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# Safe Electrical Work Practices

by Allen Hajian, Bill Pratt,
and Rod West

Protecting people and assets while balancing operational and financial pressures can be a challenge. This becomes apparent nearly every time processes or facilities are shut down for scheduled (or unscheduled) maintenance. Looking deeper into the issue reveals that the requirements found in global regulations and workplace standards[1] are aligned, and the message is clear: when working on or near electrical equipment, elimination of the hazard to protect the worker is paramount.

## Understanding Electrical Hazards

The first step in protecting workers is to identify the hazards. While at first glance the hazards associated with electricity may seem obvious, our understanding of electrical hazards has evolved significantly over the past few decades—and our ability to identify hazards, assess the associated risk, and implement risk control methods continues to improve. Today we recognize at least two primary hazards associated with electricity: electric shock and arc flash.

Electric shock occurs when current passes through the body. While most people have experienced some form of an electric shock, not all are the same. Depending on the intensity, duration, resistance, and path, shock can vary significantly from minor muscle contraction to tissue damage, ventricular fibrillation, and even death. Evidenced by the evolution of electrical equipment construction, an initial understanding of electric shock occurred in the early 20th century. As a result, the construction of equipment transitioned from open, accessible conductors to guarded systems. While the type of guard varies and may be a cabinet, enclosure, fence, or wall, it all serves the same purpose: to prevent people from unintentionally contacting energized parts.

Our understanding of electric shock increased in the 1950s when Charles Dalziel performed experiments to study the effects on animals and people. His book “The Effects of Electric Shock on Man” is still cited today, and the increased awareness helped drive the creation of occupational health and safety standards in the early 1970s.

Arc flash is a relatively newly recognized hazard compared to electric shock. An arc flash occurs when electric current passes through a conductive plasma or through ionized air and results in extremely high temperatures—in some cases as high as 15,000–20,000 °C. As with electric shock, there are varying levels of intensity and duration, but in nearly all cases the temperatures are high enough to result in significant burns. In addition, the rapid vaporization and expansion of gases and solids can result in an explosive phenomenon called arc blast. A broader understanding of arc flash began in the early 1980s when Ralph Lee authored a paper titled “The Other Electrical Hazard: Electrical Arc Blast Burns.” This paper raised the awareness of arc flash and led to the inclusion of arc flash hazards in industry workplace standards, starting with the 1995 edition of NFPA 70E. A few years later the 2002 edition of "IEEE 1584—IEEE Guide for Performing Arc Flash Calculations" was published. The IEEE 1584 guide, which was revised in 2018, has become a widely used method to calculate arc flash incident energy levels.

Similar to the changes incorporated to reduce the risk of electric shock, the awareness of arc flash hazards has also driven progress in codes, standards, and equipment design. For example, test methods and designs for arc resistant equipment began with medium voltage switchgear and has since migrated to low voltage equipment. Arc resistant equipment is designed and tested to withstand the effects of an internal arcing fault and to direct the released energy away from workers. For non-arc resistant equipment, methods to increase the distance of the worker from the hazard, such as remote racking, have become available. Even with these advancements, if doors or covers to energized equipment are opened during maintenance activities, the potential exists for risk of injury, significant equipment damage, or both.

## Risk Assessment

Other evolutions relating to electrical safety continue within the electrical industry. One of the more notable changes, which began to appear in electrical workplace standards in 2015, is the requirement for electric shock and arc flash risk assessments.

In the context of dealing with electrical hazards, a risk assessment generally includes a combination of identifying the *likelihood* of occurrence of injury or damage to health, and the *severity* of an injury, resulting in the identification and implementation of proper risk controls.

## Likelihood

The likelihood of occurrence varies with the task being performed. When energized conductors or circuit parts are exposed, there is a higher likelihood for injury, whether it be from shock or arc flash. A shock risk exists when energized parts are exposed or when they are not suitably guarded, isolated, or insulated. However, even when conductors are not exposed, and the likelihood of shock is minimal, some tasks can increase the likelihood of an arc flash incident. Examples of tasks where there is a significant likelihood of occurrence[2] of an arc flash can include the following when the equipment is energized:

- insertion or removal of circuit breakers or other components from cubicles
- insertion or removal of plug-in units from busways
- examination of insulated cable with manipulation of the cable

Conversely, some electrical work tasks are viewed as having a very low likelihood of occurrence of an arc flash. For example, routine opening and closing of circuit breakers or switches, and reading a panel meter while operating a meter switch, are tasks that are not likely to result in an arc flash provided the equipment is in a normal operating condition.

A normal operating condition is generally defined as equipment that

- is properly installed
- is properly maintained
- is used, operated, and maintained in accordance with instructions included in the listing and labeling, and in accordance with manufacturer's instructions
- has its doors closed and secured
- has its covers in place and secured
- does not show evidence of impending failure (arcing, overheating, loose or bound equipment parts, visible damage or deterioration)

To consider the equipment in a normal operating condition, all six of these conditions must be met. If the equipment has been modified in the field or if any of the above criteria are not met, the equipment is not in a normal operating condition and additional protective measures must be selected using the hierarchy of risk controls.

## Severity

The severity of electric shock depends on path, voltage, current, and duration. The severity of injury from an arc flash event is based on the incident energy. An incident energy level of 1.2 cal/cm$^2$ is sufficient to result in the onset of a second degree burn on unprotected skin. An arc flash boundary is usually established at the distance where the incident energy reaches that level. Depending on the circuit and system, the distance can vary greatly, from less than a meter to 12 meters or more.

## Hierarchy of Risk Control

Risk assessments are common tools used in occupational health and safety management system standards such as ISO 45001 and ANSI/ASSP Z10. A risk assessment is a procedure which identifies hazards, assesses risks, and implements risk controls according to a hierarchy of controls in the order shown below:

1. Elimination
2. Substitution
3. Engineering controls
4. Awareness and warnings
5. Administrative controls
6. Personal protective equipment (PPE)

Items 1–3 above are considered more effective as they are usually applied at the source and less likely to be affected by human error. Items 4-6 are less effective as they are usually not applied at the source and are more likely to be affected by human error. Note that personal protective equipment (PPE), which is often the first thought related to safety, is the last item on the list of six risk control methods—meaning it is the least effective and least preferred.

In electrical applications, some examples of each risk reduction method include:

1. **Elimination**: Disconnect and remove all power—a state in which the circuit has been disconnected from energized parts, locked/tagged in accordance with established standards, and tested to verify the absence of voltage.
2. **Substitution**: battery powered tools instead of cord-and-plug connected, low voltage control circuits.
3. **Engineering controls**: machine guards, terminal covers, live conductor barriers, GFCI (ground fault circuit interrupter), absence of voltage indicators, interlocks.
4. **Awareness and warnings**: temporary signs, personnel barricades, labels, alarms, horns, indicator lights.
5. **Administrative controls**: job planning, training, creating a safety culture.
6. **PPE**: arc rated clothing, face shields, safety glasses, electrically rated gloves, hearing protection.

## Choosing the Risk Reduction Method

The concept of electrical safety is founded on the ability to recognize the hazards associated with electrical energy and then take the necessary precautions to mitigate those hazards. Leading regulations and workplace standards recognize that the most effective method to reduce the electrical risk levels is to eliminate the hazard by creating an electrically safe condition where the equipment is de-energized and cannot be re-energized. These steps must be performed *before* an employee works on or near the equipment.

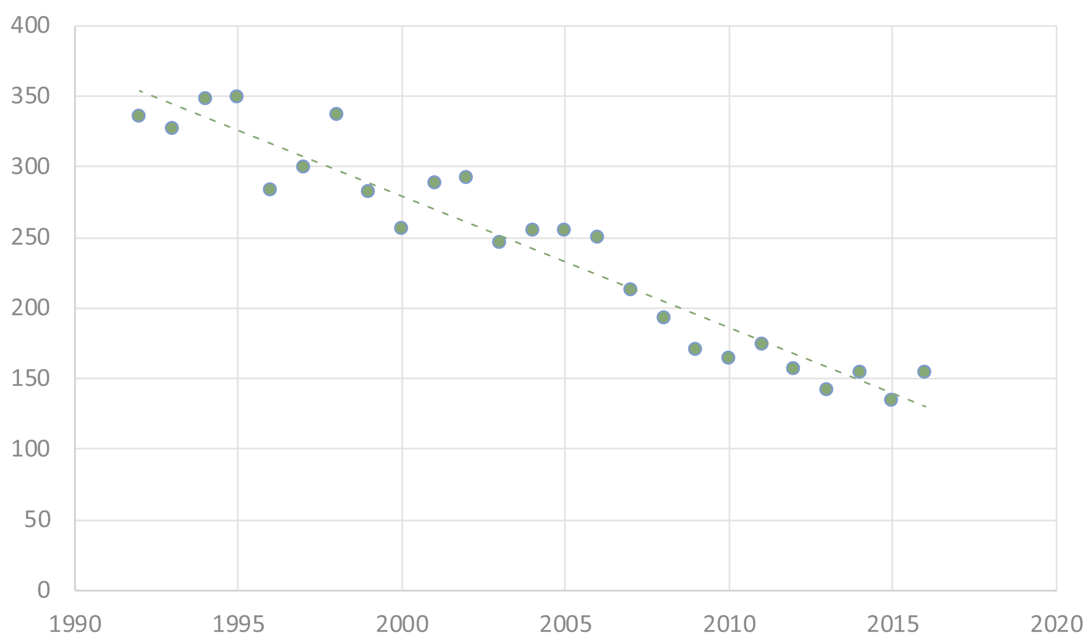
***…the most effective method to reduce the risk is to de-energize the equipment and ensure it cannot be re-energized.***

Not only does scheduling an equipment shutdown protect people with the most effective form of risk control, but it can also protect the equipment assets, preventing a prolonged unscheduled shutdown of processes, loss of production, loss of data, or injury to employees or bystanders.

While the most effective method to reduce the risk to workers is elimination, there are a few exceptions where de-energizing the system is not feasible to perform a task. For example, in some cases electrical diagnostic, testing, and troubleshooting must be performed when the equipment is energized. In these cases, other less effective risk control methods may be used, but even then, higher order controls such as substitution or alternate work practices should be considered (for example, using a hot stick vs. a handheld meter). These tasks are limited to electrical testing and diagnostic work and do not include tasks where mechanical testing, adjustment, modification, repair, or alteration of the conductors, circuit, or equipment is involved.

**Figure 1—Fatal Work-Related Electrical Injuries in the United States**

Sources: The Fire Protection Research Foundation, U.S. Bureau of Labor Statistics (BLS), and the Census of Fatal Occupational Injuries (CFOI)



## Summary

Changing the safety culture surrounding electrical work is a difficult, time-consuming task, but the benefits are clear and are measured in human lives. In the 1990s, there was an average of 350 fatal work-related electrical injuries in the U.S. every year. With the advancements in our understanding of electrical hazards and improvements in work practices, the number of fatalities was cut by more than 50% to the current level of approximately 150 electrical worker fatalities per year. That means we still experience 3 avoidable deaths per week, in the U.S. alone.

Following the most current regulations and effective methods for safe electrical work practices not only minimizes the risk of injury, but also significantly lowers the risk of unexpected equipment damage and disruption to a facility's operations. Safety is both a responsibility and a priority for us all.

# Appendix / Resources

[1] The following are examples of the codes, standards, regulations, and electrical safe workplace practices reviewed for this paper.

- NFPA 70E, “Standard for Electrical Safety in the Workplace”
- CSA Z462, “Workplace Electrical Safety Standard”
- NOM-029-STPS, “Maintenance of Electrical Installations in the Workplace – Safety Conditions”
- UK “The Electricity at Work Regulations 1989”
- UK “The Health and Safety at Work etc. Act 1974”
- UK “HSG85 Safe Working Practices (guidance)”
- Indian Electricity Act, 2003
- Indian Electricity Rules, 1956
- ISO 45001, “Occupational Health and Safety Management System”
- OHSAS 18001 (replaced by ISO 45001 in March 2018)
- EN 50110-1, “Operation of electrical installations – Part 1: General requirements”
- EN 50110-2, “Operation of electrical installations – Part 2: National annexes”
- Norwegian NEK EN 50110-1, “Regulations Concerning Safety at Work In, and Operation of, Electrical Installations”
- IEC 60364, “Electrical Installations for Buildings”
- IEC 61140, “Protection against electric shock – Common aspects for installation and equipment”
- U.S. OSHA Occupational Safety and Health Standards (29 CFR Part 1910):
  - Subpart I (Sections 1910.132 to 1910.140): “Personal Protective Equipment,” of particular interest: section 1910.137, “Electrical protective equipment”
  - Subpart S (Sections 1910.301 to 1910.399): “Electrical,” of particular interest: section 1910.333, “Selection and use of work practices”
- IEEE 1584, “IEEE Guide for Performing Arc Flash Hazard Calculations”
- IEEE C37.20.7, “IEEE Guide for Testing Metal-Enclosed Switchgear Rated Up to 38 kV for Internal Arcing Faults”
- ANSI/ASSP Z10-2012 (R2017), “Occupational Health and Safety Management Systems”
- ANSI/ASSP Z244.1, “Control of Hazardous Energy Lockout/Tagout and Alternative Methods”
- U.S. OSHA 1910.147, “The control of hazardous energy (lockout/tagout)”
- Australian / New Zealand Standard 4836, “Australian / New Zealand – Safe working on or near low-voltage electrical installations and equipment”
- Australia / New Zealand, “Safety Manual – Electricity Industry Part 3 Rules for work on equipment” published by the Electrical Engineers Association
- Australia, “Managing electrical risks in the workplace, Code of Practice,” October 2018, Safe Work Australia, Copyright 2018. An approved Code of Practice on how to manage electrical risks in workplaces, and an approved code of practice under section 274 of the Work Health and Safety publication.

[2] See *NFPA 70E, Standard for Electrical Safety in the Workplace*, for further information.

**Schneider Electric USA, Inc.**
800 Federal Street, Andover, MA 01810 USA
Telephone: +1 (888) 778-2733
www.schneider-electric.us

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