IEEE 1584 Arc Flash Calculations

Published by the Institute of Electrical and Electronics Engineers and titled "Guide to Performing Arc Flash Calculations," IEEE 1584 provides empirical formulas for determining arcing fault current, flash protection boundaries, and incident energy. The formulas are valid for systems ranging from 208 V to 15 kV. Theoretical formulas are provided for conditions outside this range.

Arc Flash Analysis Process

IEEE 1584 establishes a nine-step process for gathering information and calculating arc flash hazards. The steps are:

1. Collect electrical system data

Collecting system data is the most difficult and time-intensive step in performing an arc flash hazard analysis, but accurate information is vital to correctly calculating flash boundaries. A relatively small error at this point can invalidate all further arc flash calculations. An IEEE paper lists the minimum information that should be gathered, as shown in the table at right.

Information collected should be recorded on a one-line diagram of the facility's electrical system. This diagram should be updated whenever modifications are made to the system.

2. Determine modes of operation

Many electrical systems, especially in smaller facilities, have only a single mode of operation. In large facilities, however, it is common to find a number of operating modes, possibly including: emergency modes in which only backup generators provide power; multiple utility sources or generators that are switched in or out; and motors or portions of the system that may start or cease operation. All of these different modes cause changes in current at various points in the system, altering incident energy and flash boundaries.

Component	Required Information
Utility	SC contribution Initial voltage X/R 3-phase
Transformers	Nominal kVA Primary Voltage Secondary Voltage %Z Impedance
Conductors	Size (AWG/mm2) Length Qty. per phase Conductor material Duct material
Breakers	Model Trip or sensor setting The following information is as it applies to the particular breaker: Plug, LTPU, LTD, STPU, STD, and INST
Fuses	Model Trip
Motors	Nominal HP

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3. Determine bolted fault currents

The bolted fault current is the current that would flow through a short circuit consisting of two conductors bolted together. It is the maximum current available to flow through a short circuit. This information is used to calculate the arc fault currents. Bolted fault currents should be determined for each piece of equipment likely to require maintenance or inspection while energized.

4. Determine arc fault currents

The current that flows through an arcing fault is usually significantly less than the bolted fault current, due to greater resistance. Arc fault current calculations are based on voltage, bolted fault current, conductor gap distance, and other factors. IEEE 1584 presents two formulas for calculating arc fault currents, one for use with 0.208-1 kV systems, and the other for systems between 1 and 15 kV.

For systems between 0.208 and 1 kV:

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

For systems between 1 and 15 kV:

$$\lg I_a = 0.00402 + 0.983(\lg I_{bf})$$

where I_a = arc fault current in kA; K = -0.153 for open-air arcs and -0.097 for enclosed arcs; I_{bf} = 3-phase bolted fault current in kA; V = voltage in kV; G = conductor gap in mm.

5. Determine protective device characteristics and duration of arcs

The time-current curves (TCCs) of upstream protective devices are the major factor in determining how long an arc-fault will last. An effort should be made to determine the actual settings rather than relying on standard values, as these may cause incident energy to vary greatly.

Another consideration when analyzing protective devices is that incident energy depends on both fault current and time. Since protective devices are slower at lower currents, minimum fault currents often pose the worst-case arc flash scenario.

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6. Document voltages and equipment classes

Voltage and equipment class determine what equation should be used to find the flash boundary, as well as the bus gap distances required by the equations. Systems operating at <1 kV use a different equation than those operating between 1 kV and 15 kV. In addition, IEEE 1584 recognizes six equipment classes, as shown in the table at the right. The bus distances used to help determine the arcing fault current.

Equipment class	Typical bus distance, in mm
Open air	10-40
Low-V switchgear	32
15 kV switchgear	152
5 kV switchgear	104
Low-V MCCs and panel boards	25
Cable	13

7. Establish working distances

The working distance is the distance from a potential arc source to a worker's face and chest. It is a critical quantity in determining the flash hazard boundary, as even an increase of a few inches in working distance can cause a significant drop in incident energy. 18 inches is the working distance most commonly assumed in calculations, but efforts should be made to determine actual working distances. Some usual working distances are shown in the table at right.

8. Determine incident energies

Incident energy is defined in NFPA 70E as "the amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event." In an arc flash hazard study, the "surface" is the worker's body at the assumed working distance. Incident energy is expressed in calories/cm^2. IEEE 1584 uses the following formulas:

Equipment class	Working distance
Low-voltage switchgear	24"
15 kV/5 kV switchgear	36"
Low-voltage MCCs and panel boards	18"
Cables	18"

(1) $E = 4.184(C_f)(E_n)(t/0.2)(610^x/D^x)$

where E = incident energy in joules/cm^2; C_f is a calculation factor (1.0 for voltages above 1 kV, and 1.5 for voltages below 1 kV); E_n = normalized incident energy (from equation (2) below); t = arc duration in seconds; D = distance from arc in mm; x = distance exponent (see table below)

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Equipment Type	D (Distance Exponent)
Open air	2.0
Low-voltage (.208-1 kV) switchgear	1.473
High-voltage (1-15 kV) switchgear	0.973
Low-voltage MCCs and panels	1.641
Cables	2.0

(2) $\lg E_n = K_1 + K_2 + 1.081(\lg I_a) + 0.0011(G)$

where E_n = energy normalized for distance of 610 mm and arc duration of 0.2 seconds, in joules/cm^2; K_1 = -0.792 for open-air arcs and -0.555 for enclosed arcs; K_2 = 0 for ungrounded/high-Z systems and -0.113 for grounded systems; G = arc gap in mm; I_a = predicted 3-phase arc fault current in kA

9. Determine Flash Protection Boundary (FPB)

The FPB is the distance at which incident energy is 1.2 cal/cm2, which is the amount of heat needed to cause second-degree burns. The IEEE formula for calculating FPB is

$$D_B = [4.184(C_f)(E_n)(t/0.2)(610^x/E_B)]^{1/x}$$

where E_B is the desired incident energy at the boundary (usually 1.2 cal/cm^2, but occasionally set at a value matching proposed PPE rating), with other variables defined as for the incident energy equations above.

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Table :Arc flash category and required PPE as per IEEE 1584

Incident Energy From (cal/cm2)	Incident Energy To (cal/cm2)	IE Low Marginal (cal/cm^2)	IE High Marginal (cal/cm^2)	Hazard Risk Category	Clothing Description	Hand & Arm Protection	Foot Protection	PPE Others
0	1.2	0	1.19	0	Nonmelting, Flammable Materials	Leather Gloves	N/A	Safety glasses
1.2	4	1.21	3.9	1	Arc-rated FR Shirt & Pants	Leather Gloves	Leather work shoes	Safety glasses, electrically rated hard hat with hood and face shield.
4	8	4.1	7.8	2	Arc-rated FR Shirt & Pants	Leather Gloves	Leather work shoes	Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection.
8	25	8.2	24	3	Arc-rated FR Shirt & Pants & Arc Flash Suit	Arc-rated Gloves	Leather work shoes	Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection.
25	40	26	38	4	Arc-rated FR Shirt & Pants & Arc Flash Suit	Arc-rated Gloves	Leather work shoes	Safety glasses, electrically rated hard hat with hood and face shield. Hearing protection.
40	999	41	998	Dangerous!	No FR Category Found	Do not work on live!	Do not work on live!	No FR Category Found