Sec. 5(a) Duties:

(a) Each Employer
(1) shall furnish to each of his employees employment and a place of employment, which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees;
(2) shall comply with occupational safety and health standards promulgated under this Act.
(b) Each employee shall comply with occupational safety and health standards and all rules, regulations, and orders issued pursuant to this Act which are applicable to his own actions and conduct.”

The General Duty clause is the avenue through which safety standards are, and have been, developed and distributed by organizations other than OSHA. These safety standards may be indirectly enforced by OSHA as references in support of various regulations. When a standards organization, such as NFPA, includes specific hazards or work practices within its documents, this constitutes a “recognized hazard,” and the standard may be enforced under Section 5(a)(1). In general, this enforcement is at the discretion of the individual OSHA compliance officer, but many in industry have adopted the “best practice” approach to regulatory compliance; enforcing the safest and most stringent practice within available documents.

OSHA regulations for general industry (29 CFR 1910) contain several important sections pertinent to electrical work. Not all of these sections are devoted exclusively to electrical work, and some degree of interpretation is necessary to determine which standards apply to specific installations. This section discusses the general content of OSHA regulations that apply to electrical work and the scope of these sections.

Design Safety Standards for Electrical Systems, 1910.302-.308
This regulation was originally based on the 1978 National Electrical Code (NEC®), as extracted from NFPA 70E-1979. This regulation presents what OSHA considers the most important code requirements for personal safety with regard to the design and installation of electrical equipment. OSHA determined that significant changes had been made in the NEC® since the 1978 edition and therefore revised this section of Subpart S. Revisions to OSHA’s general industry electrical installation standard, 29 CFR 1910, Subpart S, focus on safety in the design and installation of electric equipment in the workplace. The revisions draw heavily from the 2000 edition of NFPA 70E, as well as the 2002 edition of the NEC®. OSHA does not intend for this regulation to be used in lieu of the NEC®. Always use the current edition of the NEC® when doing any electrical system design or installation work.

Electrical Safety-Related Work Practices, 1910.331-.335
This regulation, promulgated August 6, 1990, is a performance-oriented regulation that includes requirements for work performed on or near exposed energized and deenergized parts of electric equipment, use of electrical protective equipment and the safe use of electric equipment. In this context, note that performance-oriented refers to the fact that OSHA leaves the actual implementation technique to the individual company or facility. OSHA is concerned primarily with the results of the implementation rather than the specific techniques used to

accomplish it. Compliance with these safe work practices will reduce the number of electrical accidents resulting from unsafe work practices by employees.

This regulation addresses the minimum training requirements for a person to be considered qualified. OSHA also requires the use of insulated tools, electrical protective equipment and alerting techniques to help protect workers from the hazards. This regulation also contains requirements, in addition to 1910.147, to perform an electrical lockout/tagout of equipment.

Typical occupational categories of employees who are or may be exposed to, or supervise anyone exposed to, 50 volts to ground or more are required to receive training in the safety-related work practices that pertain to their respective job assignment, as follows (Table 2):

Occupation
Blue-collar supervisors
Electrical and electronic engineers
Electrical and electronic equipment assemblers
Electrical and electronic technicians
Electricians
Industrial machine operators
Material handling equipment operators
Mechanics and repairers
Painters
Riggers and roustabouts
Stationary engineers
Welders

Table 2. Occupational categories requiring training.

Workers in these groups need not be trained if their work or the work of those they supervise does not bring them or the employees they supervise close enough to exposed parts of electric circuits operating at 50 volts or more to ground for a hazard to exist.

Other employees who also may reasonably be expected to face a comparable risk of injury due to electric shock or other electrical hazards must also be trained. Work practices and training should address the procedures and precautions that must be used when working on or near energized electrical equipment to prevent electric shock or other injuries. The specific safety-related work practices must be consistent with the nature and extent of the associated electrical hazards.

These practices may include:

- electrical lockout/tagout procedures;
- energized work procedures;
- safe working clearance for qualified and unqualified persons;
- clearances required for vehicular and mechanical equipment working or operating near overhead lines;
- confined space restrictions;

- use of conductive materials, conductive apparel and cleaning materials in close proximity to exposed energized circuits or parts;
- safe use of portable and fixed electrical equipment; and
- use of insulated tools, electrical protective equipment, and alerting techniques.

With regard to insulated tools, electrical protective equipment and alerting techniques, OSHA is specific about what must be considered. The following quotes are provided for clarification:

Insulated Tools–1910.335(a)(2)(i)
"When working near exposed energized conductors or circuit parts, each employee shall use insulated tools or handling equipment if the tools or handling equipment might make contact with such conductors or parts. If the insulating capability of insulated tools or handling equipment is subject to damage, the insulating material shall be protected."

Electrical Protective Equipment–1910.335(a)(2)(ii)
"Protective shields, protective barriers, or insulating materials shall be used to protect each employee from shock, burns, or other electrically related injuries while that employee is working near exposed energized parts which might be accidentally contacted or where dangerous electric heating or arcing might occur. When normally enclosed live parts are exposed for maintenance or repair, they shall be guarded to protect unqualified persons from contact with the live parts."

This requirement ties in with the requirements of OSHA 1910 Subpart I, Personal Protective Equipment.

Alerting Techniques–1910.335(b)
"The following alerting techniques shall be used to warn and protect employees from hazards, which could cause injury due to electric shock, burns, or failure of electric equipment parts:

"(1) Safety signs and tags. Safety signs, safety symbols, or accident prevention tags shall be used where necessary to warn employees about electrical hazards which may endanger them, as required by 1910.145.

"(2) Barricades. Barricades shall be used in conjunction with safety signs where it is necessary to prevent or limit employee access to work areas exposing employees to uninsulated energized conductors or circuit parts. Conductive barricades may not be used where they might cause an electrical contact hazard.

"(3) Attendants. If signs and barricades do not provide sufficient warning and protection from electrical hazards, an attendant shall be stationed to warn and protect employees."

Control of Hazardous Energy Source (Lockout/Tagout), 1910.147
This regulation addresses practices and procedures necessary to disable machinery or equipment and to prevent the release of potentially hazardous energy while maintenance and servicing activities are performed. This regulation requires that lockout be used for equipment designed with a lockout capability except when the employer can demonstrate that use of a tagout provides full employee protection. For equipment not designed to be locked out, the employer may use tagout. This regulation also supplements and supports the existing lockout-related provisions contained elsewhere in the general industry standards.

The regulation contains definitive criteria for establishing an effective program for locking out or tagging out energy-isolating devices and requires training for authorized and affected employees. It also requires the employer to implement the specified procedures and to use effective control measures based on the workplace hazards encountered. The training required shall include the following:

(A) Each authorized employee shall receive training in the recognition of applicable hazardous energy sources, the type and magnitude of the energy available in the workplace, and the methods and means necessary for energy isolation and control.

(B) Each affected employee shall be instructed in the purpose and use of the energy control procedure.

(C) All other employees whose work operations are or may be in an area where energy control procedures may be utilized, shall be instructed about the procedure, and about the prohibition relating to attempts to restart or reenergize machines or equipment which are locked out or tagged out.

When other regulations in Part 1910 require the use of lockout or tagout, they shall be used and supplemented by the procedural and training requirements of this section (1910.147).

Electric Power Generation, Transmission & Distribution, 1910.269

This OSHA regulation addresses the work practices used during the operation and maintenance of electric power generation, transmission and distribution facilities and equipment in utilities as well as industrial facilities.

It includes requirements for:

- training;
- medical services and first aid;
- job briefings;
- live-line tools;
- confined spaces;
- hazardous energy control;
- working on or near energized parts;
- equipotential grounding for employee protection;
- work on underground and overhead installations;
- work in substations and generating plants and other special conditions and equipment unique to the generation, transmission and distribution of electrical energy.

OSHA states the following required applications of this regulation:

Note: The types of installations covered in this paragraph include the generation, transmission and distribution installations of electric utilities, as well as equivalent installations of industrial establishments. Supplementary electric generating equipment that is used to supply a workplace for emergency standby, or similar purposes only is covered under Subpart S of this part.

OSHA believes that this language will effectively extend the scope of the regulation to the types of installations that it is intended to cover, namely, electric power generation, transmission and distribution systems of electric utilities and equivalent industrial systems. It also makes clear that supplementary generating equipment, such as emergency and standby generators used to provide temporary power at a workplace, is not covered. These installations are considered to be part of the utilization system rather than separate generation installations and are addressed by existing Subpart S regulations.
OSHA establishes a detailed training requirement for qualified persons. Qualified persons must be trained and competent in the following:

1. Safety-related work practices;
2. Safety procedures;
3. Other safety requirements;
4. Applicable emergency procedures;
5. Avoidance of the electrical hazards of working on or near exposed energized parts;
6. The skills and techniques to distinguish exposed live parts from other parts;
7. The skills and techniques to determine the nominal voltage;
8. Specified clearance distances by voltage;
9. Working safely on energized circuits;
10. Demonstrate familiarity with:

a. proper use of special precautionary techniques;
b. PPE;
c. insulating and shielding materials; and
d. insulated tools.

11. First aid and CPR as applicable; and
12. Hazards of flames and electric arcs, including the proper clothing for these hazards.

OSHA further requires the employer to determine through regular supervision and through inspections conducted on at least an annual basis that each employee complies with safety-related work practices contained in this section. Retraining is required if the annual inspection indicates that employees do not comply with safety-related work practices, there is new technology, new types of equipment or changes in procedures or if the employee must employ safety-related work practices not normally used. OSHA considers tasks that are performed less often than once per year to necessitate retraining before the performance of the work practice involved.

OSHA has proposed changes to the 29 CFR 1910.269 regulation, “Electric Power Generation, Transmission and Distribution.” This regulation came into effect in 1994 and has remained virtually unchanged since then. A copy of the proposed rule can be obtained at http://dockets.osha.gov/vg001/V047A/02/19/88.PDF. Changes are proposed in several areas of this regulation, including:

- Training;
- Host-contractor responsibilities;
- Job briefings;
- Fall protection, including a requirement that harnesses be worn in aerial lifts;
- Insulation;
- Working position of employees working on or near energized parts;

- Protective clothing (new Appendix F);
- Minimum approach distances;
- De-energizing transmission and distribution lines and equipment;
- Protective grounding.

A proposed revision to OSHA 29 CFR 1910.137, “Electrical Protective Equipment,” is also included in this Federal Register, primarily to include the requirements for Class 00 rubber insulating gloves.

On June 15, 2005, OSHA issued a proposed rule to revise 29 CFR 1910.269 for general industry along with 1926, Subpart V, which is the construction equivalent. This proposed rule incorporates the arc flash requirements of NFPA 70E and the National Electrical Safety Code 2007.

Personal Protective Equipment, 1910 Subpart I
This subpart identifies the requirements for PPE used in general industry as follows:

- 1910.132 General Requirements
- 1910.133 Eye and Face Protection
- 1910.134 Respiratory Protection
- 1910.135 Head Protection
- 1910.136 Foot Protection
- 1910.137 Electrical Protective Equipment
- 1910.138 Hand Protection

Two of these Subpart I requirements are of particular interest to the electrical industry. First, an examination of 1910.132 is necessary to establish the requirement for a hazard assessment. Paragraph (d) contains very specific requirements and states, “The employer shall assess the workplace to determine if hazards are present, or are likely to be present, which necessitates the use of Personal Protective Equipment (PPE).” If such hazards are present or likely to be present, the employer shall “select, and have each employee use, the type of PPE that will protect the affected employee from the hazards identified in the hazard assessment.”

Paragraph (f)(1) states, “The employer shall provide training to each employee who is required by this section to use PPE.” Each such employee is required to be trained to know at least the following:

- When PPE/PPC is necessary;
- What PPE/PPC is necessary;
- How to properly don, doff, adjust and wear PPE;
- The limitations of the PPE/PPC; and
- The proper care, maintenance, useful life and disposal of PPE.

Included in this hazard assessment should be the three electrical hazards: electrical shock, electrical arc flash, and electrical arc blast.

The second part that requires examination is 1910.137. OSHA 1910.137 identifies the selection, inspection and use requirements for electrical PPE. OSHA does not identify specific

clothing that should be worn to protect the employee from arc-flash hazards, but OSHA specifies what type of clothing is prohibited.

OSHA has revised the electrical protective equipment requirements contained in the general industry standards. This standard identifies the design, in-service care and use requirements for electrical protective equipment. It also contains American Society for Testing and Materials (ASTM) requirements for test voltages and minimum intervals for testing and inspection of rubber insulating equipment.

Permit-Required Confined Spaces, 1910.146
This regulation contains requirements for practices and procedures to protect employees from those hazards of entry into and work within permit-required confined spaces in general industry. These can be identified by an employer exercising reasonable care. Many confined spaces pose unique problems due to their contents and/or configuration. Some of these spaces pose entrapment hazards for entrants, while others restrict air circulation so that hazardous atmospheres may accumulate quickly. Confinement itself can increase the risk of injury or death by making employees work closer to hazards than they would otherwise.

OSHA has determined, based on its review of accident data, that asphyxiation is the leading cause of death in confined spaces and that atmospheric hazards cause most confined space asphyxiation fatalities. They have also determined that confined space injuries and fatalities have occurred that did not involve asphyxiation. OSHA has documented confined space incidents in which victims were burned, ground up by auger-type conveyers or crushed by rotating or moving parts inside mixers. Failure to lock out energy to equipment inside the space was also a factor in those accidents. OSHA also determined that where multiple deaths occurred, the majority of the victims in each event died while trying to rescue the original entrant from the confined space.

A 1986 NIOSH report indicated that “rescuers” accounted for more than 60% of confined space fatalities. This evidence indicates that untrained or poorly trained rescuers constitute an especially important “group at risk.”

Standard for Electrical Safety in the Workplace, NFPA 70E
NFPA 70E is a consensus standard developed under the direction of OSHA at a time when standards and regulations did not exist for protecting workers from electrical hazards. NFPA 70E primarily addresses electrical hazard analysis for shock and arc-flash hazards and safety-related work practices intended to help protect employees who are or may be exposed to electrical hazards. It also serves as the foundation for developing OSHA’s electrical safety regulations.

NFPA 70E is a primary source for electrical hazards assessment information and protection guidelines. OSHA uses this standard to support the regulatory requirements to protect the employee from recognized hazards in the workplace.

NFPA 70E is divided into 3 chapters and 15 annexes, which include:

Chapter 1–Safety-Related Work Practices
Chapter 2–Safety-Related Maintenance Requirements
Chapter 3–Safety Requirements for Special Equipment

Annex A–Referenced Publications
Annex B–Informational References
Annex C–Limits of Approach
Annex D–Incident Energy and Flash Protection Boundary Calculation Methods
Annex E–Electrical Safety Program
Annex F–Hazard/Risk Evaluation Procedure
Annex G–Sample Lockout/Tagout Procedure
Annex H–Simplified, Two-Category, Flame-Resistant (FR) Clothing System
Annex I–Job Briefing and Planning Checklist
Annex J–Energized Electrical Work Permit
Annex K–General Categories of Electrical Hazards
Annex L–Typical Application of Safeguards in the Cell Line Working Zone
Annex M–Layering of Protective Clothing and Total System Arc Rating
Annex N–Example Industrial Procedures and Policies for Working near Overhead Electrical Lines and Equipment
Annex O–Safety-Related Design Requirements

NFPA 70E is a primary source for electrical hazards assessment information and protection guidelines. Federal OSHA uses this standard to support the regulatory requirements to protect the employee from recognized electrical hazards in the workplace.

Conclusion

Each of the three hazards of electricity (electrical shock, electrical arc-flash and electrical arc-blast) has its own unique characteristics that require special protective measures. The best way to avoid exposure to these hazards is to stay out of the circuit or to keep as far away as possible from electrical equipment and systems that have exposed live parts or where the electrical equipment is operated.

These OSHA and NFPA regulations and standards were developed for the practical safeguarding of employees in the workplace. Compliance with these regulations is mandated by OSHA, as a minimum, for the protection of employees. They define the requirements for written procedures, PPE, safe work and the training necessary to ensure that employees understand the electrical hazards found in the workplace. With this information, employees are better equipped to protect themselves when these hazards are present.

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