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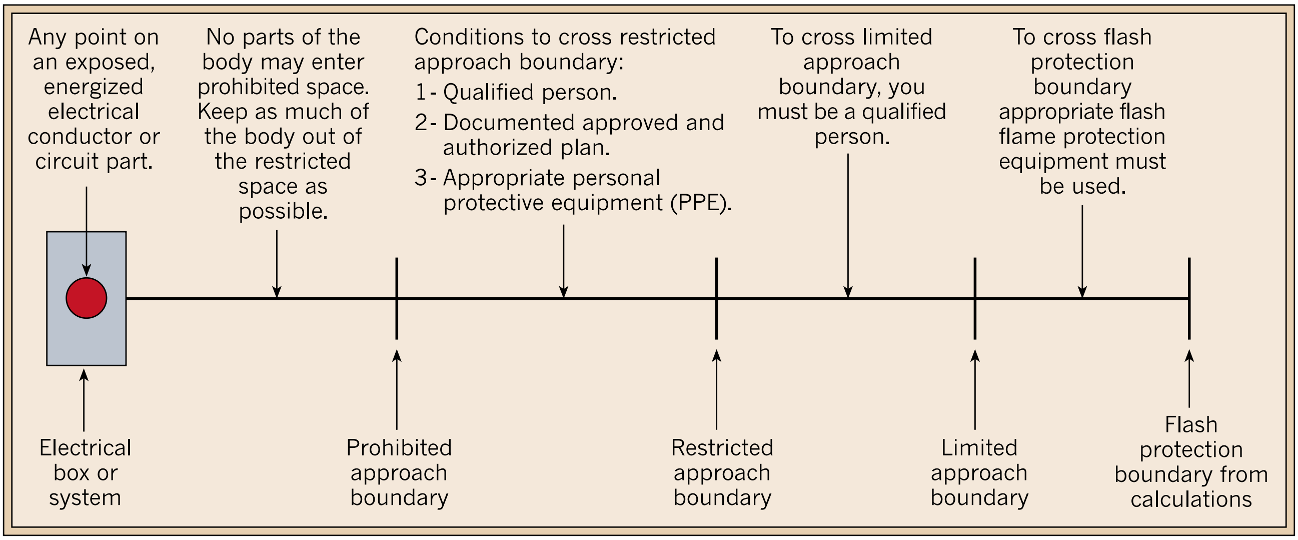
THE SECRETS OF ARC FLASH

The Secret to Understanding Arc Flash Calculations



This graphic shows a simplified limits of approach summary, as outlined in NFPA 70E.

By Mohamed G. Elgazzar, P.E., Federal Government

Applying notes from Annexes C, D, and H of 2012 NFPA 70E

A few years ago, the term "arc flash" crept into our electrical technical vocabulary. Since that time, performing arc flash calculations remains a challenge for many of us. Calculating incident energy levels and arc flash boundary distances for the purpose of estimating the hazard risk category (HRC) a worker would be exposed to while working on electrical equipment opens a window into the inner workings of the power distribution system. Arc flash calculations can tell us a great deal about how the system will behave during a fault condition. They also offer us a golden opportunity to optimize the system for safety and attempt to prevent the hazard from happening in the first place.

Arc flash regulations may be one of the best things that have ever happened to electrical designs, because they force engineers to look closer at details they might have otherwise overlooked in the past and put the power system calculations front and center in the design process. The very notion of considering arc flash early on in the design of a power distribution system is not only prudent, but also economical.

The following two documents are the foundation for truly understanding arc flash calculations:

- NFPA 70E, *Standard for Electrical Safety in the Workplace, 2012 Edition*
- IEEE Std 1584, *Guide for Performing Arc-Flash Hazard Calculations, 2002 Edition*

In this article, we'll concentrate on NFPA 70E instead of IEEE Std 1584. The calculations shown below will also focus on alternating current systems.

Chapter 1, Safety-Related Work Practices (Art. 100 Definitions). The definitions in Chapter 1 include the terms used in the calculations, which help you understand the concept.

Boundary, arc flash. When an arc flash hazard exists, an approach limit at a distance from a prospective arc source within which a person could receive a second-degree burn if an electrical arc flash occurred.

Boundary, limited approach. An approach limit at a distance from an exposed energized electrical conductor or circuit part within which a shock hazard exists.

Boundary, prohibited approach. An approach limit at a distance from an exposed energized electrical conductor or circuit part within which work is considered the same as making contact with the electrical conductor or circuit part.

Boundary, restricted approach. An approach limit at a distance from an exposed energized electrical conductor or circuit part within which there is an increased risk of shock (due to electrical arc-over combined with inadvertent movement) for personnel working in close proximity to the energized electrical conductor or circuit part.

Ground fault. An unintentional, electrically conducting connection between an ungrounded conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth.

Incident energy. The amount of energy impressed on a surface, at a certain distance from the source, generated during an electrical arc event. One of the units used to measure incident energy is calories per centimeter squared (cal/cm^2).

Incident energy analysis. A component of an arc flash hazard analysis used to predict the incident energy of an arc flash for a specified set of conditions.

Qualified person. One who has skills and knowledge related to the construction and operation of the electrical equipment and installations — and has received safety training to recognize and avoid the hazards involved.

Unqualified person. A person who is not a qualified person.

Short circuit current rating. The prospective symmetrical fault current at a nominal voltage to which an apparatus or system is able to be connected without sustaining damage exceeding defined acceptance criteria.

Informative Annex C, Limits of Approach. Annex C introduces the following logical concept. "As the distance between a person and the exposed energized conductors or circuit parts decreases, the potential for electrical accident increases." It also breaks down the discussion of safe approach distance for both unqualified and qualified persons. The Annex also illustrates the limits of approach, the basic concept of which is illustrated in the **Figure** on page 26.

Table 130.4(C)(a) of NFPA 70E introduces "Approach Boundaries to Energized Electrical Conductors or Circuit Parts for Shock Protection, Alternating-Current Voltage Systems." The prohibited approach boundary, restricted approach boundary, and limited approach boundary are all dependent on system voltage.

Informative Annex D, Incident Energy and Arc Flash Boundary Calculation Methods. Annex D introduces five sets of equations to calculate the arc flash boundary and/or the incident energy level. It also provides formulas for calculating arc flash energies and boundaries to be used with current-limiting Class L and Class RK1 fuses as well as with circuit breakers. This Annex also includes numerical examples that demonstrate the calculation procedure.

The equations in this Annex can be used for low-voltage and medium-voltage systems, but each has its own limitations. Thus, the reader must use the set of equations that best suits his/her application. The limitations are in terms of voltage, short circuit current range, open air space, or inside a cubical (applicable to arc flashes emanating from within switchgear, motor control centers, or other electrical equipment enclosures).

For typical low-voltage applications (<600V), these equations seem to best fit.

The following equation is used to estimate the incident energy in a cubic box (20 in. on each side):

$$E_{MB} = 1038.7\, D_B^{-1.4738}\, t_A\, [0.0093F^2 - 0.3453\, F + 5.9675]$$

Rating (Amp)	**Breaker** (Type)	**Trip Unit** (Type)	**Incident Energy** (J/cm2)	**Arc Flash** [Boundary (mm)]
100 to 400	MCCB	TM or M	$0.189\ I_{bf} + 0.548$	$9.16\ I_{bf} + 194$
600 to 1,200	MCCB	TM or M	$0.223\ I_{bf} + 1.590$	$8.45\ I_{bf} + 364$
600 to 1,200	MCCB	E, LI	$0.377\ I_{bf} + 1.360$	$12.50\ I_{bf} + 428$

Table 1. This is the 480V portion of Table D.7.7 of NFPA 70E.

Where:

E_{MB} is the maximum 20-inch cubic box incident energy in cal/cm^2.

D_B is the distance from arc electrodes in inches. D_B is the working distance and it is 18 in. for low-voltage application. The origin of this value is in NFPA 70 Table 110.26(A)(1) Working Space (Low Voltage).

F is the short circuit current, kA (for range of 16kA to 50kA), for the circuit under consideration.

t_A is the arc duration in seconds. To calculate t_A, first calculate the arc fault current (I_A) from the following equation:

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

Where:

I_A is the arc fault current.

I_{bf} is the bolted short circuit current (3-phase symmetrical rms kA).

G is the gap between conductors or buses. Obtain the value of G from Table D.7.2 Factors for Equipment and Voltage Classes.

K = -0.153 for open air or -0.097 for "In Box."

V is the system voltage (0.208kV to 15kV).

Then, calculate $I_A = 10\ \mathrm{lg}\ I_A$

Time is the most controllable factor in the amount of incident energy and can be controlled by the settings of the upstream circuit breaker during the time current characteristics TCC coordination study. The time can be directly obtained from protective device time current characteristics TCC curve. The maximum value for the time to be used in calculations

Planning and design	Construction and commissioning	Operations and maintenance
• Statement of work shall address the calculation submittals and identify them. • Calculations shall be conducted, upgraded, and submitted with every stage of the project as agreed upon in the statement of work. • Calculations shall reflect the contents of the one-line diagram and the electrical layout of equipment. • It is recommended to collect data during initial survey as follows: 1. Load flow at 35% 2. Short circuit at 60% 3. Coordination at 90% 4. Arc flash at 90% 5. Optimized calculations at 100%	• Optimized calculations at 100% shall be updated to reflect actual hardware and circuit breakers. • Circuit breakers settings shall be verified during commissioning. • Labels shall be produced. • PPE shall be ordered.	• Calculations shall be updated every five years or to reflect the changes in electrical circuits or available power from utilities. Facilities shall keep an updated as-built one-line diagram and electrical layout of equipment. • Labels shall be upgraded. • PPE shall be upgraded.

Electrical power calculations to be completed throughout the life cycle of a project.

Incident Energy	Hazard Risk Category (HRC)
0 to 2 Cal/cm^2	0
2 to 4 Cal/cm^2	1
4 to 8 Cal/cm^2	2
8 to 25 Cal/cm^2	3
25 to 40 Cal/cm^2	4
> 40 Cal/cm^2	Dangerous (you must de-energize to do work)

Table 2. Once you know the incident energy level, you can properly assign an HRC.

is 2 sec.

For 480V systems, the industry accepted minimum level for a sustaining arcing fault is 38% of the available bolted fault, 3-phase short circuit current. The highest incident energy exposure could occur at these lower levels where the overcurrent device could take seconds or minutes to open.

Notice that you can use 0.85 × Ia to find a second arc duration. This second arc duration accounts for variations in the arcing current and the time for the overcurrent device to open. Calculate the incident energy using both arc durations (Ia and 0.85 × Ia), and use the these two values to obtain from the TCC of the upstream protective devices two values for t_A. Then calculate the incident energy and use the largest amount.

Another set of data you will find useful when performing arc flash calculations is the 480V portion of Table D.7.7, "Incident Energy and Arc Flash Protection Boundary by Circuit Breaker Type and Rating 480V and Lower" (**Table 1** on page 28). In this table, MCCB stands for molded-case circuit breaker, TM is a thermal-magnetic trip unit, M is a magnetic (instantaneous only) trip unit, and E is an electronic trip unit that has three characteristics, which may be used separately or in combination — long time, short time, and instantaneous. The equations in the Table have one unknown: I_{bf}. When the incident energy is known, the HRC can be determined from the information in **Table 2**.

Notes:

I_{bf} is based on a working distance of 455 mm (18 in.).

I_{bf} is between 700A and 106,000A.

TCC curves are not necessary when I_{bf} is in the range above.

The equations above can be used for checking calculations or in lieu of detailed calculations.

The incident energy is in joule/cm^2 and needs to be converted to cal/cm^2 as follows:

$1\ \text{J/cm}^2 = 0.238902957619\ \text{cal/cm}^2$

Informative Annex H, Guidance on Selection of Protective Clothing and Other Personal Protective Equipment. Table H.3(b) provides guidance on selection of arc-rated clothing and other personal protective equipment (PPE) for use when incident exposure is determined by a hazard analysis. By calculating the incident energy, you can determine the HRC. Then use table H.3(b) to determine PPE.

Table H.4(a) for low-voltage systems introduces maximum 3-phase bolted fault-current limits at various system voltages and fault clearing times of circuit breakers for recommended use of 8 cal/cm^2 and 40 cal/cm^2 PPE in an "arc-in-a-box" situation.

Table H.4(b) for high-voltage systems introduces maximum 3-phase bolted fault-current limits at various system voltages and fault clearing times of circuit breakers for recommended use of 8 cal/cm^2 and 40 cal/cm^2 PPE in an "arc-in-a-box" situation.

Tables H.4(a) and H.4(b) can really help during the design and review stages of an arc flash study. These two tables can be used in several ways, as follows:

- Knowing the 3-phase fault current at a point in the system and upstream circuit breaker clearing time, you can use the Tables to check the calculations if you are reviewing a study without actually performing the calculations yourself.

- You can establish a maximum for the 3-phase short circuit current in a new system, and use it as a criterion for the design.

In conclusion, arc flash regulations have brought a great deal of challenge to the industry, but also present a great opportunity to improve the electrical safety and the quality of a power distribution system design. Electrical designers and project reviewers alike should look to arc flash calculations as a tool for continued improvement. **EC&M**

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Arc Flash Hazard Evaluation

Five ways you can ruin a study

By Steve Coleman, P.E., and Aleen Mohammed, P.E., Burns & McDonnell Engineering

If you're conducting an arc flash study, you're probably using one of the many software packages that can perform the analysis for you — at the click of a button. However, as convenient as they may seem, there are several pitfalls that can cause erroneous results if you are unaware of the underlying premises behind many of the calculations. The following five considerations are important issues to keep in mind when you're doing this type of work.

Source impedance. Fault current sources like power generators cannot supply faults in a power system indefinitely. The fault current magnitude is, in fact, limited by the generator's internal reactance, transmission line impedance, transformer impedance, and series reactors (when present). You can model the source either without these impedances (infinite source) or with these impedances. When undertaking a study for a large commercial or industrial site, assuming an infinite source for the electrical model is a big "no no."

Assumption of an infinite source results in high fault currents, which lead to faster tripping of protective devices. This, in turn, leads to less incident energy at the fault location. Incident energy in an arc flash is the measure of thermal energy that is impressed on a surface (like a person) at a certain distance from the source. It is expressed in Joules per centimeter squared (cm^2). Therefore, the faster a protective device trips, the sooner the flow of this energy (to the flash) is interrupted. Hence, trip times based on an infinite source are misleading, and incorrectly identifying a hazardous location as less hazardous because of this assumption can be fatal.

When you have the source impedance, make sure you understand at what point it is calculated. Typically, you would want it calculated up to your facility's service entrance location. If there is a transformer at the facility service entrance, make sure

Transmission line impedance is one component to consider when determining fault current magnitude.

you know whether the electric utility has provided source impedance data to the high side or low side of the transformer.

System impedance at the facility's service entrance is not always readily available. Approaching the electric utility early on, especially while scoping the project to obtain this piece of information, is necessary. When this is not feasible, the scope of work should at the very least insist on obtaining this data from the electric utility.

Incorrectly modeling the source impedance has a huge impact on the study, so make sure you have the most up-to-date and correct source information before making any calculations.

Source	Limitations/Parameters
Doughty/Neal paper	Calculates incident energy for 3-phase arcs on systems rated 600V and below; applies to short-circuit currents between 16kA and 50kA.
Ralph Lee paper	Calculates incident energy for 3-phase arcs in open-air systems rated above 600V; becomes more conservative as voltage increases.
IEEE 1584 Std	Calculates incident energy and arc flash protection boundary for: 208V to 15kV; 3 phase; 50 Hz to 60 Hz; 700A to 106,000A short circuit current; and 13 mm to 152 mm conductor gaps.
ANSI/IEEE C2 NESC Sec 410 Tables 410-1 and Table 410-2	Calculates incident energy for open air phase-to-ground arcs 1kV to 500kV for live-line work

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Limitation of independent calculation methods.

Transformer grounding. During the data collection process, it is easy to miss out on how the neutral of a transformer is grounded. You could have a solidly grounded, low-resistance grounded, high-resistance grounded, or an ungrounded system. You can make reasonable assumptions on other transformer parameters, but you cannot make an assumption on how it is grounded.

How does this affect the study? Solidly grounding the transformer provides high fault currents on its secondary side. This leads to faster protective device trip times, which results in lower incident energy at the fault. Low-resistance grounding provides much lower fault currents on the secondary, which leads to slower trip times and higher incident energy at the fault. High-resistance grounding schemes provide extremely low fault currents and do not trip for the first ground fault. Ungrounded systems also will not trip for the first fault to ground. Timing of ground fault tripping in high-resistance and ungrounded systems may depend upon the activation and timing of phase protective devices that are not as sensitive and quick to operate as a ground protective device on a solidly grounded system.

IEEE 1584 or NESC Art. 410?

Sometimes, the scope of work for an arc flash study extends beyond the indoor distribution substations to outdoor air-insulated substations or distribution lines. This raises an interesting question. Would you still apply the IEEE 1584 standard in these areas? Probably not, for the following reason: The IEEE 1584 equations were empirically derived for systems rated between 208V to 15kV with live conductor distance ranging from 13 mm to 152 mm. Arcing due to a single-phase fault in such a setup will easily flashover to the other two phases and create a full 3-phase fault. However, how often do you see a single-phase fault escalate to a 3-phase fault in a substation? Not often. Most faults are cleared within a few cycles of fault initiation. In such a scenario, using the single line-to-ground fault current to calculate the arc flash incident energy is more meaningful than using the 3-phase bolted fault current (which IEEE 1584 employs).

Thus, extrapolating a solution for an outdoor arc flash in substations or on lines rated 34.5kV or 69kV using the IEEE 1584 standard is not realistic. It will, at best, generate a conservative solution with unreasonably large working distances, such as 30 ft or more, and a requirement for higher class personal protective equipment (PPE) that limits the dexterity of a worker.

There are very few software packages in the industry that can model single-phase arcs for the purpose of determining incident energy in substations. Common practice for the utility is to follow the IEEE's National Electrical Safety Code (NESC) C2 standard. The tables in NESC Art. 410 allow for the determination of appropriate PPE based on the premise that faults are single-phase and take place between open air live-line to earth. However, to use the tables, you must know the number of cycles the upstream breaker takes (including relay operation time) to clear the fault and the available fault current in the system at the location of the fault.

Choosing the right standard for the arc flash study is just as important as proper data collection. There are several methods you can follow; however, ones that are normally used (besides NFPA 70E) are listed in the **Table** above. NFPA 70E and IEEE 1584 standards are implemented in low-voltage to medium-voltage enclosed systems, while NESC Tables are used for high-voltage open-air systems.

Bolted fault current vs. arcing fault current. These two fault currents are not the same in systems rated less than 1,000V. By definition, a bolted fault has no fault impedance while the arcing fault current has impedance associated with the arc. The bolted fault, therefore, has higher fault current magnitude than the arcing fault. The protective devices in the low-voltage systems are coordinated to trip for the higher bolted fault current and not the arcing fault current.

Because protective device clearing time is an important factor in the calculation of incident energy, you must understand that it's the trip time to clear the arcing current that's used in the calculations — not the delay time (if any) you may have programmed into the protective device for clearing of a bolted fault.

Programming relays for faster trip times based on arcing current sacrifices relay coordination and may put a large portion of the system out of service under fault. But if safety is paramount, then reducing the delay time in circuit breaker operation, by any means, is necessary.

Circuit impedance. As implied so far in this article, fault current magnitude and trip time significantly affect the incident energy in an arc flash. The available fault current in a system is a result of the way the power system network is configured and the way the power system components are connected. For example, if you have multiple transformers feeding a bus duct, the available fault current at the bus duct will increase significantly. This is due to the reduction in circuit impedance when the transformers are paralleled. Additionally, if an on-site co-generation unit is operated only during certain times of the day or month or year, then its fault contribution needs to be considered as well.

Make sure you understand how the electrical system is configured. Changes in circuit impedance can affect the fault current and thereby the incident energy. A complete understanding of the system is critical to providing an appropriate flash hazard evaluation.

The five items mentioned in this article are a few of the important parameters that require engineering expertise in establishing the basis for an arc flash hazard study. However, there are other significant considerations that must be evaluated, some of which are dependent upon the specific site conditions, switchgear or panelboard construction, and project scope. That's why it's important to realize that there is a lot more to an arc flash analysis than buying a software package and pushing the button. Your life or that of your co-workers could be dependent upon it! **EC&M**

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Don’t Leave Arc Flash Protection to Chance — Part 1

Even low-level tasks warrant labeling of arc flash risk

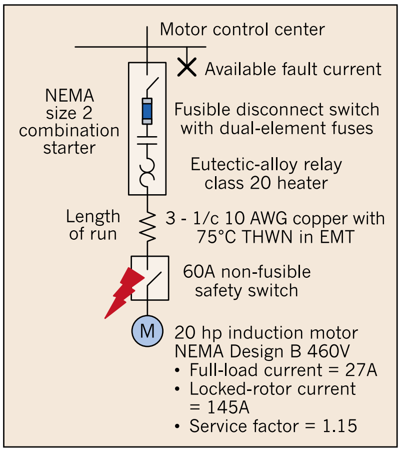
By Frank Mercede, P.E., and Joseph N. Mercede, Mercedes Electric Co., Inc.

A maintenance worker is about to open a non-fusible safety switch, which serves as a local motor disconnect, when he’s confronted by a co-worker. “Hey, what’s up?” inquires the co-worker. “I need to check voltages, because the motor is running hot,” answers the maintenance worker. Although the co-worker is not an electrician, he recalls hearing something about wearing personal protective equipment (PPE) when working on electrical equipment. “Shouldn’t you be wearing PPE?” asks the co-worker. “Don’t need PPE for this job,” he replies. Not satisfied with this simple answer, the co-worker continues with the inquiry. “Are you sure?” At this point, the maintenance worker becomes visibly irritated. “You must be kidding! I’m not about to wear PPE for this measly job!” My question to you is: Which one of these workers is correct?

Clearly, the maintenance worker is mistaken not to wear PPE for this task — and is in desperate need of training on electrical safety-related work practices. Yet, even if the right decision had been made, the absence of an NFPA 70E-compliant arc flash warning label on the safety switch leaves the selection of the appropriate levels of PPE to chance.

This is the first of a three-part series on the importance of arc flash labeling of electrical equipment in which practical examples shed light on some common misconceptions surrounding this issue.

The one-line diagram (see **Figure,** at right) depicts the electrical arrangement noted in the situation described above. The non-fusible safety switch is rated 60A and serves as the local disconnect for a 20-hp induction motor. If an arc flash event were to occur at the safety switch location, due to a fault during voltage testing, the maintenance worker must rely on the upstream fuses in the combination motor starter of the motor control center (MCC) to clear the fault.



One-line diagram of example discussed in the text.

Using IEEE 1584 as a reference document, we can calculate the incident energy (IE) in calories per square centimeter and the corresponding Hazard/Risk Category (HRC) level for variations in fuse rating and class, length of motor branch circuit conductors, and available bolted 3-phase short-circuit current at the MCC bus. These calculations were performed for four different combinations of fuse type and rating level, which are summarized in Tables 1 through 4. Let’s start by using NEC upper-limit 50A Class RK5 fuses. The results of our calculations in **Table 1** show the wide variability in IE and HRC with length of the motor branch circuit. For the second case, lower-rated 40A upstream fuses of the same class (RK5) are chosen that still permit start-up of the motor. Take note in **Table 2** of the significant reductions in IE and HRC levels with this simple change in fuse ampere rating. For the third case, we return to using 50A upstream fuses. However, this time we

Available Fault Current at MCC	Length of Run		
	200 ft	400 ft	600 ft
5kA	HRC 0 0.2 cal / cm²	HRC 1 1.5 cal / cm²	HRC 2* 5.4 cal / cm²
10kA	HRC 0 0.2 cal / cm²	HRC 1 1.3 cal / cm²	HRC 2* 5.1 cal / cm²
20kA	HRC 0 0.2 cal / cm²	HRC 1 1.2 cal / cm²	HRC 2* 4.9 cal / cm²
30kA	HRC 0 0.2 cal / cm²	HRC 1 1.2 cal / cm²	HRC 2* 4.9 cal / cm²

Table 1. NEC limit 50A Class RK5 fuses.

Available Fault Current at MCC	Length of Run		
	200 ft	400 ft	600 ft
5kA	HRC 0 0.1 cal / cm²	HRC 0 0.4 cal / cm²	HRC 1 2.0 cal / cm²
10kA	HRC 0 0.1 cal / cm²	HRC 0 0.3 cal / cm²	HRC 1 1.9 cal / cm²
20kA	HRC 0 0.1 cal / cm²	HRC 0 0.3 cal / cm²	HRC 1 1.8 cal / cm²
30kA	HRC 0 0.1 cal / cm²	HRC 0 0.3 cal / cm²	HRC 1 1.8 cal / cm²

Table 2. 40A Class RK5 fuses.

Available Fault Current at MCC	Length of Run		
	200 ft	400 ft	600 ft
5kA	HRC 0 0.1 cal / cm^2	HRC 0 0.4 cal / cm^2	HRC 2* 6.7 cal / cm^2
10kA	HRC 0 0.1 cal / cm^2	HRC 0 0.2 cal / cm^2	HRC 2* 6.2 cal / cm^2
20kA	HRC 0 0.1 cal / cm^2	HRC 0 0.2 cal / cm^2	HRC 2* 5.9 cal / cm^2
30kA	HRC 0 0.1 cal / cm^2	HRC 0 0.2 cal / cm^2	HRC 2* 5.8 cal / cm^2

Table 3. NEC limit 50A Class RK1 fuses.

Available Fault Current at MCC	Length of Run		
	200 ft	400 ft	600 ft
5kA	HRC 0 0.0 cal / cm^2	HRC 0 0.1 cal / cm^2	HRC 1 1.2 cal / cm^2
10kA	HRC 0 0.0 cal / cm^2	HRC 0 0.1 cal / cm^2	HRC 0 1.0 cal / cm^2
20kA	HRC 0 0.0 cal / cm^2	HRC 0 0.1 cal / cm^2	HRC 0 0.9 cal / cm^2
30kA	HRC 0 0.0 cal / cm^2	HRC 0 0.1 cal / cm^2	HRC 0 0.8 cal / cm^2

Table 4. 40A Class RK1 fuses.

choose Class RK1 fuses instead of RK5 (**Table 3**). Comparing the data in Tables 1 and 3, note the dramatic changes in IE and HRC levels with the change in fuse class. Finally, the fourth case involves lower-rated 40A upstream type RK1 fuses that still permit start-up of the motor. Comparing the results in **Table 4** with those of Table 2, once again we see a significant reduction in IE levels.

What can we take away from this example? First, PPE is necessary for this "measly job," and an NFPA-70E arc flash warning label on the safety switch would certainly reinforce this point. Second, an NFPA 70E-compliant label, specifying available incident energy level at 18 in. from the piece of equipment or HRC rating, would inform the worker as to the appropriate level of PPE to wear for the task at hand. Finally, this example also illustrates the importance of replacing blown fuses with identical replacements, so as not to inadvertently change the level of arc flash risk from that on the arc flash warning label. **EC&M**

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Don’t Leave Arc Flash Protection to Chance — Part 2

Expectations of arc flash risk can be erroneous in practice

By Frank Mercede, P.E., and Joseph N. Mercede, Mercedes Electric Co., Inc.

The second in a three-part series on the importance of arc flash labeling of electrical equipment, this set of articles provides practical examples to shed light on some of the common misconceptions surrounding arc flash protection.

In Part 1, which ran in the September 2011 issue, we considered the low-level task of taking measurements within a non-fused safety switch that serves as a local motor disconnect. In this piece, we learned that the level of arc flash risk for this task cannot be taken lightly, because it depends significantly on the amperage and class of the upstream fuses in the motor starter compartment and the length of the branch circuit conductors running from the fuses to the safety switch.

In this installment, we focus on the example system outlined in **Fig. 1**. Work is to be done at the next upstream level device of the electrical system (i.e., in the combination motor starter bucket of a motor control center or MCC serving a low-voltage induction motor). Unfortunately, the door of the bucket is missing an NFPA 70E-compliant arc flash warning label. Therefore, the worker cannot be sure of the level of arc flash risk at this specific location. So how should one proceed when no warning label is present?

As shown in Fig. 1, the upstream protective device that should respond to an arcing fault in the motor starter bucket is a low-voltage power circuit breaker equipped with a solid-state trip unit. The effect of the long-time (LT), short-time (ST), and instantaneous (I) settings of

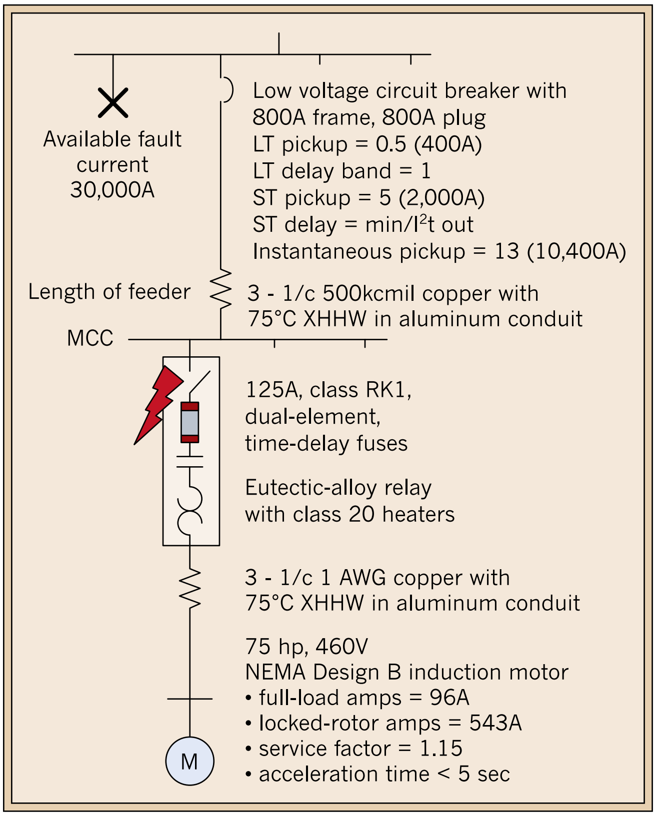

Fig. 1. One-line diagram of example.

Feeder Length and Arc Flash Risk

Length of feeder (ft)	Bolted 3-phase short-circuit current (kA)	Arc current (kA)	Worst-case arc time (sec)	Worst-case incident energy (cal/cm^2)	Hazard/risk category
20	28.0	15.8	0.01	2.8	1
50	25.4	12.3	0.19	8.1	3
150	19.1	11.4	0.19	7.5	2*
1,000	5.9	4.1	0.19	3.4	1

Feeder length and arc flash risk.

the trip unit are shown on the time-current plot in **Fig. 2**. The degree of separation of the fuse and circuit breaker time-current characteristics in the "I" region is due to the "I" pick-up setting. This setting guarantees selective coordination of these protective devices below 0.1 sec for a fault on the load side of the fuses. It's important to note that selective coordination can still be achieved at a lower "I" pick-up setting. For a discussion on this topic, see the article "Protective Device Coordination Study — Part 2 of 3," which appeared in the March 2011 issue of *EC&M*, available online at http://ecmweb.com/design_engineering/protective-device-coordiation-study-part-2-20110301/.

Calculations were performed per IEEE 1584 to determine the incident energy level in Calories per square centimeter and corresponding Hazard/Risk Category (HRC) for variation in feeder length. The results of these calculations are summarized in the **Table** (on page C10). As expected, the bolted 3-phase, short circuit current and corresponding arc current at the starter bucket decrease with increasing feeder length. IEEE 1584 recommends using the worst-case results of arc time and incident energy for 100% and 85% of the calculated arc current. These results are summarized in the Table.

What can you take away from the results shown in the Table? First, the effect of feeder length on incident energy level is not straightforward. As you can see, this value encompasses a wide range of values and covers three different HRCs. Second, the "I" pick-up setting significantly affects the arc time when calculating incident energy, besides its effect on the coordination between the fuses and circuit breaker. Note in the Table that the arc time is either 0.01 sec or 0.19 sec, depending on whether the arc current is above or below the "I" pick-up setting, respectively. Thus, a key take away from this example is that you should not change trip unit settings on the fly without careful consideration of the consequences on protection and life safety requirements. **EC&M**

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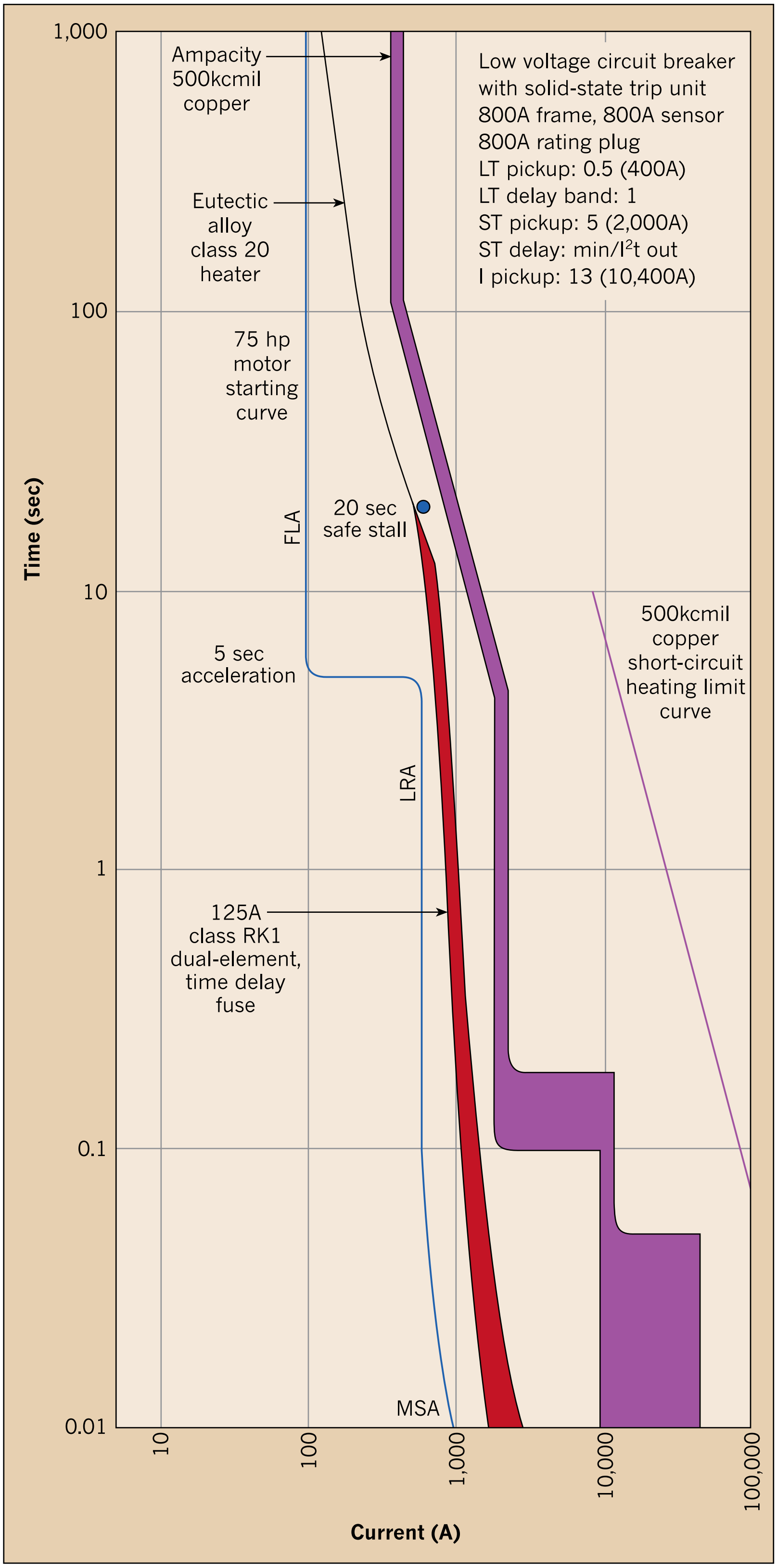

Fig. 2. Time-current plot of example.

Don’t Leave Arc Flash Protection to Chance — Part 3

A common misconception can lead to dire consequences

By Frank Mercede, P.E., Mercede Engineering LLC

This is the final installment of a three-part series on the importance of arc flash labeling of electrical equipment. In Part 1, which ran in the September 2011 issue, we considered the low-level task of taking measurements within a non-fused safety switch that serves as a local motor disconnect and learned that the level of arc flash risk can be significant, depending on the amperage and class of the upstream fuses in the motor starter compartment and the length of the branch circuit conductors running from the fuses to the safety switch. In Part 2, which ran in the October 2011 issue, we moved further upstream to a combination

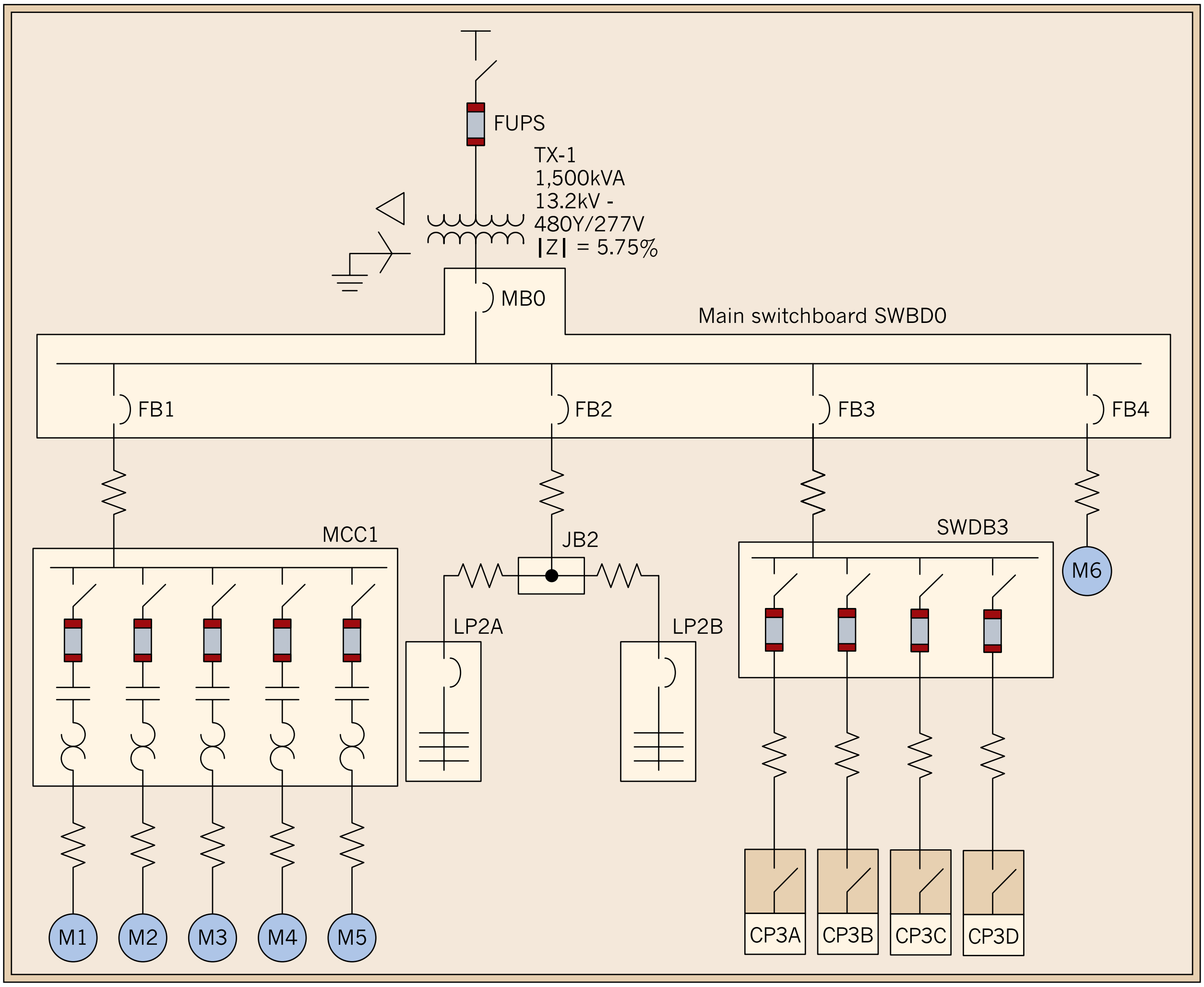

Fig. 1. One-line diagram of sample commercial system.

Arc Flash Hazard Report of Main Switchboard Breakers

Arc fault bus	Upstream trip device	Bolted fault @ 480V (kA)	Arc fault @ 480V (kA)	Arc time (sec)	Arc flash boundary (in.)	Incident energy (cal/cm^2)
SWBD0	FUPS	26.734	11.908	2.371	374.3	104.8
	MB0	26.734	14.002	0.1	42.2	5.3

Table 1. Results from arc flash calculations per IEEE Std. 1584.

Arc Flash Label Information of Main Switchboard Breakers

Breaker	Arc flash label	Incident energy at 18 in. (cal/cm^2)	Arc flash boundary (in.)	Nominal rated line voltage (V)	Date of study
MB0	Danger	105	374	480	04/16/11
FB1	Danger	105	374	480	04/16/11
FB2	Danger	105	374	480	04/16/11
FB3	Danger	105	374	480	04/16/11
FB4	Danger	105	374	480	04/16/11

Table 2. Note how the extreme incident energy level applies to all compartments in this particular switchboard.

motor starter bucket of a motor control center and learned once again that the level of arc flash risk can defy expectations, depending on the instantaneous setting of the upstream solid-state trip unit and the feeder length to the motor control center.

DANGER

Arc Flash and Shock Hazard

DO NOT WORK ENERGIZED

105 cal/cm^2	Incident Energy at 18 in.
374 in.	Arc Flash Boundary
480VAC	Nom. Rated Line Voltage
04/16/11	Date of Study

Label No. **AF010-MEC-001002**

Fig. 2. Sample of arc flash label for extreme incident energy level.

In this final installment, we focus our attention on the main switchboard in the example system shown in **Fig. 1** on page C10. As we can see in the one-line diagram of Fig. 1, the 3-phase electric service of the commercial facility is fed from the electric utility at 13.2kV and transformed to 480V via a 1,500kVA, dry-type, delta-grounded wye main transformer (TX-1). The main transformer is protected on the primary side by fused switch FUPS. On the secondary side, the main switchboard SWBD0 is composed of main secondary breaker MB0 and four feeder breakers (FB1, FB2, FB3, and FB4); all are molded-case circuit breakers equipped with solid-state trip units. The feeder breakers serve a motor control center (MCC1), two lighting panelboards (LP2A and LP2B), a conveying system switchboard (SWBD3), and induction motor drive (M6). MCC1 consists of five combination motor starters with fused disconnects for induction motors M1 through M5. The main feeder for the lighting panelboards travels some distance from FB2 to a junction box JB2, and two short subfeeders travel from JB2 to the main breakers MB2A and MB2B of LP2A and LP2B, respectively. The four fused disconnects of SWBD3 feed the integral, non-fused disconnects of the conveying system control panels (CP3A, CP3B, CP3C, and CP3D).

Table 1 on page C12 presents the results of arc flash calculations per IEEE Std. 1584 at main switchboard SWBD0. Note that the results depend on the upstream trip device that clears the arc fault. Referring to Table 1, if primary fused switch FUPS serves as the upstream trip device for an arc fault at SWBD0, the incident energy level is 104.8 cal/cm^2. This extreme incident energy level exceeds the upper limit of the highest Hazard/Risk Category 4 (i.e., 40 cal/cm^2), and work on the switchboard cannot proceed until it has been put in an electrically safe work condition per Article 120 of NFPA 70E. However, if the main secondary breaker (MB0) serves as the upstream trip device, then the incident energy level is much lower (5.3 cal/cm^2), which corresponds to a Hazard/Risk Category of 2*.

Based on Table 1, one may mistakenly believe that the extreme incident energy level applies only to the MB0 compartment of main switchboard SWBD0. However, an explosion due to an arc fault in a feeder breaker compartment could spread to all compartments of the switchboard (because the switchboard of this example is not arc resistant in construction) and render MB0 incapable of clearing the fault. Thus, the extreme incident energy level applies to all compartments of the switchboard, as shown in **Table 2** on page C12**. Figure 2** on page C12 provides a sample of an NFPA 70E-compliant arc flash label for the extreme incident energy level noted previously.

In conclusion, we hope that the examples of this three-part series reinforce the importance of conducting an arc flash study. This type of study will help you gather the information needed to meet the arc flash labeling requirement of Sec. 130.3(C) of NFPA 70E-2009, *Standard for Electrical Safety in the Workplace*.

Finally, keep in mind that an arc flash study by itself is not a substitute for electrical safety training and an ongoing electrical safety program. These types of training courses and safety procedures are still required for both in-house and contracted workers who work on or near energized electrical equipment. **EC&M**

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