All who interact with industrial or commercial electrical power systems and equipment (e.g., owners, operators, installers, maintainers, outside service personnel, design consultants, manufacturers) must be concerned with electrical safety aspects of electrical installation design. Electrical safety must be an integral part of all designs, installations and maintenance of electrical systems and equipment. An in-depth understanding of applicable codes, standards, regulations and manufacturer’s instructions is vital to electrical safety through design.

Knowledgeable in electrical safety, equipment and systems, OSH professionals must be included in project planning and design to ensure that electrical safety is discussed and included in the design. Electrical safety by design and maintenance is critical to preventing or reducing electrical incidents due to failure of electrical equipment.

Current standards and regulations place only minimum requirements on electrical system designers, installers and manufacturers, which yields only functional, reasonably safe electrical installations. Knowledge of electrical hazards can help a company exceed minimum requirements and provide safe, reliable electrical power systems and equipment.

Effective electrical preventive maintenance begins with good design. When designing a new facility, the design team should make a conscious effort to ensure optimum maintainability of installed system and equipment. Design and installation of dual or redundant circuits, tie circuits, auxiliary power sources and drawout protective devices such as power circuit breakers eases scheduling and performing required maintenance activities with minimum interruption of production. Other effective design techniques that should be considered include equipment rooms that provide environmental protection, grouping equipment for convenience and accessibility, and standardizing equipment and components.

Electrical Hazards

Understanding hazards associated with electricity and other electrical safety issues associated with design, installation and maintenance is vital to all personnel involved in electrical systems and equipment design. Hazards are identified through completing the hazard assessments required by OSHA 29 CFR 1910.132(d)(1) and the electrical hazard risk assessments required by NFPA 70E, Standard for Electrical Safety in the Workplace, sections 130.3, 130.4 and 130.5. Those involved must remember that
the physics are the same for everyone who interacts with electricity, even simply plugging in an electrical appliance, portable tool or extension cord; the physics do not change from the installer to the maintenance employee.

The three main electrical hazards are shock, arc flash and arc blast, each with physiological effects on the human body. These hazards must be understood by everyone involved in design, installation, maintenance and operations, as well as others who work on, near or interact with electrical circuits and equipment. These hazards must also be understood by designers to help them better understand what needs to be done and why, when it comes to designing hazards out and safety in.

Designing, installing and maintaining electrical equipment and systems in accordance with applicable standards and manufacturer’s instruction manuals will provide the minimum requirements for electrical safety by design. These standards include National Equipment Manufacturers Association (NEMA); National Electrical Code (NEC); National Electrical Safety Code (NESC); IEEE Color Books or the associated new “dot” standards under the IEEE 3000 Standards Collection for industrial and commercial power systems; and, where applicable, Canadian Standards Association (CSA); International Electrotechnical Commission (IEC); or other national or international standards used for the design, manufacture, installation and maintenance of electrical equipment and systems. Complying with these standards, as a minimum, for the design and installation, along with properly maintaining electrical equipment in its original condition, can dramatically reduce the risk of the electrical shock and/or arc flash hazards.

Adhering to safe work practices for personnel, along with complying with the maintenance recommendations for electrical equipment provided by OSHA, NFPA using NFPA 70E and NFPA 70B, Recommended Practice for Electrical Equipment Maintenance, the InterNational Electrical Testing Association (ANSI/NETA) Standard for Maintenance Testing Specifications for Electric Power Distribution Equipment and Systems (MTS) and NESC, along with manufacturer’s instructions, can significantly reduce the risk of a worker making contact with energized conductors or circuit parts and can reduce the risk of an arc flash event occurring, as well as significantly increasing the reliability of the electrical equipment and system.

Electrical Shock

Statistics show that approximately 24,100 nonfatal electrical injuries occurred from 2003 through 2012, and 20,033 electrical incidents resulted in 1,573 fatalities from 2003 to 2009 (BLS). Therefore, for every 13 electrical injuries, one worker dies. BLS also reported that 70% of the electrocutions occurred while the worker was performing a constructing, repairing or cleaning activity.

Electrical shock occurs when a person’s body completes the current path between two energized conductors of a circuit or between an energized conductor and a grounded surface or object. Essentially, when there is a difference in potential (voltage) from one part of the body to another, current will flow.

The effects of an electrical shock on the human body 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 (50 V to ground or more is considered by OSHA, IEEE and NFPA as being hazardous voltage);
- Amount of current flowing through the body [determined by the circuit voltage divided by the body resistance I = E (voltage)/R (resistance)];
- Current path through the body (current passing through a vital organ can be fatal);
- Area of contact;
- Duration of contact.

The shock risk assessment required by NFPA 70E, Section 130.4 provides the guidance needed to determine the level of shock hazard (voltage). This assessment also determines the shock protection boundaries, as well as the approach limits for qualified and unqualified employees, along with required PPE.

Electrical Arc Flash

In the recent revision of 1910.269 and 1926 Subpart V, OSHA identified 99 incidents that involved burns from arcs from energized equipment faults or failures, resulting in 21 fatalities and 94 hospitalized injuries for the period January 1991 through December 1998. Based on these data, OSHA estimated that an average of at least eight burn incidents occur each year involving employees doing work covered by OSHA rules, leading to 12 nonfatal injuries and two fatalities per year. Of the reports indicating the extent of the burn injury, 75% reported third-degree burns.

An electrical arc flash is the rapid release of energy due to an arcing fault of phase-to-phase, phase-to-neutral or phase-to-ground. Typically when one of these three conditions is initiated, it will end up with all three occurring because the air becomes a conductor due to ioniza-
tion, along with the plasma created from the vaporized metals, particularly copper. Simply put, an arc flash is a phenomenon in which a flashover of electric current leaves its intended path and travels through the air from one conductor to another or to ground. The results are often violent and when a human being is in close proximity to the arc flash, ignition of flammable clothing, serious injury and even death can occur. Because of the violent nature of an arc flash exposure, when an employee is injured, the injury is serious, possibly even resulting in death. It is not uncommon for an injured employee to never regain his/her past quality of life.

Various studies on causes of electrical injuries have shown that a large number of such injuries involve burns from electrical arcs. Investigations indicate that the ignition of flammable clothing is the primary cause of serious burn injuries and death. Arc-flash hazards involve three different issues: arc temperature, incident energy and pressure developed by the arc. The main concern with arc temperature, which can be as high as 36,000 °F, 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 or in other words a third-degree burn and at approximately 172 °F (78 °C) for one-tenth of a second (6 cycles) a person could receive a second-degree burn. The incident energy threshold for the onset of a third-degree burn is approximately 8 to 10.5 cal/cm² and the incident energy threshold for a second-degree burn is approximately 1.2 cal/cm². As can be seen by this, it does not take a high temperature or much incident energy to cause severe injury, which can result in extreme pain and discomfort or even death to the worker.

The arc flash risk assessment required by NFPA 70E, Section 130.5 is used to determine whether an arc-flash hazard exists. If an arc-flash hazard exists, the risk assessment must determine the required safety-related work practices to be used, establish the arc-flash boundary, and determine the level of arc-rated clothing and PPE required for protecting employees.

Electrical Arc Blast

Another major hazard of electricity is the rapid expansion of the air caused by an electrical arc. This occurrence is referred to as an electrical arc blast or in other words an explosion. The high pressures of an arc blast can easily exceed hundreds or even thousands of pounds per square foot, knocking workers off ladders, rupturing eardrums and collapsing lungs.

According to studies on the subject, the pressures from an electric arc are developed from three sources: 1) the available short-circuit current; 2) the expansion of the metal in boiling and vaporizing; and 3) the heating of the air by passage of the arc through it. When vaporized, copper expands by a factor of approximately 67,000 times; therefore 1 cubic in. of copper converts to 1.44 cubic yards of vapor instantly, which contributes to the rapid expansion and the resulting arc blast.

Coupled with the arc blast, the arc flash presents a serious and dangerous situation for anyone working on or near, or otherwise interacting with the electrical equipment. While there is PPE to protect employees from the shock and arc-flash hazards, there is little PPE available to protect against the arc-blast hazard. The best practice that can be used for protection from the arc blast is to incorporate safe work practices that include correct body positioning when operating or otherwise interacting with electrical equipment. A good practice is to never stand where the body would be in the direct line of fire should an arc flash/blast occur.

Electrical Safety Design Considerations

With the preceding information, relative to the hazards of electricity, the electrical equipment and systems engineers and designers are better equipped to design out the electrical hazards and design in electrical safety. Over the past few decades manufacturers have strived to design electrical equipment with greater emphasis on safety, not only for the equipment and installation but also for the safety of personnel who operate, maintain or otherwise interact with the equipment. When evaluating electrical safety design considerations it is beneficial to review NIOSH’s Prevention Through Design (PTD) initiative. A brief description of this initiative follows.

Hierarchy of Controls—NIOSH

The mission of the PTD initiative is to prevent or reduce occupational injuries and fatalities through the inclusion of prevention considerations in all designs that impact workers; in other words, prevent and control occupational injuries and fatalities by designing out or minimizing hazards and risks. This can be achieved by eliminating hazards and controlling risk through design, redesign and retrofit of new and existing facilities, electrical systems and equipment.

PTD encompasses all efforts to anticipate and design out hazards to workers in facilities including work methods and operations, processes, equipment, tools, products, new technologies and the organization of work. The primary focus of PTD is on the workers who execute the designs or have to work with the products of the design. The initiative has been developed to support designing out hazards, the most reliable and effective type of prevention.

The hierarchy of controls should be used at all times when implementing controls to eliminate the hazard or reduce the risk of a hazard that can cause loss, damage
or injuries. The hierarchy of hazard controls is a list that emphasizes controlling a hazard at the source. Controlling exposures to occupational hazards is the fundamental method for protecting workers. Traditionally, a hierarchy of controls has been used as a means for determining how to implement feasible and effective control solutions (Figure 1).

The idea behind this hierarchy is that the control methods at the top of the graphic are potentially more effective and protective than those at the bottom. Following this hierarchy normally leads to the implementation of inherently safer electrical systems and equipment, where the risk of injury or fatality has been substantially reduced.

1) Elimination is the most effective method to remove the hazard completely, if it is possible.

2) Substitution can involve replacing the hazard with a lesser hazard. Be careful to assess what new hazards or risks the substitute may pose.

Elimination and substitution, while the most effective at reducing hazards, also tend to be the most difficult to implement in an existing process. If the process is still at the design or development stage, elimination and substitution of hazards may be inexpensive and simple to implement. For an existing electrical system, major changes in equipment and procedures may be required to eliminate or substitute for a hazard.

3) Make engineering changes to the equipment or plant electrical systems to reduce the hazard (e.g., enclose or isolate the hazard).

4) Administrative controls establish policies and procedures to minimize the risks, job scheduling to limit exposure, posting hazard signs, restricting access and training.

5) PPE provides a barrier between the worker and the hazard. PPE items include arc-rated clothing, safety glasses or goggles, face shields, nonconductive hard hats, hearing protection (ear canal inserts), rubber insulating gloves with leather protectors and proper footwear.

Design Meeting Considerations
Another consideration would be to include the maintenance supervisor and plant or facility engineer, along with the facility safety professional, in meetings concerning the design of electrical systems and equipment. These individuals are generally not considered or included in the design, when they should have an open line of communication with design engineering and supervision. Frequently an unsafe electrical installation or one that requires excessive maintenance can be traced to improper design or construction methods or misapplication of hardware and equipment. Everyone who can be affected by the design and installation of electrical equipment and systems should be consulted early in the
design, preferably starting with the conceptual design phase of the project.

Other Design Considerations

Although electrical systems are typically designed and installed according to NEC or other applicable standards, the real safety emphasis was placed on the design and installation of electrical equipment and systems when OSHA first issued the final rule of 29 CFR 1910 Subpart S, Electrical Standards 1910.302-.308 Design Safety Standards for Electric Utilization Systems, on Jan. 16, 1981. This regulation was revised and updated on Feb. 14, 2007. This provided a federal mandate on minimum electrical design and installation issues that related to the safety of employees working on, near or interacting with electrical systems and equipment.

The emphasis increased for electrical equipment when OSHA published the final rule of 29 CFR 1910.147, Control of Hazardous Energy (Lockout/Tagout) on Sept. 1, 1989, which required that machines and equipment be manufactured with energy-isolating devices. Effective energy isolation is a key to electrical safety because it provides a means to deenergize the equipment so that it can be worked on in an electrically safe working condition.

OSHA 29 CFR 1910.147(c)(2)(iii) requires all electrical equipment be capable of being locked out:

After Jan. 2, 1990, whenever replacement or major repair, renovation or modification of a machine or equipment is performed, and whenever new machines or equipment are installed, energy isolating devices for such machine or equipment shall be designed to accept a lockout device. (OSHA, 1989)

Additional emphasis placed on electrical safety that would have a dramatic influence on the design, manufacture and installation of electrical equipment and systems has increased with the publication of OSHA 29 CFR 1910.331-.335, Electrical Safety-Related Work Practices on Aug. 6, 1990; OSHA 29 CFR 1910.269, Electrical Power Generation, Transmission and Distribution on Jan. 31, 1994, which was revised April 11, 2014; and the revisions of NFPA 70E over the past 23 years, all of which are dedicated to electrical safety.

NFPA 70E, Informative Annex O, Safety-Related Design Requirements, provides several general design considerations for electrical systems:

1) Owners, managers and employers are responsible for performing an electrical hazard risk assessment during the design of electrical systems and installations to more effectively choose design options that would reduce or eliminate employee exposure to electrical hazards and to enhance the effectiveness of electrical safety.

2) Factors that affect safety-related work practices to protect employees must be considered.

3) NFPA 70E 130.3(B)(1) Electrical Hazards Risk Assessments results should be used to compare design options and choices to facilitate decisions in the design of the electrical equipment and systems, and serve to:

- eliminate electrical hazards and risk;
- reduce frequency of exposure to electrical hazards;
- reduce the magnitude and severity of hazard exposure;
- enable the ability to achieve an electrically safe work condition as noted in the requirements of NFPA 70E Article 120, Establishing an Electrically Safe Work Condition; OSHA 29 CFR 1910.147, Control of Hazardous Energy (Lockout/Tagout); and OSHA 29 CFR 1910.333(b), Working on or near exposed deenergized parts, for performing an electrical lockout/tagout;
- enhance the effectiveness of the electrical safety program as well as the electrical safety-related work practices.

4) Arc energy reduction is another consideration through the use of:

- zone-selective interlocking;
- differential relaying;
- energy-reducing maintenance switching with local status indicator (this feature sets the circuit breaker trip unit to a faster operating time, which will reduce the incident energy if an arc flash were to occur while the worker is working within the arc flash boundary);
- high-speed microprocessor-based protective relaying;
- high-speed optic sensors.

Always keep in mind that no matter how fast the sensors or relays are, the end device is still an electromechanical circuit breaker that can fail to open in the time specified. Mechanical devices, such as circuit breakers, must be maintained in accordance with manufacturer specifications. Even this is not a 100% guarantee, but it is the best we can do to minimize the risk of an unintentional time delay or total failure of the device. (The Electrical Equipment Maintenance section includes more information on this subject.)

New Electrical Safety by Design Standard

IEEE P1814 Recommended Practice for Electrical System Design Techniques to Improve Electrical Safety is in development that will address common concerns related to electrical safety by design. The following information is provided to help establish a better understanding of the standard:

Scope: This Recommended Practice addresses system and equipment design techniques and equipment selection that will improve electrical safety. The techniques in this Practice are intended to supplement the minimum requirements of installation codes and equipment standards. It does not include communications, programming, or life safety systems such as fire alarm and security.
**Purpose:** This Recommended Practice provides a “tool kit” of techniques to enable the system designer to specify equipment features, apply protective schemes, and make informed system installation design choices.

**Need for the Project:** There is currently no publication by an accepted standards entity that effectively communicates “electrical safety by design” concepts and their benefits. Current standards place only minimum requirements on electrical system designers and manufacturers that yield functional, reasonably safe electrical installations. There is a need to capture, in one location, the wealth of “electrical safety by design” concepts that have been published in recent IEEE papers and in other industry sources.

**Stakeholders for the Standard:** Owners, operators, installers and maintainers of industrial, commercial, power generation facilities, design consultants, and manufacturers.

The standard will address the following topics:
- System Design—General;
- System Design—Operations and Maintenance;
- System and Equipment Grounding and Bonding;
- Power System Protection;
- Electrical Equipment;
- Environment (under consideration);
- Heat Tracing (under consideration);
- Labeling and Signage;
- Lighting.

Electrical equipment and systems must be designed such that no energized conductors or circuit parts are exposed when they are under normal operating conditions. When energized parts are exposed for maintenance purposes, they must be suitably guarded to prevent contact by personnel who are in the vicinity of the equipment or system.

A short-circuit current study must be performed to ensure that electrical equipment and systems have a sufficient interrupting rating for the available short-circuit current. This study should be evaluated at least every 5 years, or after any system or equipment modifications, to ensure that nothing has changed that would cause an increase in the available short-circuit current. High impedance devices such as current-limiting reactors can be installed in an electrical system to reduce the available short-circuit current. If these devices are installed, the coordination of the over-current protective devices must be verified and adjusted in order to prevent longer clearing times, which may increase the available incident energy of an arc flash. Installing current-limiting devices requires a complete electrical equipment and system coordination study to ensure that all components work together to decrease electrical hazards, especially the arc-flash hazard.

Manufacturers have designed electrical equipment, particularly metal-clad switchgear, to be arc safe or arc resistant in order to help protect workers or operators when interacting with the equipment (opening or closing the device). This type of equipment is designed with enclosure doors and latching mechanisms that are much more substantial than older equipment and are intended to help ensure that the door remains closed during an arc-flash event. These enclosures also have a pressure relief venting mechanism on the top of the equipment that will open and vent the arc-flash pressures and vapors up and through a duct system to a location outside of the electrical equipment room. This is a significant improvement for designing in electrical safety in the equipment.

This section of the article has emphasized equipment and systems design used to minimize the electrical hazards to personnel. Another major design issue that is often overlooked is the working space around electrical equipment. This working space includes the spaces required by OSHA 1910.303(g) and NEC Article 110, Part II for 600 V or less, and OSHA 1910.303(h) and NEC Article 110, Part III for more than 600 V. This working space must be designed into a facility in order to provide a safe working space for electrical workers who are required to maintain the equipment and operators who are required to operate (open or close) switches, circuit breakers or otherwise interact with the equipment. This working space must not be confused with the required electrical shock or arc-flash boundaries, which must also be considered.

**Electrical Equipment Maintenance**

Maintenance, lubrication and testing are essential to help ensure proper protection of equipment and personnel. NFPA 70E Section 205.1 requires all persons who maintain electrical equipment to be a qualified person, and Section
205.3 requires electrical equipment to be maintained according to manufacturer’s instructions or industry consensus standards such as NFPA 70B and the ANSI/NETA MTS. Section 205.4 of NFPA 70E also requires that the maintenance, tests and inspections be documented. With regard to personnel protection, NFPA 70E requires that a shock risk assessment and an arc flash risk assessment be performed before anyone approaches exposed electrical conductors or circuit parts that have not been placed in an electrically safe work condition. In addition, it requires shock protection boundaries and an arc-flash boundary to be established, along with identifying the required PPE.

All arc flash incident energy analysis calculations for determining the incident energy of an electrical arc and for establishing an arc-flash boundary, require the arc clearing time, the available short-circuit current and the distance from the potential arc to the worker. The clearing time is derived from the settings and corresponding time-current curves for the protective device; this information can also be obtained from the engineering protective device coordination study, both of which are based on what the protective devices are supposed to do.

If, for example, a low-voltage power circuit breaker had not been operated or maintained for several years and the lubrication had become sticky or hardened, the circuit breaker could take several additional cycles, seconds, minutes or longer to clear a fault condition. Following is a specific example:

Two incident energy analyses will be performed using a 20,000-A short-circuit with the worker 18 in. from the arc:
• Based on what the circuit breaker is supposed to do: 0.083 second (5 cycles);
• Due to a sticky mechanism the breaker now has an unintentional time delay: 0.5 second (30 cycles).

Example #1

\[
\begin{align*}
E_{MB} &= \text{maximum 20 in. cubic box incident energy, cal/cm}^2 \\
D_b &= \text{distance from arc electrodes, in. (for distances 18 in. and greater)} \\
t_A &= \text{arc duration, seconds} \\
F &= \text{short circuit current, kA (for the range of 16 to 50 kA)} \\

(1) D_A &= 18 \text{ in.} \\
(2) t_A &= 0.083 \text{ second (5 cycles)} \\
(3) F &= 20 \text{ kA} \\

E_{MB} &= 1038.7 D_b^{-1.4738} t_A [0.0093F^2 - 0.3453F + 5.9675] \\
&= 1038 \times 0.0141 \times 0.083[0.0093 \times 400 - 0.3453 \times 20 + 5.9675] \\
&= 1.4636 \times 2.7815 \\
&= 3.5 \text{ cal/cm}^2
\end{align*}
\]

NFPA 70E requires arc-rated clothing and other PPE that are selected based on the calculated incident energy exposure. Therefore, the arc-rated clothing and PPE must have a minimum arc rating of 3.5 cal/cm². This is the information that will appear on the warning label for the equipment and the PPE the worker will use.

Example #2

\[
\begin{align*}
E_{MB} &= \text{maximum 20 in. cubic box incident energy, cal/cm}^2 \\
D_b &= \text{distance from arc electrodes, in. (for distances 18 in. and greater)} \\
t_A &= \text{arc duration, seconds} \\
F &= \text{short circuit current, kA (for the range of 16 to 50 kA)} \\

(1) D_A &= 18 \text{ in.} \\
(2) t_A &= 0.5 \text{ second (30 cycles)} \\
(3) F &= 20 \text{ kA} \\

E_{MB} &= 1038.7 D_b^{-1.4738} t_A [0.0093F^2 - 0.3453F + 5.9675] \\
&= 1038 \times 0.0141 \times 0.5[0.0093 \times 400 - 0.3453 \times 20 + 5.9675] \\
&= 7.3179 \times 2.7815 \\
&= 20.4 \text{ cal/cm}^2
\end{align*}
\]

NFPA 70E requires arc-rated clothing and other PPE to be selected based on this incident energy exposure. Therefore the arc-rated clothing and PPE must have a minimum arc rating of 20.4 cal/cm².

If the worker is protected based on what the protective device is supposed to do, in this case 0.083 second or 5 cycles, and an unintentional time delay occurs, and the time is increased to 0.5 second or 30 cycles, the worker could be seriously injured or killed because s/he was under-protected. Maintenance is extremely important to an electrical safety program. Maintenance must be performed according to the manufacturer’s instructions in order to minimize the risk of having an unintentional time delay or complete failure of the operation of the circuit overcurrent protective device(s).

Maintenance is more than just performing the required preventive or predictive maintenance that is recommended by the manufacturer. Other maintenance practices related to electrical safety include:

1) Effectively closing unused openings in electrical equipment and devices, such as:
• when conduit is removed from an enclosure, plug the hole with an approved plug;
• when a molded case circuit breaker is removed from a panelboard, the opening must be closed using a panel compatible snap in device;
• when a low-voltage power circuit breaker is removed from the enclosure the opening in the door must be effectively closed.
2) All electrical panels (includes power and control panels), receptacles, light switches,
junction boxes, conduit bodies, etc., must have the covers securely and properly installed (all screws or bolts installed and/or all latches securely fastened).

3) All electrical panels must have danger signs installed and maintained.

•600 V or less OSHA and NFPA require: “Entrances to rooms and other guarded locations containing exposed live parts shall be marked with conspicuous warning signs forbidding unqualified persons to enter.” This would require a sign that reads “DANGER—Hazardous Voltage—Unqualified Personnel Keep Out” or similar (Figure 2).

4) The work space around electrical equipment must be maintained clear as required by OSHA and NFPA: “Working space required by this subpart may not be used for storage. When normally enclosed live parts are exposed for inspection or servicing, the working space, if in a passageway or general open space, shall be suitably guarded.”

•Over 600 V OSHA and NFPA require: “The entrances shall be kept locked unless they are under the observation of a qualified person at all times; and permanent and conspicuous warning signs shall be provided, reading substantially as follows: “DANGER—HIGH VOLTAGE—KEEP OUT” (Figure 3).

Many electrical equipment maintenance tasks require the equipment to be placed in an electrically safe condition for effective safety prior to working on it. Other maintenance tasks might specifically require or permit equipment to be energized and in service while the tasks are being performed. Examples include taking voltage or current readings, troubleshooting, taking an oil sample from a transformer or oil circuit breaker for analysis, observing and recording operating characteristics such as temperatures, load conditions, corona, noise or performing thermographic surveys while the equipment is under normal load and operating conditions. Coordinating maintenance and inspection with planned or scheduled production outages can provide an added safety environment for employees and may also provide a means to avoid major disruptions of operations.

When performing required maintenance and testing of electrical equipment, there are two sets of values or readings that should always be recorded: The “as-found” and “as-left” values. The as-found tests are performed on equipment when initially installed and before being energized or after it has been taken out of service for maintenance, but before any maintenance work is performed. The as-left tests are performed on equipment after preventive or corrective maintenance has been completed and immediately prior to placing the equipment back in service.

When equipment is taken out of service for maintenance, performance of both an as-found and as-left test is highly recommended. The as-found tests will show any deterioration or defects in the equipment since the last maintenance period and can indicate whether corrective maintenance or special procedures should be taken during the maintenance process. The as-left tests will indicate the degree of improvement in the equipment during the maintenance process and can also serve as a benchmark for comparison with the as-found tests during the next maintenance cycle.

Conclusion
Each of the three hazards of electricity (shock, arc flash and arc blast) has its own unique characteristics that require special attention to the hazard and risk assessments, electrical safety programs and procedures, PPE, and the design, installation and maintenance of electrical equipment and systems.
Personnel safety should be a primary consideration in electrical systems design and in establishing safety-related work practices when performing preventive maintenance for electrical systems and equipment. Maintenance must be performed only by qualified persons trained in safe maintenance practices and the special considerations necessary to maintain electrical equipment. Safe work practices must be instituted and followed to prevent injury or death to those who are performing tasks, as well as others who might be exposed to the hazards. Among the hazards associated with working on energized electrical conductors or circuit parts are the hazards of electricity, any one of which may result in severe injury or death to employees. Preventive maintenance should be performed only when equipment is in an electrically safe work condition.

Equipment should always be deenergized for all inspections, tests, repairs and other servicing. Where maintenance tasks must be performed while the equipment is energized, provisions must be made to allow maintenance to be performed safely, as required by NFPA 70E, Standard for Electrical Safety in the Workplace. For the purposes of this article, deenergized means the equipment has been placed in an electrically safe work condition in accordance with NFPA 70E, Article 120, and OSHA 1910.147 and 1910.333(b) requirements.

The best way to avoid exposure to electrical hazards is to keep as far away as possible from electrical equipment and systems that have exposed energized parts or where the electrical equipment is being operated or maintained.

References
Institute of Electrical and Electronics Engineers (IEEE). Recommended Practice for Electrical System Design Techniques to Improve Electrical Safety (IEEE P1814).
NFPA. (2013). Recommended practice for electrical equipment maintenance (NFPA 70B).

**Dennis K. Neitzel, CPE, CESCP**, director emeritus of AVO Training Institute Inc., Dallas, TX, has more than 48 years’ experience in the electrical industry in various capacities, specializing in electrical equipment and systems maintenance, testing, engineering, inspection and safety. He has served on many standards committees, and is a coauthor of *Electrical Safety Handbook*. Neitzel holds a bachelor’s degree in electrical engineering management and a master’s degree in electrical engineering applied sciences.
ByDesign is a publication of ASSE’s Engineering Practice Specialty, 520 N. Northwest Highway, Park Ridge, IL 60068, and is distributed free of charge to members of the Engineering Practice Specialty. The opinions expressed in articles herein are those of the author(s) and are not necessarily those of ASSE. Technical accuracy is the responsibility of the author(s). Send address changes to the mailing address above; via fax to (847) 768-3434; or via e-mail to customerservice@asse.org.