

THE EVOLUTION OF DC IN NFPA 70E

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ABSTRACT

NFPA 70E[®] is the *Standard for Electrical Safety in the Workplace*^{®1} and is a companion document to the *National Electrical Code*[®] (*NEC*[®])², both of which are published in the U.S.A. by the National Fire Protection Association[®]. NFPA 70E is widely recognized in North America and around the world as the standard that establishes safe electrical work practices and outlines the necessary personnel protective equipment (PPE) for people working on energized electrical equipment. It has become widely visible in the past few years because of its regulations and guidance pertaining to “Arc Flash” and “Arc Blast”.

Because batteries are stored energy, any work on battery systems must necessarily be considered “energized work” (a.k.a. “live work”). However, NFPA 70E has historically been written predominantly around ac equipment, so people working with dc equipment in general - and batteries in particular - have had little clear guidance on what work practices, clothing, and tools would be acceptable – or unacceptable – to the authority having jurisdiction (AHJ).

The 2012 edition of NFPA 70E is nearing completion of another revision cycle. The next edition will include some steps toward addressing dc electrical safety such as new tables for work around dc systems, and the removal of many of the prescriptive installation requirements that were in past editions. However, the changes are not as broad and are different from what an IEEE Task Group had proposed.¹

This paper will discuss what the final document will probably look like when it is published in 2011, what it will mean for battery technicians, and how the reader can make his or her voice heard.

WHAT IS NFPA 70E?

Background: NFPA 70E has been around since 1976, but only in the past decade has it gained wide-spread recognition (both in the USA and internationally). This recognition has come about mostly because of its regulations on arc flash, arc blast, and electrical shock PPE. For many years the NEC has provided installation requirements for electrical systems. However, in the mid 1970’s it was recognized that there was a need for a standard that could provide a practical safe working area for employees relative to the hazards arising from the use of electricity. To address this need, an NFPA technical committee was formed “to assist the U.S. Occupational Safety and Health Administration (OSHA) in preparing electrical safety standards that would service OSHA’s needs and that could be expeditiously promulgated.”³ The standard covers a variety of activities including the installation, inspection, operation, maintenance, and demolition of electrical equipment and associated conductors and accessories.

While best practice would dictate that no work should be performed on energized (“live”) equipment, it is recognized that “live work” cannot always be avoided. Work on stored electrical energy devices, such as batteries, is one example where de-energizing the dc circuit may be infeasible. However, the standard has always focused most of its attention on alternating current (ac) applications at voltages that could be harmful to human beings.

¹ Actions or views attributed to the IEEE or to the IEEE Stationary Battery Committee throughout this paper are the actions or views of individual IEEE Stationary Battery Committee Codes Working Group members and do not represent official IEEE policy.

Most of the notoriety of NFPA 70E derives from its definitions and requirements for approach boundaries, calculations of incident energy and flash protection boundaries, hazard evaluation procedures, and protective clothing. All of these pertain to live work and most of the procedures are found in 15 annexes. The standard is divided into three chapters. Chapter 1 applies generally for safety-related work practices. Chapter 2 applies to safety-related installation and maintenance requirements for electrical equipment in workplaces. Chapter 3 supplements or modifies Chapter 1 with safety requirements for special equipment. Chapter 3, Article 320, is for “Safety Requirements Related to Batteries and Battery Rooms”.

NFPA 70E defines an “arc flash hazard” as a dangerous condition associated with the possible release of energy caused by an electric arc. The primary concerns are heat and electric shock. While the term “Arc blast” is not defined in NFPA 70E, it is used to describe the substantial audible and physical pressures associated with an arc flash... in other words, an explosion. An “arc flash hazard analysis” is required to determine a worker’s potential exposure to such energy release, and is the basis for determining what PPE is appropriate at the working distance.

Today, the use of Personal Protective Equipment is the primary protective strategy for electrical workers who interface with live equipment. While the awareness is quickly improving on AC systems, unfortunately, some battery system workers currently choose not to wear appropriate PPE. Some workers argue that the required PPE limits their dexterity and/or vision. One of the concerns about PPE for personnel working on battery systems is the use of gloves. Heavy duty leather gloves can make the handling of tools and instruments difficult, possibly increasing the risk of accidental contact or a short circuit. In response to this, the NFPA 70E committee typically responds by requiring the use of insulated tools – thus reducing the risk of creating a short circuit while maintaining protection for the worker.

NFPA 70E is nearing completion of a revision cycle that will result in the 2012 edition. NFPA 70E follows the same process as other NFPA standards, with a cycle that consists of four major steps. The schedule for NFPA 70E-2012 at the time of this writing is:

- Step 1 - The public submits proposals; the Technical Committee (TC) responds to each and publishes a Report on Proposals (ROP) – Status: completed
- Step 2 - The public submits comments in response to the TC’s actions; The TC responds to each and publishes a Report on Comments (ROC) - Status: completed
- Step 3 - NFPA Annual Meeting – a public hearing at which the public can respond in-person to the ROC – Status: hearings June 12-15, 2011
- Step 4 - NFPA 70E-2012 published - Status: scheduled 4th Quarter 2011

BATTERY SYSTEMS IN NFPA 70E

Today: As noted previously, Article 320 contains most of the requirements specific to battery systems. The current edition, NFPA 70E-2009, contains a lot of prescriptive requirements for battery system design and installation. Some of these requirements are inconsistent with the NEC. The following are some examples of installation requirements found in the standard:

- rating of cables, busbars, or busways for short circuit withstand
- insulation of cables and busbars
- cable connection and support methods
- placement of busbars
- dc switching equipment installation
- intercell and battery terminal connector construction
- shrouds and physical barriers over terminals
- ground fault detection
- dc circuit protection
- location of batteries
- separate rooms for batteries rated over 24 volts and 10 ampere-hours (at 1-hour rate)
- arrangement and accessibility of cells

- battery ventilation
- physical installation requirements:
 - access; piping; passageways; emergency exits; clearances; floor loading; floor construction and finishing; battery layout and floor area; battery termination, take-offs and busbars; inter-tier and inter-row connections; barriers; luminaires and fixtures; emergency lighting; power outlets; enclosure construction
- protection
 - overcurrent protection devices – requirements and location; switching and control equipment; ground fault protection; main isolating switch; section isolating equipment;

Recall that NFPA 70E is focused on work practices, not installation requirements. Because of issues raised by IEEE in the previous revision cycle, NFPA created a task group to remove all installation requirements from NFPA 70E-2009. Members of the IEEE Stationary Battery Committee were key contributors on that task group.

Future -- NFPA 70E-2012: As a result of recommendations by the IEEE Stationary Battery Committee to the Task Group, almost all of the above installation requirements will be deleted, with the remainder re-written or moved. For example, ground fault detection circuits will be changed from requirements to informational notes describing various grounding methods, for some of which ground detection would be inappropriate.

Several definitions will be deleted because they are not used in the document. Some new definitions will be added to harmonize more closely with IEEE definitions, including: battery; cell; electrolyte; nominal voltage; pilot cell; vented cell; and VRLA cell.

References to IEEE documents on battery system design and/or installation will be removed.

Because NFPA 70E deals with electrical safety, proposals having to do with battery handling (e.g., compliance with NIOSH lifting standards) were considered to be outside of the standard’s scope and were rejected. There was debate about whether chemical hazards should be considered outside the scope as well, but ultimately the committee decided that potential exposure to battery electrolyte is inherently associated with electrical service activities.

Harmony with the NEC: One might question what happens to all these installation requirements. Where do they go? The answer is that they will become proposals for inclusion in the National Electrical Code. Article 480 of the NEC covers storage batteries. It is a fairly short section today, but it could conceivably grow by quite a bit if and when many of the previous NFPA 70E requirements are accepted for inclusion in the NEC.

NEC-2011 was just published at the end of 2010. NFPA 70E-2012 will be out by the end of 2011. There will be about a two year gap between the time when the battery installation requirements disappear in NFPA 70E and they reappear (in some form) in the NEC. During that two year “hole”, stakeholders will have opportunity to submit proposals and comments. Despite this gap, the November 25, 2011 deadline for submitting proposals to the 2014 NEC is quickly approaching.

DC arc flash protection in NFPA 70E-2012: Although a number of proposals from the IEEE Stationary Battery Committee were accepted in full or in part, several did not make it through the NFPA 70E Technical Committee. Among them were several guidelines for PPE associated with specific battery service activities. These were not accepted primarily because no testing has been performed that could support the recommendation. In anticipation of this, IEEE had proposed to put *recommendations* into an informative annex based upon many decades of industry best practices. An “informative annex” cannot contain mandatory requirements.

The IEEE and NFPA currently have a joint project to quantify and characterize arc flash under various conditions⁴. This collaborative effort involves the collection of data from multiple tests and will undoubtedly increase the understanding of the arc flash phenomena. While the results of this project will provide information that can improve electrical safety standards, they are somewhat limited. Unfortunately the present funding is focused on ac systems and does not include arc flash characteristics of dc power or battery systems. DC study is needed – recall that IEEE could produce no certified test data and thus the NFPA technical committee voted to reject the proposal. IEEE argued that “something is better than nothing” and that the guidelines could be updated once test data becomes available. However, the TC concluded that even guidance in an informative annex that is not substantiated by test data is nothing more than subjective opinion and is therefore unacceptable.

Because the NFPA 70E Task Group Chair would not support a proposal to add or modify tables (because such work would be outside the scope of the Task Group), one of the task group members (APC) independently proposed the table shown in Tables 1A and 1B. The tables are shown here to identify several battery-specific tasks.

Battery System Hazard Risk Category Classifications. Use of insulating gloves, and use of insulating and insulated hand tools.			
Tasks performed on energized equipment	Hazard risk category	Rubber insulating gloves	Insulated & insulating hand tools
Battery systems rated 250 Vdc and below			
Perform infrared thermography and other non-contact inspections outside the restricted approach boundary	0	N	N
CB or fused switch operation with covers on	0	N	N
CB or fused switch operation with covers off	0	Y	Y
Work on individual battery containers or series-connected cells <50 Vdc nominal	0	N	Y
Work on series-connected batteries 50 to 250 Vdc nominal	1	N	Y
Work on energized dc distribution and charging systems	1	Y	Y
Remove/install battery circuit breakers, disconnect switches, fuses, or fused switches	1	Y	Y
Remove terminal covers (to expose bare, energize conductors and circuit parts)	1	Y	
Remove bolted covers (to expose bare, energize conductors and circuit parts)	1	Y	Y
Remove hinged covers (to expose bare, energize conductors and circuit parts)	0	N	N
Work on energized dc utilization equipment fed directly by a dc circuit	1	Y	Y

TABLE 1-A
Rejected Proposal for gloves and insulated tools for dc systems – Below 250 Volts

Tasks performed on energized equipment	Hazard risk category	Rubber insulating gloves	Insulated & insulating hand tools
Battery systems rated 250 to 600 Vdc			
Perform infrared thermography and other non-contact inspections outside the restricted approach boundary	0	N	N
CB or fused switch operation with covers on	0	N	N
CB or fused switch operation with covers off	2	Y	Y
Work on series-connected batteries 250 to 600 Vdc nominal	2	Y	Y
Remove/install battery circuit breakers, disconnect switches, fuses, or fused switches	2	Y	Y
Remove terminal covers (to expose bare, energize conductors and circuit parts)	2	Y	Y
Remove bolted covers (to expose bare, energize conductors and circuit parts)	2	Y	Y
Remove hinged covers (to expose bare, energize conductors and circuit parts)	1	N	N
Work on energized dc utilization equipment fed directly by a dc circuit	2	Y	Y

TABLE 1-B
Rejected Proposal for gloves and insulated tools for dc systems – 250 to 600 Volts

Tasks performed on energized equipment	Hazard risk category	Rubber insulating gloves	Insulated & insulating hand tools
Battery systems rated > 600 Vdc			
Perform infrared thermography and other non-contact inspections outside the restricted approach boundary	1	N	N
CB or fused switch operation with covers on	1	N	N
CB or fused switch operation with covers off	2	Y	Y
Work on series-connected batteries >600 Vdc nominal	3	Y	Y
Work on energized dc distribution and charging systems	3	Y	Y
Remove/install battery circuit breakers, disconnect switches, fuses, or fused switches	3	Y	Y
Remove terminal covers (to expose bare, energize conductors and circuit parts)	2	Y	Y
Remove bolted covers (to expose bare, energize conductors and circuit parts)	3	Y	Y
Remove hinged covers (to expose bare, energize conductors and circuit parts)	2	N	N
Work on energized dc utilization equipment fed directly by a dc circuit	3	Y	Y

TABLE 1-C
Rejected Proposal for gloves and insulated tools for dc systems – Greater than 600 Volts

Despite these setbacks, some information related to dc did actually make it into the Standard. A separate NFPA 70E Task Group, headed by NFPA 70E Technical Committee member Bobby Gray, had been formed to investigate the hazard differences between ac and dc. Although this task group likewise could not produce any certified test data, they did uncover several papers that addressed the subject including some based on computer modeling.^{5,6,7,8,9,10, 11}

The Herbert paper started off with a statement that “48Vdc is not susceptible to arc flash because the voltage is below that necessary to sustain an arc.” This was consistent with what the IEEE task group had been telling the Technical Committee, that dc can create a spark, but not necessarily an arc. Herbert’s conclusion (unsubstantiated with test data) expressed the opinion that systems designed for higher voltage dc (such as 400 Vdc for information and communications technology equipment [ICTE], or 1000’s of volts for utility, industrial, or alternate energy solutions), would not have the safety features typically found in lower voltage centralized battery systems and therefore should be distributed as close to the load as possible.

The Gordon paper proposes that a “one size fits all” philosophy is inappropriate, and that frequency and current must be factors as well. He looks at work being done by Los Alamos National Labs for the U.S. Department of Energy (DOE) and proposes five hazard classes, one of which is for batteries. He would further break down the hazard class into four “power” sub-classes: <100W; 100-1000W; 1kW – 30 kW; and >30 kW.

As a result of the dc Task Group proposals, NFPA 70E will now likely contain the following TABLES 2 and 3 which can also be found in the Report on Comments.¹² The tables are based upon voltage - the power categories suggested by Gordon did not make it into NFPA 70E. TABLE 2 identifies the approach boundaries for electrical equipment energized at various dc voltages. Formatted similar to the AC tables, the electrical hazard is a function of both the distance of a person from the equipment and the voltage of the exposed equipment. TABLE 3 identifies the hazard risk category for various voltage levels and the corresponding PPE requirements for rubber gloves and insulated tools. It also defines arc flash boundary and the criteria for arc duration and working distance.

While electric shock is widely understood, arc flash and arc blast are less known categories of electrical hazards. An arc flash can occur when two energized parts (or an energized part and ground) come in contact with each other or come close enough for electricity to bridge the insulation gap between the two parts. This can be caused by situations such as a dropped tool across a pair of exposed current-carrying parts/conductors/terminals, improperly installed equipment, damaged equipment, deteriorated equipment, or improperly rated equipment. Arc flash events can generate temperatures in excess of 35,000° F which can ignite clothing and burn skin.

The heat associated with an arc flash event produces explosive expansion of the air and can even vaporize metals. The resulting blast can generate hazardous noise levels in excess of 160 dB. In addition, the high pressures can be on the order of thousands of pounds per square foot.

Hazard boundaries NFPA 70E establishes invisible boundaries around any piece of energized equipment. The distance from the equipment and the personnel protective equipment (PPE) that must be worn in order to step inside each boundary is determined by the level of potential harm that could occur from electric shock or injury in the event of an arc flash. It is important to note that one does not need to contact the energized equipment to be in harm's way; one need only be in the vicinity.

- *Prohibited Approach* (inner boundary) is the distance from an exposed part that is considered the same as making contact with the live part.
- *Restricted Approach Boundary* is the distance from an exposed live part at which there is an increased risk of shock.
- *Limited Approach Boundary* is the distance from an exposed live part where a shock hazard exists.
- *Flash Protection Boundary* is the distance at which a person would be exposed to a curable second degree burns in the event of an arc flash

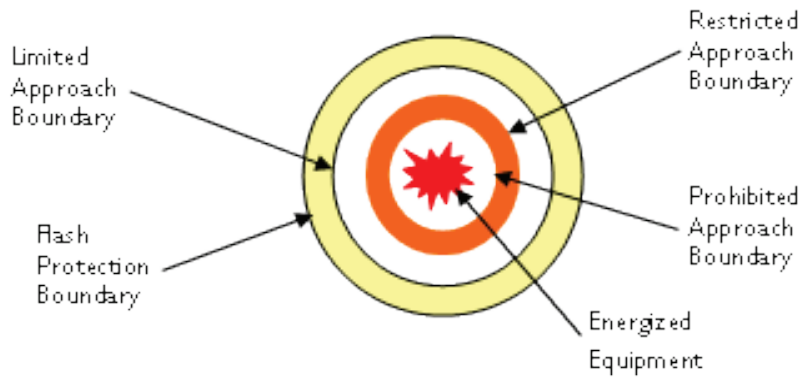


FIGURE 1 - Arc flash approach boundaries

The proposed approach boundaries for protection against electric shock from dc equipment are based solely on voltage and are shown in TABLE 2. The lower threshold for dc voltage is 100 Vdc. This is identified as Table 130.4(C)(2) in the standard.

Approach boundaries to energized electrical conductors or circuit parts for shock protection, DC voltage systems
Limited Approach Boundary

Nominal Potential Difference	Exposed Movable Conductor²	Exposed Fixed Circuit Part	Restricted Approach Boundary, Includes Inadvertent Movement Adder	Prohibited Approach Boundary
Less than 100 V	Not specified	Not specified	Not specified	Not specified
100 V to 300 V	3.05 m (10 ft 0 in)	1.07 m (3 ft 6 in)	Avoid contact	Avoid contact
301 V to 1 kV	3.05 m (10 ft 0 in)	1.07 m (3 ft 6 in)	304.8 mm (1 ft 0 in)	25.4 mm (0 ft 1 in)
1.1kV to 5 kV	3.05 m (10 ft 0 in)	1.53 m (5 ft 0 in)	431.8 mm (1 ft 5 in)	101.6 mm (0 ft 4 in)
5kV to 15 kV	3.05 m (10 ft 0 in)	1.53 m (5 ft 0 in)	660.4 mm (2 ft 2 in)	177.8 mm (0 ft 7 in)
15.1 kV to 45 kV	3.05 m (10 ft 0 in)	2.44 m (8 ft 0in)	38.2 mm (2 ft 9 in)	431.8 mm (1 ft 5 in)
45.1 kV to 75 kV	3.05 m (10 ft 0 in)	2.44 m (8 ft 0in)	914 mm (3 ft 2 in)	609.6 mm (2 ft 1 in)
75.1 kV to 150 kV	3.425 m (10 ft 8 in)	3.05 m (10 ft 0 in)	1.22 m (4 ft 0 in)	914 mm (3 ft 2 in)
150.1 kV to 250 kV	3.56 m (11 ft 8 in)	3.56 m (11 ft 8 in)	1.52 m (5 ft 3 in)	1.53 m (5 ft 0 in)
250.1 kV to 500 kV	6.10 m (20 ft 0 in)	6.10 m (20 ft 0 in)	3.35 m (11 ft 6 in)	3.05 m (10 ft 10 in)
500.1 kV to 800 kV	7.92 m (26 ft 0 in)	7.92 m (26 ft 0 in)	4.88 m (16 ft 5 in)	4.88 m (16 ft 5 in)

TABLE 2
Proposed approach boundaries for shock protection from energized electrical conductors or circuit parts on dc systems

NFPA 70E requires a hazard analysis before any work can be performed on energized electrical equipment. Table 3 defines the hazard categories for dc-voltages and shows the proposed rules for gloves and insulated tools. This table was approved by the Technical Committee and is identified as Table 130.8(C)(15)(2) in the proposed standard.

Tasks Performed on Energized Equipment	Hazard/Risk Category	Rubber Insulating Gloves ^(b)	Insulated and Insulating Hand Tools
Storage Batteries, Direct-Current Switchboards and other DC supply sources >100V <250V Parameters: Voltage: 250V Maximum Arc Duration and Working Distance: 2 sec @ 18"			
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥ 1 kA and <4 kA Potential arc Flash Boundary using above parameters at 4kA: 36 inches	1 ^a	Y	Y
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥ 4 kA and <7 kA Potential arc Flash Boundary using above parameters at 7kA: 48 inches	2 ^a	Y	Y
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥ 7 kA and <15 kA Potential arc Flash Boundary using above parameters at 15kA: 72 inches	3 ^a	Y	Y
Storage Batteries, Direct-Current Switchboards and other DC supply sources $\geq 250V$ <600V Parameters: Voltage: 600V Maximum Arc Duration and Working Distance: 2 sec @ 18"			
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥ 1 kA and <1.5 kA Potential arc Flash Boundary using above parameters at 1.5kA: 36 inches	1 ^a	Y	Y
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥ 1.5 kA and <3 kA Potential arc Flash Boundary using above parameters at 3kA: 48 inches	2 ^a	Y	Y
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥ 3 kA and <7 kA Potential arc Flash Boundary using above parameters at 7kA: 72 inches	3 ^a	Y	Y
Work on energized electrical conductors and circuit parts, including voltage testing where arcing current is ≥ 7 kA and <10 kA Potential arc Flash Boundary using above parameters at 10kA: 96 inches	4 ^a	Y	Y

General Notes (applicable to the entire table):

(a) If acid exposure is possible, the clothing shall be protective from acid and arc rated to the hazard according to ASTM F1891 or equivalent and evaluated by ASTM F1296 for acid protection.

(b) In clean rooms or other electrical installations, which cannot allow leather protectors for arc flash exposure, ASTM F496 shall be followed for using rubber insulating gloves without leather protectors and the rubber gloves chosen shall be arc rated to the potential exposure level of the HRC category.

TABLE 3
Proposed Hazard/Risk Category Classifications and Use of
Rubber Insulating Gloves and Insulated and Insulating Hand Tools—dc Equipment

WHY THIS IS IMPORTANT

It has been argued that an arc flash study can be expensive, increasing in cost depending upon factors such as size of the facility for data collection, revision of one-line drawings, short-circuit and protective device coordination studies, warning label installation, and arc flash training. For all of their good intentions, companies may be slower to spend money on inspections until the need for them is obvious. Others might argue that the need is indeed obvious.

During a seven-year study conducted by the U.S. Dept. of Labor's Bureau of Labor Statistics, 2,576 U.S. workers died and another 32,807 sustained lost-time injuries, missing an average of 13 days away from work due to electrical shock or burn injuries. These statistics were validated in a second study involving more than 120,000 employees that determined arc flash injuries accounted for 77% of all recorded electrical injuries. The average cost of medical treatment for survivors of arc flash incidents is \$ 1,500,000.

Although not listed by Radibratovic, some companies may be reluctant to conduct a study on dc circuits when the nature of dc arc flash is not well known. While it is clear that more study is needed to better understand the nature of dc arc flash, the level of electrical safety can, and should be improved step by step.

SUMMARY

NFPA 70E is a large document that is undergoing hundreds of changes, some of which will affect how work is performed on dc systems. Work should never be performed on energized equipment if such work can be reasonably avoided, but such work may be unavoidable on stored electrical devices such as batteries. The hazards associated with working on energized circuits include electric shock and arc flash/arc blast.

Much has yet to be learned about the nature of arc flash. Studies are under way to characterize ac arc flash, but little has been done to fully understand the causes, nature and hazards associated with dc arc flash. NPFA 70E has started to introduce guidelines for workplace safety around dc systems, but it will be several more years before knowledge and guidelines match the body of knowledge around ac. To the extent that NFPA 70E addresses battery safety, it is mostly focused on voltage. Little consideration has been given to calculating the fault potential and its contribution to arc flash by the stored energy in batteries.

There is little or no government funding of arc flash research, so private funding must come from within the industry. An estimated four million dollars would be required from manufacturers, users, integrators, installers and maintainers and other stakeholders in order to fund the necessary research. Until somebody steps forward with research money, NFPA 70E will continue to apply rules to batteries and dc systems that are largely derived from ac systems.

This paper has shared only a few of the proposals addressing dc in the upcoming revision of NFPA 70E. At the time of this writing the tables presented here are only proposed - they are not approved. The proposed changes are still working through the standards adoption process. Public hearings on the document will be held in June 2011. The 2012 edition of the standard will be published in late 2011. People wishing to comment on the standard at the public hearing must have already submitted a notice of intent by May 6, 2011. The next cycle for NPFA 70E will begin in 2012 with proposals due around November 2012. The next code cycle for the NEC starts in 2011 with proposals due no later than November 25. Anybody can submit comments, you do not have to be a member of NFPA. Forms and schedules can be downloaded from the NFPA web site at: www.nfpa.org/standards.

NOTES

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- ¹ NFPA 70E, *Electrical Safety in the Workplace*, National Fire Protection Association, 2009
- ² NFPA 70: *National Electrical Code (NEC)*, National Fire Protection Association, 2011
- ³ NFPA 70E, *Electrical Safety in the Workplace*, “Forward”, National Fire Protection Association, 2009
- ⁴ <http://standards.ieee.org/esrc/arcflash/index.html> The tests are expected to provide the data needed to develop equations and more. Researchers are measuring the thermal energy transfer of an arc flash, plus such effects as air pressure, sound waves, the toxicity of gases released from the conductors’ metals and insulating materials, and energy radiated at infrared, visible, ultraviolet, X-ray, and other wavelengths. Other tests will examine how enclosures affect the energy released in an arc flash. Information to be uncovered will enable manufacturers to better design equipment that can mitigate the effects of an arc flash.
- ⁵ Ammerman, Ravel; Gammon, Tammy; Sen, P.K., and Nelson, John, “DC Arc Models and Incident Energy Calculations[®]” Institute of Electrical and Electronics Engineers (IEEE), Paper No. PCIC-2009-7
- ⁶ Herbert, Edward, “Arc Flash Protection for a 400 Vdc Power Distribution System With a Large Central Battery,” 2010
- ⁷ Keyes, Carl; and Maurice, Claude, “DC Arc Hazard Assessment, Phase II,” Kinectrics Inc. Report No. K-012623-002-RA-R00, 2007
- ⁸ Doan, Daniel, “Arc Flash Calculations for Exposures to DC Systems,” Institute of Electrical and Electronics Engineers (IEEE), Paper No. ESW2007-19
- ⁹ Gordon, Lloyd; and Cartelli, Laura, “A Complete Electrical Hazard Classification System and Its Application,” Institute of Electrical and Electronics Engineers (IEEE)
- ¹⁰ Doan, Hoagland and Neal, *IEEE IAS Electrical Safety Workshop Conference Proceedings*,; “Update of Field Analysis of Arc Flash Incidents, PPE Protective Performance and Related Worker Injuries,” 2010
- ¹¹ Radibratovic, Brian, “Conducting an Arc Flash Study, *CSE Magazine*, Dec 28, 2010
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- ¹² “2011 Annual Revision Cycle, Report on Comments (ROC),” NFPA 70E, National Fire Protection Association