Calculating Arc Flash Hazard Levels

Discover common mistakes in calculating arc flash hazard levels and how to avoid them.

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IEEE Standard 1584-2002, Guide for Performing Arc Flash Hazard Calculations, is the most widely used method of calculating arc flash hazard levels, and a realistic available fault current value provides critical input for proper evaluation. The analysis method requires a second calculation at 0.85 of the originally calculated arc fault current. This calculation is designed to transform the given available fault current and other parameters to a calculated arc flash current value.

Relying on the IEEE equations to compensate for an inaccurate available fault current can yield unacceptable results. IEEE 1584 wasn't designed with safety factors to accommodate all bolted fault current inaccuracies. This article focuses on some specific pitfalls in calculating the arc fault current for up to 1 kV.

IEEE 1584 BACKGROUND

Arc flash energy can inflict injury on nearby workers—and greater potential energy yields greater hazards. Engineers and facility operators are now determining the correct arc flash boundaries and personal protective equipment (PPE) requirements to protect workers from arc flash dangers. The OSHA Code of Federal Regulations is mandating adequate protection required by law. NFPA 70E: Standard for Electrical Safety in the Workplace was developed by consensus to explain how to comply with the OSHA laws.

NFPA 70E-2004 requires arc flash hazard analyses by either calculation or its table method. The 2009 edition will require visible posting of analysis results on the equipment. A calculation method was refined in the late 1990s and formally documented in IEEE 1584-2002, Guide for Performing Arc Flash Hazard Calculations.

Other calculation methods are used, but IEEE 1584 is the most widely applied and accepted, and can be more easily defended in a court situation.

IEEE 1584's calculation method predicts the arc flash dangers in terms of an arc flash protection boundary and the PPE level needed for worker safety. Engineers often use industry software packages to calculate arc flash hazards; however, without proper training, engineers can easily make erroneous conclusions. Common misapplications come from making assumptions similar to short circuit analyses, which aren't valid with arc flash analyses.

THE ROLE OF ARC FLASH CURRENT

To following equation demonstrates the concept of arc flash energy:

E = I2 * R * t

Where:

E = Energy released from arc flash in joules

I = Current through the arc flash in amps

R = Resistance of the arc flash in ohms

t = Duration of the arc flash in seconds

While this equation explains the energy concept, the variables are complex to use. The arc current value isn't the available bolted fault current; it's a smaller value because of the series arc flash resistance in the circuit. From this equation one can conclude that the arc current value greatly affects the resulting energy. The arc flash duration is also directly proportional to the energy released.

The upstream protective device operation controls the arc flash duration. A fuse or properly maintained overcurrent protective device has a predictable time to open the circuit with a specific arc current value. Thus, arc current impacts the released energy in two ways: directly through the current itself, and then through interacting with the overcurrent protective device to change the duration. This dual role of the arc current can disqualify some typical assumptions made with bolted fault-interrupting current analyses.

OVERVIEW OF THE CALCULATION PROCEDURE

To determine the required level of PPE, first calculate the heat energy density at a standard distance. This energy density can then be adjusted for the distance to the worker and the different channeling effects of an arc flash occurring in open air, as compared to those of an arc flash in a box.

The IEEE 1584 arch flash calculation includes nine steps:

Step 1: Collect the system and installation data

Step 2: Determine the system modes of operation

Step 3: Determine the bolted fault currents

Step 4: Determine the arc fault currents

Step 5: Find the protective device characteristics and the duration of the arcs

Step 6: Document system voltages and classes of equipment

Step 7: Select the working distances

Step 8: Determine the incident energy for all equipment

Step 9: Determine the flash-protection boundary for all equipment.

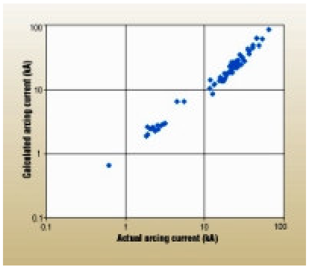
Commercially available software programs typically use this nine-step procedure. However, as mentioned above, without proper training, incorrect assumptions for data collection can be made. Incorrect data in the software program could yield inaccurate results.

For example, if the collected system data in Step 1 included only an estimate of available fault current from the utility that was actually the utility maximum value, that value could be misleading. An additional calculation with the minimum available fault current is required. The worst-case energy release can occur at either the minimum or maximum current value.

DEVELOPMENT OF THE ARC FLASH CURRENT EQUATION

The IEEE 1584 developers used an empirical calculation method instead of a theoretically based equation for the kV and below analysis.1 This empirical method was derived by taking data from laboratory-controlled conditions and altering many variables. The effects were examined on the arc current and the resulting released arc energy. The calculation considered open-circuit voltage, system grounding, bolted fault current, X/R ratio, gap between electrodes and box, and box size. The equations were developed using statistical analysis programs, including regression and curve-fitting analyses.

Upon completion, some variables were found to be more significant than others. Arc current depends primarily on the available bolted fault current, and arc time is proportional to the energy released from the arc fault.



The arc current can be found from equation 36 in IEEE 1584-2002, as shown in Figure 1. Used in its stated range, it has an R-square value of 98.3% (see Figure 2 on left). This means it's a predictor of the arc current value under standard laboratory conditions if the bolted fault current, system voltage, configuration, and distance between conductors are entered into the formula correctly.

The first use for the arc fault current is to calculate the heat density released by the arc flash for a standardized time. The equations developed in IEEE 1584 depend on this current value for subsequent steps. The heat energy density value will be used with the duration of the arc flash to find the resulting energy released.

Second, the arc fault current indicates duration by using the arc current going through the overcurrent protection device. This device opening time is often nonlinear, so a small change in current can result in a major duration variance.

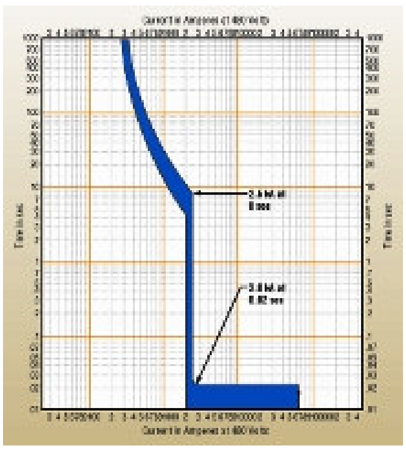


Figure 3, on left shows a device with a steeply sloped time-current curve. A minor change from 3 kA to 2.5 kA in arc current through the circuit breaker could result in the time duration increasing from 0.02 s to 8 s, a factor of 400. For this reason, the IEEE 1584 procedures require two separate calculations. Although the equations are accurate, variables in the arc flash event create a range of possible values.

The initial IEEE equation was modified to give lower arc fault currents in 95% of the situations, to be safe when the actual arc flash draws less current than the average. The final equation was developed from laboratory data, where the exact available fault current was known.

The resulting IEEE 1584 procedure for arc fault current determination uses an accurate bolted fault current for the first calculation and requires a second calculation using a 0.85 factor of the bolted fault current. Finally, the calculation uses the worst case for the total energy released. Sometimes the lower bolted current has much more energy released and has a higher hazard level.

Data input from the research labs was checked using the nine IEEE 1584 procedures against the resulting recommended PPE levels. The initially proposed equations didn't have enough safety factors built into them at 1 kV or less.

The final incident energy equation has a "calculation factor" of 1.5 that makes the total process safer, as described in Figure 4.

This results in PPE that has sufficient protection for 95% of incidents and, when added to the 0.85 procedure, results in a 95% confidence level. Table 1 illustrates the achievement of the 95% confidence through the selection of a 1.5 calculation factor. This is only valid using the correct values of the available bolted fault current. Further information on the variability of the arc flash safety PPE has been investigated.2,3

COMMON ERRORS IN DETERMING HAZARD LEVELS

The first common error in using available fault currents to determine hazard levels is assuming a high fault current. It can be confusing when someone trained to determine available bolted fault currents becomes responsible for determining arc flash hazard levels. If the person is trained only to calculate the available fault currents to determine interrupting rating requirements, rounding up the available fault currents can be misconstrued as a conservative procedure.

Utility companies usually give out the highest available fault current from their connections, because they assume customers are calculating their interrupting rating requirements. However, calculating arc flash hazard levels requires both the minimum and maximum available fault current. A person trained only in calculating interrupting rating requirements finds this concern with minimum ratings counterintuitive.

If the arc flash hazard calculations are only performed with the highest possible available fault current, the resulting hazard calculations could be too low. Therefore, a conservative assumption for an interrupting rating calculation could be a dangerous assumption for an arc flash hazard analysis.

The second common error using available fault current values is to assume that accurate values aren't necessary, because the 0.85 procedure will compensate for approximate values. The 0.85 factor was developed to achieve safe results only with the actual bolted fault current known.

The arc fault current equation was developed empirically from data when the actual fault current was known in the laboratory. The 0.85 multiplier procedure predicts the minimum arc fault current 95% of the time. If the actual available fault current is lower, the arc current will be lower. This could result in an arc current duration 400 times longer with significantly more arc flash energy released.

In short, at least four calculations are required. The first two involve the highest available fault current and the lowest available fault current. These are called scenarios. The second two calculations are then performed with 0.85 times the bolted fault current of each scenario. The most hazardous values are used for future steps, ensuring that such conditions are identified.

SUGGESTED PROCEDURE

Obtain the best minimum and maximum available fault current values from the utility. Be prepared to explain why the minimum and maximum values are needed. If the utility is uncooperative, use engineering judgment to determine the minimum and maximum values. These two values will form the basis of at least two scenarios for the calculations.

Consider other scenarios as well. Some examples are large motor loads (both running and off), on-site generation used in sole-source and parallel with the utility configurations, and tie circuit breakers in every allowable condition. The number of scenarios required increases rapidly with the system's greater complexity.

Calculate each scenario at the full arc fault current value, and then again using a 0.85 factor, to determine the most hazardous condition. Use the worst case of all the scenarios, unless maintenance practices ensure that some specific scenarios won't occur.

SUMMARY

IEEE 1584 is the standard most recognized by codes and regulations for calculating arc flash dangers and PPE for up to 1 kV. For that reason, it has been incorporated into standard industry software programs. Engineers, familiar with calculating bolted available fault currents for interrupting ratings, tend to make similar assumptions when calculating arc fault currents. Be aware, however, that some invalid assumptions can cause errors.

PPE Level	Two High	One High	Same	One Low	Two Low
Calculation Factor					
1.00	1	10	129	25	0
1.25	1	30	113	21	0
1.50	2	49	106	8	0
1.75	2	75	86	2	0
1.90	2	82	79	2	0

Table 1: This table shows calculated versus actual PPE required for LV data from IEEE 1584.

The proper determination of fault currents is critical. The IEEE equations incorporate some general safety factors, but using inadequate bolted fault current data can provide unsafe results.

Author Information

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