Arc Flash Analysis: IEEE Method versus the NFPA 70E Tables

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Summary

1.0 Abstract

Recent changes in workplace safety regulations have heightened the awareness of hazards associated with electrical arcs. The hazard level must be quantified and workers properly protected before entering proximity of exposed energized conductors. National Fire Protection Association's (NFPA) standard 70E provides the guidelines for work involving electrical hazards and the selection of arc flash protective equipment. In order to properly select the protective gear one must have knowledge of the potential thermal energy of the electric arc. Institute of Electrical and Electronics Engineers (IEEE) standard 1584 has been the de facto standard for calculating the arc energy levels at different points in the electrical power system.

However, NFPA 70E also provides the option of using the Hazard/Risk Category (HRC) task tables for personal protective equipment (PPE) selection. These tables provide pre-defined levels of PPE, which are based on the available short circuit current and the speed of the overcurrent protective device. Therefore, in order to properly apply the tables, some degree of electrical calculations must be performed and the tables could be subjected to misuse if they are applied without knowledge of the necessary
calculations.

In this paper the basic differences between the IEEE 1584 method and the NFPA 70E task tables are discussed and a recommended specification is provided for facility owners who are interested in achieving compliance with the regulations.

2.0 OSHA and NFPA Rules

OSHA has enacted new rules in a concerted effort to reduce electrical-related work fatalities. Part 1910 of 29 CFR contains several rules that prescribe requirements for clothing, training, and hazard assessment when employees are exposed to electrical hazards. OSHA has been writing citations to facilities that are not in compliance with arc flash requirements.

NFPA 70E, the Standard for Electrical Safety in the Workplace, was created to provide OSHA a standard for establishing safe work practices for electrical workers. Among other things, this document requires hazard analysis and aids in the selection of personal protective equipment (PPE). Minimum approach boundaries are also established. NFPA 70E states that facilities must provide:

1. A safety program with defined responsibilities
2. Calculations for the degree of arc flash hazard
3. PPE for workers
4. Training for workers
5. Tools for safe work practices

It must be noted that de-energizing equipment does not absolve the facility from the responsibility of performing the arc flash analysis or providing the necessary PPE. Both OSHA and NFPA have basic rules that prohibit energized work. In order to establish that a circuit is de-energized, the circuit must be approached to verify that it has been de-energized. Until the verification testing is completed, the circuit must be considered energized per NFPA 70E. Therefore, the worker who approaches the circuit for verification testing must wear full PPE. Hiring contractors to perform electrical work does not absolve the facility from performing the calculations and providing the arc flash exposure levels to the contractor's workers.

3.0 Use of NFPA 70E Tables

NFPA 70E provides Hazard/Risk Category tables, which highlight specific personnel protective equipment to be used on various electrical distribution equipment. However, these tables are based on fundamental assumptions about the available fault current and the overcurrent device clearing time.

In order to use the tables, the person in charge must verify that the available fault current and the overcurrent protective device (OCPD) tripping time are both equal to or lower than the values assumed for developing the tables. This essentially requires performing the majority of the calculations that are necessary for determining the arc flash energy.

However, a common but incorrect approach to using the tables is to select the PPE based on the equipment and voltage levels only and ignore the limitations imposed by the fault current and overcurrent protective device operating time. This simplistic

3.0 Use of NFPA 70E Tables (con't.)

approach could subject the electrical workers to either too little PPE (risk of injury) or too much PPE (risk of reduced mobility). In order to provide appropriate protection for electrical workers, the necessary calculations must be performed to establish the short circuit currents and the OCPD opening times. Only then can the NFPA 70E tables be effectively used. In fact, the NFPA 70E committee recognized the importance of these parameters and moved them from the end notes to the body of the table for the 2012 edition in order to draw attention to this important information.

Table 1 summarizes the basic differences in methodology between the simplistic method of using NFPA 70E task tables (without performing short circuit and coordination studies) versus the IEEE 1584 method.

Table 1

Specification Item	IEEE 1584 Method	Mis-Applied Table[1] Method	Description of Specification Item and Why it is Important
Provide complete electrical system data collection	Yes	No	During data collection all components of the electrical system are documented to establish their characteristics and settings
Establish all modes of operation	Yes	No	Which modes of operation may be in effect? (Utility feeders, generators, UPS systems, etc.)
Establish available fault current at each piece of equipment under study (short circuit study)*	Yes	No	Available fault current must be accurately known in order to verify proper equipment application
Determine arcing fault current for each piece of equipment under study	Yes	No	The arcing current must be determined in order to calculate the arc flash hazard levels
Determine protective device characteristics and arc fault duration	Yes	No	Arc fault duration is critical to establish the arc flash hazard incident energy and PPE requirements
Determine incident energy (calories per CM^2) for each piece of equipment under study	Yes	No	Incident energy calculation will determine the Personal Protective Equipment (PPE) that workers must wear
Document system voltages and classes of equipment	Yes	Yes	Voltage level for each piece of equipment must be known and labeled for shock protection
The work shall be overseen by registered professional engineers (P.E.)	Yes	Unknown	By state law, engineering work must only be performed by engineers licensed in the state where the facility is located
The work shall identify opportunities to improve code compliance and over-dutied equipment and make recommendations on strategies to reduce high arc flash hazard levels (time-current coordination study)	Yes	No	In order to make equipment maintainable, this information must be known. System reliability requires properly coordinated overcurrent devices.
Arc Hazard warning labels shall be provided for the equipment	Yes	Yes	Required by the NFPA 70E

(1) Incorrect application of the task tables without evaluating short circuit currents and OCPD opening times

* The short circuit study establishes the available fault current.

The NFPA 70E task tables 130.7(C)(15)(a) will provide estimates of the PPE hazard risk category, but they cannot be used properly without knowing the available fault current and clearing time.

4.0 IEEE 1584 Analysis Procedure

The IEEE 1584 analysis procedure begins with a complete data collection from the power system. Characteristics of the power source – utility or generator – and the power system components such as transformers and cables, as well as the tripping characteristics of overcurrent protective devices are identified and entered into a digital computer program. The program first calculates the bolted 3-phase short circuit current at each bus of concern in the system. Then the arc fault current is calculated at each location. For low voltage systems, the arc fault current will be lower than the bolted fault current because of arc impedance.

Next, under the arc-fault current condition, the clearing time of the protective device protecting the bus is determined. For fuses, the manufacturer's total clearing time is used. For low voltage breakers, the right hand side of the manufacturer's time-current curve band is used. For relayed medium voltage breakers, the relay's curve shows only the relay operating time and the particular breaker's opening time must be added to this time.

Following the clearing time determination, the working distance at each bus is selected. Next, incident energies are calculated for each bus. Incident energy is the amount of energy impressed on the face and body of the electrical worker. One of the units used to measure incident energy is calories/cm^2.

The flash protection boundary based on an incident energy of 1.2 calories/cm^2 is calculated. This is the generally accepted energy level that causes the onset of a second-degree burn. Finally, the hazard risk category and the worker's protective clothing system for each bus under consideration are determined.

All arc flash hazard analysis results are presented in an easy to understand format. A summary spreadsheet, such as the one shown below, will be presented as part of the final analysis.

Adequate PPE may be required during load interruption, during the visual inspection that verifies that all disconnecting devices are open, and during the lockout/tagout.

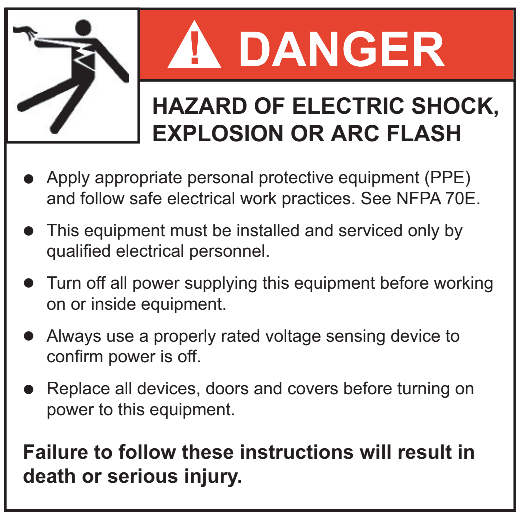
Table 2: Example of information provided in the final analysis.

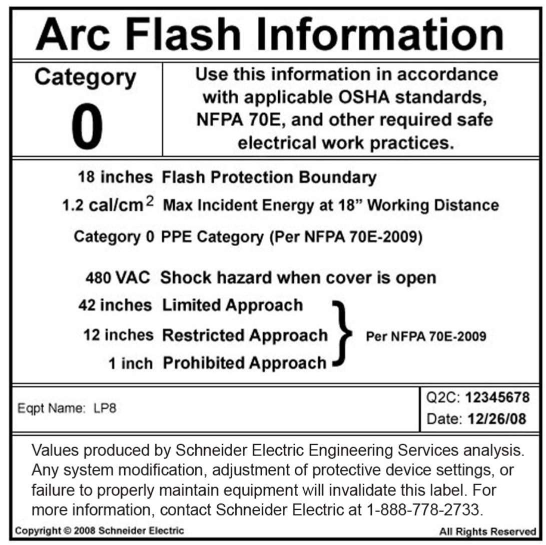
	BUS Name		
	100 T-920A	**101 PNL PCA**	**102 TD-304**
Protective Device Name	004 Dual	101 PCA Main	101 PCA-10
kV	0.48	0.48	0.48
Bus Bolted Fault (kA)	14.81	14.31	7.51
Protective Device Bolted Fault (kA)	13.65	13.15	7.51
Arcing Fault (kA)	8.45	8.19	5.14
Time / Delay Trip (sec)	1.451	0.04	0.017
Breaker Opening Time (sec)	0	0	0
GND	Yes	Yes	Yes
Equipment Type	PNL	PNL	PNL
GAP (mm)	25	25	25
Arc Flash Boundary (in)	145	18	7
Working Distance (in)	18	18	18
Incident Energy (cal/cm^2)	36.8	1.17	0.27
Hazard / Risk Category Number	4	0	0

5.0 Arc Flash Labels

Where specified in the scope of work, arc flash labels are provided. The data in the labels will be populated based on the arc flash calculation software output. The labels must have the following characteristics.

1. UL 969 standard compliance for durability and adhesion
2. Include shock protection data per NFPA 70E in addition to arc flash hazard data





6.0 Conclusion

In order to correctly apply the NFPA 70E Hazard/Risk Category task tables, knowledge of the available short circuit current and the opening time of the overcurrent protective device is required. A common misapplication of the tables occurs when they are applied solely based on the class of equipment and the system voltage. This results in an incomplete hazard evaluation and PPE that may be too little or too much.

The IEEE 1584 method, however, is a systematic approach which calculates the exact arc flash energies from the electrical power system parameters. Schneider Electric Engineering Services (SEES) recommends a complete data collection from the power system in order to generate short circuit and coordination studies in addition to arc flash energy calculations. Our recommended specification for arc flash studies is provided in the next section.

7.0 Recommended Specifications: Electrical System Power Studies

Part 1: General

1.01 Summary

A. A registered electrical engineering firm shall provide electrical power sytem studies for the project. The type and content of each study is specified in the following articles.

1.02 Submittals

A. Completed electrical power system studies shall be submitted to the facility owner in electronic format using Adobe Acrobat.

Part 2: Product

2.01 Manufacturers

A. The specified electrical power system studies shall be performed by Schneider Electric Engineering Services or approved equal.

2.02 Electrical Power System Studies

A. Power System Data Collection

1. Power system data collection shall be performed by or under the direction of a professional engineer.
2. Complete data shall be obtained from
   - The power sources (utility, generator or UPS)
   - Impedance components such as transformers, cable and busway
   - Overcurrent protective devices such as fuses, circuit breakers and relays
   - Equipment short circuit ratings

B. Short Circuit Analysis

1. Calculation of the maximum root mean square (rms) symmetrical three-phase short-circuit current at each significant location in the electrical system shall be made using a digital computer.
2. Appropriate motor short-circuit contribution shall be included at the appropriate locations in the system so that the computer calculated values represent the highest short-circuit current the equipment will be subjected to under fault conditions.
3. A tabular computer printout shall be included which lists the calculated short-circuit currents, X/R ratios, equipment short-circuit interrupting or withstand current ratings, and notes regarding the adequacy or inadequacy of the equipment.

7.0 Recommended Specifications (con't.)

4. The study shall include a computer printout of input circuit data including conductor lengths, number of conductors per phase, conductor impedance values, insulation types, transformer impedances and X/R ratios, motor contributions, and other circuit information as related to the short-circuit calculations.
5. Include a computer printout identifying the maximum available short-circuit current in rms symmetrical amperes and the X/R ratio of the fault current for each bus/branch calculation.
6. The system one-line diagram shall be computer generated and clearly identify individual equipment buses, bus numbers used in the short-circuit analysis, cable and bus connections between the equipment.
7. A comprehensive discussion section evaluating the adequacy or inadequacy of the equipment must be provided and include recommendations as appropriate for improvements to the system.
8. Any inadequacies shall be called to the attention of the facility owner and recommendations made for improvements as soon as they are identified.

C. Protective Device Time-Current Coordination Analysis

1. The time-current coordination analysis shall be performed with the aid of a digital computer and shall include the determination of settings, ratings, or types for the overcurrent protective devices supplied.
2. Where necessary, an appropriate compromise shall be made between system protection and service continuity.
3. A sufficient number of computer generated log-log plots shall be provided to indicate the degree of system protection and coordination by displaying the time-current characteristics of series connected overcurrent devices and other pertinent system parameters.
4. Computer printouts shall accompany the log-log plots and shall contain descriptions for each of the devices shown, settings of the adjustable devices, the short-circuit current availability at the device location when known, and device identification numbers to aid in locating the devices on the log-log plots and the system one-line diagram.
5. The study shall include a separate, tabular computer printout containing both the existing settings as well as the recommended settings of all adjustable overcurrent protective devices, the equipment designation where the device is located, and the device number corresponding to the device on the system one-line diagram.
6. A computer generated system one-line diagram shall be provided which clearly identifies individual equipment buses, bus numbers and device identification numbers.
7. A discussion section which evaluates the degree of system protection and service continuity with overcurrent devices, along with recommendations as required for addressing system protection or device coordination deficiencies.

7.0 Recommended Specifications (con't.)

8. Significant deficiencies in protection and/or coordination shall be called to the attention of the facility owner and recommendations made for improvements as soon as they are identified.

D. Arc Flash Hazard Analysis

1. The Arc Flash Hazard Analysis shall be performed with the aid of a digital computer in order to calculate Arc Flash Incident Energy (AFIE) levels and arc flash protection boundary distances.
2. The Arc Flash Hazard Analysis shall be performed in conjunction with a short-circuit analysis and a time-current coordination analysis.
3. Results of the Arc Flash Hazard Analysis shall be submitted in tabular form, and shall include device or bus name, bolted fault and arcing fault current levels, flash protection boundary distances, personal-protective equipment classes and AFIE levels.
4. Circuits less than 240 V supplied from transformers less than 125 kVA may be omitted from the computer model and will be assumed to have a hazard risk category 0.
5. The Arc Flash Hazard Analysis shall be performed utilizing mutually agreed upon facility operational conditions, and the final report shall describe, when applicable, how these conditions differ from worst-case bolted fault conditions.
6. The Arc Flash Hazard Analysis shall be performed by a registered professional engineer.
7. The Arc Flash Hazard Analysis shall be performed in compliance with IEEE Standard 1584-2002, the IEEE Guide for Performing Arc Flash Calculations.
8. The Arc Flash Hazard Analysis shall include recommendations for reducing AFIE levels and enhancing worker safety.
9. The Arc Flash Hazard Analysis shall report incident energy values based on the existing incident energy values at all buses within the scope of the study in addition to incident energy values based on the recommended overcurrent device setting changes.
10. The proposed vendor shall have at least 10 years experience performing Arc Flash Hazard Analysis Studies and demonstrate their experience by submitting names of at least 10 actual Arc Flash Hazard Analyses it has performed in the past year.
11. The proposed vendor shall include a separate line item in their quote to provide equipment labels. The labels shall comply with relevant NEC and NFPA standards as well as UL 969 and must include the following information:
    - Equipment Name
    - AFIE value (cal/cm^2)
    - System Voltage
    - Restricted Approach Boundary
    - AFIE flash hazard boundary
    - Hazard Risk Category
    - Limited Approach Boundary
    - Prohibited Approach Boundary
12. The data fields on the label shall be populated from the results of the Arc Flash Hazard Analysis. Where circuits have been omitted from the computer model as permitted by an applicable industry standard a generic label shall be provided.

7.0 Recommended Specifications (con't.)

13. The proposed vendors shall include separate line items in their quote to provide AFIE label installation.
14. Single phase AC distribution systems are not included in the scope of the analysis.

Photo © Oberon 2005

8.0 References

1. Occupational Safety and Health Standards, 29CFR, Part 1910, Subpart S, Electrical, *Occupational Safety and Health Administration (OSHA)*

2. Standard for Electrical Safety in the Workplace, NFPA 70E - 2012, *National Fire Protection Association (NFPA), Quincy, MA*

3. IEEE Guide for Performing Arc-Flash Hazard Calculations, IEEE Standard 1584 – 2002, *Institute of Electrical and Electronics Engineers, New York, NY*

4. Update of Field Analysis of Arc Flash Incidents, PPE Protective Performance and Related Work Injuries, Doan, Hoagland and Neal, *IEEE IAS Electrical Safety Workshop, February 1-5, 2010, Memphis, TN*