DC Arc Flash: 2013 Regulatory Updates and Recommended Battery Risk Assessment Guidelines

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Abstract
There continues to be confusion in the stationary battery community about how to protect battery maintenance personal from chemical, electrical and arc-flash hazards. If one were to strictly interpret the current standards published by NFPA and IEEE, the Personnel Protective Equipment (PPE) required would make it impossible – or at best unsafe - to work around batteries. The IEEE Stationary Battery Committee Codes Task Force has spent considerable time working on proposals to NFPA 70E with the intention of providing practical guidance for PPE required for battery maintenance. This task force has also worked with the NFPA 70E dc task group.

NFPA 70E recently has taken a special interest in separating the hazard from the risk, something it has not done previously.

This paper proposes a thought process that can be used to, first, evaluate if and where a hazard may exist in workplaces where dc voltage sources are present, then to determine the degree of risk, and ultimately to determine the PPE that would be appropriate for any given battery activity. A flow chart is presented with guidance for how to use it.

This paper will also update the community on the status of codes and standards relating to dc arc flash.

Introduction
When it comes to safety around stationary batteries, there is no one definitive source that dictates, or recommends, the proper PPE needed. This causes confusion in the industry and as a result many battery technicians are either severely under-protected or overburdened with safety equipment.

The Occupational Safety & Health Administration (OSHA) has jurisdiction over most US organizations to identify and enforce safe work practices. While OSHA does not have comprehensive guidelines for work on or around stationary battery installations, OSHA does require each employer to “furnish to each of his employees employment and a place of employment which are free from *recognized* hazards that are causing or are likely to cause death or serious physical harm to his employees”. The interpretation of this mandate is that employers need to follow industry ‘best practices’. Two of the most well known sources of stationary battery ‘best practice’ guidelines are from IEEE and NFPA.

IEEE has developed a series of recommended practices for battery maintenance. The most well known of these documents is IEEE 450[1], which is the recommended practice for maintaining vented lead-acid batteries. While these recommended practices outline required PPE, the documents do not provide any guidance on when to use what PPE. It could be assumed that all listed PPE should be used for any work on or around a battery. The reality is that the user has the burden to determine the proper PPE for each task. In addition, the IEEE recommended practices heretofore have not included the arc-flash hazard in the recommended safety PPE. Furthermore, the IEEE recommended practices are not codes so they are typically non-enforceable. Most of the PPE recommendations in the IEEE documents focus on electrolyte safety.

IEEE 1584[2] is a guide for performing arc-flash hazard calculations. Unfortunately, neither the existing version of IEEE 1584 nor the proposed revision includes guidance for dc arc-flash analysis.

The National Fire Protection Association (NFPA) creates several codes and standards to help mitigate fire and other hazards. The most well known NFPA document is NFPA 70® [3], the *National Electric Code® (NEC®).* The NEC is adopted by most of the jurisdictions across the United States. NFPA also publishes NFPA 70E®[4], which is the *Standard for Electrical Safety in the Workplace®*. NFPA 70E is not a code and is typically not adopted by jurisdictions, but it is used extensively to identify electrical hazards and required PPE and is referenced by OSHA.

NFPA 70E has provided guidance for arc flash hazards in ac systems for a number of years. In the 2012 version, guidance on arc flash hazards in dc systems was added. This addition has caused concern in the stationary battery industry since arc flash PPE in the stationary battery world has been mostly ignored up to this point.

Arc flash is defined in the latest draft of IEEE 1584 [5] as "a hazardous event usually caused by a metallic tool, test probe, under-rated test instrument or loose equipment part contacting energized bare parts and creating a short circuit or ground fault. It is an explosion with a loud noise, bright light, smoke emitted, and parts thrown. A person standing nearby may be injured or killed. The most common injury is severe burns caused by the intense heat which can ignite clothing."

Stationary Battery Hazards

The predominant stationary battery chemistry is lead-acid. The second most predominant chemistry is nickel cadmium. There are many new technologies such as lithium-ion but at the time of this writing such technologies have relatively low penetrations into the stationary battery market. This paper will focus on lead-acid batteries, although most of the practices would apply to nickel cadmium as well. All of these practices discussed herein can certainly be adapted to any of the other technologies.

The four major stationary battery hazards are chemical, shock, arc flash, and thermal.

Chemical hazards. The hazard that most people think of when considering battery safety is the chemical hazard. For lead-acid batteries, the chemical is the electrolyte that consists of a dilute (~<30%) mixture of sulfuric acid and water. For Ni-Cd batteries, the electrolyte is a hydroxide solution. While either electrolyte can be hazardous, for most battery related activities the risk is minimal. Damage to the human eyes is the most serious concern with electrolyte.

Shock hazards. The shock hazard is a well understood risk. The National Electric Code (NFPA 70) and NFPA70E both identify a shock hazard for any system (ac or dc) over 50 volts nominal. This is typically understood to exclude any 48 dc volt system even if the actual float voltage is above 50 volts (typical 48 volt systems operate between 52 and 54 volts).

The data show that the dc shock threshold is at least twice the voltage of the ac shock threshold. Tables 1, 2 and 3 are from IEC 60479-5[6] and demonstrate this point (reproduced here by permissions from the IEC). Similar data is published in *NFPA 70E Handbook for Electrical Safety in the Workplace-2012*[7][table 340.1]

Table 1 - Current Threshold Values [6]

Type of Threshold	Current Path	a.c. current (mA)	d.c. current (mA)
Current of startle reaction	Hand-to-hand	0.5	2
	Both hands-to-feet	0.5	2
	One hand-to-feet	0.5	2
Strong muscular reaction	Hand-to-hand	5	25
	Both hands-to-feet	10	25
	One hand-to-feet	5	25
Ventricular fibrillation	Hand-to-hand	100	350
	Both hands-to-feet	40	140
	One hand-to-feet	57	200

Table 2 - Ventricular fibrillation for alternating current 50/60 Hz[6]

Ventricular fibrillation Current threshold	mA	AC touch voltage thresholds for long duration V								
		Saltwater-wet			Water-wet			Dry		
		Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact
Hand-to-hand	100	90	160	257	98	165	260	99	99	260
Both-hands-to-feet	40	20	36	94	24	71	149	33	82	149
Hand-to-seat	57	27	49	99	31	65	100	34	65	100

Table 3 - Ventricular fibrillation for direct current[6]

Ventricular fibrillation Current threshold	mA	DC touch voltage thresholds for long duration V								
		Saltwater-wet			Water-wet			Dry		
		Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact	Large contact	Medium contact	Small contact
Hand-to-hand	350	263	351	467	264	353	470	264	264	470
Both-hands-to-feet	140	68	121	220	75	143	223	87	143	223
Hand-to-seat	200	83	126	201	85	127	203	85	127	203

DC Arc Flash Hazard. The arc flash hazard around batteries is potentially the most severe, yet it is the least understood. A 2012 Battcon paper[8] summarized the potential arc flash hazard with respect to batteries and dc systems. The problem with dc arc flash, as was outlined in the 2012 paper, is that there is very little dc arc flash test data available to be able to create accurate models. The models that are available are very conservative and do not take into account the dynamic energy of an electro-chemical device.

NFPA and IEEE have been collaborating "to fund and support research and testing to increase the understanding of the arc flash phenomena"[9]. Although dc testing is a future goal of this collaboration, the dc testing portion has not yet been accomplished.

Thermal hazard. The final hazard discussed herein is the risk of a burn from a thermal event other than an arc flash event. Because batteries have a great deal of energy that can be released quickly, a short across a cell or a portion of the battery can melt metal and cause severe burns. If the voltage is high enough, an arc flash can occur. However, there are many situations in which the short circuit potential has inadequate energy for an arc flash to occur.

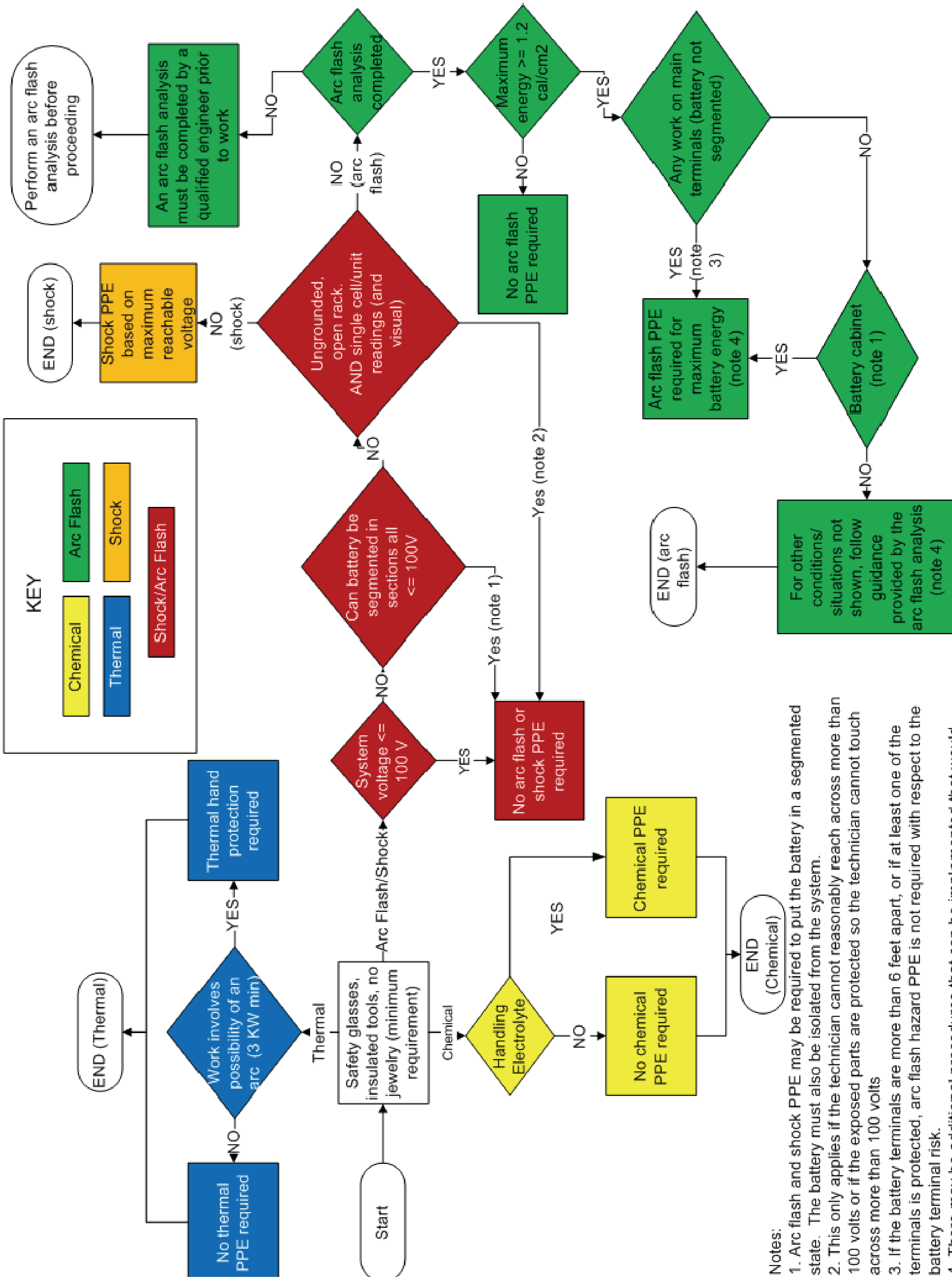
Battery Hazard Risk Assessment

As discussed in the previous section, a stationary battery has many hazards that can cause severe injuries or death. Without considering the relative risk, it would be nearly impossible, or impossible, to be able to perform battery maintenance because the PPE required would be so restrictive as to prevent the technician from doing anything useful. In addition, it may be impossible for someone to purchase shock and arc flash rated gear that would also be rated for the chemical hazard.

Special considerations for selecting PPE for battery systems based on the type of activity

Because stationary batteries come in a variety of forms, sizes and types, and because stationary batteries cannot be de-energized, the PPE required has to be carefully evaluated for each situation. The hazard analysis will depend not only upon the proximity of the worker to the battery system, but also upon the work being performed.

The flow chart in **Figure 1** can be used to help with the PPE analysis. All four hazards need to be considered.



Notes:

1. Arc flash and shock PPE may be required to put the battery in a segmented state. The battery must also be isolated from the system.
2. This only applies if the technician cannot reasonably reach across more than 100 volts or if the exposed parts are protected so the technician cannot touch across more than 100 volts
3. If the battery terminals are more than 6 feet apart, or if at least one of the terminals is protected, arc flash hazard PPE is not required with respect to the battery terminal risk.
4. There may be additional procedures that can be implemented that would further reduce the arc hazard risk and required PPE.

Figure 1 - Risk Analysis Flow Chart – Stationary Batteries

In all cases, safety glasses should be worn. Additionally, insulated tools must be used when in the vicinity of a stationary battery. Test equipment should comply with applicable codes and standards. Conductive articles of jewelry and clothing (such as watchbands, bracelets, rings, key chains, necklaces, metalized aprons, cloth with conductive thread, metal headgear, or metal frame glasses) must not be worn.

It should be noted that batteries are typically part of dc system which can include many other electrical hazards. While all of the hazards need to evaluated, the use of everyday work clothing[4][table H.2] is recommended as a minimum clothing standard while working around stationary batteries.

Chemical Hazard

Referring to the yellow section of the flow chart in **Figure 1**, chemical PPE is only required if electrolyte is being handled. Activities that would be considered handling of electrolyte would include acid adjustment and removal of excess electrolyte. Most normal battery maintenance activities do not involve handling of electrolyte and therefore do not require the use of chemical gloves or aprons.

Utilizing a bulb hydrometer could be considered as handling electrolyte. However, most electronic density meters only require a few drops of electrolyte and would not be considered as handling electrolyte and the use of chemical PPE would be optional.

If electrolyte is handled, the following chemical rated PPE is recommended:

- Protective gloves, aprons and safety shoes
- Goggles and face shields

Thermal Hazard

Referring to the blue section in the flow chart in **Figure 1**, if there are activities that could produce a spark, thermal gloves may be required. These activities may include connecting or disconnecting cables and/or intercell connections when current is flowing. The required use of gloves for chemical, arc flash and/or shock may preclude the need for thermal gloves. Most normal battery maintenance activities, such as routine inspection and measurements, do not involve a risk of a spark and therefore do not require the use of thermal gloves.

Arc flash and electric shock hazards

Referring to the red section of the flow chart in **Figure 1**, there are several conditions that would preclude the need for any arc or shock PPE. If the system voltage is less than or equal to 100 volts, there is an insignificant risk of shock or arc flash and PPE for these hazards is not needed.

The 2012 version of NFPA 70E has a minimum shock threshold of 50 volts for both dc and ac. As shown in Tables 1, 2 and 3, the minimum lethal voltage of dc is at least twice that of ac voltages. In addition, Gordon and Cartelli [10] stated that research over the past century supports a 100 vdc threshold for shock.

The minimum dc voltage for arc flash is not well documented. In the 2012 version of NFPA 70E, no minimum voltage for arc flash is mentioned. While the dc arc flash tables in 70E start at 100 volts dc, this is not considered the minimum arc flash voltage by NFPA. Using the 70E 2012 guidance, the 2012 Battcon paper[8] found that theoretically a 10 volt battery has the potential of an arc flash.

Realistically, there is a minimum dc voltage where it would be improbable to have an arc flash. For example, dc arc welders can have an open circuit voltage of up to 80 volts dc which is known not to be an arc flash risk. In addition, telephone companies have been using 48 volt dc systems for nearly 100 years without a concern for arc flash protection. It is well known that a short of a large 48 battery can vaporize metal and cause significant contact burns, but this is mainly a thermal hazard and not an arc flash hazard. Only testing can determine the minimum voltage where arc flash is a realistic risk. However, a preponderance of the evidence suggests strongly that systems below 100 volts dc have a minimal risk of arc flash.

If the stationary battery is greater than 100 volts but it can be isolated from the system and segmented into sections less than 100 volts, arc flash and shock PPE is optional. However, in order to segment the stationary battery, arc flash and shock PPE may be required.

One typical technique to segment a stationary battery is to have a multi-pole circuit breaker that segments that battery in the middle. Another technique is to install quick disconnect connectors between battery cells or units. This method is often seen between shelves of battery cabinets. If the segments are above 100 volts, shock/arc flash PPE will still be required, but any segmenting of the battery will reduce the potential energy for an arc flash.

If the system voltage is over 100 volts and the battery cannot be segmented, other considerations must be assessed. For example, if the battery is ungrounded and the work to be performed will not subject personnel to the possibility of reaching across more than 100 volts, shock protection is optional. To prevent personnel from reaching across more than 100 volts, protective material can be placed on the main battery terminals and/or on the battery connections.

The majority of high voltage batteries (> 100 volts) are ungrounded and employ ground detector circuits and limit the current between the battery and ground to a non-lethal value. If the battery is ungrounded and the ground detector is designed properly, is operating properly, and is not detecting ground faults, then personnel touching any point on the battery while grounded should be safe from electrocution. None of the conditions should be assumed and it is the responsibility of the work supervisor to ensure that the aforementioned conditions exist as to prevent a shock hazard between the battery and ground. If the battery is solidly grounded or is referenced to ground with enough potential current to cause harm, shock protection must be employed for all personnel who may touch the battery at any point.

Referring to the green section of the flow chart in **Figure 1**, the arc flash hazard must be assessed using either Table 130.7(C)(15)(b) in NFPA 70E 2012 or calculated using the formulas in Annex D of NFPA 70E 2012. If the battery system parameters are not in-line with the ones listed in the table, the calculation must be used. Work or maintenance on a battery should not take place until the arc flash hazard is assessed.

In order to use either of the aforementioned assessment methods, the maximum battery short circuit current must be known. It is recommended that the maximum short circuit for each cell or unit be obtained directly from the battery manufacturer and calculated for the entire system. There is no universally accepted method to determine the system short circuit value using the manufacturer’s rate sheets.

In order to determine the worst case arc flash potential, several factors must be taken into consideration. First and foremost is to calculate the available short circuit current from the battery as discussed above. The short circuit value obtained from the manufacturer may or may not have taken into consideration the resistance of intercell/interunit resistances. To determine the maximum arc flash potential of the entire battery system, all cable and connection resistances must be considered.

Also, the time of the arc is a significant factor in the arc flash calculation. Since most batteries do not have an internal overcurrent protective device (OCPD), the time of the arc is indeterminate. For lack of better guidance, a sustained arc of two seconds is typically used. The working distance is also an important factor. Typically 18" is used to account for the reach of a person.

Location of activity.
Once the maximum arc flash hazard is known, the actual risk for working on all parts of the battery system needs to be evaluated. The maximum arc flash hazard is based on a conservative estimate of a short of the entire battery's energy.

(a) Proximity to main terminals. If the main battery terminals are fully protected from a short and/or no work is being done on the main battery terminals, creating the maximum arc flash is not possible. The actual hazard could be much less or even non-existent further down the battery string from the terminals. For example, an ungrounded open rack battery has very little or no chance of creating an arc flash when working on parts of the string away from the main terminals. A battery with a disconnect device that breaks the string in the middle can reduce or even eliminate the arc flash hazard for most locations on the battery.

(b) Batteries in cabinets. In contrast, a battery within a cabinet in which the main positive and negative buses are in close proximity with each other may actually be at an even greater arc flash hazard than NFPA 70E tables/formulas would indicate. This is due to the concentrated blast that would be directed toward the opening in the cabinet. Because battery cabinets differ greatly from one to the next, the hazard will also vary, so analysis must be done on a case-by-case basis.

(c) Other high arc flash potential locations.
- A battery disconnect cabinet is another location where the maximum arc flash hazard may be present.
- A grounded battery may be another location where an arc flash risk may be present throughout the battery string.

Shock hazard analysis
The shock hazard also needs to be assessed. The shock hazard is fully dependent on the maximum reachable voltage. Although the battery voltage may be as high as 500 volts, if the main terminals are protected (or more than 6 feet apart), there may be no risk of shock if personnel cannot reach across more than 100 volts. If a shock hazard exists, electrical insulating gloves, rated for the maximum working voltage, are required.

Recommendations
There are many hazards associated with stationary batteries. The most effective methodology for ensuring worker safety is to provide proper training and employ safe work practices. Only personnel trained in battery and dc systems should be allowed to perform battery installations or maintenance, and only on the type(s) of battery on which they have been trained. It is recommended that battery personnel training programs follow the guidelines of IEEE 1657[11]. Hand tools utilized on battery installations must be insulated, be rated for the proper voltage, and meet the industry standards such as ASTM F 1505. In addition, it is critical that personnel remove all conductive jewelry and conductive clothing prior to working on or around stationary batteries.

Many hazards can be mitigated or eliminated through good design practices. A stationary battery should be designed so that there are large gaps between points on the battery where the differential voltage is above 100 volts. The negative and positive terminals of the battery should never be designed so that they are in close proximity, especially in high voltage dc systems. Ideally the main battery terminals should be spaced far apart to eliminate any possibility of a short. For stationary batteries above 100 volts, the main battery terminals should be protected with non-conductive material to prevent personnel from contacting the terminals. While these protective covers should be removable for maintenance, they should remain in place at any times when access to energized components is not absolutely required.

System designers should include a method for segmenting the battery to reduce the shock and arc flash hazard during battery maintenance activities, especially in cabinetized battery systems.

The system designers must be responsible for calculating the arc flash hazard and provide clear labeling to allow maintenance personnel to be able to properly asses the arc flash potential risk. Arc flash calculations should only be performed by qualified engineering personnel. While the guidance for calculating dc arc flash is limited and conservative, NFPA 70E and the Battcon 2012[8] paper provide sufficient information to allow the arc flash potential to be determined. The job of calculating arc flash potentials and boundaries should not be left up to maintenance technicians.

Personnel who are responsible for providing battery installation and maintenance services must assess the hazards and the risk of the work they will be performing for every job. It is recommended that the methodology shown in Figure 1 (and described herein) be utilized to assess these hazards. Based on the hazards for a particular job, proper PPE must be utilized and excessive PPE can be avoided.

Personnel safety can only be ensured if the system designers, site owners, service organizations and installation/maintenance personnel each take ownership of their responsibility in hazard prevention, preparation, avoidance and protection.

Regulatory Updates

At the time of this writing, NFPA 70E is in the middle of an update cycle. Proposals were submitted to increase the minimum shock voltage for dc systems to 100 volts and to provide practical guidance for dc arc flash PPE. These proposals were rejected at the initial NFPA 70E technical committee meeting. Based on this outcome, it appears that the guidance for dc arc flash will have few changes from the current version.

The Canadian Standards Association (CSA) has a similar document to NFPA 70E, CSA Z462. There has been an interest from some members of the technical committee of CSA Z462 to incorporate the guidance from Figure 1.

NFPA and IEEE are collaborating on an arc flash research project. This project is funded through donations. Arc flash testing of ac systems has been conducted and continues to be conducted through this project. It is expected that this project will conduct dc testing by the end of this calendar year or early 2014. This testing will help to better characterize the arc flash hazard for dc systems and should result in improved PPE recommendations and guidance.

IEEE 1584[2] currently provides for guidance for performing arc flash calculations only in ac systems. This document is currently being revised. Although the original plan was to incorporate calculations for dc systems into the next revision of IEEE 1584, that is no longer the case. It is expected that the next revision will be balloted after the NFPA/IEEE ac arc flash testing is completed later this year. Once the dc arc flash testing is completed, dc guidance may be incorporated into IEEE 1584 or it may be placed in another IEEE document.

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