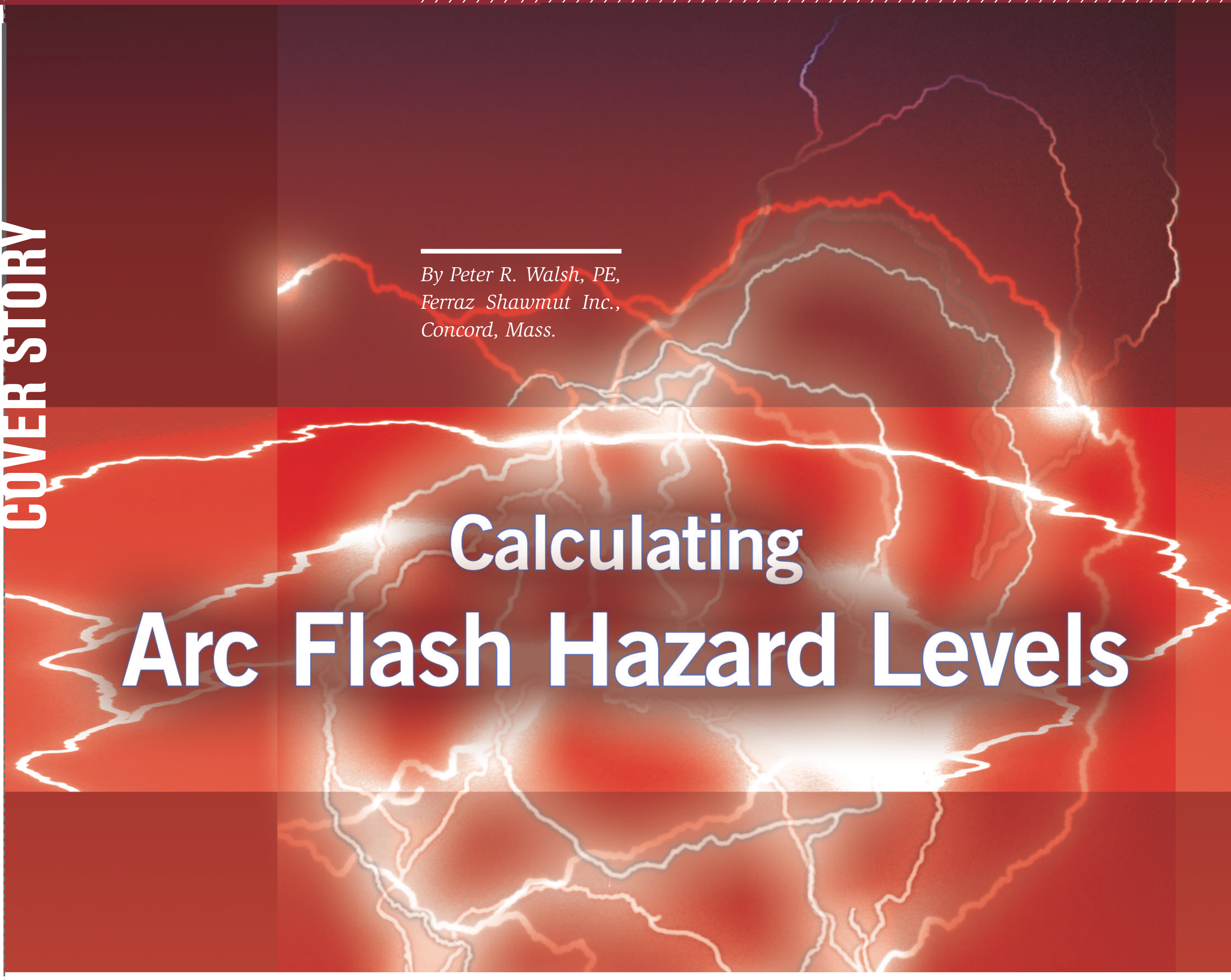


By Peter R. Walsh, PE,
Ferraz Shawmut Inc.,
Concord, Mass.

Calculating Arc Flash Hazard Levels

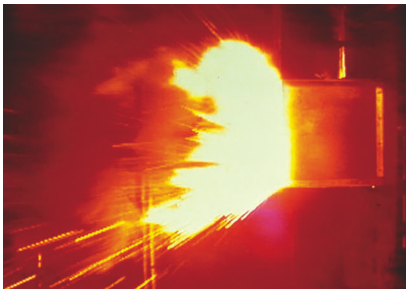
Discover common mistakes in calculating arc flash hazard levels—and how to avoid them.

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.



Arc flash can extend from equipment and severely injure nearby people. Photo: Ferraz Shawmut test laboratory

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:

$$E = I^2 * R * t$$

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,

$$I_a = 10^{\lg I_a}$$

$$\lg I_a = K + 0.662 \lg I_{bf} + 0.0966V + 0.000526G + 0.5588V (\lg I_{bf}) - 0.00304G (\lg I_{bf})$$

Where:

I_a = arcing current in kA

$\lg = \log_{10}$

$K = -0.153$ for open air or -0.097 for box

$I_{bf} = 3\Phi$ sym RMS bolted fault current

V = system voltage in kV

G = gap between conductors

Figure 1: The arc current equation from IEEE 1584 can be used to predict the arc current value under standard laboratory conditions. ©IEEE

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). 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 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]

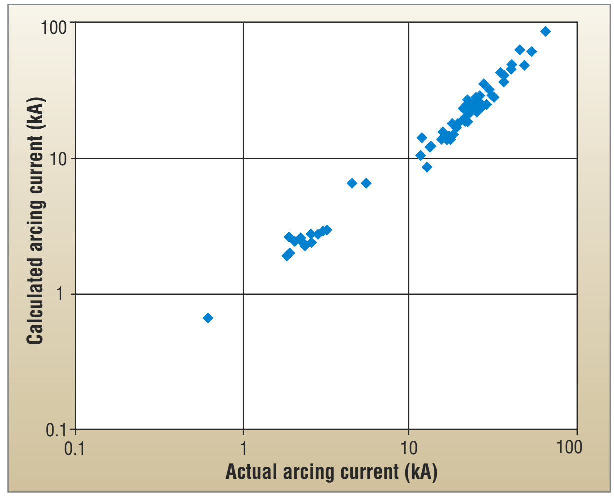


Figure 2: Comparison of IEEE 1584 predicted and actual measured values. Source: Wilkins, R., M. Allison, and M. Lang. "Improved Method for Arc Flash Hazard Analysis." Presented at IEEE Industrial and Commercial Power Systems Technical Conference, May 2004. ©IEEE

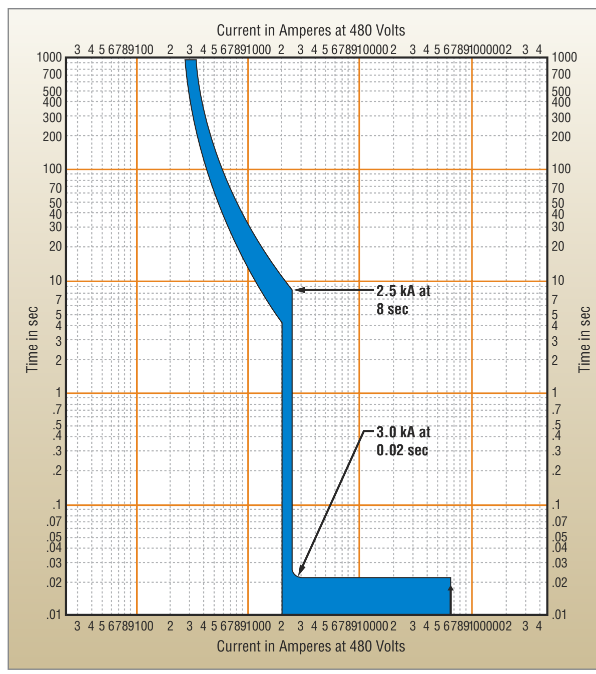


Figure 3: Steeply sloped time-current characteristics demonstrate how a minor change in arc current can greatly increase the duration of an arc fault. Source: Screen shot of EasyPower software

$$E = 4.184\, C_f\, E_n\, (t/0.2)*(610^x/D^x)$$

Where:

- E = incident energy cal/cm²
- C_f = 1.5 for voltages ≤ 1 kV valid for 95% of tests
- E_n = incident energy normalized
- t = arc duration (seconds)
- X = distance exponent from IEEE Table 4
- D = distance from the possible arc

Figure 4: The incident energy equation from IEEE 1584 includes a 1.5 "calculation factor" for safety. ©IEEE