Electrical System Safety Through the Years
HOW DID WE GET HERE?

Worker protection against arc flash incidents has a personal history all its own

By Mark Franks, Avo Training

In 1989, OSHA promulgated a much-needed regulation in the General Industry Regulations; 29 CFR 1910.147, the control of hazardous energy, or lockout/tagout. Analysis at the time indicated that more than 14,000 injury incidents were occurring annually in industry as a result of “accidental activation.” This regulation was nicknamed the “machine lockout standard,” due to the fact that the regulations did not have specific provisions for the control of electrical energy for electrical work on utilization installations. Furthermore, the regulation excluded electrical work on power generation, transmission, and distribution installations in utilities. This is typical of utility companies in the United States. There was an immediate response by industry to establish the Energy Control Program as required by the regulation. Equipment assessments, specific machine procedures, training for personnel, and lockout/tagout supplies were some of the action items necessary to meet the comprehensive compliance requirements put into effect by the regulation. The effects of implementing the requirements of this regulation have been felt throughout all industry in the United States. This implementation resulted in the reduction of tens of thousands of injury incidents and hundreds of fatalities since its inception in 1989.

Almost parallel to 29 CFR 1910.147, the control of hazardous energy, OSHA established 29 CFR 1910.331-.335 (Electrical) Safety-Related Work Practices in Subpart S of the General Industry Regulations. Included in this new standard announced in 1990 were the requirements for electrical lockout/tagout for “qualified electrical workers” working on de-energized electrical utilization installations. The addition of the requirements specific for electrical work to the requirements in 1910.147 has equipped industry with the requirements to address the majority of the hazardous energy control issues encountered. Exceptions usually arose where the industry was involved in co-generation of electricity and also in owned power transmission lines, substations, or distribution facilities that were utility-like in design. These installations required procedures that were not totally addressed in 1910.147 or 1910.333, and industry was forced either to create or to borrow from utility organizations’ effective procedures.
Finally in 1995, OSHA was successful in promulgation of regulations for utility installations and utility-like installations of industrial facilities. 29 CFR 1910.269, electric power generation, transmission, and distribution, contained comprehensive regulations and addressed control of hazardous energy sources for power plant locations and also the much needed 1910.269(m), deenergizing lines and equipment for employee protection, which codified and clarified the use of “clearances” for hazardous electrical energy control in utility-like and utility installations.

By late 1995, industry in the United States had comprehensive regulations for the control of hazardous energy sources covering utilization, utility-like, and utility installations. In addition to these performance-oriented regulations for hazardous energy control, OSHA decreed in 1910.335 the requirement for protecting workers from electrical arc flash and burning from electrical explosions. OSHA further expanded the requirements to protect workers from arc flash hazards in 1910.269 by prohibiting a worker from wearing clothing that could be ignited and continue to burn, thus increasing the extent of injury to the worker. Certain fabrics or blends of fabrics that would burn readily or melt when exposed to flames or electric arcs were prohibited. The NFPA 70E 1995 Edition, formally identified the arc flash hazard and promoted the analysis of the hazard in the workplace.

Following 1995, industry in the United States had studied, tested, invented, tried, failed, succeeded, and moved forward in addressing the complex issues of arc flash hazard analysis. Successive NFPA 70E standards and the IEEE 1584 IEEE Guide for Performing Arc-Flash Hazard Calculations of 2002 have catapulted the process of calculating and analyzing arc flash energy. Protective equipment innovations have generated numerous options for protection of workers in wearing apparel, as well as arc flash protective suits ranging from 15 cal/cm² to 100 cal/cm² of incident energy.

Fast forward to 2013, and most industries know about arc flash hazard analysis. Many companies have completed the comprehensive engineering-supervised studies required to produce the results and have undertaken the hazard labeling of equipment, training of personnel, and application of arc-rated protective wearing apparel and arc-rated flash protective suits necessary to protect employees. Much of industry today has completed the analysis or it’s currently in progress or the analysis is planned for the near future to meet the compliance requirement and to stave off the possibility of a severe arc flash incident. Arc flash hazard analysis has a significant impact on the energy control program and specific equipment procedures for lockout/tagout. Many locations are experiencing changes in operational procedures necessary to address the levels of energy identified in the arc flash hazard analysis. Staff training, qualifications, safety backups, and maintenance of PPE are just a few of the issues being addressed (Figure 1).
Today, industry in the United States is experiencing:
• significant expense associated with the engineering studies necessary to identify arc flash hazards in the workplace
• the necessity of integrating the results of arc flash hazard analysis with current energy control procedures
• the need to train and re-train operational and maintenance personnel in arc flash hazards, PPE, and changes in energy control procedures
• significant expense in special equipment for remote operation, racking, and grounding, especially in locations identified with dangerous energy levels
• increased supervision and auditing responsibilities required to meet OSHA compliance requirements regarding electrical hazards and energy control.

In summary, competent engineering analysis, well-written energy control procedures integrating arc flash hazard analysis, training of personnel, PPE, and special equipment are requirements today and will continue to be addressed in future years.

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Electrical arc flash accidents that result in a serious injury or fatality occur five to 10 times every day in the United States. Approximately one fatality per day results from an electrical arc flash accident. The human consequences of these accidents are devastating to the victims and their families. If the victim survives a serious electrical burn injury, the injury is often so disabling that the victim is never able to recover sufficiently to return to work. The financial consequences are also very damaging to the employers and their insurers.

Electrical accidents have been occurring for more than 100 years, and the accident statistics have been fairly consistent until recently. The electrification of facilities that began during the early industrial revolution has continued with facility growth and process demands constantly requiring more and more electrical power density to sustain operations. At the same time, the manufacturers of electrical equipment improved on their products, developing improved designs to more safely control the electrical energy, protect workers and others from injury, and provide high reliability, reduced maintenance requirements, and long equipment service life.

With the current focus on arc flash safety and the availability of means to upgrade obsolete and poorly maintained equipment, the path to safety and improved reliability is easier to navigate, but the first step is to be aware of the implications of poor maintenance and make a decision to improve it (Figure 1).

Development of the electrical safety standards
The hazards of electric shock have been fairly well understood by most qualified electricians, and they have been reasonably well trained in the techniques of working safely to avoid shock and electrocution hazards. Arc flash and blast hazards were not really well understood until the late 1990s. The reason for the lack of awareness stems from the fact that, until 1999, consistently accurate methods to calculate potential arc flash hazards did not exist.

In spite of the statistical frequency of arc flash accidents prior to 1999, the amount of arc flash incident energy (thermal energy) wasn’t easily predictable, so means of protecting workers...
(personal protective equipment) wasn’t readily available for arc flash hazards. IEEE Standard 1584, IEEE Guide for Performing Arc Flash Hazard Calculations, was published in 2002. This document contained accurate formulas to calculate prospective incident energy levels based on empirical data from repeatable and accurate laboratory tests that were performed.

The first mention of arc flash hazard in NFPA 70E (Standard for Electrical Safety in the Workplace) appeared in the 1995 edition of that consensus standard. Subsequent editions of NFPA 70E have documented improved safety practices through the use of personal protective equipment (PPE) and other safety equipment and safer work procedures. Since then, considerable work has been done to improve arc flash calculation methods, improvements on PPE design to protect workers, training, and increased awareness of arc flash hazards (Figure 2).

**Arc flash — causes and effects**

An arc flash results from some condition that compromises the insulation distance between two phase conductors or a phase conductor and a grounded conductor or surface. The cause is rarely the result of equipment failure. Evidence suggests that a very high percentage (more than 95%) of these events that cause injury or fatality to a worker were caused by some unsafe act by the worker.

A tool or other conductive metallic object dropped into energized electrical equipment or a tool that slips and shorts between components is a very common cause of arc flash accidents. Once the arc forms, it heats the air around it very rapidly and the space around the arc becomes more conductive because of ionized metallic particles within the arc plasma. This exacerbates the condition and the arc will continue to develop as long as there’s sufficient voltage and current feeding the arc.

The arc plasma temperature can in some cases exceed 35,000 °F, so the primary mechanism of injury is the thermal release of incident energy causing tissue burns and clothing ignition. A secondary arc hazard is called arc blast. Under certain arc conditions a pressure wave develops reaching a pressure of 2,500 lb/sq ft. This blast pressure wave can cause significant injury, as well.

The amount of the arc flash thermal energy (incident energy) that is released in the arcing event depends on many factors, including voltage, available fault current/arcing current, and, most significantly, the time duration of the arc until it is extinguished. The incident energy released is directly proportional to the time duration of the arc. If the arc duration doubles, the incident energy doubles, as well. Overcurrent protective devices (circuit breakers and fused devices) must be capable of recognizing the fault condition and opening the circuit very quickly to extinguish the arc.

**Response time is key**

Once an arc initiates, there are only two things that will stop it. Either the circuit protective device ahead of the arc will sense it and open the circuit (fuse or circuit breaker, for example)
or the arc will burn enough conductive material away so that the arc gap distance becomes so great the arc can no longer bridge the gap, and the arc collapses. In the first scenario the arc duration is usually expressed in tens of thousandths to a few hundreds of thousandths of a second (milliseconds). In the second scenario the arc might continue for seconds or even minutes, and this is an extremely hazardous situation for the worker and for the equipment in the system. Ideally the arc duration would be less than one electrical cycle. One electrical cycle is about 17 thousandths of a second (17 milliseconds).

Where arc flash hazards exist
In single-phase and three-phase AC systems, lower voltages such as 120 V do not present much propensity to develop a dangerous arcing condition. Even the 208-V phase-to-phase voltage in three-phase-system voltages normally can’t produce arcs that sustain, even under the most favorable test conditions. It has been shown in many laboratory tests that arcs will not sustain at these lower voltages long enough to become a serious arc hazard. However, IEEE 1584 and NFPA 70E both take a very conservative approach on this.

However, all voltages of 240 V and greater can and do produce very dangerous arc flash conditions. In fact there are probably far more serious arc flash injuries in three-phase systems operating at 480 V than in any other system voltage in common use in the United States. The reason for this is 480 V three-phase systems are installed in almost every facility of any size in the United States, and workers are often far too comfortable with them to be fully aware of their hazard potential.

Designing for safety
Today there is a significantly heightened awareness of arc flash hazards, and consulting engineers who design power systems for new facilities are striving to design the safest possible system for their clients. The normal best practices in electrical system design that were commonly used in the past, in some cases, are no longer the best design choices for arc flash potential reduction. This “design for safety” is becoming more common, resulting in safer electrical systems for new construction projects.

The roots of the problem
For existing facilities, there are several conditions that affect the safety of the system. The first of these is the age of the equipment. It’s common to find electrical power and control equipment in service that is more than 50 years old. It’s common to find electrical power and control equipment in service that is more than 50 years old, and most of this equipment is no longer supported by its manufacturer. In some cases the equipment manufacturer — for example, Federal Pacific Electric or Westinghouse — is no longer in the electrical power equipment...
business. Power equipment is designed to have an effective service life of 25-30 years, with proper maintenance.

Electrical power and control equipment can be thought of as having two types of components — passive components and active components. Passive components are such things as equipment steel enclosures and structural framing, busbars, cables, and insulators. Active components are the circuit protective devices such as circuit breakers, protective relays, and fusible devices, as well as some metering devices.

**Electrical equipment failures**
An unusual characteristic of electrical equipment circuit protective devices is that they will almost always fail in a closed position, giving absolutely no indication of that failure. Even after failure occurs, they will stay closed and continue to provide power. Operation in the failed condition can sometimes extend for years or even decades. The failure will not be discovered until there is a critical fault event that occurs, or someone does performance testing of the device. These profound failures are usually the result of normal aging of the components, which is exacerbated by failure to perform required regular maintenance and testing (Figure 3).

Most everyday consumer devices, such as automobiles, refrigerators, televisions, and air conditioners, do not exhibit this unusual failure-mode characteristic. When these devices fail, the failure “feedback” is immediately obvious to the user, because they no longer perform their intended function.

**Why maintenance and testing are important**
Electrical circuit protective devices are critical for arc flash safety and system reliability and protection because they are designed to detect a fault condition and operate very quickly to disconnect power to the faulty circuit. Since clearing time is the critical element affecting the release of arc flash incident energy and the subsequent hazard level, poorly maintained circuit protective devices either will not operate as quickly as designed or, in the worst case, will not open under any fault condition. In that case, it’s impossible to predict arc flash hazard levels so workers can sufficiently protect themselves with personal protective equipment when they must work on the equipment while it’s energized.

Most electrical power equipment is so well designed that it will tolerate gross maintenance neglect over a long period of time and continue to provide power. It will usually survive in service much longer than it was designed for, and it will appear to continue to be fully functional, even long after it has failed. Because of these high reliability characteristics, owners of this equipment often don’t consider maintenance to be a very high priority on their
financial priority lists. Often the equipment doesn’t get any attention until it explodes or the lights go out and production stops. When that happens, maintenance money seems to come from every direction to get the power restored quickly. Breakdown maintenance is far more expensive, as well as hazardous, than preventive maintenance is.

**Electrical equipment maintenance requirements**

Maintenance requirements for electrical equipment will vary, depending on factors such as the operating environment, duty cycle, and the type of equipment and its voltage class (Figure 4). Small molded-case circuit breakers, for example, require almost no maintenance. Their internal mechanisms are designed to be relatively maintenance-free over their designed service lives. Maintenance requirements for these devices are limited to operating the breaker on and off two or three times annually. This is called “exercising the breaker,” which helps to distribute lubrication in its pivot/bearing points and wipes the pole contacts to keep them clean. Circuit breaker plastic cases should be examined periodically to ensure the cases aren’t damaged or cracked. Cable lugs should be checked to ensure they’re tightened to factory specifications. Periodic infrared inspections are a good way to easily identify any loose cable lug terminations.

The other end of the electrical maintenance requirement spectrum is large power circuit breakers, either in the low-voltage or medium-voltage categories. These are very complex electromechanical devices and may also contain digital electronic components, typically in their trip units. Power circuit breakers usually control larger blocks of power in the distribution system, so failure can cause very widespread process disruption. Because they’re typically higher-amperage devices with higher available fault currents, a malfunctioning device may have a very high risk factor for arc flash worker safety, as well.

Maintenance requirements for these larger power devices are quite extensive. Maintenance and testing for this kind of equipment should only be performed by qualified electrical maintenance personnel who know the maintenance protocol and have the test and safety equipment to do the work properly and safely. Equipment-specific maintenance and testing requirements can be found in the original equipment manufacturer’s operation and maintenance documentation or in a document titled, “NFPA 70B - Recommended Practice for Electrical Equipment Maintenance.” The current edition of NFPA 70B is the 2010 edition, and it’s available to order at www.nfpa.org.

Organizations often lack the internal resources to do this kind of testing and maintenance, but many suppliers have the expertise to do this work effectively and safely. For liability reasons it’s always a good practice to make certain the company you choose follows the electrical safe work practices outlined in NFPA 70E and enforced by OSHA. Safety-related maintenance requirements for electrical equipment comprise Chapter 2 in NFPA 70E 2012.
Retrofit or replace?

At some point in the life cycle of your electrical distribution system, decisions must be made to replace the equipment. Maintenance and testing costs for very old equipment will eventually reach a point of diminishing return, and replacement becomes the best option. It seems to be a simple decision to tear out the old equipment and put in new equipment, but there are some things to consider that are certainly not widely understood.

First, consider the length of the process or production outage for this strategy. Demolition and replacement can often take weeks to complete, even when carefully planned, staged, and executed. If anything goes wrong, as it inevitably will, things can get out of control very quickly.

Second, consider the footprint of the equipment, that is, the overall dimensions of the existing equipment. For example, low voltage 480-V switchgear that was made before the mid-1980s typically had section widths of 30 in. or 32 in. That means each vertical section was 30 or 32 in. wide. If the switchgear had six vertical sections, then the overall width of the switchgear would be 180-192 in.

For most manufacturers, the current vertical-section-width design for that type of equipment is considerably narrower, perhaps by 8 or 10 in. Of course, smaller seems better, but the problem that most people fail to anticipate is the placement of the conduits in the slab below, or overhead conduits above the equipment. With narrower equipment, if the conduits won’t line up with the new vertical sections incoming conduit spaces, the costs of and the time required for the replacement project can escalate very dramatically.

Good options exist today to retrofit the existing equipment in place to a like-new condition and with reasonable cost and minimal outage and process interruption. The reason this is possible is because some equipment suppliers have developed replacement products for the active components called “direct replacement” devices. Versions of these direct replacement devices are available for nearly all equipment regardless of the manufacturer of the existing equipment.

This retrofit option is typically used for low-voltage or medium-voltage switchgear, low-voltage switchboards, and low-voltage motor control centers. Similar options are available for lighting and distribution panel boards, but, in the case of panel boards, the entire panel interior with its circuit breakers is replaced, and a new custom cover is made to fit the existing back box.

With power equipment upgraded in this way, the equipment will be in like-new condition, with an expected service life the same as new equipment. At the same time, both reliability and safety are vastly improved, and, in most cases, future maintenance requirements and costs will be substantially reduced.

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The Missing Link in Arc Flash Hazard Analysis

By Charles Helmick, Avo Training Institute

Arc flash hazard analysis is looming large in the world of electrical safety; and rightly so. The arc flash hazard is something that must be addressed. The burns associated with arc flash are catastrophic and largely avoidable with correct work practices. This paper presents a brief history of safety measures addressing the arc flash hazard. The performance of the arc flash analysis is like any other safety measure. It is not complete in itself. The arc flash analysis can be performed and the equipment can all have up-to-date and accurate labels but employees still need to know how the information provided fits into the overall protection scheme. Risk assessment must take into account the information from the arc flash hazard analysis but that is not all there is to it.

In the fall of 2001 the 2002 National Electric Code (NEC) introduced a new requirement. Article 110.16 required electrical equipment to be field marked, to warn qualified persons about the arc flash hazard associated with exposed energized conductors. The equipment required to have this field marking (warning label) has been more clearly defined through subsequent editions of the NEC. Basically the only electrical equipment which is excluded from this requirement is in dwelling occupancies. Fine Print Note (FPN) no.1 to that article listed the NFPA 70E-2000 Electrical Safety Requirements for Employee Workplaces as a source of information that would aid in determining severity of potential exposure, planning safe work practices and selecting personal protective equipment. FPN no. 2 listed ANSI Z535.4-1998, Product Safety Signs and Labels as a guide for designing labels (field marking). Normally new requirements in the NEC are only applicable to installations built after the implementation of that edition. This is known as “grandfathering”. In this case, because of the possibility of an imminent hazard in the workplace, the Authority Having Jurisdiction (OSHA) only allows a reasonable amount of time to get into compliance. According to the 2000 Edition of the NFPA 70E Part II Safety-Related Work Practices, Chapter 2 General Requirements for Electrical work Practices 2-1.3.3 the flash hazard analysis needed to be done before a person approached an exposed electrical conductor or circuit part. To perform a flash hazard analysis an electrical engineer must know the:

1. Short circuit current available at each piece of equipment
2. Clearing time of the upstream overcurrent device
3. The working distance for each task to be performed. (The working distance at 600 volts
and below is usually 18 to 24 inches and above 600 volts should be 3 feet.)

NOTE: Subsequent editions of the NFPA 70E have emphasized the need for the electrical system information to be current (5 year review) and the maintenance program for the overcurrent protective devices must be considered.

The information provided by the flash hazard analysis was the available incident energy at the working distance to allow selection of personal protective equipment (PPE) and flame-resistant (FR) clothing and the distance at which the incident energy would be reduced to a level known as onset of second degree burn criteria. This information allowed for the establishment of a boundary known as the flash protection boundary and PPE and FR clothing selection for working inside the flash protection boundary. The NFPA 70E-2000 introduced a new Article 3-3.9.1 to provide aid in selection of PPE and FR clothing. The article required the use of Table 3-3.9.1 Hazard/Risk Category (HRC) Classification and 3-3.9.2 Protective Clothing and Personal Protective Equipment (PPE) Matrix. The HRC Classification table was established by a task group, taking into account their collective experience and system criteria based on:
1. Voltage level of equipment to be worked on
2. Tasks to be performed
3. Specific available fault current limits and clearing times for overcurrent protective devices.
   (Notes to table clarified the fault current and clearing time criteria)

The Table provided information to determine HRC 0-1-2-2*-3 or 4 and direction for selection of voltage rated gloves and voltage rated tools. The article stated that for systems that did not fit within the HRC table criteria for available fault current and clearing time, a flash hazard analysis had to be performed. It should be noted that the HRC was based on two pieces of information the estimation of the hazard and the estimation of the risk. The estimation of the hazard involved many assumptions and the estimation of the risk was based on the years of experience in the task group. The reason for quoting the previous editions of the NEC and NFPA 70E is to make it clear that this requirement has been on the books for a long time. Clear definitions of terms associated with the flash hazard are primarily found in the NFPA 70E. The current edition of the NFPA 70E-2012 refers to the flash hazard analysis as the arc flash hazard analysis, the flash protection boundary is now known as the arc flash boundary, the use of FR clothing has been replaced with the requirement for clothing that is arc rated and the HRC 2* level has been eliminated. Another major change to the current NFPA 70E is that the available fault current and clearing time criteria, required for the use of the HRC tables, has been incorporated into the text of the task tables rather than Notes. (It has become apparent through the years that many were using the HRC tables without knowing the information required in the Notes.) The introduction of these Articles in the NEC and the NFPA 70E has dramatically changed the way electricians face their tasks today. The level of awareness, concerning the arc
flash hazard and PPE to mitigate the hazard, has increased exponentially.

The requirements for these articles have been clarified and expanded further and are in the current editions of NEC-2011 article 110.16 Arc Flash Hazard Warning and the NFPA 70E-2012 Article 130.5 Arc Flash Hazard Analysis. This article in the NFPA 70E requires an arc flash hazard analysis to determine the arc flash boundary, the incident energy at the working distance and the personal protective equipment to be used within the arc flash boundary. The arc flash hazard analysis should be considered the primary means to determine safe work practices for the arc flash hazard but the article does have an Exception that allows the use of 130.7(C)(15) and its associated tables. Tables 130.7(C)(15)(a) & (b) may be used in lieu of an arc flash hazard analysis. The missing link to the arc flash hazard analysis is the risk associated with each task. A typical arc flash label establishes the arc flash boundary and the PPE to be worn in that boundary but there is no specific direction concerning tasks to be performed.

The HRC tables describe tasks such as thermography, voltage testing and racking out circuit breakers. It is clear in the tables that the PPE selections are based on the estimated risk associated with the tasks. When arc flash labels are used, the qualified persons performing the work must still perform a risk assessment to determine the safest way to perform the work. It is imperative that qualified persons be trained in risk assessment skills. For example: An electrical worker that selects an 8 cal/cm² shirt and pants, 12 cal/cm² balaclava sock hood, 12 cal/cm² face shield and Class 0 gloves with leather protectors based on an arc flash hazard warning label which states the available incident energy in a 600 volt class switchgear is 7.5 cal/cm² at the working distance of 18 inches may have adequate protection for voltage testing but if it is known that the switchgear has not had the circuit breakers racked out for many years the worker should not assume the same PPE will provide protection for racking out the circuit breaker.

Finally it must be pointed out that the arc flash warning label or field marking based on an arc flash hazard analysis only provides information for when the equipment doors are open and the energized conductors are exposed. The arc flash warning label does not provide information for when the doors are closed. However because of the HRC task group’s consensus, it has been determined that an electrical worker that is operating a switch with the door closed on metal clad switchgear 1 kV to 38 kV is required by the HRC table to use HRC 2 PPE. In this case the PPE is based on risk assessment associated with the task. In conclusion it must be emphasized that even though the arc flash analysis has been performed and the equipment is labeled correctly, specific risk assessments for the tasks to be performed are still required to work safely. The information provided by the arc flash analysis is much more specific and undoubtedly better than the estimate of the HRC tables but it does not replace the need for a risk assessment based on knowledge of equipment conditions and specific tasks to be performed.

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About AVO Training Institute

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