Arc Flash Hazard - The Basics

Robert E. Fuhr, P.E. Senior Member IEEE, Viet Tran, IEEE, and *Tam Tran, IEEE*

There is a new buzz in the electrical engineering industry regarding arc flash hazard, calculations, and labels. Everyone's wondering what they are and the concepts behind the idea. We engineers at Powerstudies.com 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 numerous physical injuries such as outward blasts of molten metal and shock hazard when in contact with energized conductors. Arc faults can also produce damages such as 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 the arc flash heat exposure program was developed in an attempt to educate workers and reduce the number of injuries and deaths.

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" 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 ups against walls.

At this time (2009), only arc flash hazards from three-phase faults (arcing faults) in enclosures have been studied and researched. There is little test information on arc flash hazards produced by phase-to-phase and phase-to-ground faults. Arc flash hazards have not been studied for a bolted fault??? because it does not radiate any flash energy.

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 regulations apply to every worker that may approach or be exposed to energized electrical equipment. Failure for an employer to conform or follow 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
- NFPA 70B 2002 "Recommended Practice for Electrical Equipment Maintenance."
- NFPA 70E 2009 "Standard for Electrical Safety in the Workplace."
- OSHA Standards 29-CFR, Part 1910 sub part S (electrical) Standard number 1910.333

QUESTION #4 – WHAT IS INCIDENT ENERGY?

Incident energy is the energy per unit area received on a surface located 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 24 inches for Switchgear.. The distance is longer as the 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 in 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.

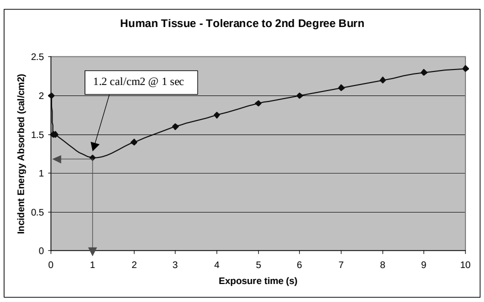

Figure 1: Human Tissue – Tolerance to 2nd Degree Burn

QUESTION #5 – WHAT ARE THE LIMITED, RESTRICTED, PROHIBITED, AND FLASH PROTECTION BOUNDARIES?

NFPA 70E has developed several protection boundaries based upon the employee's training and personal protective equipment. The Limited, Restricted, and Prohibited Boundaries are based on the voltage of the energized equipment. The Flash Protection Boundary is based 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:

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. The boundary is determined by NFPA 70E Table 130.2(C) and is based on the voltage of the equipment (2009 Edition).

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. This boundary is determined from NFPA Table 130.2(C) and is based on the voltage of the equipment (2009 Edition).

C. Prohibited Approach Boundary

Only qualified personnel wearing appropriate personal protect equipment (PPE) can cross the prohibited approach boundary. Crossing this boundary is considered the same as contacting the exposed energized part. Therefore, personnel must obtain a risk assessment before the prohibited boundary is crossed. This boundary is determined by NFPA 70E Table 130.2(C) and is also based on the voltage of the equipment (2009 Edition).

D. 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 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.

Figure 2 summarized the four boundaries previously mentioned:

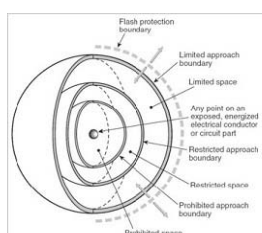

Figure 2: Working Boundaries

QUESTION #6 – WHAT IS PPE?

Personnel can be protected from some of these flash hazards by wearing personal protective equipment (PPE) such as clothing, gloves, tools, 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-2009.

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)
Untreated cotton 4.0 oz. Weave	2.0
Single layer FR cotton 7.5 oz. Weave	6.0
Single layer FR 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 FR Cotton	31.0
12 oz Cotton (4 oz) under FR cotton (8 oz)	12.5
Switching suit of FR 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

Table 4 shows the PPE rating with six divided risk categories.

PPE Class	Incident Energy Range (cal/cm2)	Min PPE Rating (cal/cm2)	Clothing Description
0	0-2	N/A	Untreated Cotton
1	2-5	5	FR Shirt&Pants
2	5-8	8	FR Underwear+FR shirts & Pants
3	8-25	25	Cotton Underwear+FR shirts & Pants
4	25-40	40	Cotton Underwear+FR Shirt & Pant FR Coverall
5	40-100	100	Cotton underclothing plus FR shirt, pants, plus multi-layer switching suit

Table 4: PPE Class, PPE Rating, & Required Clothing

QUESTION #7 – WHAT IS AN ARC FLASH WARNING LABEL?

Section 110.16 of the NEC 2002 code requires switchboards, panel-boards, industrial control panels, and motor control centers to be field marked with warning labels to warn personnel of the potential electric arc flash hazards. The markings are to be located so they are visible to the personnel before examination, adjustment, servicing, or maintenance of the equipment. An example of an arc hazard label is shown below on figure 3.

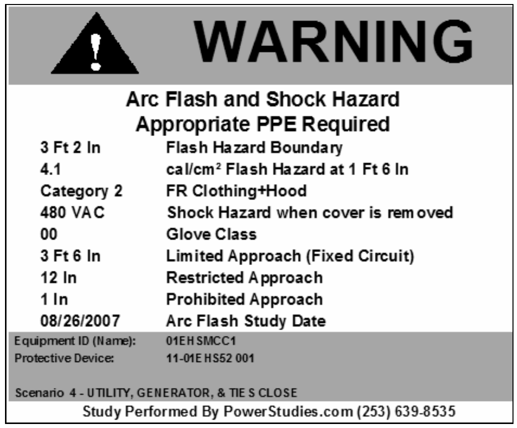

Figure 3: Arc Flash Hazard Label

Note that the Flash Hazard Boundary takes precedence over the Approach Boundaries (Limited, Restricted, or Prohibited). The Approach Boundaries are based only upon the equipment voltage; whereas, the Flash Hazard Boundary takes into account several factors such as voltage, available fault current, and the time for the protective device to operate and clear the fault. In this example, although the limited Approach Boundary would have allowed an unqualified person to stand within 42 inches of the energized equipment, the Flash Hazard Boundary calculation takes precedence and requires the qualified person standing 38 inches from the energized equipment to wear a personal protective equipment of Class 2, fire retardant shirt and pants.

Currently, the NEC does not require the label to list the Flash Hazard Boundary, Incident Energy, Approach Boundaries (Limited, Restricted, or Prohibited), or PPE requirements. Only the top two information boxes are required (Warning! & Arc Flash and Shock Hazard). However, the fine print note #1 references NFPA 70E-2004 to provide assistance in determining the severity of potential exposure and note #2 states that ANSI Z535.4-1998 to provide guidelines for the design of safety signs and labels. Future NEC revisions will require the incident energy and PPE to be listed on these labels.

QUESTION #8 – WHAT IS AN ARC FLASH HAZARD STUDY?

An Arc Flash Hazard Study 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.

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 current) 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, boundary distances, and assists the owner in complying with the NFPA guidelines that are enforced by OSHA inspectors. The result of the Arc Flash Study will include the following:

1) Short Circuit Current Values
2) Protective Device Settings (Protective Device Coordination Study)
3) Arc Flash Incident Energy Levels
4) Boundary Distances for
    a) Arc Flash Protection
    b) Limited Approach
    c) Restricted Approach
    d) Prohibited Approach
5) Personal Protective Equipment (PPE)
6) Arc Flash and Shock Hazard Warning Labels (listing items #3 and #4a-d) for select equipment.
7) Complete report including
    a) Introduction
    b) Executive Summary
    c) Short Circuit Study
    d) Short Circuit Equipment Summary Sheets
    e) Protective Device Coordination Study
    f) Protective Device Setting Sheets
    g) Time Current Curves
    h) Arc Flash and Shock Hazard Study
    i) Arc Flash Calculations

QUESTION #9 – **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) inspectors are currently enforcing National Fire Protection Association (NFPA) document NFPA 70E. This document states that a "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 you 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). And as we just discussed, NFPA 70E describes the flash hazard analysis and goes on to describe 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, OSHA and NFPA requirements.

PowerStudies.com 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.

Telephone: (253)639-8535
Fax: (253)639-8685
E-mail: fuhr@PowerStudies.com
Web: www.PowerStudies.com

About the Authors

Robert Fuhr graduated with a B.S.E.E. from the University of Wisconsin in 1980. Before graduating, Mr. Fuhr worked for Madison Gas and Electric in Madison, WI and Tennessee Valley Authority in Knoxville, TN. After graduation, he worked for General Electric Company from 1980 to 1986 as a Field Engineer, performing commissioning and start up tests on many different types of power distribution equipment. Mr. Fuhr worked as a Senior Facilities Engineer at the University of Washington from 1986-1989. There he re-commissioned the electrical power distribution system for University Hospital.

In 1986, Mr. Fuhr established PowerStudies.com, 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 Washington, Oregon, California, and Alaska.

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.

Viet Tran graduated from Washington State University in 2003 with a B.S.E.E degree. Prior to graduation, Viet interned at PowerStudies.com in Covington, WA. As an Intern Student, he performed various tasks including short circuit and protective device coordination studies.

After graduation, Viet was hired by Power Studies.com to work as a staff Electrical Engineer. Viet had done various power system studies on industrial and commercial projects.

Tam Tran graduated from the University of Washington in 2009 with a B.S.E.E degree. Prior to graduation, Tam interned at PowerStudies.com in Covington, WA. As an Intern Student, he performed various tasks including short circuit and protective device coordination studies.

After graduation, Tam was hired by Power Studies.com to work as a staff Electrical Engineer.