Arc Flash Hazard - The Basics

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OSHA is now enforcing NFPA 70E and the requirements within this document. The requirements for Arc Flash Hazard Assesments/Studies and Arc Flash labels have changed with the new release of NFPA 70 in September of 2015. These new changes affect arc flash, calculations, labels, and personal protective equipment. There is a lot of confusion on this topic. The engineers at Powerstudies, Inc. will provide a basic and easy explanation of the concepts by answering the most frequent asked questions around the industry.

QUESTION #1 – WHAT IS ARC FLASH?

Arc flash is a phenomenon that occurs when live, exposed conductors are shorted and the air begins to ionize. During the ionization of the air, the large amount of arc fault currents produce tremendous heat that can severely burn human skin and even set clothes on fire. In addition to unbearable heat, arcing fault can produce strong shock waves capable of blowing personnel off their feet, and bright light (arc plasma) that can result in temporary or permanent blindness.

In summary, arc flash is a very dangerous phenomenon caused by arcing fault that can potentially be fatal to working personnel. Personnel injury is the biggest concern and is why it is important to protect the workers from these hazards. NFPA 70E was developed in an attempt to educate workers and reduce the number of injuries and deaths.

Figure 1 - Arc Flash Accident

QUESTION #2 – WHAT CAUSES ARC FLASH HAZARDS?

In short, electrical short circuits and their effects cause the arc flash hazards. Electrical faults on electrical systems can be in the form of phase-to-ground, double phase-to-ground, and three-phase. In some cases, the amount of energy in an arc flash can be enormous and create plasma, hot vapors, and gases that can rise up to 23,000 °F. The heat produced can ignite clothing more than 10 feet away and the amount of burning is based upon the amount of "Incident" (arc flash) energy (Question #4) created by the fault.

One of the many events that can occur during the arc flash is the intense thermal radiation and damaging noise levels. When the air begins to expand, explosive pressure waves can blow personnel across rooms and against walls.

At this time (2015), only arc flash hazards from three-phase faults (arcing faults) have been studied and researched. There is little test information on arc flash hazards produced by phase-to-phase and phase-to-ground faults. IEEE 1584 Working Group (Guide for Performing Arc-Flash Hazard Calculations) have been conducting experiments with line to ground faults for the last couple of years. The results of these tests will be incorporated in the revised IEEE 1584 Standard.

QUESTION #3 – WHY SHOULD I BE CONCERNED ABOUT ARC FLASH?

As stated in the answers from questions #1 & #2, a tremendous amount of heat is generated when these arcing faults occur and can potentially be fatal to working and near-by personnel. When it comes to human lives, we can never be too careful. Another reason to be concern about Arc Flash Hazard is liability and government regulations. OSHA and some State regulations apply to every worker that may approach or be exposed to energized electrical equipment. Failure for an employer to conform or follow State, OSHA and NEC requirements can lead to injuries, fines, penalties, and expensive law suits.

Arc Flash Hazard Studies are performed to determine the risk to personnel, warn them of the potential hazards, and instruct them as to what kind of personal protective equipment (PPE) they must wear.

Several regulations that address arc flash hazards include:

- National Fire Protection Association (NFPA) Standard 70. Better known as "The National Electric Code." The NEC® 2005 addresses the arc flash hazard in Article

110.16. This section of the code has a fine print note referencing NFPA 70E.

- NFPA 70E "Standard for Electrical Safety in the Workplace."
- NFPA 70B "Recommended Practice for Electrical Equipment Maintenance."
- OSHA Standards 29-CFR, Part 1910 sub part S (electrical) Standard number 1910.333

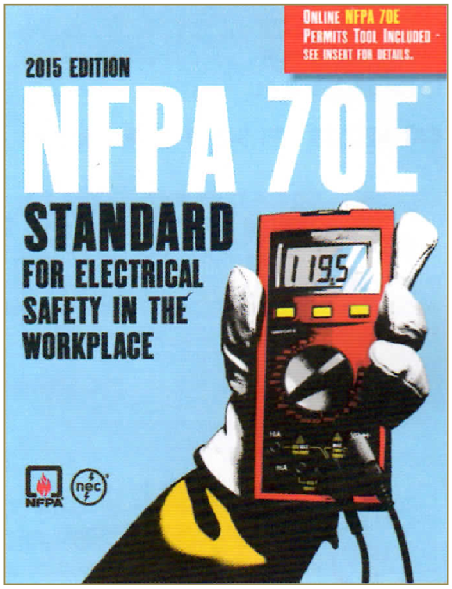

Figure 2 – NFPA 70E Standard

QUESTION #4 – WHAT IS INCIDENT ENERGY?

Incident energy, also known as arc flash energy, is the energy per unit area received on a surface located at a working distance away from the flash location. The working distance is the distance from where the worker to the flash location. This is basically an arm length away or approximately 18 inches for low voltage panelboards, smaller equipment, and 36 inches for Switchgear. The distance increases as voltage increases.

The unit of incident energy is cal/cm^2. The threshold value of incident energy for 2nd degree burn of the human skin is about 1.2 cal/cm^2. One cal/cm^2 is equivalent to the amount of energy produced by a cigarette lighter on the palm of the hand for one second. It is the incident energy that causes burns to the human skin. Table 1 illustrates the potential damage of incident energy.

Incident Energy (cal/cm^2)	*Degree burn*
1.2	2nd degree burn to bare skin
4	Ignite a cotton shirt
8	3rd degree burn to bare skin

Table 1: Incident Energy & Damage Level

Incident energy is both radiant and convective. It is inversely proportional to the working distance squared. It is directly proportional to the time duration of the arc and to the available bolted fault current. It should be noted that time has a greater effect on the incident energy than the available bolted fault current.

Both the NFPA-70E and IEEE Standard 1584 uses the assumption that an arc flash generating 1.2 calorie/cm^2 (1.2 calorie/cm^2 = 5.02 Joules/cm^2 = 5.02 Watt-sec/cm^2) for 0.1 second will result in a second-degree burn. It is also assumed that a second-degree burn will be curable and will not result in death. Figure 1 illustrates these points.

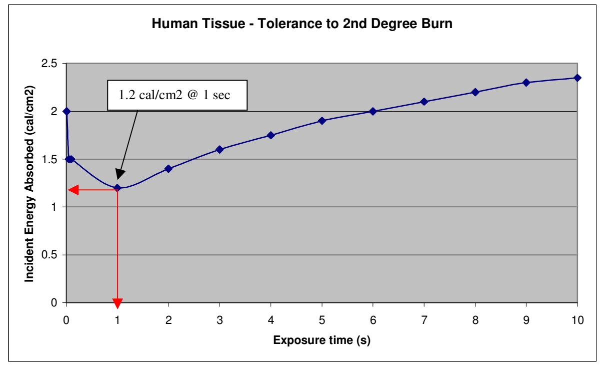

Figure 3 - Human Tissue – Tolerance to 2nd Degree Burn

QUESTION #5 – WHAT ARE THE LIMITED, AND RESTRICTED BOUNDARIES

NFPA 70E has developed several protection boundaries based upon the employee's training and personal protective equipment. The shock boundaries Limited and Restricted Boundaries are based on the voltage of the energized equipment. These distances increase as the voltage increases. These boundaries are summarized as followed:

A. Limited Approach Boundary

The limited approach boundary is the minimum distance from the energized item where the untrained personnel may safely stand. No unqualified (un-trained) personnel may approach any closer to the energized equipment than the boundary given unless they are escorted by a qualified person. The boundary is determined by NFPA 70E Table 130.4(D)(a) for AC systems and Table 130.4(D)(b) for DC systems. The distance is based upon the nominal phase to phase voltage of the equipment. These distances increase as the voltage increases.

B. Restricted Approach Boundary

The restricted approach boundary is the distance where qualified personnel may not cross without wearing the appropriate personal protective equipment (PPE). In addition, they must have a written approved plan for the work that they will perform. The boundary is determined by NFPA 70E Table 130.4(D)(a) for AC systems and Table 130.4(D)(b) for DC systems. The distance is based upon the nominal phase to phase voltage of the equipment. These distances increase as the voltage increases.

Question #6 – **What is the Arc Flash Protection Boundary?**

The Arc Flash Protection Boundary is based upon the amount of energy available at a given working distance. It is dependent not only on voltage, but also on the available fault current and the time it takes for the upstream protective device to operate and clear the fault. These boundaries are summarized as followed:

Flash Protection Boundary

The flash protection boundary is the closest approach allowed by qualified or unqualified persons without the use of personal protection equipment (PPE). This boundary is calculated based upon several factors such as voltage, available fault current, and the time for the protective device to operate and clear the fault. It is defined as the distance at which the worker is exposed to 1.2 calorie/cm^2 for 0.1 second.

For low voltage, both IEEE Standard 1584 and NFPA 70E 2009 Edition details the procedure and equations used to calculate the incident energy and flash boundary. Please note that these equations make several assumptions that may not be valid for your facility. For voltages above 600 V, please refer to the IEEE Standard 1584 (Guide for Performing Arc-Flash Hazard Calculations) for the proper calculations, procedures, and equations.

The main thing to remember about the calculation of the Incident Energy level and Flash Boundary is that the time it takes for the protective device to operate plays a bigger role than the amount of available fault current. Longer protective device delay time equate to higher incident energy level. Lower fault currents cause longer protective device delay times. Due to the inverse characteristics of protective devices (e.g. fuses, relays, and circuit breakers), lower fault currents can increase the trip (opening) times and thus can increase the arc flash energy.

Unlike the shock boundaries, the arc flash boundary is not voltage dependent. It is based upon the amount of incidental energy. At some locations, the arc flash boundary is less than the limited approach (shock) boundary. At other locations, the arc flash energy can be much greater than the approach boundary.

Question #7 – **What Is PPE?**

Personnel can be protected from some of the shock and arc flash hazards by wearing personal protective equipment (PPE) such as clothing, gloves, face protection, and glasses. The main goal of arc flash protection is to prevent burns to the body, head, and chest area that could cause deaths. Although burns on the person's limbs are serious, they usually are not likely to cause death.

Different types of clothing have different ratings. Table 2 through 4 illustrates the different clothing and their ratings, which are all from NFPA 70E.

Table 2 shows the glove classifications required when working at different voltages.

Glove Class	**Voltage Rating**
00	2.5 kV
0	5.0 kV
1	10 kV
2	20 kV
3	30 kV
4	40 kV

Table 2: Glove Class Requirement for Various Voltages

Table 3 lists the thermal capabilities for some clothing articles typically worn by personnel.

Apparel	**PPE Rating (cal/cm^2)**
Single layer AR cotton 7.5 oz. Weave	6.0
Single layer AR cotton 9.3 oz. weave	7.9
PBI fiber blend 4.5 oz. Weave	6.1
Single layer Aramid 4.5 oz. Weave	4.6
Single layer Aramid 6.0 oz. Weave	6.4
Nomex III 4.5 oz. Weave	9.1
Nomex III 6.0 oz. Weave	13.7
Nomex (2 layers) 12 oz. Weave	22.6
6.0 oz. Aramid over 10 AR Cotton	31.0
12 oz Cotton (4 oz.) under AR cotton (8 oz.)	12.5
Switching suit of AR coverall 24-30 oz. weave	40.0$^+$
Clear U/V Face Shield	1.2
Gold Reflective U/V Face Shield	7.33
Electrical Arc Hood	45-75

Table 3: PPE Rating for Various Apparel

Question #8 – **What is an Arc Flash Hazard Study?**

An Arc Flash Hazard Study (Incident Energy Analysis) is an analysis and assessment of the arc flash and shock hazards at a facility. The purpose of the study is to calculate the Incident Energy and identify the appropriate level of Personal Protective Equipment (PPE) for the personnel at various locations throughout the facility. These locations include switchgear, switchboards, substation, panel-boards, motor control centers, and industrial control panels. NFPA 70E also includes electrical equipment… "likely to require examination, adjustment, servicing or maintenance while energized shall be field marked with a label…"

The arc flash study is a combination of a short circuit study and protective device coordination study. Both these studies must be completed before an Arc Flash Hazard Study can be done. The bolted three-phase current (short circuit study) is needed at each location as well as the upstream device operating time (protective device coordination study) for the reduced arcing fault current.

The arc flash study will determine energy levels and boundary distances, and assist the owner in complying with the NFPA guidelines that are enforced by OSHA inspectors. Part of the study includes the creation of Arc Flash Hazard warning labels (See Question #10).

QUESTION #9 – WHAT IS THE DIFFERENCE BETWEEN NFPA 70E AND IEEE 1584 ARC FLASH STUDY METHODS?

There are two methods to perform the arc flash studies. These methods are the NFPA 70E Task Table 130.7(C)(15)(A)(b) and IEEE 1584 (Guide for Performing Arc-Flash Hazard Calculations).

Although the NFPA 70E method appears simple and easy to use, it has a very limited range of use with limits on device times and short circuit currents. To properly use and apply the tables, the user must know the available short circuit current (obtained from a short circuit study) and upstream protective device operating time (obtained from manufacture's time current curves). These values must then be compared to the tables' parameters. If the short circuit currents and device operating times are exceeded, then the IEEE 1584 method must be used.

Extreme caution must be exercised by the user to prevent the table from being misapplied. The user must be trained on how to perform a short circuit study and then how to read the manufacture's time current curve to obtain the device operating time.

The NFPA 70E task table method enables the user to determine the arc flash boundary, Arc Flash PPE Category and additional PPE. In 2015, the standard was revised changed the Hazard Risk Category (HRC) to Arc Flash PPE Category. This revision also eliminated category 0. Once the Category is known, then the appropriate Arc Rated PPE can be determined from Table 130.7(C)(16).

IEEE 1584 (Guide for Performing Arc-Flash Hazard Calculations) is a publication created by the IEEE 1584 Working Group. This guide provides a step by step method to determine the arc flash boundary and incidental energy. It requires completing a short circuit study and using the protective device settings to determine the device operating times. The equations have a wider range of use and provide more accurate values of energy and boundary distances.

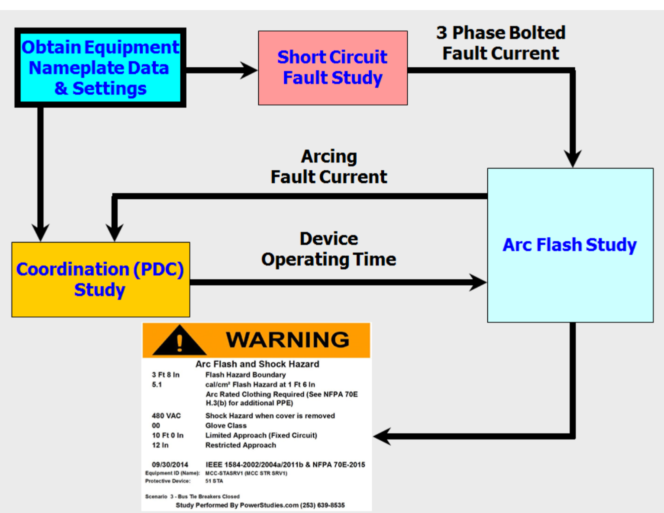

Figure 4 – IEEE 1584 Procedure

After using this method and the arc flash energy calculated, then the PPE can be determined by using NFPA 70E Table H.3(b), Note that the NFPA 70E – 2015 now prohibits the use of HRC when using this method. Below is a summary of the two methods.

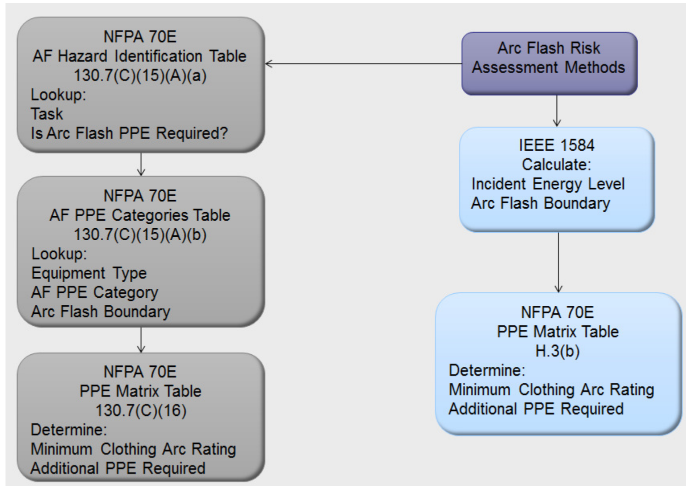

Figure 5 – Summary of NFPA 70E Task Table & IEEE 1584 Methods

QUESTION #10 – WHAT IS AN ARC FLASH WARNING LABEL?

Section 110.16 of the NEC 2011 code requires electrical equipment, such as switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers, that are in other than dwelling occupancies, and are likely to require examination, adjustment, servicing, or maintenance while energized, shall be field marked to warn qualified personnel of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified personnel before examination, adjustment, servicing, or maintenance of the equipment.

There are two fine print notes shown below that are very important.

FPN No. 1: NFPA 70E, Standard for Electrical Safety in the Workplace, provides assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment.

FPN No. 2: ANSI Z535.4, Product Safety Signs and Labels, provides guidelines for the design of safety signs and labels for application to products. An example of an arc hazard label is shown below on figure 3.

The section 110.16 of the NEC clearly indicates that electrical equipment must be field marked and that NFPA 70E is to be used to determine the severity of the arc flash hazard and how to select personal protective equipment. NFPA 70E states what should be on the arc flash label. It is our opinion that Generic Arc Flash Labels do not meet the NEC and NFPA 70E requirements.

The purpose of the arc flash label is to (1) warn the personnel of the potential hazards, (2) show what action they should take to reduce the hazard. There are many different types of labels that are being created. Per NFPA 70E, the labels must have

1) At least one of the following:
   a) Available incident energy and the corresponding working distance
   b) Minimum arc rating of clothing
   c) Required level of PPE
   d) Highest Hazard/Risk Category (HRC) for the equipment
2) Nominal system voltage
3) Arc flash boundary

PowerStudies, Inc. produces labels with more than the required information. We also include the operating scenario for the displayed energy level. This is important for facilities where the short current can vary due to the closure of bus tie breakers or on site emergency generators.

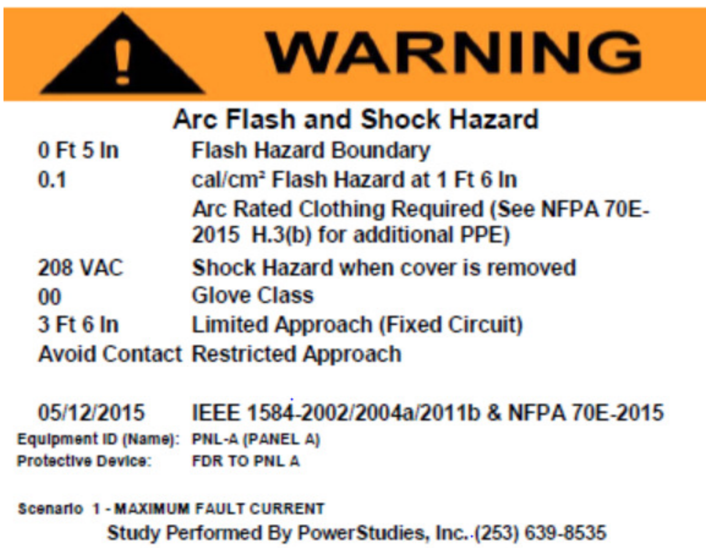

Figure 3: Arc Flash Hazard Label

QUESTION #11 – WHAT IS NEXT? DO I REALLY NEED AN ARC FLASH HAZARD STUDY?

The short answer is "YES, you need to do an Arc Flash Hazard Study for your facility!"

The Occupational Safety and Health Administration (OSHA) or State OSHA inspectors are currently enforcing National Fire Protection Association (NFPA) document NFPA-70E. This document states that a "arc flash hazard analysis shall be done before a person approaches any exposed electrical conductor…" Even though you may think you will not be getting a visit from your friendly OSHA inspector anytime soon, you certainly would want to be in compliance if you do.

On the other hand, your chances of seeing an electrical inspector may be pretty high. The National Electric Code (NEC) states in Article 110.16 that Arc Flash labels must be applied to your electrical equipment. The current NEC only requires "generic" warning labels stating: "Warning! Arc Flash and Shock Hazard Exists". However, the fine print notes of NEC Article 110.16 references NFPA 70E and ANSI Z535.4-1998 (Product Safety Signs and Labels). Some Washington State Cities now require arc flash labels on new equipment that is installed. And as we just discussed, NFPA 70E describes the flash hazard analysis and how to perform the calculations.

So…where does this leave us? Clearly, the intent of the Standards is to increase the safety of your employees and protect them from the hazards of arc flash. Currently, NFPA 70E requires arc flash calculations, and NEC Article 110.16 references arc flash calculations. But the trend is increasingly toward the requirement for facilities to have arc flash calculations done.

Although the current NEC code only requires "generic" warning labels, future code revisions will require labels reflecting detailed calculations. These future labels will require that the incident energy level, protective boundaries, and level of personal protective equipment be displayed. Due to the complexity of these studies, it is highly recommended that trained, experienced personnel specializing in performing power system studies perform these studies.

You need an Arc Flash Hazard Study to:

1) Reduce Shock Hazards
2) Reduce Arc Flash injuries
3) Increase Personnel Safety
4) Comply with NEC, NFPA, Federal and State OSHA requirements.

QUESTION #12 – WHO IS RESPONSIBLE FOR DOCUMENTATION, AND INSTALLATION, AND MAINTENANCE OF THE ARC FLASH LABELS?

Per NFPA 70E section 130.5(D) the owner of the electrical equipment is responsible, not the electrical contractor or commissioning agent.

QUESTION #13 – WHAT DOES AN ARC FLASH HAZARD STUDY INCLUDE?

An Arc Flash Study will include at a minimum, a report and arc flash labels. If your facility is older than ten years, you may want to consider having the engineering firm perform a device short circuit evaluation study (in conjunction with the short circuit study) and a protective device coordination study. These two studies will identify underrated (for short circuit) equipment and determine settings to increase equipment protection and selective coordination. These three studies serve as a safety and code compliance inspection of your electrical equipment. More information about the report options is described in the document, Arc Flash Study Descriptions and Options.

A typical Arc Flash Study will include the following:

4) Short Circuit Current Values

5) Protective Device Settings (Protective Device Coordination Study)
6) Arc Flash Incident Energy Levels
7) Boundary Distances for
   a) Arc Flash Protection
   b) Limited Approach
   c) Restricted Approach
8) Personal Protective Equipment (PPE)
9) Arc Flash and Shock Hazard Warning Labels.
10) Complete report including
    a) Introduction
    b) Executive Summary
    c) Impedance One Line Drawing
    d) Short Circuit Study
    e) Short Circuit Equipment Summary Sheets
    f) Protective Device Coordination Study
    g) Protective Device Setting Sheets
    h) Time Current Curves
    i) Arc Flash and Shock Hazard Study
    j) Arc Flash Calculations

PowerStudies, Inc. can perform this study for your facility. Feel free to call us, fax us, or e-mail us. We would be happy to talk to you about your facility and ways to comply with the OSHA and NEC requirements.

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In 1986, Mr. Fuhr established PowerStudies, Inc., a consulting firm that specializes in power systems studies, power quality services, and commissioning services. He also teaches classes in protective relaying, electrical systems, safety, power factor correction, harmonics and filter design. Mr. Fuhr is a Professional Engineer registered in Alaska, Arizona, California, Colorado, Delaware, Florida, Hawaii, Idaho, Iowa, Nevada, New Mexico, New York, New Jersey, Maryland, Oregon, Pennsylvania, Virginia, Washington, and British Columbia.

Mr. Fuhr has been actively involved in Institute of Electrical and Electronic Engineers (IEEE) and the Industrial Applications Society (IAS) since 1986. He served as an officer for IAS from 1988 to 1992 and was the 1991-92 Chairperson of IAS and was a Member-at-large for the Seattle Section of IEEE from 1992-93. Mr. Fuhr is an IEEE Senior Member, a member of the Building Commissioning Association, and a member of the Electric League of the Pacific Northwest. He is a member of the IEEE 1584 Working Group (Guide for Performing Arc-Flash Hazard Calculations)

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