



## Arc Flash Basics and Hazard Planning Program

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## ARC FLASH BASICS AND HAZARD PLANNING PROGRAM

This course gives an overview of arc flash hazards and concisely reports the different causes, nature, findings, directions and processes related with arc flash hazards. In order to address the hazard, it is first required to formulate an understanding of the process. Points are given in the next sections.

An electric arc or an arcing fault is a flashover of electric current through air in electrical devices from one exposed live conductor to another or to ground. Arc flash hazard is the risk of excessive heat exposure and severe burn hurt due to arcing faults in electrical systems. Electric arcs generate intense heat, sound blast and pressure waves. They have really high temperatures, radiate acute heat, can inflame clothes and induce serious injuries that can be fateful.

The requirement for uninterrupted supply of power has lead about the requirement for electrical staff to complete maintenance jobs on exposed live parts of electrical devices. Apart from the existence of electrical shock incidents that results from direct contact of live conductors with body parts, there also exists a probability of electric arcs hitting across live conductors. Even though electrical safety procedures have existed since the beginning of electricity, arc flash hazard has not been conspicuously treated until recently.

### ELECTRIC ARC CAUSES

Arcs can be started by the following:

- Glow to arc discharge
- Dust and impureness: Dust and impureness on insulating areas can give a path for current, allowing it to flashover and start arc discharge across the surface. This can grow into bigger arcs. Fumes or vapor of chemicals can decrease the breakdown voltage of air and induce arc flash.

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- Corrosion: Corrosion of device elements can leave impureness on insulating areas. Corrosion also breaks the contact between conductor terminals, enhancing the contact resistance through oxidation or different corrosive pollution. Heat is produced on the contacts and sparks may be generated, this can head to arcing faults with nearby exposed conductors of different phase or ground.
- Condensation of vapour and water dropping can induce tracking on the coat of insulating materials. This can induce a flashover to ground and possible increase to phase to phase arcing.
- Spark discharge:
- Incident touching: Incidental contact with live exposed elements can start arc faults.
- Dropping tools: Incidental dropping of tools may induce momentary short circuit, generate sparks and start arcs.
- Over-voltages across narrow gaps: When air gap between conductors of various phases is very narrow (due to poor craftsmanship or damage of insulating materials), arcs may hit across during over-voltages.
- Break down of insulating materials. Electric arcs are also induced by the following:
  - o Improperly made or used devices.
  - o Wrong work processes.

### **ELECTRICAL ARC NATURE**

Electric arcs generate some of the greatest temperatures known to exist on earth – up

to 35,000 degrees Fahrenheit. This is four times the surface temperature of the Sun.

- The acute heat from arc induces the fast expansion of air. This ends in a blow with very strong air pressure (Lightning is a natural arc). All known materials are vaporized at this temperature. When materials vaporize they expand in volume (Copper – 67,000 times, Water–1670 times). The air blow can spray molten metal to far distances with great force.
- For a low voltage system (480/277 V), a 3 to 4-inch arc can turn “stabilized” and exist for a prolonged period.
- Energy discharged is a function of system voltage, fault current magnitude and fault duration.
- Arcs in enclosures, such as a Motor Control Center (MCC) or switchgear, amplify blow and energy transferred as the blow is pushed to the open side of the enclosure and toward the staff.

### **ARCING FAULTS HAZARDS**

Some of the arcing faults hazards are:

- Heat: Fateful injuries can happen when staff is few feet from the arc. Dangerous injuries are frequent at a distance of 10 feet. Completed experiments have recorded temperatures higher than 437°F on the neck area and hands for a person standing close to an arc blast.
- Objects: Arcs spray drops of molten metal at high-speed pressure. Blast shell can enter the body.
- Pressure: Blast pressure waves have thrown staff across rooms and knocked them off ladders. Pressure on the chest can be greater than 2000 lbs/sq.ft.

Clothing can be combusted few feet away. Clothed areas can be combusted more badly than exposed skin.

- Hearing loss from sound blow. The sound can have a magnitude as high as 140 dB at a distance of 2 feet from the arc.

### **SURVIVAL PROBABILITY**

Traumas due to arc flash are known to be very serious. According to statistics from the American Burn Association, the chance of survival diminishes with the increasing age of the arc flash burn victim.

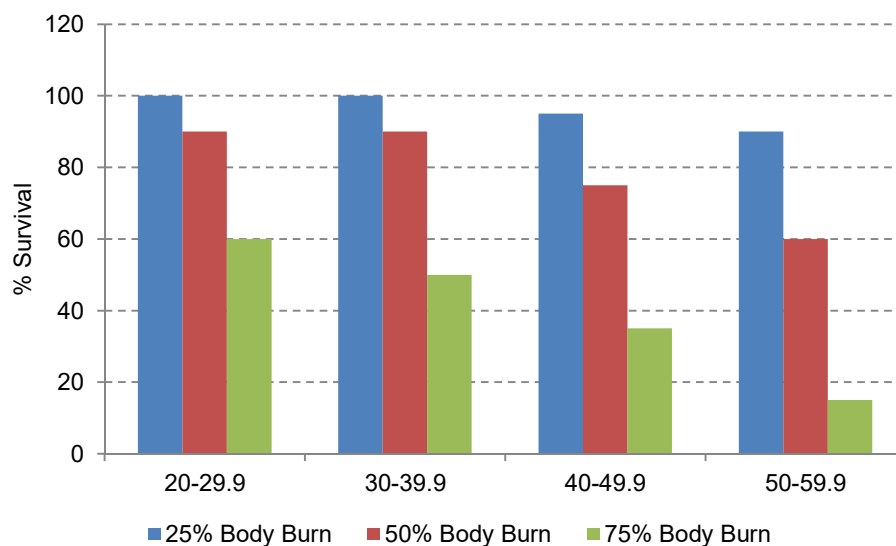


Figure 1. Burn injury statistics – probability of survival (source: American Burn Association, 1991-1993 Study; Revised March 2002)

### **ARC FLASH IMPACT**

Treatment may need years of skin grafting and rehabilitation. The victim may never go back to duties or keep the same life quality. Some of the direct expenses are:

- Treatment can surpass \$1,000,000/case.
- Litigation costs
- Manufacturing loss

## ARC FLASH POTENTIAL EXPOSURE

Even though it may seem that arc flash occurrences are unusual, statistics imply that the harm they make is significant. Bureau of Labor Statistics information for 1994 indicated 11,153 cases of accounted days away from job due to electrical burns, electrocution/electrical shock injuries, fires and blasts. The Census of Fatal Injuries acknowledged 548 employees died from the causes of electrical current exposure, fires and blasts of 6,588 work associated fatalities around US. In the US Chemical Industry, 56% of the fatalities that happened over a 5-year period were assigned to burns, fires and blasts, with many of the firing sources being associated to electrical activity.

It was reported that there are 5 to 10 arc flash injuries per day leading to hospitalization. Many arc flash incidents/injuries happen that do not need a stay or are not adequately reported for national tracking needs. The number of arc flash incidents is higher than many engineers actualize since most arc flash incidents do not reach the daily news. IEEE Standard 1584, IEEE Guide for Performing Arc Flash Hazard Calculations, presents arc flash injury case histories. An abbreviated description is given for each situation on accident setting, electric system, devices, staff activity, event, clothes worn by the staff and the results of the accident. Readers are recommended to read these scenarios to get insights on different circumstances leading to such accidents.

The exposure to arc flash depends on the following:

- Number of times staff works on exposed live devices.
- Complexity of the completed task, requirement to use force, available space and

safety limits, reach, etc.

- Training, skills, mental and physical agility, coordination with helper.
- Devices and tools utilized.
- Device condition.

### **ARC FLASH HAZARD RECENT DEVELOPMENTS**

National Electric Code (NEC) and other safety standards have been dominantly related with protection from fire, electrocution, and shock hazard – arc flash hazards were not covered. This is now changing. The 2002 NEC now has demands for warning labels. The National Fire Protection Association (NFPA) is responsible for the NEC.

Since the NEC was primarily pertained with electrical design, construction and inspection, it could not be followed by management and staff with respect to adopting rules for workplace safety. In order to overcome this gap, a new standard, NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplaces, was created. NFPA 70E is meant for use by management, staff, and the Occupational Safety and Health Administration (OSHA). NFPA 70E (2000) recognize arc flash hazard as a potential risk to staff near and around live exposed electrical elements. NFPA 70E and IEEE Standard 1584 give instructions on carrying out adequate safety rules and arc flash computations. For the real wording, see section 6.1.2. NEC Article 110.16 demands "field marking" of possible arc flash hazards for panels likely to be fixed or examined in an energized condition. This article also comprises a fine print note (FPN) regarding adequate signage and an FPN regarding NFPA 70E. These FPNs are not part of the NEC, but are suggested procedures. OSHA has not specifically covered arc flash hazards; nevertheless, there exists proper safety demands for managers to follow to make sure the safety of the staff in the workplace. The Code of Federal Regulations (Standards – 29 CFR) Part 1910 treats occupational safety and health regulations. Regulations on personal protective equipment (PPE) are highlighted in subpart 132.

## NFPA 70E AND ARC FLASH HAZARD - PROTECTION BOUNDARIES

NFPA 70E defines a series of boundaries associated to electrical safety when working on energized devices. Only "qualified" staff can enter these boundaries and they are demanded to wear adequate PPE within these boundaries. The four protection boundaries are:

1. Flash Protection Boundary
2. Limited Approach Boundary
3. Restricted Approach Boundary
4. Prohibited Approach Boundary

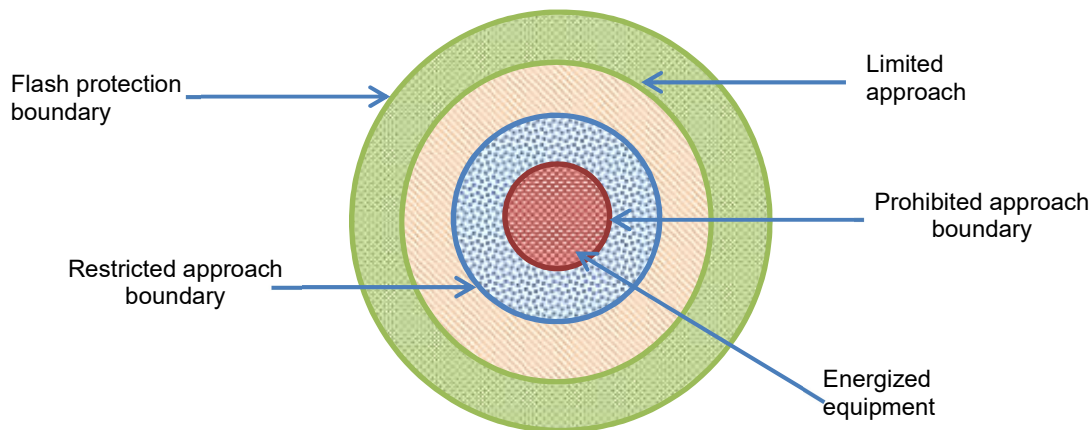


Figure 2. Protection boundaries

### FLASH PROTECTION BOUNDARY

The flash protection boundary is the distance from the arc source (energized exposed device) at which the possible incident heat energy from an arcing fault falling on the surface of the skin is  $1.2 \text{ calories/cm}^2$ . An exposure to  $1.2 \text{ cal/cm}^2$  would typically end in a curable second-degree burn. Within this boundary staff is demanded to take protective clothing like fire resistant (FR) shirts and pants, and other equipment to cover various parts of the body. This distance may change from device to device since it is a



function of the available short circuit current of the system at that point, the voltage and the tripping features of the upstream protective element as well as some other features.

## **PERSONAL PROTECTIVE EQUIPMENT**

NFPA defines the need of personal protective equipment (PPE) for staff within the flash protection boundary. All parts of the body which may be exposed to the arc flash have to be protected by the adequate type and quality of PPE. The complete PPE set may be constituted of FR clothing, helmet or headgear, face shield, safety glasses, gloves, shoes, etc. depending upon the magnitude of the arc energy. The quantity of PPE needed and its quality has to be decided on the basis of the computed incident energy on the staff body. The computations have to be completed by a qualified person such as an engineer. The protective clothing should fix the incident energy arriving at the chest/face of the employee to less than  $1.2 \text{ cal/cm}^2$ . FR clothing gives thermal insulation and is also self-extinguishing. Protective clothing is rated in  $\text{cal/cm}^2$ .

## **HAZARD/RISK CATEGORY CLASSIFICATION**

NFPA 70E presents five levels of risk category for arc flash hazard founded upon the computed incident energy at the working distance, as shown in Table 1. Examples of usual protective clothing that protect the torso are also given in this table. Other PPE are also needed to cover different parts of the body.

Table 1. Hazard/risk categorization as per NFPA 70E-2000

Category	Energy Level	Typical PPE Examples
0	N/A	Non-melting, flammable materials (e.g. untreated cotton, wool, rayon, etc.)
1	$5 \text{ cal/cm}^2$	FR shirt and FR pants
2	$8 \text{ cal/cm}^2$	Cotton underwear plus FR shirt and pants
3	$25 \text{ cal/cm}^2$	Cotton underwear plus FR shirt and pants plus FR coverall
4	$40 \text{ cal/cm}^2$	Cotton underwear plus FR shirt and pants plus double layer switching coat and pants

## **CALCULATING FLASH PROTECTION BOUNDARY AND HAZARD CATEGORY**

NFPA 70E presents two methodologies of deciding flash protection boundary as

outlined in Part II section 2-1.3.3.2:

- A fixed distance of 4.0 ft. for a short circuit with the product of short circuit current and fault duration less than 5000 ampere seconds.
- Ralph Lees' formula. In NFPA 70E, three acceptable methodologies for calculating flash protection boundary and hazard class are given. They are listed below:
  - o Simplified NFPA 70E tables: Table 220.2(B)(2)(C) for flash protection boundary and Table 220.6(B)(9)(A) for hazard category.
  - o Computations based on NFPA 70E Annex B.
  - o Computations based on IEEE Standard 1584.

IEEE Standard 1584 suggests that the staff completing arc flash hazard study should understand the limitations of the methodology. Some of the limits are:

- The formulas utilized in the standards are based on experiments completed in a laboratory and the circumstances may vary from those in the plant where the application of the standards is searched.
- The formulas are based on a range of test figures such as available short circuit current, arc gap, enclosure size, etc. It is required to verify if parameters existing for the plant are within the same range.
- The stochastic nature of arcs makes it very hard to precisely model the arc. The approximation given by the formula for arc current in the regulations is an “mean” figure.

All of the known regulations or methodologies have some limits. The tables may be easy to use and need less or no calculation. Nevertheless, these are founded on usual

equipment and systems and are very approximate. Comprehensive assessment yields different findings than the tables do. Hence, whatever regulation you may select, it is required to understand its limits. Further detailed assessment can get over some of these limits.

### **DIFFERENCE BETWEEN NFPA 70E AND IEEE 1584 COMPUTATIONS**

NFPA 70E methodology approximates incident energy based on a theoretical maximum figure of power dissipated by arcing faults. This is trusted to be conservative. In contrast, IEEE 1584 approximates incident energy with empirical formulas formulated from statistical assessment of findings taken from numerous laboratory tests. The IEEE methodology was meant to be more realistic rather than conservative, and aims to avert incidents due to limits provided by over-protection to staff. Over-protection can also cause restriction of visibility and movement, discomfort and cuts down worker productivity.

### **HAZARD STUDY METHODS**

Arc flash hazard computation can be completed in few ways. The selection of methodology may be founded on available data, volume of computation work, requirement for accuracy, availability of resources and quality of arc flash hazard mitigation program. Whatever methodology is utilized, the qualified staff completing the study needs to be aware of the limits of the method used, and should complete additional engineering assessment to reach the best results.

Table 3-3.9.1 Hazard Risk Category Classifications in NFPA 70E gives a simple method to check the hazard category.

1. Simplified tables of NFPA 70E: You can look up Table 220.2(B)(2)(C) and Table 220.6(B)(9)(A) to complete hazard study for small radial distribution electrical system. This methodology needs the least time and is adequate when limited data is available on the electrical power system. This is the least precise methodology since it is very

generalized. These tables do not give you with the precise PPE rating that is needed in cal/cm<sup>2</sup>.

2. Hand computations: You can complete hand-computations using NFPA 70E formulas or IEEE 1584 formulas for small radial electrical distribution systems. This is very time consuming and is not practical for large systems. While completing many hand computations, unnoticed errors may be brought in the computations.

3. Spread sheet calculator: IEEE Standard 1584 comes with a spreadsheet calculator that can be utilized to check arc flash hazards. Similar spreadsheets can be easily made using NFPA 70E formulas. This tool asks the user to enter available short circuit current information for each point of evaluation. Demanded information for each point includes short circuit current and protective device trip times for each power source. Because of the inability of the spread sheet tool to decide the trip time and short circuit currents and because of the time-consuming nature of this procedure, approximations have to be introduced, which compromise accuracy. This methodology is limited to radial single source electrical systems and errors increase with the size of the electrical system.

4. Commercial software: This is useful for all electrical systems with more power sources and more study cases of interconnections where better accuracy is needed and where the electrical system goes through ongoing variations over time. Once the information is put into the software, completing hazard study takes very little time. The findings are momentarily observed. Graphical power system software can complete numerous aspects of engineering assessments at once. For example, software can complete short circuit computations, protective device coordination, and arc flash computation and graphically show results with few mouse clicks. Software usually gives an active self-documenting arc flash assessment program to meet the requirements of today's developing electrical systems.

The findings of the study can show up on single line drawings, comprehensive arc flash reports and warning labels that can be put on the hazardous location or devices. An

additional software advantage is the possibility to assess and vary the protective device settings in order to decrease exposure to arc flash hazard. The software can automatically get the precise arcing time from the trip characteristics of the protective elements. All other methodologies lack this feature and hence need to rely on some approximate figure for arcing time.

### HOW TO REDUCE EXPOSURE TO ARC FLASH HAZARD

In order to decrease exposure of staff to arc flash hazard, management and staff can take the next steps:

1. Understand arc flash and its related hazards and acknowledge the presence of the hazard.
2. Study the scale of the hazard. Develop an arc flash hazard program and put it into the safety program.

### ARC FLASH HAZARD PROGRAM

An arc flash hazard program is used as part of the electrical system safety program, which in turn is part of the overall company safety program. The main aim of the program is to stop or minimize injuries to staff from arc flash. Since arc flash hazard reduction is a fairly new concept in the industry, it is expected that significant efforts and allocation of resources will be needed to provide an initial thrust to successfully start the program. The quantity of additional resource allocation needed for the program and the likely success of the program may depend on what elements are already available in the company and the associated and existing safety procedures. This is the first step in completing an arc flash hazard program.

The arc flash hazard program is done through following steps:

1. Hazard study: An engineer completes computations based on power system features and data to find out the flash protection boundary, the incident energy a staff may be

subject to and the hazard/risk category. The vital task in the study is reviewing available technical information and collecting the remaining necessary information. The regulations themselves do not give the various practical issues in completing hazard study.

2. Documentation: It is essential to document the findings of arc flash hazard study in reports and drawings, and also give signs and labels on devices and at hazardous locations. Documentation is also a part of the planning procedures before working on live elements and after, if work modifications are made to the devices or electrical system. Documentation of training given to staff is also needed.

3. Personal protective equipment (PPE) procedure: Based upon the hazard study the adequate PPE must be selected and given to the staff. Employees have to properly wear the PPE, take care and maintain the PPE, check it before every use and throw it away after its useful life has completed.

4. Organizing processes to reduce hazard: The potential hazards can be reduced by organizing safer working methods, giving protective shields, adequate work planning, etc. The exposure to arc flash can also be decreased by improving electrical system designs, utilizing current-limiting elements and solid state relays, and adjusting relay and trip elements to safer settings.

5. Staff training: Staff who is exposed to arc flash hazard should be properly trained to understand what the hazard is, how it is started, how to read the documents and warning labels, how to adequately wear PPE, and how the hazard can be decreased with safer working practices. Various tasks will demand various work procedures.

6. Continual advancement: It is expected with more research and development in arc flash hazard, that there will be more additions to what we already know. The arc flash hazard program can be continually enhanced by including new findings in regulations, industry procedures and PPE. Since the power system within a company can keep altering with time, it is mandatory to update arc flash study data on a regular basis. Also,

experience can introduce new ideas from staff that can be put in the program. For this reason, it is mandatory to keep the program live rather than implement it as a one-time project.

7. Safety audit: Safety checks should be frequently completed to assess different aspects of a safety program. The safety check should include arc flash hazard. If the arc flash hazard program is in its starting phases, then a closer check is needed.

8. Corporate-wide plan: Corporate-wide plan should be used to ensure consistency in safety procedures. It is not recommended to have different safety programs throughout various plants, divisions or sections. Communication channels should be made and responsibility should be distributed between different plants or divisions, taking a common approach.

### **PLANNING PROCESS OVERVIEW**

Arc flash hazard planning process determines the following:

1. Needs -What is to be done?
2. Implementation - Who is responsible for what?
3. Program - When and how long?
4. Methods and processes – How to go about it?
5. Budgeting - How much will it cost?
6. Final outcome - What is to be achieved?

The elements of the planning procedure are:

1. Review of existing procedures and resources:
  - a. The scale of exposure to hazard.
  - b. Existing safety program.
  - c. Human resources.
  - d. Electrical power system size and available technical documents.
  - e. Budget.
2. Formulation of values and outcomes for the program.
3. Selection of resource staff.
4. Selection of study methodology.
5. Assessment for human efforts (hours of work).
6. Budget.

The financial costs of PPE can be calculated only after completion of the hazard study, nevertheless, the tentative starting costs can be quantified for budgeting needs.

### **EXISTING PROCEDURES AND RESOURCES REVIEW**

Before starting an arc flash hazard program, it is mandatory to study the safety procedures and exposure to hazards. An arc flash hazard program is typically part of the electrical safety process, which in turn, is part of the complete safety process within the company. The company and its staff have to oblige to other safety standards along with the processes made to reduce exposure to arc flash hazard. Arc flash practices are integral with existing electrical safety processes such as lockout/tag out.



## **ADVANTAGES OF EXISTING PROCEDURES REVIEW**

A review of existing conditions will give the following advantages:

1. Present an idea of staff that may be needed, and how responsibility may be shared within the existing work teams.
2. Give an idea of what further training is needed. If the existing training level is inappropriate for other safety processes, arc flash training can be mixed with other safety training so that the total cost, time and efforts are reduced. The training process can also be made to suit the understanding and experience level of the staff.
3. A snapshot study of company safety procedures: A companies stance on safety issues, and its commitment and priorities are likely to influence the character of any safety program it is about to introduce. The procedures would include vision and value procedures with regard to safety issues, objectives and measurements, corporate safety division and sharing managerial responsibility for safety and cost allocations. This assessment would give a platform for changing procedures if required.
4. Give an idea of how much investment is needed. The exact quantity of resources needed will be clear only after a comprehensive plan is made. Nevertheless, the study is a starting point for conducting a safety program. If a company already has very strong safety procedures, then incorporating the arc flash hazard program will not take as many resources as it would take in a company where marginal processes or none at all, have been introduced. The complete cost needed also depends on the scale of the safety program a company may want to introduce.

## **UNDERSTANDING MAJOR RISK TO AN ARC FLASH HAZARD**

The introduction of an arc flash hazard mitigation program would depend on the level of risk staff may be exposed to. In order to check risk level, the next considerations should be made:

1. Procedures on operating on energized devices: Some companies do not allow electrical staff to work on energized devices – work is completed only after switching off electrical devices. Working on de-energized devices should be the objective of every company. In such situations, there is minimal arc flash risk. Nevertheless, it must be noted that arc flash can happen while switching off a circuit breaker or a switch to de-energize devices. Arcs can also be started by sparks from corroded electrical elements. Staff nearby may be exposed to arc energy even though they may not be operating on devices.
2. Number of staff operating on or near live devices: The higher the number of employees, the higher the risk. Hence, the requirement to have a more elaborate arc flash hazard mitigation program. Consideration must be devoted to integrate contractors to comply with a program.
3. In many situations employees are exposed to live devices: When the frequency of exposure to live device is small, an elaborate program may not be required – a few simple rules may be sufficient.
4. Voltage level: For low voltage devices (240V or less) being supplied by small transformers (125kVA or less), the potential risk is small, and hence does not need to be included in arc flash hazard study. The greater the voltage or transformer rating, the greater the risk.
5. Continuous processes: Continuously operated plants may need operation on energized devices like MCC's and panels. The exposure to risk is greater for such plants. When feasible, plan work during plant shutdowns.
6. System size: Large electrical systems are likely to have higher arc flash hazard due to the greater fault currents.
7. System condition: Electrical systems that do not get periodic planned service are likely to have a greater risk of arc flash accidents.

8. Modifications in electrical system: Since the level of risk depends on the possible magnitude of arc current, that in turn depends on the connections within the power system, a system that develops with time due to the needs of the company will require assessment of arc flash hazard when the modifications are introduced. More effort will be required to be introduced into the safety program to address modifications. A static electrical power system will need the study only once and the safety processes will remain intact unless the fault level of the utility changes or OSHA and NFPA standards change.

9. Environmental issues: Are the exposed live elements of electrical devices subject to corrosive vapors (such as in chemical plants, sea-side, etc.), oxidation, bees, dust, rodents or birds introducing electrical disturbances resulting in spark and finally arc flash? The possibility of arc flash exposure is greater in such cases.

### **EXISTING SAFETY PROGRAM ASSESSMENT**

When introducing a new arc flash hazard mitigation process, the additional efforts, human resources, cost and time that is needed will depend upon what is already used and what resources are available to the company. As noted in the previous paragraphs, the arc flash hazard process is an extension of the existing safety process and is not about just putting labels on devices and wearing flash suits. The following points should be taken into account in the preliminary planning stage.

- Existence of an electrical safety process: If no such process exists, the company will have to introduce the program from the beginning. Companies with strict safety processes can easily introduce the arc flash hazard process since much of the program is similar to the electric shock hazard. The vital differences lie in the PPE and the review process that need comprehensive computations that should be completed by an experienced electrical engineer familiar with power systems computations. Some questions to ask are:

1. Does the company have a safety department?

2. If the company is small, does it have safety personnel with a safety coordinator?

- Are safety meetings periodically organized and before starting the work?
- Do employees get safety training? How often? Is the training documented?
- Has review of electrical hazards been carried out? How often? Are warning labels put in these areas?
- Has safety check been completed? How often?
- Is PPE given to staff? Is the PPE sufficient? Is PPE adequately used and serviced?
- Does each plant have up-to-date electrical drawings, short circuit, and protective device coordination assessments?
- Is each plant simulated with graphical power system software to self-document the electrical network and safety review in line with NFPA-70E?
- Has the company produced any processes for safety? Do the employees follow them?
- Are contractors needed to follow the same or similar safety processes?
- Is safety training given to outsourced personnel or contractors?
- Willingness of staff to follow changes in safety program:

Accepting the arc flash process and wearing arc flash PPE is a major change to operating habits. Experience tells that staff does not like to use additional clothing.

- Existence of arc flash hazard processes: If some kind of arc flash hazard process

already exists, then enhancing the process will not be difficult since the basic principles will already have been introduced. Any enhancement will come in the form of better precision in hazard assessment, better documentation, training and selection of PPE. Since the basic information for computations will be readily available, the study can be quickly completed.

### AVAILABLE HUMAN RESOURCES ASSESSMENT

- Does the company employ safety staff?
- Does the company employ specialized electrical engineers? How much time can they devote to arc flash hazard process? Can they manage this assessment? Are they trained or experienced in short circuit current computations, protective device coordination and arc flash hazard studies?
- Does the company employ electrical technicians or use outside technicians for routine inspection and maintenance?
- Does the company have safety staff for different locations? How much time can they devote to an arc flash hazard process, for both learning and implementing?
- Does the company have staff for managing the complete arc flash safety process?
- How much time can staff devote to learning about arc flash hazard and its prevention as well as introduction of processes at work?

### POWER SYSTEM SIZE AND RECORDS

The source of power supply, more grid interconnections, co-generation and more

generators impact the available fault level, the complexity of the arc flash hazard study and the number of study cases that will be needed for assessment. Information is needed from the serving utilities.

- Radial distribution versus loop distribution systems: Radial distribution electrical systems are easier to deal with and hand computation can be completed for small electrical systems. Looped electrical distribution systems need more rigorous computations.

Multiple voltage levels: The nature of arcs and hence the computation methodology changes with the voltage level, and so does the risk.

- Number of connection points (buses): Each bus needs to be reviewed for arc flash hazard, and hence impacts the total project size.
- Number and types of devices/load: Different information sets are needed for different devices. The computation details may also change.
- Diversity in settings and features of protective elements (i.e. fuses, relays, circuit breakers). This impacts data gathering and assessment of arcing time.
- Frequency of modifications in the electrical system: If the electrical system is frequently changed, then documentation, study and PPE upgrading may be needed for each change. A robust and simpler methodology of achieving all of the needs must be used.
- Does the company have up-to-date electrical drawings and device data readily available?

Has a short circuit and protective device coordination assessment been recently carried out for the existing electrical system? This determines how much extra work may be required.

## FINANCIAL RESOURCES

What financial resources (budget) is being planned for safety?

- Is this sufficient to meet the safety objectives?
- What further allocations can the company make?
- Does the company treat this as cost or investment?
- What are the costs of insurance and employee's compensation?

## VALUES AND OBJECTIVES

Companies typically define their standards for human life and safety in their safety procedures. These values make the basic foundation for majority of their actions. The following reasons for completing an arc flash hazard process tie in with company standards and missions.

## REASONS TO ADDRESS ARC FLASH HAZARD

Keep the staff from potential harm and prevent loss of life. Comply with Occupational Safety and Health Administration (OSHA) codes and with National Fire Protection Association (NFPA) standards on staff safety, NFPA-70E.

- Stop loss to companies through loss of trained manpower, litigation costs, higher insurance costs, and loss of morale.
- Increase process uptime by avoiding accidents.
- Needed by insurance carrier.

## OBJECTIVES OF ARC FLASH HAZARD PROCESS

Train all electrical staff on the potential danger.

- Keep away from arc flash related incidents.
- Reduce exposure of body parts to arc flash in case of accidents.

## OBJECTIVES

Objectives are typically an extension of the goals, but are more precise. Usually companies relate measurable statistics with objectives. Some objectives may be related with the final result, (for instance, zero accidents), whereas some may be objectives of the program involving "what to do" or "how to do". For instance, the process associated objectives could be:

- Train 50% of staff with an elementary level course and 50% of staff with an advanced level course within 6 months.
- Organize and implement strict processes to avoid incidents within 3 months.
- Accomplish arc flash hazard review in 25% of the plant locations within 6 months.
- Select and obtain 50% of the needed PPE in three months and finalize distribution in six months.
- Give consistent processes to all plants for OSHA compliance.

Similarly, the result related objectives could be:

- Decrease the lost work day case accidents rate (LWDCIR) by 50% within 1 year.
- Decrease OSHA recordable accidents by 30% in the year 2004.

Decrease the insurance costs by 10% within 2 years. These are typical examples for safety related processes, but specific objectives may be set for arc flash hazards. Some goals may be set to tie in with the regular safety checks. This is beneficial for on-going processes. For example,



- Decrease improper use of PPE to zero.
- Decrease improperly labeled or non-labeled hazardous locations to zero.
- Decrease electrical system change documentation time to one week. In many plants, documentation is not completed after change is introduced in the system. This may cause accidents. Some companies inspect their plants to update the drawings every few years. The best process is to document the modifications as soon as they are finalized.

The role of defining goals is vital because program design and resource allocation are based on the objectives.

### **SELECTION OF RESOURCE STAFF**

Arc flash hazard study can be very complex. There are many elements that are dependent on electrical power system conditions and the infrequent nature of arcs make it mandatory to study multiple study cases based on statistical information. It is mandatory to make a proper understanding of the results of the different methodologies before choosing the method. Hence, it is mandatory to involve trained and knowledgeable staff in an arc flash hazard process.

There are three methods to choose resource staff for the arc flash hazard process:

1. In-house staff: Large companies with high exposure to hazards usually employ trained and experienced engineers, safety professionals and trainers. This resource staff can help establish and implement the process.
2. Consultants: Outsourcing is usual in small and mid-sized companies that do not hire adequate professionals. Some large companies do not have the required staffing or

expertise. Consultants work closely with the company staff giving most, or all, of decision-making tasks in the program.

3. Combined introduction: Companies that want their own staff to manage all the work in the future, hire consultants for a specific period. The consultant oversees the procedure and gives instructions and training. The internal resource employees get trained during the initial steps of the process.

### ARC FLASH HAZARD ASSESSMENT METHOD

It is important to understand each arc flash hazard assessment method before selecting the method that is best for specific application and company.

Table 2. Guide for selection of assessment method

Attribute	NFPA Tables	Hand Calculations	Spread sheet	Integrated software
Number of buses	<25	<25	<50	50+
Number of Voltage Levels	1-2	1-2	2-3	3+
Radial/Loop Distribution	Radial	Radial	Radial	Either
Power Sources	1	1	1	Multiple
Frequent Changes in System	No	No	No	Yes
Diversity in Protective Devices	Small	Small	Medium	High
Need for Accuracy	Low	Medium	Medium	High
Separate Short Circuit Studies	Yes	Yes	Yes	No
Separate Coordination Studies	Yes	Yes	Yes	No

Table 2 gives a guideline for the selection of study methodology based upon different system characteristics. This guide has been made taking the following considerations:

- Overall engineering time for determination of hazard/risk category and boundary.
- Accuracy needed.

- Possibility of errors in the different methodologies.
- Ease of documentation and production of single-line diagrams.
- Complete cost of different methodologies.

### **SIMPLIFIED NFPA 70 TABLES**

Table 220.2(B)(2)(C) in the NFPA 70E – gives the flash protection boundary based on system voltage and enclosure model. This gives very broad ranges and may be too high or too low at times.

Table 220.6(B)(9)(A) in the NFPA 70E gives the hazard/risk category based on available short circuit current, voltage, fault clearing time, type of work to be completed and type of device. The available short circuit current is usually not known until someone computes it from the system information. If the available short circuit current is not known, then computations will need to be completed. Once the short circuit currents are known, then it is fairly simple to look up the tables to find the hazard category. The fault clearing time may not be the same as it is assumed in this methodology. This could lead to erroneous findings and hence could be risky.

### **HAND COMPUTATIONS**

Hand calculations can be completed either using NFPA 70E Annex B or Annex C methodologies, or using IEEE Standard 1584 formulas. Please consult individual standards for more information.

### **SPREADSHEET CALCULATOR**

The IEEE 1584 spread sheet calculator gives a fast way to get arc flash hazard findings. Nevertheless, like both of the previous methodologies, this needs the input of available short circuit current and the fault clearing time. For some usual protective elements, the overall let through energy can be calculated without the need for inputting the clearing time. Also if the protective element is a current-limiting element for which characteristics

has been determined, the decreased arc current and the related decreased arc flash energy is computed. The calculator provides users to input what percent of arc current is going through the protective element. This can only be determined from short circuit studies. Typically, loads such as motors, contribute to the arcing fault current. The calculator does not take this into consideration.

### **ACCURACY AND CONSERVATISM**

Before completing an arc flash hazard study, it is vital to decide how precise or conservative the study needs to be. Arc flash study methodologies rely on theoretical and empirical formulas. It has been noted that there is some changing behavior of arcing faults that may end in actual occurrences that are different from anticipated figures. Even though the theoretically maximum arcing power has been used by NFPA methodologies (which is believed to be safer) arcing currents can randomly change. This impacts the fault clearing time, and therefore the incident energy to which staff may be exposed.

Hence, when completing the review, it is vital to address all aspects of variability in order to be truly conservative. This demands us to take into account a range of possible values rather than just a single value collected from short circuit studies.

Additional assessment time is needed to consider a range of figures instead of a single figure. Nevertheless, this eliminates possibilities of error and gives higher accuracy. Recently, it was proposed that over-protection of staff could cause higher chances of accidents as the staff movement could be limited due to excess PPE. The IEEE Standard 1584 was made using test findings to avoid over-protection from theoretical formulas. Even though completed tests may have shown that the theoretical maximum arc power was not met during the tests, the chance of its occurrence cannot be neglected. Hence, taking theoretical formulas to be conservative is valid. Even though not always true, the table below gives typical observations on various calculations methodologies.

Table 3. General observations on various calculation methodologies

Method	Description
NFPA 70E Annex B	Conservative
IEEE 1584	Statistically Probable
Scenario Analysis	Improved Accuracy

Study case assessment is a standard feature in power system study software and it provides easy assessment of all system arrangements and operating conditions and for bracketing arcing current ranges.

### OVERPROTECTION

When arc flash hazard study is too conservative, the analysed hazard/risk category or the incident energy may need the staff to wear more protective gear than is practically needed. Extra layers of thick fire resistant clothing, face shields, and thick gloves may render the work rather hard. This situation has the following drawbacks:

1. The difficulty given by the PPE may lead to incidents that can be prevented by slightly less but sufficient PPE.
2. Longer time is taken by an employee to complete a task when wearing heavier PPE, hence reducing overall productivity. Safety should not be compromised to enhance productivity, nevertheless, over-protection cannot achieve higher safety.
3. Staff may be demoralized with the chore of having to put on extra PPE.

### ESTIMATE OF HUMAN RESOURCES

Table 4 gives a guide for assessment of the hours of work needed for different types of work for an expert level. Novices and trainees should allow for additional 50-100% of time to produce the study. Table 4 presents an estimate of hours of work needed for arc flash hazard study for a typical facility. This is only an example and the needs for human effort may differ with company, system complexity, and data availability. In this example, all the assessment is done from the beginning, i.e. no short circuit assessment was previously completed. Some companies may have up-to-date information of the

electrical power system with short circuit and coordination studies already performed. For such companies arc flash hazard study is just another step. The given approximations include comprehensive written assessments for each aspect of the study. This type of comprehensive documentation gives the basis for an overall safety process, and ensures elaborated reasoning and application should OSHA or your insurer start an audit due to an incident.

**Table 4. A guide for assessing time to perform arc flash hazard study**

<b>Task</b>	<b>Category</b>	<b>Hours</b>	<b>Per Equipment</b>
Data Collection		2	Substation
		0.1	Load
Data Entry and Verification	Short Circuit	0.15-0.25	Bus
	Protective Device Data	0.1-0.25	Device
Short Circuit Study	Analysis	0.1-0.25	Bus
	Report	0.1-0.25	Bus
Protective Device Coordination	Analysis	0.4	Device
	Report	0.15-0.4	Device
Arc Flash Hazard	3-Scenario Analysis	0.25	Bus
	1-Scenario Analysis	0.1-0.25	Bus
	Report	0.1-0.25	Bus
	Warning Labels (by program)	0.05	Equipment

Typically, approximations can be completed for other activities such as staff training, safety check, documentation (much of the documentation has already been completed during the study), procurement and distribution of PPE and finalizing safety processes for arc flash hazard.

**Table 5. Assessment of hours for arc flash hazard study for a facility with 350 buses at four different voltage levels and 56 substation, using commercial power system software**

<b>Task</b>	<b>Hours</b>	<b>% of Total</b>
Data Gathering	136	18%
Data Input and Verification	64	9%
Short Circuit Computations	80	11%
Protective Device Coordination	336	46%
Arc Flash Hazard Study	120	16%
<b>Total</b>	<b>736</b>	

## BUDGET ESTIMATES

Budget estimates for human efforts can be obtained from the hours of work required for the arc flash hazard process. The PPE cost can be evaluated using the highest likely risk category. This can be roughly decided using the table methodology for the greatest available fault current. Other expenses will include consulting fees for safety training, printing warning labels, etc.