# Evaluating the Hazards of Low-Voltage Arcs

By Albert Marroquin

When it comes to power system design and operation, there should be no greater concern than safety. Not only must electrical system designers implement safeguards to protect equipment and processes, they must also evaluate the hazards associated with arc faults.

For example, in many electrical facilities, it's a common practice to set protective device settings to high-interrupting fault currents to avoid nuisance trips, which result in undesired interruption and costly shutdowns and re-starts. However, protective device settings may perform poorly when it comes to protecting the people working on energized equipment in the event of a low-voltage arc fault.

Protective device trip settings for many electrical facilities have been set solely based on bolted three-phase short-circuit criteria. However, low-voltage arc faults (< 1.0 kV) may produce a current magnitude much smaller than the circuit's maximum available 3-phase bolted short-circuit current. Of course, the incident energy expected to be released should be smaller at lower current magnitudes; however, in some situations it may turn out that overcurrent devices take much longer to trip, and thus the release of incident energy could last for seconds or minutes.

Exponentially longer arc fault clearing times encountered at steep portions of the time current characteristic curves (TCCs) translate into much higher amounts of incident energy release (see Figure 1).
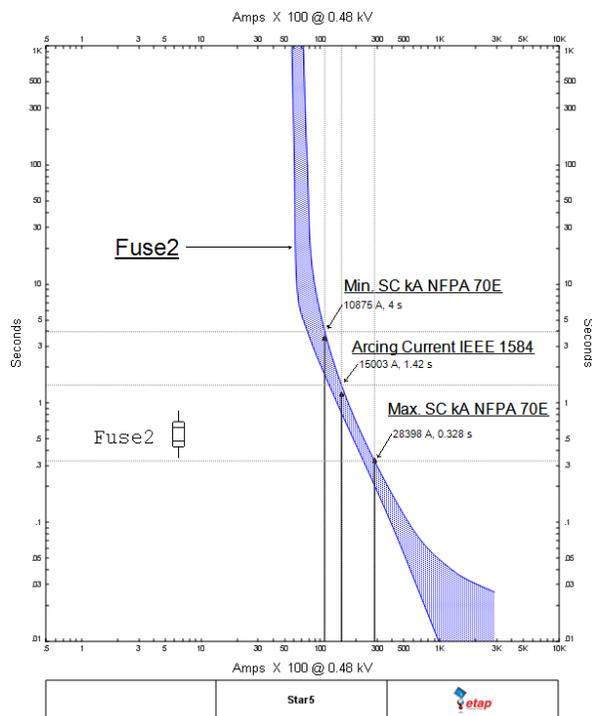
Figure 1: Fuse TCC showing long times at steep portions of the curve

This article discusses methods available for calculating the incident energy released by an arc fault in low-voltage equipment. It also presents considerations which should be made to determine the worst-possible hazard associated with energized work at different locations of the equipment. In addition, it will cover methods to reduce the hazard level like maintenance mode settings and arc flash sensor relays.

Two Calculation Methods

The majority of the arc flash analyses are performed using the IEEE 1584 and NFPA 70E methods. Both methods consider the low-current magnitude phenomenon, but have different ways of accounting for its effect in the calculation of the incident energy.

The NFPA 70E 2004 method recommends that the incident energy for equipment 600 Volts and below be determined from the "maximum" and "minimum" short-circuit currents. In fact, in this model a 62% reduction of the maximum available short-circuit current is recommended to

determine situations at which the upstream overcurrent device could take seconds or minutes to operate (NFPA 70E 2004 Annex D.6). This reduction percent corresponds to the industry accepted minimum current level for self sustaining arc faults. Equation [D.6.2 (a)] can then be used to calculate the incident energy.

The IEEE 1584[TM]-2002 and 2004a "IEEE Guide for Performing Arc-Flash Hazard Calculations" (sections 5.1 to 5.5) provides a second method to calculate the incident energy for low-voltage equipment. The IEEE 1584 empirically-derived equations can predict very low arc fault current values. IEEE 1584 2002 equation 1 can be used to determine the magnitude of the actual arc fault current (instead of the available short-circuit current as used by the NFPA 70E method).

In fact, for the simple electrical system described in this article, the calculated arcing current magnitude can be as low as 45% of the maximum available bolted 3-phase short-circuit current. The 45% value already accounts for the additional 15% reduction recommended by IEEE 1584 for systems with nominal voltages less than 1000 Volts (section 5.2 of IEEE 1584a 2004).

The lower magnitude of low-voltage arc faults raises arc flash analysis problems. The results can be very different depending on which method is used to determine the incident energy results, but no matter what analysis method is used to perform arc flash analysis, it may be necessary to run several variations in the arc fault current magnitude to attain with certainty the absolute highest incident energy value which can be released.

Identifying Low-Voltage Arc Hazards
To properly identify the hazards of low-voltage arcs, it is necessary to consider all the possible arc locations and the protective devices involved for protecting the circuit. Furthermore, it may be necessary to run two sets of calculations (i.e., one for maximum and a second for the minimum currents).
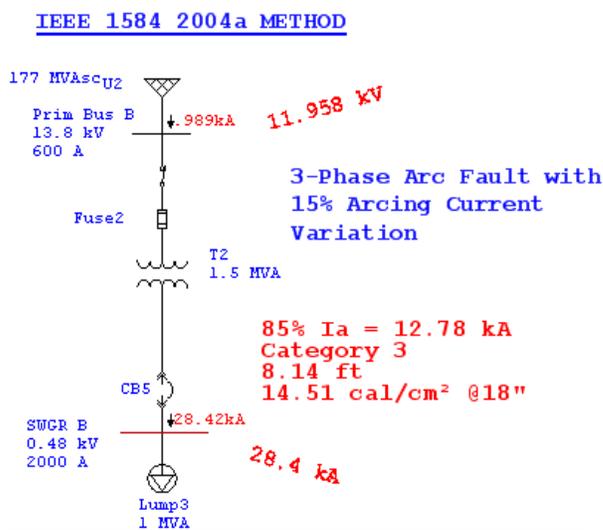
To illustrate how to determine the hazards of low-voltage arcs, we can perform arc flash analysis at two locations for the system shown in Figure 2. This system has a typical arrangement for overcurrent and short-circuit protection. The 1.5 MVA transformer is fed from a 177 MVAsc utility connection, and it is protected for short-circuit with a 100-Amp, 15.5 kV standard speed fuse located on the 13.8 kV primary voltage side. The transformer feeds a 480-Volt switchgear with a main 2400-Amp power circuit breaker with a solid state trip device.

Using power system analysis software, we can simulate an arc fault on the switchgear bus bars at the "SWGR B" location. Figure 2 shows the computer program results for a fault at this bus using the IEEE 1584 2004a method. The NFPA 70E method is also

IEEE 1584 2004a METHOD

177 MVAsc U2
Prim Bus B
13.8 kV
600 A

↓.989kA   11.958 kV

3-Phase Arc Fault with
15% Arcing Current
Variation

Fuse2

T2
1.5 MVA

85% Ia = 12.78 kA
Category 3
8.14 ft
14.51 cal/cm² @18"

CB5

SWGR B   ↓28.42kA
0.48 kV
2000 A   28.4 kA

Lump3
1 MVA

Figure 2: Arc Fault at Bus SWGR B showing IEEE 1584 results

results for a fault at this bus using the IEEE 1584 2004a method. The NFPA 70E method is also

used to evaluate the arc fault at the same location for both maximum and minimum expected short-circuit currents. The protective device expected to trip the arc fault is the main breaker CB5. The results of the four different arc fault analysis are listed in Table 1.

If you use the maximum short-circuit current to determine the incident energy, the results reveal that because of the fast action of the instantaneous part of the solid state trip device in CB5, the incident energy released at the bus is 2.69 cal/cm² with a hazard category of 1, based on NFPA 70E-2004, Table 130.7(C)(11).

However, if you use the minimum short-circuit current, the resulting incident energy can reach as high as 25 cal/cm² (category 4). This is caused by the much longer clearing time of CB5.

The IEEE 1584 method predicts hazard category 3 results (12.5 to 14.51 cal/cm²) as the worst-case scenarios. The IEEE 1584 method provides the more accurate results in this case since it is using the actual arcing current (Ia) to determine the time it takes the CB5 breaker to operate.

Table 1: I.E. for a fault at Bus "SWGR B" @ 18.0 inch working distance

Method	Ibf or Ia at Fault loc. (kA)[1]	Power Circuit Breaker Opening Time (sec.) for CB5	Incident Energy at Bus SWGR B (cal/cm²)	Hazard Cat
NFPA 70E Max kA	28.42 (Ibf)	0.05	2.69	1
NFPA 70E Min kA	10.84 (Ibf)	0.500	25.01	4
IEEE 1584 (100% Ia)	15.03 (Ia)	0.250	12.50	3
IEEE 1584 (85% Ia)	12.78 (Ia)	0.346	14.51	3

The previous simulation may not be sufficient to establish the worst-case incident energy for this low-voltage equipment. If you simulate an arc fault at the main breaker compartment, as shown in the Figure 3, the incident energy released at this location can be much larger since the primary protective device would be Fuse2 with a longer clearing time.
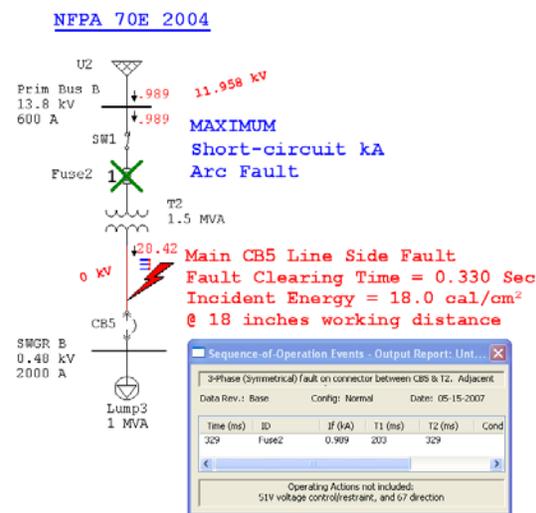

Figure 3: Arc Fault at line side of CB5 showing NFPA 70E results

The results shown in Table 2 indicate that the incident energy released for a fault located at the line (incoming) side of the circuit breaker CB5 can be far more dangerous because of the longer operating time of the fuse. Figure 1 shows the Time Current Characteristic (TCC) of Fuse2 along with the expected fault clearing times for the minimum, maximum and arcing fault values.

Note that a small reduction in the fault current leads to a much longer total clearing time. There have been several documented arc flash incidents in low-voltage equipment which have lasted for several seconds or even minutes because of the slow response of upstream protective devices.

Table 2: I.E. for a fault at CB5 @ 18.0 inch working distance

Method	Ibf or Ia at Fault loc. (kA)[1]	Fuse Total Clearing Time (sec.) for Fuse[2]	Incident Energy at CB5 (cal/cm²)	Hazard Cat
NFPA 70E Max kA	28.42 (Ibf)	0.330	18.0	3
NFPA 70E Min kA	10.84 (Ibf)	4.139	>>40.0	N/A
IEEE 1584 (100% Ia)	15.03 (Ia)	1.42	>>40.0	N/A
IEEE 1584 (85% Ia)	12.78 (Ia)	0.346	>>40.0	N/A

Note 1: Ibf or Ia denotes whether the bolted 3-phase short-circuit (Ibf) or the arcing current (Ia) were used to determine the fault clearing time.

Note 2: The Fuse total clearing time was determined from the current at the 13.8 kV base. (see Figure 1)

Reducing the Hazard Risk

One of the most effective ways to reduce the hazard associated with low-current magnitude arc faults in low-voltage equipment is to modify the settings of the protective devices to reduce the arc fault clearing time. Typically main power circuit breakers do not have their instantaneous response enabled because of coordination with downstream devices. For the case of the arc faults at the bus, temporarily setting the instantaneous pickup of the main power circuit breaker to the left of the lowest expected arc fault current value should significantly reduce the fault clearing time.

There are devices available in the market which have "Maintenance" modes which automatically override the normal protective device coordination settings and introduce an instantaneous pickup setting, which is low enough to pickup the arc fault current magnitude. When the energized electrical work or maintenance is complete, the main protective device can be set back to normal operation settings. Figure 4 illustrates the maintenance mode settings and the fault arrow marked as "Minimum Arcing Current" shows the absolute lowest arcing current magnitude.
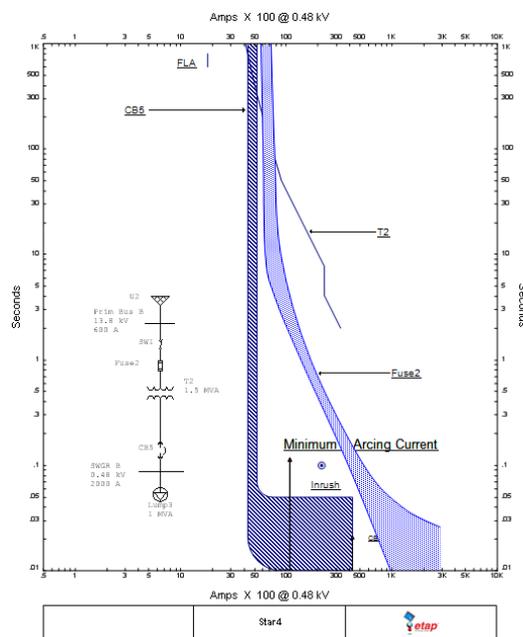

Figure 4: TCC showing Maintenance mode for CB5

The addition and reduction of instantaneous pickup settings is just one way to reduce the hazard associated with low-voltage arcs. Light detecting relays or "Arc Flash Sensors" are devices which detect the light emitted by the arc fault. In the event of an arc, the light sensors send a trip signal to relay which in turn can trip the breaker in less than 2 cycles.

Arc sensors are also used in combination with overcurrent relays. The arc sensor relay would only send the tripping signal if both overcurrent and light sensors indicate the presence of an arc fault. This more advanced setup helps to prevent nuisance trips caused by non arc flash related light sources.

The bottom line is that no matter what analysis method is chosen for the analysis (IEEE 1584 or NFPA 70E or a combination), it is important to consider the extremely low magnitudes of the arc faults in low-voltage equipment. Both the maximum and minimum arc fault current levels need to be analyzed to properly evaluate the hazard of energized electrical work.

Serious consideration should be given to not performing energized work in high risk locations which depend on upstream overcurrent protective devices to trip the fault, unless some method is used to minimize the hazard. These strategies for reducing the incident energy are just some of several available to reduce or eliminate the risk of potentially fatal arc flash incidents.

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