An Overview of Arc Flash Risk Assessments

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Abstract

Recently, arc flash risk assessments have become more challenging as a result of additional researching and modelling implications required to comply with the 2015 version of the NFPA 70E. Prior to 2015, the applicable codes defaulted to the IEEE, which states "equipment below 240V need not be considered unless it involves at least one 125 kVA or larger low-impedance transformer in its immediate power supply". The current updates now require a hazard analysis for all equipment rated higher than 50V.

Electrical arc flash protection is becoming a larger concern throughout the industry as a result of numerous injuries, especially with work on live equipment becoming more commonplace in many industries. Arc fault can result from many things, including failed/damaged equipment or wiring, loose connections, transients, and system faults. Arc flash is a rapid release of energy due to an arcing fault, in which the air serves as the conductor. Typically, the bus voltage is greater than 120V since lower levels generally will not sustain an arc. After the initial flash, the fault is sustained through highly conductive plasma which typically vaporizes the bus bars, causing an explosive blast creative, releasing radiation and creating shrapnel as it dissipates.

These events raise concerns for nearby safety personnel and property. Some key considerations for individuals responsible for facility safety relating to these events include:

- Protecting personnel from potential harm (severe burns, hearing damage, and eye injuries) and preventing loss of life.
- Complying with Occupational Safety and Health Administration (OSHA) codes and with National Fire Protection Association (NFPA) standards on employee safety, NFPA 70E.
- Preventing loss to companies through loss of skilled laborers, litigation fees, higher insurance costs, and loss of morale.
- Reducing accidents that result in increased process uptime.
- Meeting requirements of insurance carriers.

This paper identifies the codes that help to establish safer practices relative to arc flash. The basis for the arc flash protection of personnel as defined by the industry is to establish guidelines to limit injuries to onset of second degree burns ($\leq$ 1.2 calories/cm^2). The basic means to do this fall into the following categories:

- Ensure that only qualified personnel are completing work on the electrical system.
- Energized work is only permitted where it can be demonstrated that de-energizing the equipment will introduce additional hazards/increased risk, or that the task to be performed is infeasible in a de-energized state due to equipment design or operational limitations. In any of these cases an energized work permit shall be completed to justify those limitations. Otherwise, all equipment should be placed in an electrically safe condition.

- Proper PPE shall be worn at all times while completing electrical work, but should be considered a last line of defense, and not as a replacement for safe work practices or engineering controls that can help limit exposure to arc-flash hazards.
- A hazard risk assessment/analysis shall be completed for all systems. The key variables for determining arc flash hazards are distance, magnitude, time, and PPE.

Methodology

The following steps are required in order to complete the hazard analysis:

1. Data Collection: conduct site visit to collect relevant information including:
   - Utility source – available short circuit current under normal conditions (and if available under contingency conditions such as minimum short circuit current, line/transformer out-of-service, and maximum short circuit), voltage, and transformer X/R ratio
   - Protective devices – fuses (manufacturer, type, size/rating, and speed), relays (manufacturer, type, settings, current transformer ratios, circuit breaker opening time)
   - Transformers – nominal rating (kVA), primary/secondary voltages, percent impedance, grounding configuration (solidly, impedance grounded, ungrounded)
   - Conductors – size, type, conduit material, conductors/phase, length, insulation type
   - Motors – size (hp), voltage, locked rotor code
   - Grounding system - configuration grounded/ungrounded, high/low resistance grounding
   - Distribution Equipment – type (switchboard, switchgear, motor control center, panel, other)
   - Over Current Devices – low voltage circuit breakers (manufacturer, model, trip sensor ratings, available settings, exiting settings), fuses (manufacturer, model, current ratings), overcurrent relay (manufacturer, model, available settings, existing settings, current transformer ratio, circuit breaker opening time)
   - Determine power system mode of operation
2. Develop Single line
3. System modelling
4. Utilize software to create computer model and develop arc flash hazard analysis.
5. Arcing short circuit calculations
   - Apply 3 phase fault to each bus in the power system to calculate the bolted fault current at each bus and the bolted fault current through each protective device.
   - Calculate the arcing fault current at the bus and through each protective device. IEEE 1584; refer to calculation options section.
   - Determine the arcing duration.
6. Time current curve evaluation
7. Incident energy calculations

8. Determine working distances
9. Flash boundary calculations
10. Determine Personal Protective Equipment (PPE) requirements
11. Produce/install arc flash labels for installation on equipment. In accordance with recent updates to NFPA-70E, only one method of labelling may be used for a particular piece of equipment (use of general tables or incident energy calculations, not both).
12. Produce report of recommendations (low or no-cost, higher level of investment)

Two additional procedures are recommended to optimize the results of the study. Both of these steps require work from the client:

- Integrate the results of the study into your company's safety program (keep it simple, 1 or 2 standards to apply to multiple locations)
- Train employees

Calculations & Models

Arc flash hazard calculations can be carried out in several ways. Factors affecting the best method choice include available information, volume of calculation work, necessity for accuracy, availability of resources, and quality of arc flash hazard mitigation program. Whatever method is used, the qualified person performing the assessment should be aware of the limitations of the method employed, and should perform further engineering analysis to achieve best results.

Theoretical model

The Ralph Lee model tends to be conservative; the results of the theoretical model tend to be conservative for any system. In addition, since the theoretical model does not take into account other important factors, such as whether the arcing fault occurs in open air or inside an equipment enclosure, it is not suitable for calculation of incident energy levels or flash-hazard boundaries in a typical industrial or commercial facility. However, this method is useful for calculations where no other method has been developed (open air transmission systems and above 15kV).

NFPA 70E

NFPA 70E contains equations that allow for calculation of flash-protection boundary distances for systems operating at 600V or less, and also contains a method for selecting PPE that requires minimal calculations. Tables contained in Article130.7 define situations which require PPE and provide a simplified means to assign a PPE category for specific situations. These tables can be useful where minimal system information is available. This is the least accurate method and does not specify the exact PPE rating required (in cal/cm) due to the generalized nature of the method.

IEEE Standard 1584

The IEEE Guide for Performing Arc-flash Hazard Calculations provides the most comprehensive set of equations for calculating incident energy levels and flash-protection boundaries. These equations can

be utilized through multiple methods. The standards also present two calculation methods—general equations and simplified equations for circuit breakers and fuses.

Hand calculations

Hand calculations can be performed using NFPA 70E equations or IEEE 1584 equations for small radial distribution systems. This is time consuming and unsuitable for large systems. When performing many hand calculations, the risk of unnoticed errors being introduced into the calculations increases.

Spreadsheet calculator

IEEE Standard 1584 comes with a spreadsheet calculator that can be used to assess arc flash hazards. Similar spreadsheets can also be easily created using NFPA 70E equations. This calculator requires the user to enter available fault current data for each point of assessment. Required data for each point includes short circuit current and protective device trip times for each source. Because of the inability of the spreadsheet calculator to determine the trip time and short circuit currents, and because of the time-consuming nature of this process, assumptions and approximations have to be made, which compromise accuracy. This method is limited to radial single source systems, and the probability of errors increases with the size of the system.

Commercial integrated software

This is practical for all systems with multiple power sources and multiple scenarios of interconnections where improved accuracy is desired and where the system goes through ongoing changes over time. Once the data is entered into the software, carrying out hazard assessment takes very little time. Graphical integrated power system software packages (SKM, EasyPower, ETAP) can perform multiple aspects of engineering studies at once, such as short circuit calculations, protective device coordination, and arc flash assessment.

Differences

The NFPA 70E method estimates incident energy based on a theoretical maximum value of power dissipated by arcing faults, based on Ralph Lee's work. This is believed to be generally conservative. In contrast, IEEE 1584 estimates incident energy with empirical equations developed from statistical analysis of measurements taken from numerous laboratory tests. The IEEE method was intended to be realistic rather than conservative, and aims to avoid accidents due to limitations provided by over-protection to workers. Over-protection can also lead to the restriction of visibility and movement, discomfort, and reduces worker productivity. NFPA tables and hand calculations can be adequate (providing low to medium accuracy) for cases with a relatively low number of buses, limited voltage levels, radial systems with a single power source, and limited system changes. These methods require separate analysis for short circuit and selective coordination studies. Spreadsheets provide a method for increased buses, but still provide moderate accuracy and required separate studies for the various components of the analysis. Integrated software is more applicable to larger systems, with additional voltage levels and multiple power sources and changes in the system.

Selection of Optimal Method

Given the various methods, which is the best means to analyze your system, considering accuracy and conservatism? While several methods are available for calculation of arc-flash incident energy levels and flash-protection boundaries, they may yield widely different results for a given system location. There is not a clear-cut single method that is best for all situations. This is determined based on a number of aspects:

- Ensure the system falls within the constraints/limits of the specific method used.
- If using calculations or software, be sure to utilize the most up-to-date versions, since the methodologies are frequently updated based on new findings.
- Know which device clears the fault and use realistic fault current values.
- Quantify critical variables such as working distance, bus gap, equipment configuration, and system grounding.
- Typically, specific equations are optimal, but in situations where motor contribution makes up a significant portion of the total available fault current, use of the IEEE 1584 general equations over simplified, device-specific equations may be preferable. Incident energy is cumulative from the utility, generators, and motors.