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Special Report

SPECIAL FOCUS: ELECTRICAL SAFETY

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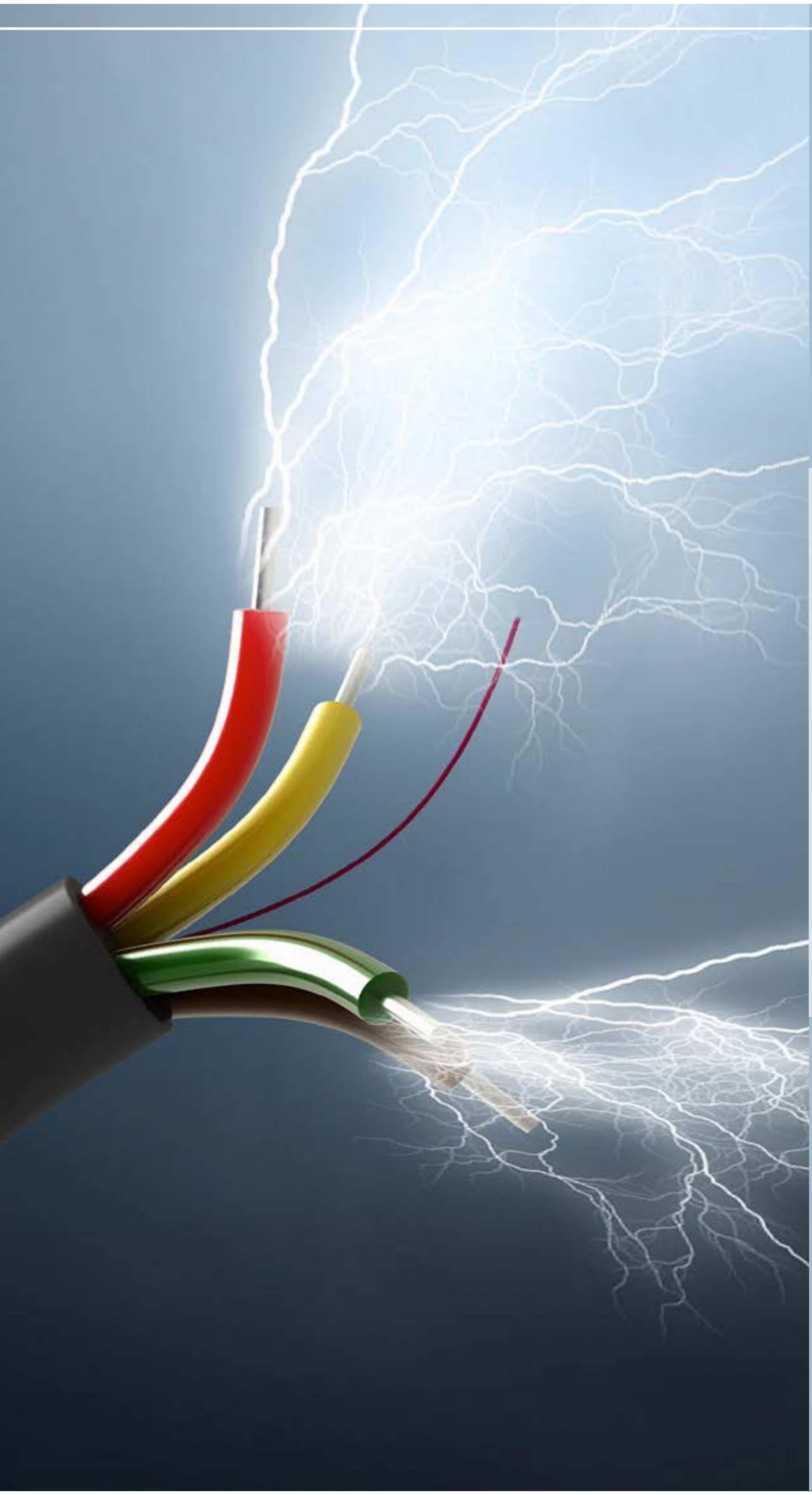

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By Joseph Weigel, Electrical Safety Works;
Johan Roels, Loss Control Centre Belgium;
and Charlie Palmgren, Innovative InterChange

ELECTRICAL DANGER

PREPARE FOR IT; MANAGE IT

Serious workplace injuries and fatalities from electrical arc flash incidents have been occurring ever since electrical energy was first generated and distributed for productive applications. Arc flash accidents that result in a serious injury or fatality occur five to 10 times a day in the United States. Approximately once per day a worker involved in an electrical accident does not survive. Recently, in an effort to improve workplace safety, the industry has begun to focus on protecting workers from the arc-flash and arc-blast hazards that are present when they must perform work on energized electrical equipment.

One of the results of that focus has been the development and publication of NFPA 70E — Standard for Electrical Safety in the Workplace. NFPA 70E is an industry consensus standard that defines the specific requirements for safely working on or around electrical equipment. OSHA recognizes the NFPA 70E standard as a written, published standard, available to the industry, and it cites the requirements of this standard for employers. NFPA 70E is updated every four years. It defines specific safe work practices and personal protective equipment (PPE) for workers to help protect them from these hazards (Figure 1). OSHA recognizes this important document and will use these requirements to determine compliance for employers regarding electrical workplace safety.

An arc flash results from a short circuit or fault condition that occurs when the insulation between energized electrical phase conductors, or between a phase conductor and ground, is somehow compromised. The other type of major electrical fault is called a "bolted fault." During a bolted fault, the fault current normally flows over a conductive path and is not usually released outside of that path. While such faults can be damaging, little energy is released into the surrounding environment during the fault, and an upstream overcurrent protective device will respond rapidly to open the faulted circuit.

During an arcing fault however, the fault current flows through the air rather than through a conductor or other conductive component, and a great deal of thermal energy is released into the environment. This sudden release of thermal energy, similar to that seen in an electrical arc furnace, is referred to as an arc flash event. As a result of the sudden release of energy, a pressure wave also develops and expands outward at a high velocity. This pressure wave is usually called arc blast when it is a result of an arc flash event. Arc blast is another human hazard that may cause serious injury, and workers must be protected from it, as well.

The degree of arc flash hazard is measured by the incident energy that is released, which is expressed in calories or joules per square centimeter. This incident energy defines the thermal exposure that a worker standing at a certain distance from the source of the arc (the "working distance") would expect to receive on the head and torso. In addition to the thermal energy release, there are other hazards produced by these events, including arc blast (a high-pressure wave), sound levels that can lead to permanent hearing damage, and often a ballistic threat from high-speed flying particles and objects.

The incident energy level at a given location in an electrical system is dependent on many factors, such as system voltage and component impedance, available fault current, and the arcing fault duration. The faster an arcing fault is detected and cleared from the system, the less energy it releases into the air, so the action of the overcurrent protective device — specifically, how quickly it can detect and clear the fault — is a critical parameter in determining the level of arc flash hazard in a given system. In fact, in most cases the fault clearing time is the only variable in the equation that can reasonably be controlled in order to limit the incident energy that will be produced by an arcing fault.

The human damage and financial costs that result from arc flash accidents can be very significant. It is estimated that a serious accident from which the victim survives will on average cost more than $10 million, which is a combination of direct and indirect costs. Some very serious accidents have resulted in much higher costs. The victim often suffers permanent and disfiguring physical trauma that shortens the life span and prevents them from ever returning to work. This is a serious risk, not only to the worker and the worker's family, but to the employer and its insurers. For small employers, the company itself may not survive.

DE-ENERGIZED FOR SAFETY

One of the most fundamental safety requirements for electrical workers is to turn off the power to the equipment before they attempt to work on it. This is usually done through a documented process called lockout/tagout (LOTO). Obviously, electrical equipment, or any other type of equipment, that has been safely disconnected from its energy source is no longer a threat to the worker from any possible electrical or other kinetic energy exposure. But sometimes, turning off the power is not a reasonable option, especially if doing so might actually cause a safety hazard in another way.

SAFETY DEFINED

Figure 1. NFPA 70E defines specific safe work practices and personal protective equipment (PPE) for workers to help protect them from these hazards. (Source: Oberon Company)

BEHAVIOR ROUNDTABLE

Because human behavior is such an important ingredient in improving workplace safety and managing loss control exposures, a better understanding of the principles of human behavior will lead to more effective outcomes in the area of workplace safety.

Workplace safety has in the past decade become a very high management priority for most responsible business leaders. Awareness of the workplace safety subject and the technology supporting safety has experienced significant developmental growth in recent years.

Charlie Palmgren, a senior management consultant and executive coach, has spent decades researching, writing, and coaching about organizational development, human behavior, and human transformation. Johan Roels is owner and principal thought engineer at Loss Control Centre Belgium, a consulting business that specializes in safety culture change.

Weigel: In your loss control white paper, titled, "The Risks and Causes of Accidents," you stated, "Among the practical principles of professional management is the principle of multiple causes." Would you elaborate on that, please?

Roels: Problems and loss-producing events are seldom if ever the result of a single cause. The idea of integrated loss control aims at the control of hazards, risks, undesired events, and losses. Integrated loss control deals in particular with identifying the multiple causes of those undesired events and strives to minimize the effects of them. The principle of multiple causes recognizes the complexity of the event chain that leads to accidents. The main difference between a risk and a cause is that the cause is an element of the past once that undesired event has happened, and a risk is an element of both the present and the future until the undesired event happens. So if you wait long enough, every risk eventually becomes a cause. Therefore the principle of multiple causes/risks is an essential principle for loss control management.

Weigel: In that same white paper, you have a section titled, "Management Responsibilities." Would you please elaborate on management responsibilities involved within the loss control system?

RISK MANAGEMENT
Figure 2. From a risk-management perspective, safety training is a cost-effective strategy an employer can provide to employees exposed to workplace hazards.

AN UNFORTUNATE SERIES OF PREVENTABLE ERRORS

Electrical accidents that cause human injury and fatality almost always are initiated by some unintentional human error and almost always result from an unfortunate series of preventable errors. Electrical equipment is designed to operate safely and reliably throughout its service lifetime, often for several decades. It is very rare for electrical equipment to fail spontaneously, even when it suffers abuse from long-term maintenance neglect. When these rare failures do occur, there is usually no person standing near the equipment, so the equipment is often damaged or destroyed but no one is involved or injured in the event.

When the accident results in an injury or fatality or even a "near miss," the initiating cause is usually some error by the worker. Accidents are never a result of an intentional act. Electricians never leave home in the morning and say, "Honey, I am going to do something really dangerous today, and I might not be coming home." Electrical accidents always result from a lack of awareness of safe work practices, which can also be stated as a lack of training.

SAFETY TRAINING

Safety training for a "qualified person," which is required by the standards, is one of the most important requirements for workplace safety, and especially electrical workplace safety (Figure 2). It is also the easiest compliance requirement for employers to implement, and perhaps the least costly, as well. From a risk management and safety perspective, safety training is probably the most cost-effective strategy that an employer can provide to its employees who may be exposed to workplace hazards. Many of the other contributing factors that might lead to an accident are existing substandard conditions or substandard practices. The human error factor is simply the initiator when the accident involves an employee.

Roels: Management has to create and manage its loss control system and the standards that support it and also provide for the necessary means to enable it. Management not only plans and organizes the work to be done to meet those standards, it also evaluates results, identifies needs, and corrects and commends performance. This is the essence of management control. This also means that management is responsible for continuous improvement of the loss control system by adding system activities and by specifying adapted standards of criteria. Adequate standards are essential for adequate control. Lack of compliance to those standards is a common reason for lack of control.

Developing an adequate loss control system and standards are an executive function, aided by supervisors. Maintaining compliance with those standards is a supervisory function, aided by executives. It is a management team effort all the way.

Weigel: Workers seem to have the most at risk as they perform their assigned duties. How can workers best be convinced that their safety is critical, and how do you change behavior that may be potentially unsafe?

Palmgren: Mr. Roels suggested that loss control management must take a multi-causal approach when developing a safer workplace. You stated that accidents that cause human injury and fatality almost always are initiated by some unintentional human error. And if, as you suggest, electrical accidents always result from a lack of awareness, it becomes imperative that leaders, managers, and supervisors become more safety-minded or mindful. The obvious devil in the details is how you help people change the way they think. The short answer is, you don't. They must see the value of such a change and be willing to pay the price it takes to keep the change. That price is the willingness to learn new habits of thinking and becoming aware.

Weigel: What is the missing ingredient that is needed to change safety behaviors?

Palmgren: The new paradigm needs management and workers to accept together their responsibilities and to work together to find the underlying multi-causes of accidents or other undesired events. In addition to planning, organizing the work, meeting the standards, evaluating results, identifying needs, correcting and commending performance, executives and managers must model and live the safety behavior they proclaim. Employees must not only hear about the value of safety behavior, they benefit most when they can see and above all experience that behavior in the workplace. The time has come for transforming wishful thinking into safety-mindedness.

TRAIN TO SUSTAIN
Figure 3. The first line of defense against human behavior is training.

Most other types of accidents involve the same common causality — that is, human error is, in most cases, the most significant contributing factor to the accident. For example, a study on motor vehicle accidents, the Indiana Tri-Level Study, done in 1979 concluded that 90.3% of motor vehicle crashes involved some type of at-risk driver behavior. The vehicle was designed to be safe to operate, but the safety variable factor was the behavior of the driver. For those of us who drive motor vehicles, that is probably not a very surprising statistic. It is true that even with motor vehicle accidents there are usually multiple causes that culminate in the accident.

HAZARD ELIMINATION

Most companies recognize that equipment modifications can help to improve safety. These things are relatively easy to identify and address by the employer who cares about workplace safety. Machine safeguarding is an example of what OSHA terms as an "Engineering Control." Machine safeguarding can prevent a worker from being injured by a machine. Reducing hazards to the greatest extent possible by "engineering them out" is an excellent first-step approach, and eliminating an electrical or other kinetic machine hazard is even better. However a worker's unsafe behavior is likely to be the most important variable to identify and correct.

The first line of defense is to address the human behavior, and the key to that is training (Figure 3). Other activities that comprise a good safety management control system involve observation of current work practices, identifying safety vulnerabilities, and eliminating or correcting them. Recognizing these factors, most companies that are serious about workplace safety now rely on safety management systems that approach the problem from multiple perspectives, and the most important of these system components is called "behavioral safety."

Start Seeing Anomalies

Use infrared inspection to determine thermal patterns of electrical systems

BY JAMES BRADY, BRADY INFRARED INSPECTIONS

Throughout the evolution of infrared technology for predictive maintenance applications, electrical system inspections have remained the cornerstone of the industry. Despite being somewhat overshadowed in recent years by building science applications, the demand for infrared inspections of electrical systems remains high. Accurate diagnosis begins with understanding electricity and what causes thermal anomalies. Several types of defects, including those associated with compromised connections, overload conditions, load imbalances, harmonics problems, and inductive heating may be encountered during an infrared inspection.

ELECTRICITY, CURRENT, AND HEAT

Electricity is energy made available by the flow of electric charge through a conductor. It travels at different potentials that are measured in Volts. Common voltage classes include 120/208 V and 277/480 V. In most of these settings, the wiring is specified as having three hot legs commonly termed A-, B- and C-phase, and a neutral leg, although exceptions occur where three hot legs are present in places where motors are the load device.

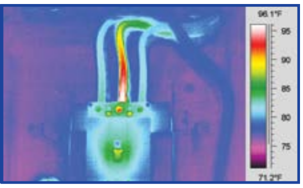
Voltage classes obtain their values by the potential that exists between each phase and between each phase and neutral and/or ground. For example, in a 120/208 voltage class system, 120 V is measured between the neutral wire and one of the hot phases. In the same system, 208 V of potential exists between each of the hot legs (Figure 1). The same principles would apply for a voltage class of 277/480 V and others.

The flow of current is necessary in an electric system for infrared to be an effective diagnostic tool. Current is measured in Amperes and is defined as the movement or flow of electrically charged particles through a conductor. As charged particles flow through a conductor, they interact with one another to generate heat that is detectable with an infrared camera. The National Electric Code specifies conductor sizes for specific current flow so that excessive heat does not persist under specified load conditions. In correctly designed electrical systems, the heat generated by circuit load should fall within published standards for absolute maximum allowable temperature criteria.

Where current flow exceeds the design capacity of a conductor, a higher concentration of current flow is created for a given area of conductor, and it in turn generates heat. The amount of current flow and severity of resistance will dictate the amount of heat generated.

ONLINE FIGURE GALLERY

The infrared images in this story are too numerous to include. To see the complete gallery of images, visit www.plantservices.com/thermalpatterns. There, you'll find the accompanying images that are referenced by their figure numbers in the story.



AMMETER AND TEMPERATURE COMPARISON

An infrared camera can decipher thermal patterns associated with circuit load; however, it isn't able to determine the amount of load on a circuit. An ammeter provides this information to the thermographer and allows the comparison of temperatures of different components under similar/identical loads. For example, 10 A of current flowing through a #12 wire on one circuit should be the same temperature as 10 A of current flowing through a #12 wire on an adjacent circuit, assuming they're operating in the same ambient temperature. If there is a deviation from this, it may suggest an abnormal condition that requires further investigation.

When using an ammeter, it isn't always possible to locate another circuit with similar load conditions. If this is the case, the same circuit under question can be used to compare a temperature against itself. This is done by measuring the load-side conductor temperature to the line-side conductor temperature to obtain a delta temperature. This method is particularly useful when looking at single pole breakers. Measure the temperature of the problem area against the temperature of the wire conductor some distance away from the problem to get a reference temperature. This method assures that temperatures are referenced on components under identical loads.

CONDUCTORS

Conductors serve as pathways for current flow and consist of either copper, aluminum, or some hybrid of these two elements combined. Common examples of conductors are wire (stranded, solid), bus bars (usually flat, rectangular shaped, although outdoor substations commonly have tubular bus systems), and miscellaneous components that are present in breakers, disconnects, contactors, thermal overloads, motors, transformers, and other devices where electricity flows.

COMPROMISED CONNECTIONS

All electrical systems have various mechanical connections that join conductors together so that current can flow uninterrupted. Examples of connection types include screw-in or bolted receivers, clips, blades, crimps, sleeves, pressure contacts, and others. Any or all of these types of connections can be encountered during a typical infrared inspection. Some of these connections are visible with direct line of sight, such as a load-side wire connection on a single pole breaker. Others may not be visible, such as internal contacts on a three-pole circuit breaker or contacts on a motor contactor. Regardless of their accessibility to sight, the one common function that connections have is to provide a seamless path of electrical continuity from one conductor to the next.

Connections can be compromised either through looseness, breakage, corrosion, or any other means whereby

SO MUCH POTENTIAL

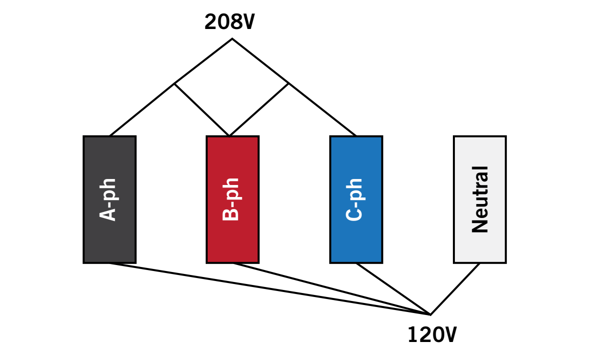


Figure 1. Voltage classes obtain their values by the potential that exists between each phase and between each phase and neutral and/or ground. The same principles apply to other voltage class systems.

current flow is retarding either partially or completely. Heat is generated at these sites through the physical reduction of conductive surface area created by the compromised connection. Figure 2 shows a schematic cross section of three different wires with increasing degrees of resistance as a result of compromised connections (light blue areas). Assuming that load conditions remain constant for each wire below, the figure shows that current flow becomes more concentrated in conductive areas as areas of resistance increase, resulting in localized hot spots. In effect, a hot spot is a localized overload condition in a conductor's pathway.

Compromised connections are one of the most common problems encountered by thermographers. They're recognized by having a localized heat pattern at the highest point of resistance that dissipates away from the loose connection. When a direct line of sight to the component is available, it's easily recognized (figures 3 and 4 at www.plantservices.com/thermalpatterns).

Typical line-of-sight connection problems include:

- line- and load-side conductor connections to breakers, contactors, thermal overload devices, bus bars, and other electrical components
- bus-to-bus bolted connections
- breaker-to-bus connections
- fuse clip connections
- knife blade and pivots on disconnect switches
- wire connections at terminal blocks
- wire nuts and other splices.

When connections aren't readily visible from a direct line of sight, determining thermal problems can be challenging. The heating pattern on these types of problems can vary, depending upon the component and the barriers that prevent a direct line of sight. Two examples of internal contact problems are shown in figures 5 and 6 (www.plantservices.com/thermalpatterns). Figure 5 shows centralized heat in the middle of a breaker where the internal connection is located. Figure 6 shows an enclosed fuse block with the middle phase showing a heat pattern that propagates through the fuse block and along the line and load side conductors. When evaluating a thermal pattern such as this, it is important to check amperage to make sure that the thermal pattern you are seeing is not load-generated heat.

Figures 7 and 8 (www.plantservices.com/thermalpatterns) are examples of deteriorated connections on an enclosed overhead bus duct. If an overload or load imbalance condition existed here, one would expect to see a warm thermal anomaly along the entire length of the bus. However, the warm thermal pattern is restricted to a small section of bus.

Figures 9 and 10 (www.plantservices.com/thermalpatterns) are examples of loose connections obstructed by the components inside the electrical enclosure. Figure 9 is a wire harness on a three-pole circuit breaker inside a motor control bucket. The actual loose connection is a spring tension clip that attaches to the bus behind the bucket enclosure. Figure 10 is suspected to be a loose bolted bus connection that is obstructed from view by a piece of insulation board.

Typical blocked line of sight connection problems include:

- internal contacts on breakers, contactors, and fuse blocks
- bus-to-bus bolted connections on enclosed overhead bus work
- pressure/blade contacts on transfer switches and other disconnects
- various connections hidden from view inside switchgear enclosures
- any other type of connection that is obstructed from view.

OPEN CIRCUITS

Conductors displaying a colder-than-normal pattern under normal operating conditions, when compared to adjacent conductors under similar loads, usually signify an open circuit somewhere along the line. The reason a cold thermal pattern exists is the lack of current flow. This can happen for various reasons, but the most common situations arise from broken conductors and single phased motors.

During a recent inspection at an industrial site, a 25 °F degree temperature rise was observed on one of two 400 A rated parallel feed conductors that linked an 800 A three-phase breaker to a motor control center. When performing infrared inspections of parallel feed conductors, it is important to understand that paired conductors are sharing load and therefore should have identical thermal patterns. An Ampere reading showed that the warm conductor was carrying 450 A, while the paired conductor, which showed a much cooler temperature, had less than 1 A (Figure 11a at www.plantservices.com/thermalpatterns). An infrared inspection at the main lug compartment of the motor control center showed the same thermal relationship as observed at the main breaker but also showed a deteriorated connection that no longer was capable of carrying load (Figure 11b at www.plantservices.com/thermalpatterns).

A similar situation was encountered during an inspection of a motor control center bucket. It was noticed that the C-phase thermal overload unit appeared appreciably cooler than the A- and B-phase thermal overload units (Figure 12a at www.plantservices.com/thermalpatterns). An amperage check showed no current flow on the C-phase circuit, running under a single phase condition. The motor that was being fed from this bucket was inspected and found to have an operating temperature of 248 °F, as compared to a tandem motor operating at 156 °F (Figure 12b at www.plantservices.com/thermalpatterns). The motor was taken out of service and replaced.

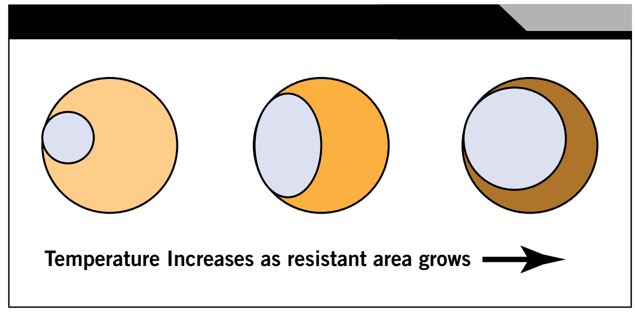


Figure 2. The cross-section view of a conductor under normal load conditions increases in degrees of resistant. As resistant area increases, conductive pathway area decreases and the amount of heat will rise.

OVERLOAD CONDITIONS

Electrical systems are designed and sized to meet anticipated load demands based on a facility's operations. Load demand is calculated based on the number of motors, lights, receptacles, machinery and other load devices present in a facility. Ideally, electrical systems are engineered around a facility's specific needs and include additional capacity to accommodate future expansion. Over the course of 10 years of infrared inspections for any given facility, load capacities can range from 25% up to 70%, with an ideal system operating at just less than 50% capacity.

National Electric Code 220-10(b) states that circuit load should not exceed 80% of conductor ampacity or 80% of the over-current device rating. This includes main branch circuits as well as individual single-pole circuits. If this criterion is exceeded, an overload condition develops.

Overload conditions arise in electrical systems for various reasons. Common reasons include:

- the expansion of a facility's electrical needs outgrows the original design capacity
- conductors and other components aren't sized properly in the original design to meet load demands
- permanent and/or temporary load devices are added to a circuit after the original design that causes loads to exceed the capacity of the circuit.

Infrared cameras are capable of detecting load-generated heat in electrical systems. Load-generated heat develops through the interaction of electrical particles as they move through a conductor. A typical load heat pattern is uniform in appearance and propagates through an entire circuit. The amount of heat generated depends upon the amount of load and the ambient operating temperature of the equipment. Figure 13 ( ) shows a circuit breaker panel under normal operational load. Notice the uniform heat pattern on each breaker and the slight thermal differences between breakers of varying loads. Figure 14 (www.plantservices.com/thermalpatterns) shows a three-phase transformer bank and service feed to a building that shows load-related heat responding to the building's operations. Under normal conditions, load-generated heat should show small to moderate temperature rises above no-load circuits and not pose an unsafe condition to the electrical system.

> **Document a circuit as a thermal exception when its load is at or near 80% load capacity.**

Circuits with elevated heat patterns as shown in Figures 15 and 16 (www.plantservices.com/thermalpatterns) are examples of over-load conditions. To determine if a circuit is operating within its rated ampacity, the amount of load on a circuit must be measured using an ammeter. Simple calculations can be run to determine if a circuit is operating below an 80% load capacity. Document a circuit as a thermal exception when its load is at or near 80% load capacity. As a precautionary measure, service and/or replace components that have been under high load conditions once the abnormal load condition is rectified, as extended periods of elevated load and subsequent heat can weaken connections.

Determining the difference between thermal patterns caused by load and those created as a result of a compromised connection is established by comparing load readings. Load-related thermal exceptions only are present under abnormal high circuit loads. Connection problems will show abnormal heat patterns under normal load conditions, as well as elevated load conditions. If a component displays an abnormal heating pattern under normal load conditions, a compromised connection, either internally or externally, is most likely the cause.

Improperly sized electrical components can also create overload conditions. This is common in fused components where a fuse is inadvertently replaced by a smaller size fuse. Figure 17 (www.plantservices.com/thermalpatterns) shows a three-phase disconnect operating at 70 A of current per phase. The A-phase fuse has a rating of 75 A, and the B- and C-phase fuses are rated at 100 A and 125 A, respectively. The thermal pattern for each fuse reflects the load capacity for each circuit: A-phase operating at 93% load capacity, B-phase at 70%, and C-phase at 56%.

LOAD IMBALANCE

Ideally, three-phase electrical systems should have similar operating load conditions on each phase for what is known as a "balanced load." While a perfect load distribution is not always achievable, load differences shouldn't vary greatly between phases in any given system. In commercial office buildings, hospitals, and other places where lighting and receptacle loads make up a large portion of load, unevenly distributed loads can occur. Conversely, in systems where motors make up a large portion of load devices, loads should be evenly distributed between phases with little variation.

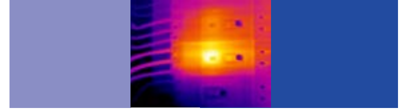
Uneven loads cause conductors to heat unevenly and are readily detectable with an infrared camera. As with all load-generated heat, the entire conductor warms evenly, but the one or more conductors will have either warmer or cooler temperatures (figures 18 and 19 at www.plantservices.com/thermalpatterns).

HARMONIC PROBLEMS

Perhaps one of the least understood of the thermal problems is harmonics. Destructive harmonics are a distortion in the electrical power waveform caused by nonlinear loads. Common load devices that cause harmonic problems include:

- solid-state electronics
- office equipment
- high-intensity discharge lamps (HID lamps)
- electronic lighting ballasts
- variable-frequency drives (VFDs)
- UPS systems.

Common symptoms of harmonics are overheated transform windings and neutral wires (Figure 20 at www.plantservices.com/thermalpatterns). When inspecting hot transformer windings, it's important to verify load conditions using a true RMS ammeter. Load conditions should be close to balanced and running within specified current ratings; if not, the problem could be caused by a load imbalance or caused by overload condition.



When hot neutral wires area observed, harmonic problems are confirmed and higher load is found on the main neutral conductor than on any of the other hot legs (Figure 21 at www.plantservices.com/thermalpatterns). Another testing method to confirm harmonic issues is using waveform analyzers.

Harmonic problems aren't as common in newer electrical systems as they are in older systems that have installed electronics, UPSs, VFDs, and other nonlinear loads. Newer systems have oversized neutral wire mains and, if necessary, harmonic filtering devices installed to counteract the effects of harmonics (Figure 22 at www.plantservices.com/thermalpatterns).

> **A typical load heat pattern is uniform in appearance and propagates through an entire circuit.**

INDUCTIVE HEATING

The magnitude and intensity of inductive heating shouldn't be underestimated when performing infrared inspections of electrical switchgear. Inductive heating is derived from the proximal interaction of noncarrying electric devices with the magnetic field around conductors.

Inductive heating affects ferrous metals causing inexplicable heating on noncurrent-carrying components (figures 23, 24, and 25 at www.plantservices.com/thermalpatterns). The intensity of heating is a function of the amount of current passing through the conductor and not so much the voltage class. The affected components can reach temperatures in excess of several hundred degrees.

Common components that can be affected by inductive heating include:

- parts of switchgear cabinets
- bolts and other hardware used to support insulation between conductors
- conductors of one phase that are bound together
- bus work that travels though walls and other tight areas.

During a recent inspection at a power generation plant, two examples of inductive heating were observed near the plant's step-up transformers. Images captured show intense heating on a noncurrent-carrying support pole and bus transition box, both close to iso-phase bus entering a13 kV to 230 kV step-up transformer (figures 26 and 27 at www.plantservices.com/thermalpatterns). Temperatures documented on these devices were in excess of 400 °F. Being the starting point of transmission service, a heavy current load would be expected on energized equipment.

Often, engineering designs on switchgear enclosures and other electrical equipment don't take into consideration the interaction of noncurrent-carrying ferrous devices within electromagnetic fields. In some cases, these situations can pose safety hazards when the affected component is in contact with combustible materials or heat structures that are accessible to human contact. When faced with perplexing heat patterns on components that shouldn't be hot, inductive heating might be to blame.

DEFECTIVE EQUIPMENT

Defective electrical components commonly display abnormal heating patterns. Examples include:

- UPS batteries
- ribbon bus circuit boards
- current transformers (CTs)
- lightning arresters
- VFD fans
- metering devices/meter cans
- stand-off bushing inside main switchgear cabinets.

A complete set of some examples of the above-mentioned defects are shown online in figures 28-34 (www.plantservices.com/thermalpatterns).

CONCLUSION

Infrared technology is a powerful tool that can be used to detect thermal anomalies in electrical systems. Understanding the relationship between current flow through conductors and the heat pattern associated with current flow is critical for properly diagnosing electrical problems. Furthermore, an understanding of the operating nature of electrical components and the construction details of electrical systems is essential. These skills are gained over time by working closely with qualified electricians who are willing to share their knowledge and through mentorship programs with experienced thermographers.

While loose connections are the most commonly detected thermal exceptions, overloaded circuits, open circuits, and other electrical defects can pose a great threat to the safety and reliability of electrical systems. Learning to recognize the significance of abnormal heating and the ramifications it has on the operation of an electrical system legitimizes the use of infrared technology and solidifies the role of an infrared thermographer as a key player in the electrical maintenance industry.

James Brady is a level III certified infrared thermographer at Brady Infrared Inspections (www.bradyinfrared.com) in Stuart, Florida. Contact him at (772) 288-9884 or jbrady@bradyinfrared.com.

QUALIFIED & COMPLIANT

Objective and measurable techniques to determine best safety practices on electrical systems

By Robert S. LeRoy, Electrical Safety and Compliance Consultant

Companies must acknowledge hazards that exist in their facilities and operations and agree upon the safe work practices employees will use when working on or near them. Training then follows to ensure employee knowledge and monitoring processes established to ensure compliance. Variations of this model exist worldwide.

The mandate, problem, and solution techniques can be used on electrical safe work practices. It should be recognized that this model could be adapted for any aspect of an employer's workforce.

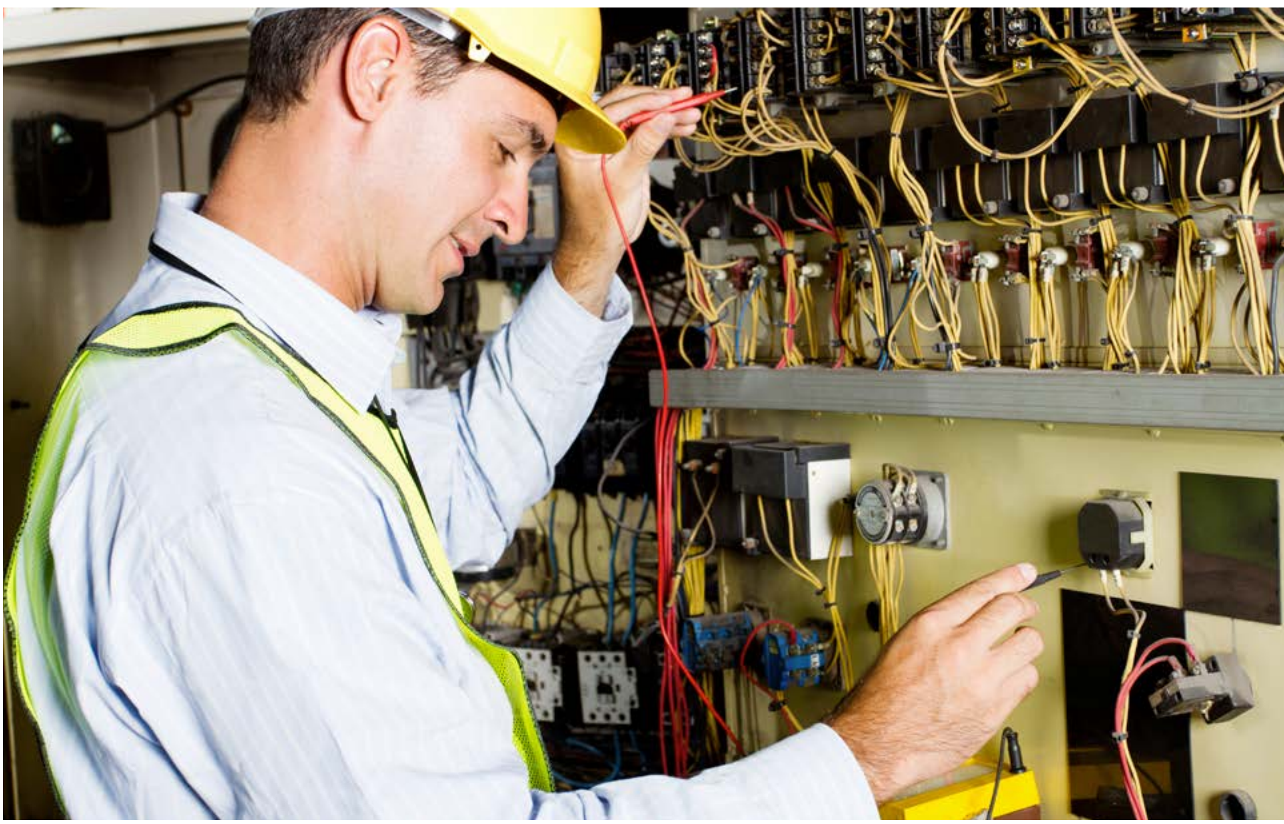
If employees are a company's most valuable asset, a natural follow-up would be to prepare, preserve, and protect the human asset with the same vigor that is afforded the mechanical equipment those humans work with on a daily basis. Both the human and hardware must be correctly selected for an intended outcome and maintained for optimal performance. Where humans are involved, optimal performance begins and ends with safety.

The basis for monitoring safe work compliance is rooted in the Occupational Safety and Health Act with techniques described in NFPA 70E. These two documents become the operating manuals for the human asset, the employee, in which every supervisor must be well-versed. They provide both the requirements and compliance processes for safe and efficient operation and outcome. Workers must first be qualified for the task and then monitored to ensure their daily work habits reflect the training elements used to determine their qualification status while following company-provided work procedures.

The benchmark of effective training and workforce development must meet three interconnected requirements:

- targeted to the topic (equipment and work practice)
- measured for understanding
- monitored for compliance.

In recent years, training models have evolved by adapting to client's scheduling and budgeting restraints with a diligent eye on the effects on the company's overall financial health. Training providers, whether in-house or outsourced, continue to develop new delivery models that ensure training effectiveness and the best return for the investment.



The employment process determines a worker's ability to perform employer-directed tasks or the need for initial training so that the worker may achieve the necessary level of documented independent work performance. Technical competence is a foundational aspect to consider when determining the qualification of any worker.

In a previous position, I was tasked with staffing outages, or turnarounds, in an electrical generating plant. These are work-intense and time-constrained projects endured by many large industrial-type facilities, and they require great planning and preparation to achieve a safe, successful, and reliable result. These annual projects typically occur in low electrical load times of the year, spring and fall, throughout the industry. After a particularly negative result the previous year, I'd decided to give a basic-level electrical test to all applicants, even though they may have had extensive experience performing this work in the past. To my chagrin, or maybe not, it was discovered that only 22% of the temporary workers could pass this basic test. To ensure some level of fairness, I also gave the test to the full-time company employees, half of which had less than five years' experience. Only one of the 23 tested individuals possessed an electrical license or had experience in taking similar type testing. Licensing of electrical workers within a company maintenance environment is not a mandate in many states, as was the case with the state in which this occurred. All of the company employees passed the test.

What was revealed was actually a factor of basic human behavior and performance. People work to their areas of strength but, when confronted with areas of weakness, often will remain silent for fear of reprisal. The temporary workers I had hired previously were specialists. They were very good at certain aspects of their work but extremely weak in others. As an employer, the responsibility of determining the readiness of the workforce to perform any requested task and the preparation for that task rested firmly on my shoulders. What became painfully clear was that a safe, efficient, and valuable workforce is not hired; it is developed.

A company must use all diligence to hire qualified candidates for its electrical workforce, but with full awareness must consider these new hires, or those in their existing workforce that have neither been tested nor been measured for understanding, are just that, qualified candidates. Qualification requires a process of answering key questions to determine baseline factors upon which to act.

- What is the existing level of expertise and understanding of the workers for the task they are expected to perform?
- Where deficiencies are noted, how can these be addressed best to ensure effectiveness of any required training?
- How will I be alerted when additional training is required to best spend the training dollars available and, more importantly, ensure the safety of the worker while doing the tasks expected?

Let's attack these questions one at a time. The definition of "qualified electrical worker" by OSHA and the recommendations of 2012 NFPA 70E both reference the mandate that a qualified worker have understanding of construction, operation, and maintenance of the electrical equipment with which that worker intends to interact.

The employer must audit the workforce to first determine the level of qualification and compliance that exists. After this determination is made, processes must be put in place to raise any level that falls short of the electrical safe work practices (ESWP). For the level of work practices to remain at this high level of expectation, further processes are required to monitor compliance and immediately unleash a predetermined action plan to regain the ground that has been lost.

THE NEW O&M

Often, plant managers examine work tasks to properly place them in either the operations or the maintenance category. They must further audit performance to ensure this separation remains.

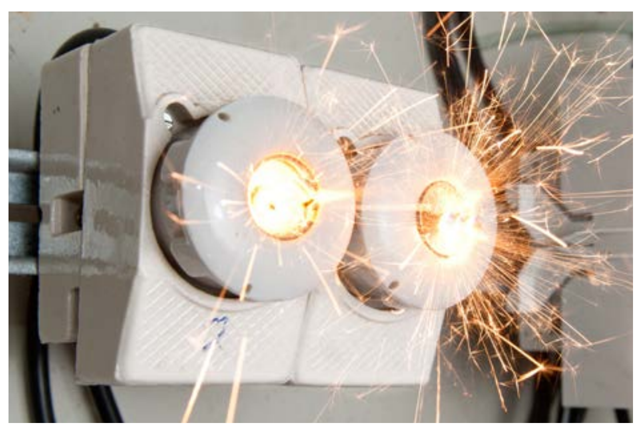
An audit is a systematic process for objectively obtaining information and evaluating, or measuring, the data against a known foundation. Two key words emerge that often are missing in most cursory examinations: "objective" and "measurable."

These assessments often become subjective in nature, accompanied by statements such as, "I think he knows," or, in exasperation, "With all the training they've received, surely they understand." To be considered objective, the results should conclude at least one of the following:

- "I heard him say the proper thing."
- "I see the correct answer was marked."
- "I observed the worker doing it correctly."

For an objective conclusion to be made, it must be measured against an accepted standard. The standards for the qualification are determined by regulations, by industry best practices, and, most importantly, by applicability to the requested task. These expectations must first be given in the form of training and then followed up with a means to measure understanding. With a goal of 100% demonstrated proficiency this then becomes a baseline upon which to measure the need for refresher training as time goes by.

Employees work under a mindset of consent. "My employer consents to my employment because I am a recognized valuable asset to the company." Often consent is assumed in the absence of guidance. Companies view the bottom line of the financial statements as the measurable outcome in determining success. Internal processes ensure honesty, integrity, and fairness to have confidence in the result. In the same way, workers view the successful completion of a task as their goal and measure. Too often, the emphasis and acknowledgement is on the goal; little time, effort, or thought is given on how it was achieved. The worker is rewarded for exceeding expectations when in fact the worker may have cheated, in the sense that



safe work practices were ignored or guidelines altered to complete what the worker thought was the goal of work performance and success. To the worker, success is keeping the plant running or getting the power back on as quickly as possible, which in the worker's mind justifies the work practices used. Success can't be measured by a decrease in lost-time incidents or accident reports alone. True success only can be achieved by comparing the results with the practices that achieved those results.

Even with this essential determination of qualification, the employer can't assume a worker will interact with electrical equipment safely, unless given the company's expectations of how to work with energized and de-energized equipment, show proficiency in demonstrating skills and techniques necessary to safely perform the work task, and be monitored periodically for compliance and understanding. Objective tools must then be used to measure this level of qualification. There can be no hint of subjectivity in the process, because employee understanding and compliance is being measured against this minimal safe standard.

Additionally, the employer must audit its electrical safety program to ensure compliance with current standards, measure against industry best practices, and identify any shortfall in providing a safe work environment. Processes must be in place to track these benchmarks and immediately formulate a plan to regain compliance.

These ongoing processes involved procedures that are both equipment- and system-specific. The electrical safe work practices are incorporated into the task-specific procedures and utilized as the work practice norm. Each task is thoroughly examined and written as the road map a worker will follow in performance of the task. Milestones are identified along the road with points assigned for successful achievement. After the task is completed, a total score is determined by adding up the milestones achieved and compared against the predetermined score goal. Action plans are put in place to immediately remediate the milestones missed. The result is a document whereby observable compliance is not only measured, but reasonable employer response can be ensured.

These new processes are a definite change from what has been the established norm. Employers seek to hire the most technically competent workers. Assumptions are made that the terms "technically competent" and "qualified" are synonymous, when in fact they are two entirely different processes an employer must undertake. The employer must ensure technically competent workers understand the hazards encountered in the performance of their work and how to remain safe while doing it. This has been one of the most radical shifts in employer duties in the past decade.

To embrace change from the boardroom down to the plant floor, a progression of steps must be followed:
- acknowledge the need
- own the culture
- establish the guidelines
- acquire the knowledge
- train for the expectations
- provide positive mentoring
- apply the solution
- monitor the process
- document the effectiveness.

Change can't be driven from the top down, nor is it driven from the bottom up. Real change, lasting change, is driven from the inside out. Workers need a mirror in which to examine work practices against expected behaviors and be rewarded more for the process than the result. The days of electrical heroes who are rewarded for work efficiency, regardless of the means used, must come to an end. This culture must be confronted head-on with established guidelines and expectations, which then are monitored for understanding and compliance.

The workforce is any company's greatest asset and like other assets must be well-constructed and appropriately maintained. Equipment maintenance requires gathering baseline and operational data to make prudent decisions on any necessary action. So also the workforce, when it's regarded as the most critical of company assets, requires being given the guidelines around which electrical work is to be performed and measurable tools put in place to monitor operational effectiveness.

Some employers are well on their way to achieving workplace safety. They may request industry experts to review their electrical safety programs, provide a gap analysis should any gaps exist, and advise them on training and tools monitoring worker compliance. Others are just beginning to walk down this road and need a guide to recommend which pathway will obtain their desired results expending the least amount of time, effort, and training dollars. The vast majority of companies find they're somewhere in the middle and formulate a plan from a list of benchmarks meeting the unique circumstances and need to which they find themselves today.

Developing a safe and efficient workforce requires more than yesterday's training models. The days of providing disconnected courses driven by an immediate need or worker request with hopes that somehow employees will get some of what they need or find a resource from which to get it are over. World-class employers know that to provide the level of safely delivered expertise required to succeed, nothing can be left to chance.

Robert S. LeRoy is an electrical safety and compliance consultant. Contact him at rleroy01@gmail.com or (863) 944-3369.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NEC CHANGES WILL AFFECT PLANTS

NFPA members vote on final amendments to 2014 NEC

By Randy Barnett, NTT Training

Whether you're moving a production line or replacing a broken 120-V receptacle, the National Electrical Code applies. Compliance with building codes, such as the NEC, is not an option. Plant managers, engineers, and maintenance staff must be aware that, for 2014, the electrical code will change. During the week of June 10, 2013, NFPA committee members met in Chicago to vote on the final amendments to the 2014 NEC.

The changes will be published in October 2013 and become effective January 1, 2014.

There will be many changes in the new code, and a good percentage will affect how electrical work is performed in manufacturing plants. These include the addition of new topics to the code, enhancement of personnel safety, and the revision, deletion, and addition of various general requirements.Four new articles have been incorporated for 2014 to address the needs of industry:

- Article 750 will address energy management systems. As saving energy dollars becomes more important in plants, the electrical code now will give guidance on the installation of smart grid management systems. Requirements will go right down to the marking symbol on controlled receptacles.
- Article 393 will cover low-voltage, suspended-ceiling power-distribution systems. These are 30-V lighting systems attached to the suspended-ceiling grid. Such systems will be found in office and other administrative areas where suspended ceilings are common.
- Article 646 on modular data centers will be incorporated into the code to keep up with modern technology. Though available in many sizes and configurations, the individual "building block" units typically consist of data servers, associated power supplies, and cooling units that can be easily expanded in capacity over time by adding more prefabricated modules.
- Article 728 will address fire-resistant cable systems. Should a plant fire occur, it's vital that certain cables continue to function. Such cables will be required to meet specific criteria and installation requirements.

The newly revised NEC will enhance personnel safety through centralizing and clarifying requirements for the use of lockable disconnects. Locking out and properly verifying a circuit de-energized is vital for plant personnel safety. Arc-flash warning label requirements will undergo some changes. Also, methods used to mitigate the arc-flash hazard in distribution systems will be revised. Interestingly enough, one particular proposal that would have increased the requirements for equipment grounding conductors to reduce the chance of shock or electrocution to persons working on rooftop HVAC units probably won't be approved for final inclusion into the code. Though based on a recent tragic accident that was the result of a faulty conduit system, the committee members note that, had the conduit system been properly maintained after initial installation, the accident would not have occurred. The NEC does point out in one of its very first sections that electrical systems and equipment must be maintained to remain safe after installation.

PLANT MAINTENANCE AND ENGINEERING DEPARTMENTS SHOULD DETERMINE WHEN THE 2014 NEC BECOMES EFFECTIVE AT THEIR FACILITIES.

Other topics that will change and affect plants in various ways include:

- personnel door requirements for electrical rooms
- new identification methods for DC positive and negative conductors
- GFCI requirements in non-dwelling unit garages
- grounding and bonding requirements including a new table in Article 250
- marking requirements on cable trays
- receptacles supplying vending machines
- labeling on generators and new generator receptacle requirements
- expansion of requirements for office furnishings, especially prewired workstations.

Plant maintenance and engineering departments should determine when the 2014 NEC becomes effective at their facilities, because jurisdictional requirements vary. Once published, affected personnel should update themselves on these recent changes and verify all maintenance and plant retrofit work conforms to the 2014 National Electrical Code.

Randy Barnett is director of electrical programs for NTT Training. Contact him at rbarnett@nttinc.com.

Additional Resources

FOR MORE INFORMATION CLICK ON THE LINKS BELOW

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Informational E-Book from AVO Training

This interactive and informational e-book includes Electrical Safety and Maintenance Self-Assessment Tests, electrical safety statistics, facts, links to white papers/articles and links to courses designed to get you properly trained in electrical safety and maintenance.

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SB6100 GFCI Video

The SB6100 Series Industrial Shock-Block(tm) Ground-Fault Circuit Interrupter (GFCI) is the first and only UL listed device that provides personnel protection at 480 V or 600 V. Due to potential safety concerns with other products on the market, some of which are claiming that they meet non-applicable UL standards, UL developed a new UL Standard 943C Class C and Class D for industrial facilities. Watch this video to learn more about the Industrial Shock-Block.

The ultrasound approach

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Whitepaper on Training Wheels for Electrical Wave Files

This whitepaper discusses how to review and analyze electric emissions of arcing, tracking, and corona using spectral analysis. All voltages — low, medium, and high — are discussed with an explanation of what type of emission will be present at each level and what to look for. There is also a review of how to distinguish between mechanical looseness and corona.