

Arc Flash Hazard Analysis

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“If a worker is required to be within the Flash Protection Boundary, then PPE must be selected for the expected incident energy.”

Arc Flash Hazard Analysis is Required

OSHA's 29 CFR Part 1910.132(d) states:

The employer shall assess the workplace to determine if hazards are present, or are likely to be present, which necessitate the use of personal protective equipment (PPE). If such hazards are present, or likely to be present, the employer shall:

1910.132(d)(1)(i)

Select, and have each affected employee use, the types of PPE that will protect the affected employee from the hazards identified in the hazard assessment;

1910.132(d)(1)(ii)

Communicate selection decisions to each affected employee; and,

1910.132(d)(1)(iii)

Select PPE that properly fits each affected employee.

Additionally 29 CFR Part 1910.335 calls for the employer to provide “...electrical equipment that is appropriate for the specific parts of the body to be protected and for the work to be performed...” when employees are called upon to work wherever there is a potential electrical hazard.

NFPA 70E Standard for Electrical Safety in The Workplace is viewed by OSHA as an industry consensus standard that can be used by employers as guides to making the assessments required by OSHA standards. Section 110.8(B)(1) of NFPA 70E requires that an electrical hazard analysis be performed to ensure that workers are properly protected whenever they work on or near equipment that is not in an “electrically safe condition”. This includes work required to deenergize the equipment. Refer to Article 120 for guidance on putting equipment in an electrically safe condition.

Part of an electrical hazard analysis is an arc flash hazard analysis. According to NFPA 70E Section 130.3, the goal of arc flash hazard analysis is to identify:

The Flash Protection Boundary, defined in Article 130.3(A) as “an approach limit at a distance from exposed live parts within which a person could receive a second degree burn if an electrical arc flash were to occur.”

The proper personal protective equipment (PPE) and protective clothing necessary, based on an incident heat energy calculation for the working distance for the task to be performed, as described in Article 130.3(B) and Article 130.7. The results of the incident energy calculations are typically expressed in cal/cm².

Appropriate safety related work practices.

NFPA 70E cites two approaches to proper PPE selection: an analytical method and a table-based method. Performing an arc flash hazard analysis by an analytical method provides the additional benefit of an in-depth look at your electrical system. The results of the analysis can be used to reduce arc flash energies, improve overall system performance, reduce downtime and better manage costs.



Figure 1: PPE for Hazard/Risk Category 2 (right) and 4 (left). {Courtesy of WH Salisbury Co.}

Using an Analytical Method to Select PPE

Appendix D of NFPA 70E and the IEEE Standard 1584™-2002, Guide for Performing Arc Flash Hazard Calculations, provide guidance on performing an arc flash hazard analysis. IEEE 1584 identifies a systematic, nine-step approach for performing a comprehensive arc flash hazard analysis.

Since fault current and time are two of the most important variables in the calculations, the process begins with a short circuit study to determine the available “bolted” fault current at each location in the system. Arcing fault currents are less than the maximum bolted fault current and must be estimated. Let through data must be obtained for current limiting overcurrent protective devices. Clearing times for all other overcurrent protection device must be obtained to accurately predict the duration of the arc fault current. See the following section for additional details and other factors that affect arc flash energies.

A choice of formulas for calculating the Flash Protection Boundaries and incident energy can be found in NFPA 70E and IEEE 1584. Note that IEEE 1584 contains separate equations for calculating the dramatic reduction in arc flash energies possible with certain current limiting fuses. Using these fuses can significantly reduce the energy delivered to an arc fault and thus the category of PPE workers are required to wear. See Arc Flash Notes 2 and 4 for additional information.

If a worker is required to be within the Flash Protection Boundary, PPE must be selected for the expected incident energy calculated during the analysis. Protective clothing must be chosen so that the clothing rating in cal/cm² is greater than the calculated incident energy. When this rating is determined by testing according to appropriate ASTM standards, the clothing should, in most cases, protect the majority of the worker’s body from receiving 2nd degree burns.

NFPA 70E 130.7(C) contains extensive information and guidelines on the selection of PPE for work where electrical hazards are present. These sections include protection of head, face, neck , chin, eyes, body, arms, hands, feet and legs. Section 130.7(C)(13) covers arc flash protective equipment in more detail.

NFPA 70E provides Table 130.7(C)(11) for general information for selecting clothing based on Hazard / Risk Categories. These categories are referred to frequently in selecting PPE. Note that with the exception for Category 0, Flame-Resistant (FR) clothing of adequate rating is required for all workers that must be within the Flash Protection Boundary. As the table indicates, layering is typically required to achieve higher ratings. Non-FR synthetic fiber clothing, including blends of synthetic fibers with cotton, is prohibited for all layers because it not only easily ignites but can melt into workers flesh - even as an under layer. For a discussion about APTV and E_{BT}, see the note to the table in NFPA 70E.

Hazard/ Risk Category	Clothing Description	Number of Layers	Minimum Arc Rating of PPE (cal/cm ²)
0	Non-melting, flammable materials such as untreated cotton	1	N/A
1	FR Shirt and FR pants or FR coverall	1	4
2	Cotton underwear plus Category 1	2	8
3	FR Coverall over Category 2	3	25
4	Multi-layer flash suit over Category 2	4	40

Table 1: Typical Protective Clothing Characteristics taken from Table 130.7 (C) (11) from NFPA 70E

Working on energized components, and hence selection of PPE should be the last alternative considered. As such, PPE should be viewed as the last line of defense for protecting workers.

The Nine Steps of Arc Flash Hazard Analysis

Section 4 of IEEE 1584 states that the results of the arc flash hazard analysis are used to “identify the Flash Protection Boundary and the incident energy at assigned working distances throughout any position or level in the overall electrical system.”

Section 4 also suggests a nine-step approach to arc flash hazard analysis. The following contain a brief synopsis of each step. Refer to IEEE 1584 for more information and be certain to read the cautions and disclaimers carefully.

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Step 1: Collect System and Installation Data.

The data needed for an arc flash hazard analysis is similar to that needed for a short circuit and coordination study. It is essential to model the system in detail to get a reasonable assessment of the arc flash hazard. For many facilities, this will mean collecting all the data needed to build an up-to-date one-line diagram.

For facilities with a recent short circuit study, it may mean:

- Extending the existing study to include control equipment.
- Refining a study that omitted impedances to ensure calculations of the highest possible short circuit currents. Worst-case arc flash energies may be achieved with lower fault currents if clearing times for overcurrent protective devices are considerably longer.

Suggested data collection forms are included in the IEEE guide, as are other useful tips on collecting data from your system and your utility.

Step 2: Determine System Modes of Operation.

The IEEE 1584 guide provides examples of different modes of operation, including operation with more than one utility feed, tie breakers opened or closed, and generators running. This information is important in determining the different short circuit currents that might be available to each location for the different modes. As noted in Step 1, the highest available fault current may not yield the worst-case arc flash energy, since the worst-case energy also depends on the opening time of the overcurrent protection devices.

Step 3: Determine Bolted Fault Currents.

Calculate the bolted fault currents from the data gathered in Step 1 and Step 2. Refer to IEEE Std 141-1993 (IEEE RedBook™) for details on methodology pertaining to these calculations. The typical method is to enter the data into a commercially available software program that allows you to model your system and easily switch between modes of operation.

Step 4: Determine Arc Fault Currents.

The bolted fault current calculated for each point in the system represents the highest possible fault current expected to flow to that point. In the case of an arcing fault, the current flow to the fault will be less, due to the added impedance of the arc. It is important to adequately predict these lower current levels, especially if the overcurrent protective devices are significantly slower at these reduced levels, as these situations have been known to provide worst-case arc fault hazards.

Step 5: Find Protective Device Characteristics and Duration of Arcs.

IEEE 1584 offers guidance on using the time-current curves of overcurrent protective devices including how to handle average-melt-time-only curves and relay-operated circuit breakers, for example. For certain types of current limiting fuses, time-current curves are not required, because their characteristics have been incorporated into the final Flash Protection Boundary and incident energy equations.

Step 6: Document System Voltages and Classes of Equipment.

Factors that affect arc energies, such as bus gap and voltage, are required for IEEE 1584 equations. A table is provided with typical bus gaps for various equipment up to 15kV.

Step 7: Select Working Distances.

Typically, this is assumed to be the distance between the potential arc source and the worker's body and face. Incident energy on a worker's hands and arms would likely be higher in the event of an arcing fault because of their closer proximity to the arc source. Typical working distances for various types of equipment are suggested in a table.

Step 8: Determine Incident Energy for All Equipment.

The analyst will need to choose equations based upon voltage level, type of overcurrent protective device and equipment. In addition to the current limiting fuse equations, the IEEE guide provides other equations that call for the data described above. These calculations provide heat energy densities in either cal/cm² or joules/cm², values necessary in selecting appropriate PPE and FR clothing. Because of the complexity and number of manual calculations possible, software is recommended to complete this step. Most software gives you a choice of equations, including three other incident energy equations identified in Appendix D of NFPA 70E. Factors affecting the choice of equations include: type of equipment, voltage levels and protective devices. A spreadsheet-type calculator is included with IEEE 1584 and can be useful for sample calculations and small systems.

Step 9: Determine Flash Protection Boundary for All Equipment.

Instead of solving for cal/cm² at a given working distance, this equation solves for a distance at which the incident heat energy density would be 1.2 cal/cm² (or 5.0 joules/cm²). Due to the same reasons mentioned in Step 8, software is also recommended for this calculation.

Using the Table Method to Select PPE

NFPA 70E also offers Table 130.7(C)(9)(a) as an acceptable method for selecting protective clothing and other PPE. In order to do so, you must be certain that the parameters of your electrical system are covered by these tables and their various footnotes.

The steps required to select PPE with the table method are:

1. Identify the type of equipment that will be accessed while not in an electrically safe condition.
2. Confirm that fault current limits identified in 130.3(A) for flash protection boundary apply. If the available fault current is less than 50,000A and the clearing time is less than 6 cycles (300kA cycles) then the default Flash Protection Boundary of 4 feet can be used.
3. Confirm that the notes of Table 130.7(C)(9)(a) regarding available fault current and clearing times apply to the application.
4. Locate the equipment and task to be performed within Table 130.7(C)(9)(a), .
5. Identify the Hazard/Risk Category and the need for Voltage Rated gloves and tools.
6. Identify the required Flame-Resistant (FR) clothing and other personal protective equipment using Table 130(C)(10), Protective Clothing and Personal Protective Equipment Matrix.

An excerpt of Table 130.7(C)(9)(a) is shown below in Figure 2 for selecting the proper PPE for testing voltage in a 480V motor control center that is protected by a circuit breaker with a clearing time of 2 cycles for the available fault current of 25,000A. Since the fault current is less than the 65,000A identified in Note 2 and the clearing time is within the approved range, the table is acceptable. For this situation the Hazard / Risk Category is 2* and both voltage rated gloves and tools are required.

Referring to Table 130(C)(10) reveals that Hazard / Risk Category 2* requires the following:

- A short sleeve T-shirt and long pants made from untreated natural fiber or other fiber that is nonmelting per ASTM F1506-00.
- An outer layer of a FR long sleeve shirt and FR pants. Alternatively FR coveralls are allowed.
- The "2*" requires the use of a double layered arc flash rated hood.
- Other PPE identified includes a hard hat, safety glasses (or goggles), hearing protection, leather gloves and leather work shoes.

See NFPA 70E 130.7 for more information on the requirements for PPE and FR clothing. Use of current limiting fuses may reduce the level of PPE required. See Arc Flash Note 2.

Standards Referenced

- OSHA 29 CFR Part 1910.132
- OSHA 29 CFR Part 1910.335
- NFPA 70E Standard for Electrical Safety in the Workplace
- IEEE Std 1584™ - 2002
IEEE Guide for Performing Arc-Flash Hazard Calculations

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Task Assumes Equipment is Energized and Work is Done Within the Flash Protection Boundary	Hazard / Risk Category	V-Rated Gloves	V-Rated Tools
600 V Class Motor Control Centers (MCC's) - Notes 2 (except as indicated) and 3			
Work on energized parts, including voltage testing	2*	Y	Y
Work on control circuits with energized parts >120V, exposed	2*	Y	Y
Insertion or removal of individual starter buckets from MCC—Note 4	3	Y	N

Figure 2: Hazard/Risk Category Classifications excerpted from NFPA 70E Table 130.7(C)(9)(a).

Note:

- V-rated Gloves are gloves rated and tested for the maximum line-to-line voltage upon which work will be done.
- V-rated Tools are tools rated and tested for the maximum line-to-line voltage upon which work will be done.
- 2* means that a double layer switching hood and hearing protection are required for this task in addition to the other Hazard/Risk Category 2 requirements of Table 130.7(C)(10).
- Y= Yes (required); N= No (not required)

Notes:

- 2. (Maximum of) 65kA short circuit current available , 0.03 second (2 cycle) fault clearing time.
- 3. For < 10kA short circuit current available, the hazard/risk category required may be reduced by one number.

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