# Electrical Safety & Arc Flash Protection

**Introduction**

There is a great deal of activity in the electrical industry concerning electrical safety. The focus is on the two greatest electrical hazards to workers: shock and arc flash. In recent years significant knowledge has been gained through testing and analysis concerning arc flash hazards and how to contend with this type of hazard. This hazard exists when a worker is working on or near exposed electric conductors or circuit parts that have not been placed in a safe work condition. If an arcing fault occurs, the tremendous energy released in a fraction of a second can result in serious injury or death. However, there is a great challenge in getting the message to the populace of the electrical industry so that safer system designs and safer work procedures and behaviors result. Workers continue to sustain life altering injuries or death. NFPA 70E "Standard for Electrical Safety Requirements for Employee Workplaces" is the foremost consensus standard on electrical safety. As of this writing, the current version is NFPA 70E – 2000 and NFPA 70E – 2003 is in development. Each succeeding revision advances the safety requirements.

Why is there an NFPA 70E? In 1976 a new electrical standards development committee was formed to assist the Occupational Safety and Health Administration (OSHA) in preparing electrical safety standards. This committee on Electrical Safety Requirements For Employee Workplaces, NFPA 70E, was needed for a number of reasons, including: (1) the NEC® is an installation standard while OSHA also addresses employee safety in the workplace, (2) not all sections in the NEC® relate to worker safety and these are therefore of little value to OSHAs focus and needs, (3) many safety related work and maintenance practices are not covered, or not adequately covered, in the NEC® and (4) a national consensus standard on electrical safety for workers did not exist, but was needed – an easy to understand document that addresses worker electrical safety. The first edition was published in 1979.

The current NFPA 70E - 2000 consists of four parts;

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| Part I | Installation Safety Requirements |
| Part II | Safety-Related Work Practices |
| Part III | Safety-Related Maintenance Requirements |
| Part IV | Safety Requirements for Special Equipment |

**Only Work On Equipment That Is In A Safe Work Condition**

The rule for the industry and the law is **"don't work it hot"**. Per OSHA 1910.333(a)(1) and NFPA 70E–2000 Part II 2-1.1.1, workers should not work on or near exposed live parts except for two demonstrable reasons:

1. deenergizing introduces additional or increased hazards (such as cutting ventilation to a hazardous location) or
2. infeasible due to equipment design or operational limitations (such as when voltage testing is required for diagnostics).

Financial considerations are not an adequate reason to work on or near energized circuits. To violate these regulations and practices is a violation of federal law, which is punishable by fine and/or imprisonment.

Note: deenergized electrical parts are considered as energized until all steps of the lockout/tagout procedure are successfully completed [OSHA 1910.333(b)] and the equipment has been successfully put in a "safe work condition" (NFPA 70E). Voltage testing of each conductor, which is a necessary step while completing the lockout/tagout procedure (putting the equipment in a safe work condition), is considered as working on energized parts per OSHA 1910.333(b) and NFPA 70E – 2000 Part II 5-1.

*Therefore, adequate personal protective equipment is always required during the tests to verify the absence of voltage after the circuits are deenergized and properly locked out/tagged out. Adequate PPE may also be required during load interruption and during visual inspection that verifies that all disconnecting devices are open.*

So no matter how well a worker follows safe work practices, there will always be a risk associated with electrical equipment – even when putting equipment in a "safe work condition". And there are those occasions where it is necessary to work on energized equipment such as when a problem can not be uncovered by trouble shooting the equipment in a deenergized state.

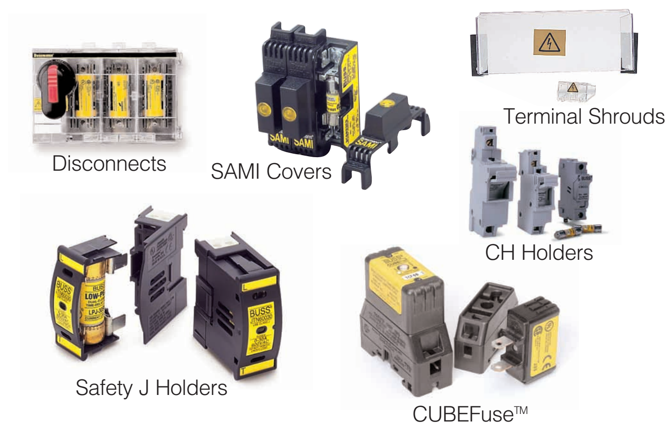
**What Can Be Done To Lessen the Risk?**

There are a multitude of things that can be implemented to increase electrical safety, from design aspects and upgrading systems, to training, implementing safe work practices and utilizing personal protective equipment (PPE). Not all of these topics can be covered in this section. The focus of this section will mainly concern some overcurrent protection aspects related to electrical safety. For some other related electrical safety topics, read the Bussmann® Safety BASICs™ Handbook and visit the Safety BASICs™ webpage at www.bussmann.com.

**Shock Protection**

There are three shock approach boundaries required to be observed in NFPA 70E - 2000 Part II Table 2-1.3.4; these shock approach boundaries are dependent upon the system voltage. The significance of these boundaries for workers and their actions while within the boundaries can be found in NFPA 70E or the Bussmann® Safety BASICs™ Handbook. See Figure 2 for a graphic depiction of the three shock approach boundaries with the flash protection boundary (following the section on Flash Hazard Assessment). For hazard analysis and worker protection, it is important to observe the shock approach boundaries together with the flash protection boundary (which is covered in paragraphs ahead).

Although most electrical workers and others are aware of the hazard due to electrical shock, it still is a prevalent cause of injury and death. One of the best ways to help minimize the electrical shock hazard is to utilize finger-safe products and non-conductive covers or barriers. Finger-safe products and covers reduce the chance that a shock or arcing fault can occur. If all the electrical components are finger-safe or covered, a worker has a much lower chance of coming in contact with a live conductor (shock hazard), or the risk that a conductive part falling across bare, live conductive parts creating an arcing fault is greatly reduced (arc flash hazard). Shown below are the new CUBEFuses™ that are IP20 finger-safe, in addition, they are very current-limiting protective devices. Also shown are SAMI™ fuse covers for covering fuses, Safety J fuse holders for LPJ fuses, CH fuse holders available for a variety of Buss® fuses and Bussmann® disconnect switches, with fuse and terminal shrouds. All these devices can reduce the chance that a worker, tool or other conductive item will come in contact with a live part.




**Arc Fault Basics**

An electrician, that is in an energized panelboard or just putting a system in a safe work condition is potentially in a very unsafe place. A falling knockout, a dislodged skinned wire scrap inadvertently left previously in the panelboard or a slip of a screwdriver can cause a phase-to-phase or phase-to-ground arcing fault. The temperature of the arc can reach approximately 35,000°F, or about four times as hot as the surface of the sun. These temperatures easily can cause serious or fatal burns and/or ignite flammable clothing.

Figure 1 is a model of an arc fault and the physical consequences that can occur. The unique aspect of an arcing fault is that the fault current flows through the air between conductors or a conductor(s) and a grounded part. The arc has an associated arc voltage because there is arc impedance. The product of the fault current and arc voltage concentrated at one point, results in tremendous energy released in several forms. The high arc temperature vaporizes the conductors in an explosive change in state from solid to vapor (copper vapor expands to 67,000 times the volume of solid copper). Because of the expansive vaporization of conductive metal, a line-to-line or line-to-ground arcing fault can escalate into a three phase arcing fault in less than a thousandth of a second. The speed of the event is so rapid that the human system can not react quickly enough for a worker to take corrective measures. If an arcing fault occurs while a worker is in close proximity, the survivability of the worker is mostly dependent upon (1) system design aspects, such as characteristics of the overcurrent protective devices and (2) precautions the worker has taken prior to the event, such as wearing personal protective equipment appropriate for the hazard.

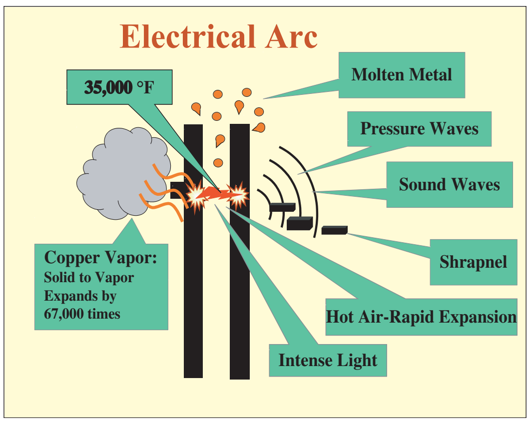



**Figure 1. Electrical Arc Model**

The effects of an arcing fault can be devastating on a person. The intense thermal energy released in a fraction of a second can cause severe burns. Molten metal is blown out and can burn skin or ignite flammable clothing. One of the major causes of serious burns and deaths to workers is ignition of flammable clothing due to an arcing fault. The tremendous pressure blast from the vaporization of conducting materials and superheating of air can fracture ribs, collapse lungs and knock workers off ladders or blow them across a room. The pressure blast can cause shrapnel (equipment parts) to be hurled at high velocity (can be in excess of 700 miles per hour). And the time in which the arcing event runs its course can be only a small fraction of a second. Testing has proven that the arcing fault current magnitude and time duration are the most critical variables in determining the energy released. Serious accidents are occurring at an alarming rate on systems of 600V or less, in part because of the high fault currents that are possible. But also, designers, management and workers mistakenly tend not to take the necessary precautions that they take when designing or working on medium and high voltage systems.

It is important to note that the predictability of arc faults and the energy released by an arc fault is subject to great variance. Some of the variables that affect the outcome include:

available bolted short-circuit current
the time the fault is permitted to flow (speed of the overcurrent protective device)
arc gap spacing
size of the enclosure or no enclosure
power factor of fault
system voltage
whether arcing fault can sustain itself
type of system grounding scheme
distance the worker's body parts are from the arc

Typically, engineering data that the industry provides concerning arcing faults is based on specific values of these variables. For instance, for 600V and less systems, much of the data has been gathered from testing on systems with an arc gap spacing of 1.25 inches and incident energy (to be discussed later in this section) determined at 18 inches from the point of the arc fault.

**The Role of Overcurrent Protective Devices In Electrical Safety**

The selection and performance of overcurrent protective devices play a significant role in electrical safety. Extensive tests and analysis by industry has shown that the energy released during an arcing fault is related to two characteristics of the overcurrent protective device protecting the affected circuit. These two characteristics are 1) the time it takes the overcurrent protective device to open and 2) the amount of fault current the overcurrent protective device lets-through. For instance, the faster the fault is cleared by the overcurrent protective device, the lower the energy released. If the overcurrent protective device can also limit the current, thereby reducing the actual fault current that flows through the arc, the lower the energy released. Overcurrent protective devices that are current-limiting, and thus may greatly reduce the current let-through, can have a great affect on reducing the energy released. The lower the energy released the better for both worker safety and equipment protection.

The photos and recording sensor readings from actual arcing fault tests (next page) illustrate this point very well. An ad hoc electrical safety working group, within the IEEE Petroleum and Chemical Industry Committee, conducted these tests to investigate arc fault hazards. These tests and others are detailed in “Staged Tests Increase Awareness of Arc-Fault Hazards in Electrical Equipment”, IEEE Petroleum and Chemical Industry Conference Record, September, 1997, pp. 313-322. This paper can be found at www.bussmann.com under Services/Safety BASICs. One finding of this IEEE paper is that current-limiting overcurrent protective devices reduce damage and arc-fault energy (provided the fault current is within the current-limiting range). To better assess the benefit of limiting the current of an arcing fault, it is important to note some key thresholds of injury for humans. Results of these tests were recorded by sensors on mannequins and can be compared to these parameters:

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| **Just Curable Burn Threshold:** | **80°C / 175°F (0.1 sec)** |
| **Incurable Burn Threshold:** | **96°C / 205°F (0.1 sec)** |
| **Eardrum Rupture Threshold:** | **720 lbs/ft$^2$** |
| **Lung Damage Threshold:** | **1728 - 2160 lbs/ft$^2$** |

**OSHA Required Ear Protection Threshold: 85 db** (for sustained time period)
(Note: an increase of 3 db is equivalent to doubling the sound level.)

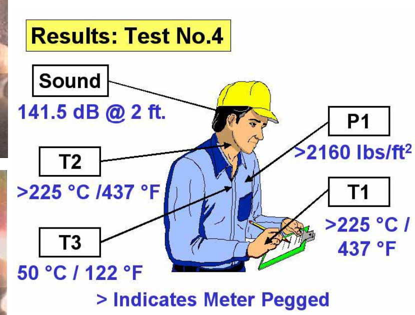
**Test 4, Test 3 and Test 1: General**

All three of these tests were conducted on the same electrical circuit set-up with an available bolted three phase, short-circuit current of 22,600 symmetrical rms amperes at 480V. In each case, an arcing fault was initiated in a size 1 combination motor controller enclosure with the door open, as if an electrician were working on the unit “live” or before it was placed in a safe work condition.

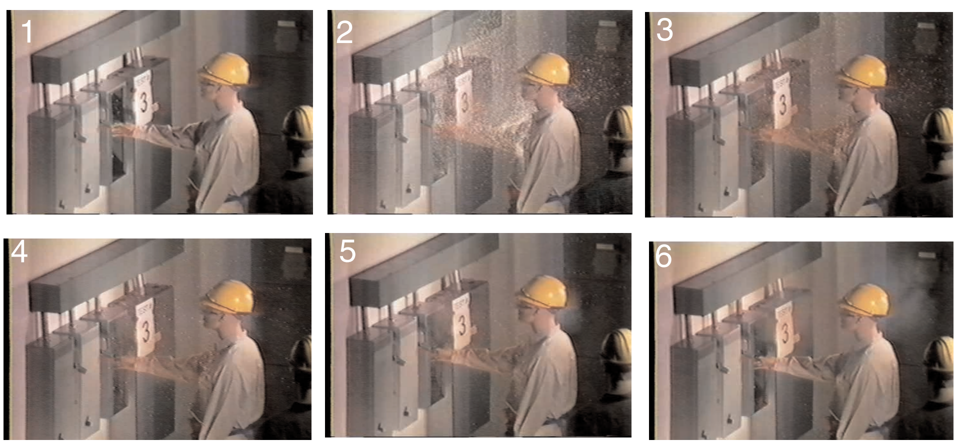
Test 4 and Test 3 were identical except for the overcurrent protective device protecting the circuit. In Test 4, a 640 ampere circuit breaker with a short-time delay is protecting the circuit; the circuit was cleared in 6 cycles. In Test 3, KRP-C-601SP, 601 ampere, current-limiting fuses (Class L) are protecting the circuit; they opened the fault current in less than 1/2 cycle and limited the current. The arcing fault was initiated on the line side of the motor branch circuit device in both Test 4 and Test 3. This means the fault is on the feeder circuit but within the controller enclosure.

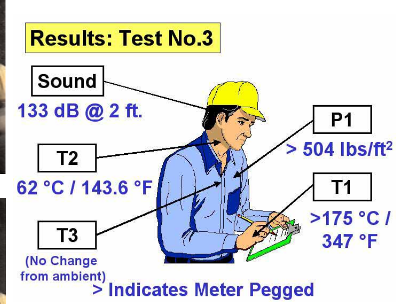
In Test 1, the arcing fault is initiated on the load side of the branch circuit overcurrent protective devices, which are LPS-RK 30SP, 30 ampere, current-limiting fuses (Class RK1). These fuses limited this fault current to a much lower amount and clear the circuit in approximately 1/4 cycle or less.

Following are the results recorded from the various sensors on the mannequin closest to the arcing fault. T1 and T2 recorded the temperature on the bare hand and neck respectively. The hand with T1 sensor was very close to the arcing fault. T3 recorded the temperature on the chest under the cotton shirt. P1 recorded the pressure on the chest. And the sound level was measured at the ear. Some results “pegged the meter”. That is, the specific measurements were unable to be recorded in some cases because the actual level exceeded the range of the sensor/recorder setting. These values are shown as >, which indicates that the actual value ***exceeded*** the value given but it is unknown how high of a level the actual value attained.

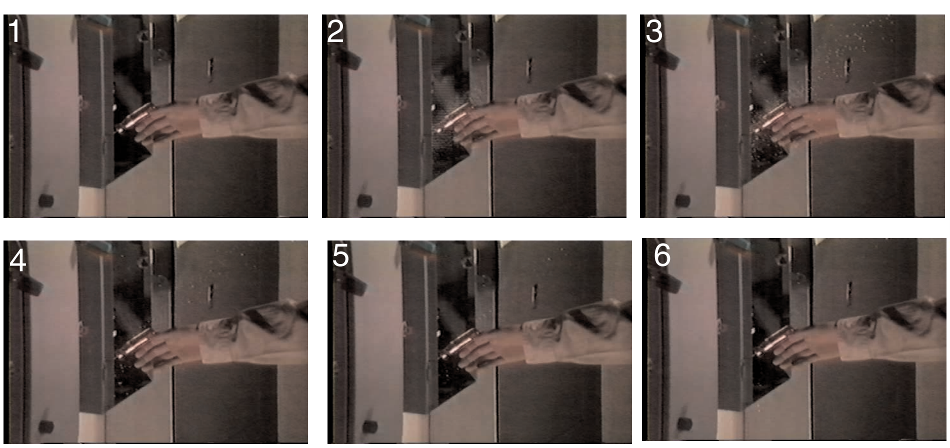



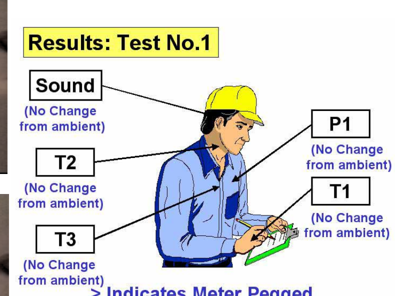

**Photos and results Test 4:** Staged test protected by circuit breaker with short-time delay (not a current-limiting overcurrent protective device). Short-time delay intentionally delayed opening for six cycles (.1 second). Note: Unexpectedly, there was an additional fault in the wireway and the blast caused the cover to hit the mannequin in the head.




**Photos and results Test 3:** Staged test protected by KRP-C-601SP LOW-PEAK® Current-Limiting Fuses (Class L). These fuses were in their current-limiting range and cleared in less than a 1/2 cycle (.0083 seconds).



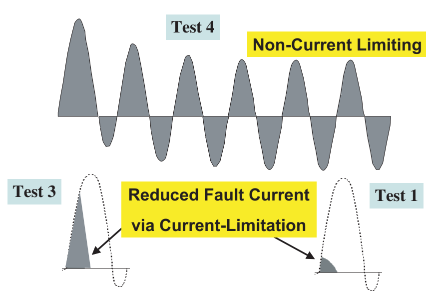

**Photos and results Test 1:** Staged test protected by LPS-RK-30SP, LOW-PEAK® Current-Limiting Fuses (Class RK1). These fuses were in current-limiting range and cleared in approximately 1/4 cycle (.004 seconds).

A couple of conclusions can be drawn from this testing.

(1) Arcing faults can release tremendous amounts of energy in many forms in a very short period of time. Look at all the measured values compared to key thresholds of injury for humans given in a previous paragraph. Test 4 was protected by a 640 A, non-current limiting device that opened in 6 cycles or .1 second.

(2) The overcurrent protective devices' characteristic can have a significant impact on the outcome. A 601 ampere, current-limiting overcurrent protective device, protects the circuit in Test 3. The current that flowed was reduced (limited) and the clearing time was 1/2 cycle or less. This was a significant reduction compared to Test 4. Compare the Test 3 measured values to the key thresholds of injury for humans and the Test 4 results. The measured results of Test 1 are significantly less than those in Test 4 and even those in Test 3. The reason is that Test 1 utilized a much smaller (30 ampere), current-limiting device. Test 3 and Test 1 both show that there are benefits of using current-limiting overcurrent protective devices. Test 1 just proves the point that the greater the current-limitation, the more the arcing fault energy may be reduced. Both Test 3 and Test 1 utilized very current-limiting fuses, but the lower ampere rated fuses limit the current more than the larger ampere rated fuses. It is important to note that the fault current must be in the current-limiting range of the overcurrent protective device in order to receive the benefit of the lower current let-through. See the diagram that depicts the oscillographs of Test 4, Test 3 and Test 1.

**Current-Limitation: Arc-Energy Reduction**




(3) The cotton shirt reduced the thermal energy exposure on the chest (T3 measured temperature under the cotton shirt). This illustrates the benefit of workers wearing protective garments.

### Flash Hazard Assessment

NFPA 70E has developed requirements to reduce the risk of injury to workers due to shock and arc flash hazards. There are three shock approach boundaries required to be observed in NFPA 70E - 2000. As discussed, arc fault currents can release tremendous amounts of energy. NFPA 70E – 2000 requires that before a worker approaches exposed electric conductors or circuit parts that have not been placed in a safe work condition; a flash hazard analysis must be performed. The flash hazard analysis should determine the flash protection boundary (FPB) and level of personal protective equipment (PPE) that the worker must wear. The flash protection boundary is the distance from the energized parts at which a worker could sustain a just curable burn (bare skin) as a result of an arcing fault. A worker entering the flash protection boundary must be qualified and must be wearing appropriate PPE. Figure 2 depicts the flash protection boundary and the three shock approach boundaries that shall be observed per NFPA 70E - 2000. In an actual situation, before a worker is permitted to approach equipment with exposed live parts, these boundaries must be determined. In addition, the worker must be wearing the required level of PPE, which can be determined by calculating the incident energy. Until equipment is placed in a "safe work condition" (NFPA 70E – 2000 Part II 2-1.1.3), it is considered "live". It is important to note that conductors and equipment are considered "live" when checking for voltage while putting equipment in a "safe work condition".

The incident energy is a measure of thermal energy at a specific distance from an arc fault; the unit of measure is typically in calories per centimeter squared (cal/cm$^2$). The distance from the fault in determining the incident energy depends on the worker's body position to the live parts. After determining the incident energy in cal/cm$^2$, the value can be used to select the appropriate personal protective equipment. There are various types of PPE with distinct levels of thermal protection capabilities termed "Arc Thermal Performance Exposure Values (ATPV) rated in cal/cm$^2$. Note: the most common distance for which incident energy has been determined in tests is 18 inches. If it is necessary to determine incident energy at a different distance, NFPA 70E - 2000 has equations that can be used in many situations (for greater than 18 inches).

Both the FPB and PPE level are dependent on the available fault current and the overcurrent protective device - its clearing time and if it is current-limiting. Knowing the available bolted short-circuit current, the arcing fault current, and the time duration for the equipment supply overcurrent protective device to open, it is possible to calculate the Flash Protection Boundary (FPB) and Incident Energy Exposure level. NFPA 70E - 2000 provides the formulas for this critical information. By reviewing the calculations, it is important to note that current-limiting overcurrent protective devices (when in their current-limiting range) can reduce the required FPB and PPE level as compared to non-current-limiting overcurrent protective devices.

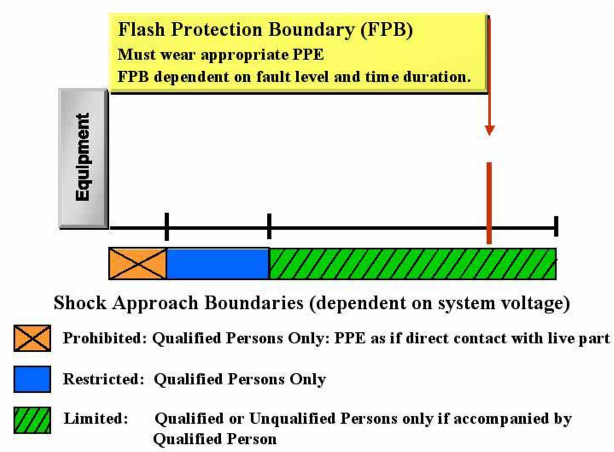



**Figure 2**

**Simple Method for Flash Hazard Analysis**

Anytime work must be done on or near energized electrical equipment or equipment that could become energized, a flash hazard analysis must be completed. This flash hazard analysis includes, but is not limited to, determining:

1. the Incident Energy Exposure to select the level of PPE needed to complete the task
2. the Flash Protection Boundary to know the approach point to the equipment where PPE will be required.

Various information about the system may be needed to complete this analysis but the two pieces that are absolutely necessary are:

1. the available 3Ø bolted fault current
2. the fuse or circuit breaker type and ampere rating.

Consider the following one-line diagram and then follow the examples that take the steps needed to conduct a Flash Hazard Analysis (The following information utilizes formulas based upon IEEE *Guide for Arc Flash Hazard Analysis,* P1584. It is expected that this information will be included in the upcoming edition of NFPA 70E-2003.). Be sure to read the Notes associated with each section.

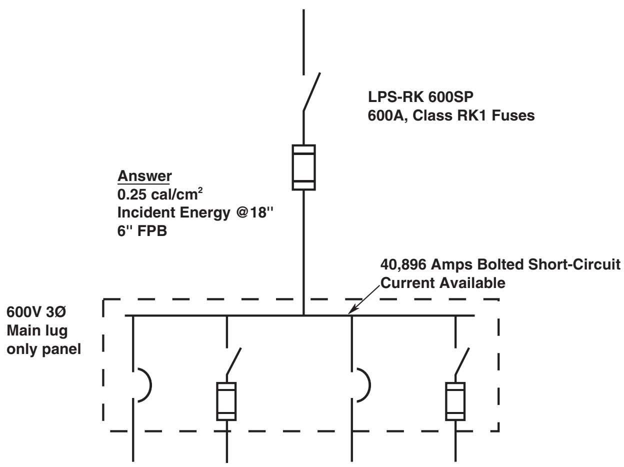



**Figure 3**

**Example 1: Flash Hazard Analysis using Bussmann® Current Limiting Fuses.**

The following is a simple method when using certain Bussmann® fuses; this method is based on actual data from arcing fault tests with Bussmann® current-limiting fuses. Using this simple method, the first thing that must be done is to determine the incident energy exposure. Bussmann has simplified this process when using LPS-RK-(amp)SP, LPJ-(amp)SP, LP-CC-(amp) or KRP-C-(amp)SP LOW-PEAK® fuses or JJS-(amp) TRON® fuses. In some cases the results are conservative; see Note 12.

In this example, the line side OCPD in Figure 3 is a LPS-RK-600SP, LOW-PEAK® current-limiting fuse. Simply take the available 3Ø bolted short-circuit current at the panel, in this case 40,896 amps, and apply it to the horizontal axis of the chart in Figure 4.

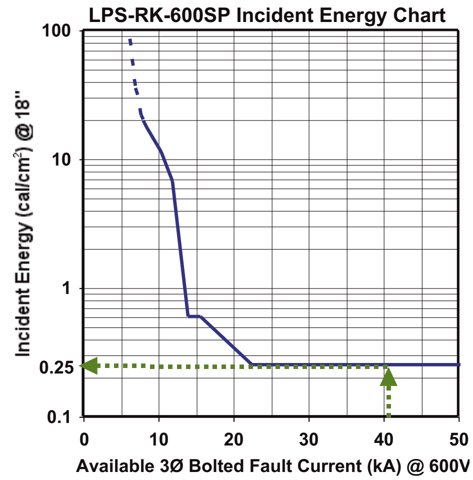



**Figure 4 Important: for proper use of this curve, see Figure 6 and associated notes.**

With 40,896 amps of 3Ø bolted short-circuit current available, the curve shows that when relying on the LPS-RK-600SP LOW-PEAK® fuse to interrupt an arcing fault, the incident energy is 0.25 cal/cm$^2$. Notice that no calculations were needed to obtain this value and the variables required are the available 3Ø bolted fault current and the ampacity of the current-limiting fuse. See Notes 11 and 12.

The next step in this simplified flash hazard analysis is to determine the Flash Protection Boundary (FPB). After obtaining a value for incident energy exposure, the chart in Figure 5 can be consulted to determine the FPB. With an incident energy exposure of 0.25 cal/cm$^2$ and using the chart in Figure 5, the Flash Protection Boundary is approximately 6 inches. See Note 10. This FPB distance means that anytime work is to be performed inside of this distance, including voltage testing to verify that the panel is deenergized, the worker must be equipped with the appropriate PPE.

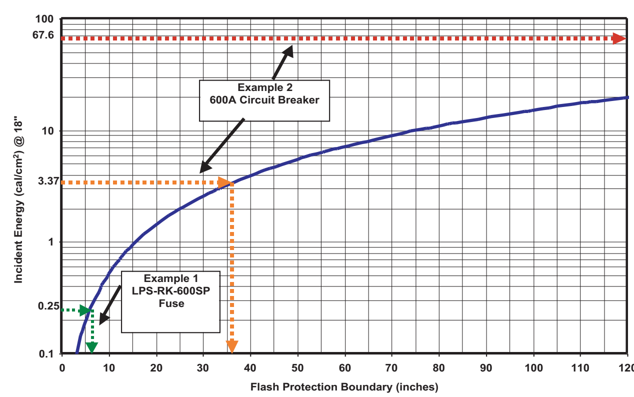



**Figure 5 Important: for proper use, see notes.**

The last step in the flash hazard analysis is to determine the appropriate PPE for the task. To select the proper PPE, utilize the incident energy exposure values and the requirements from NFPA 70E. NFPA 70E has requirements for PPE that are based upon the incident energy exposures. When selecting PPE for a given application, keep in mind that these requirements from NFPA 70E are minimum requirements. Having additional PPE, above what is required, can further assist in minimizing the effects of an arc-flash incident. See Note 3. Another thing to keep in mind is that PPE available on the market today does *not* protect a person from the pressures, shrapnel, and toxic gases that can result from an arc-blast. Existing PPE is only utilized to minimize the potential for burns from the arc-flash. See Note 2.

See Notes on next page for proper use of charts.

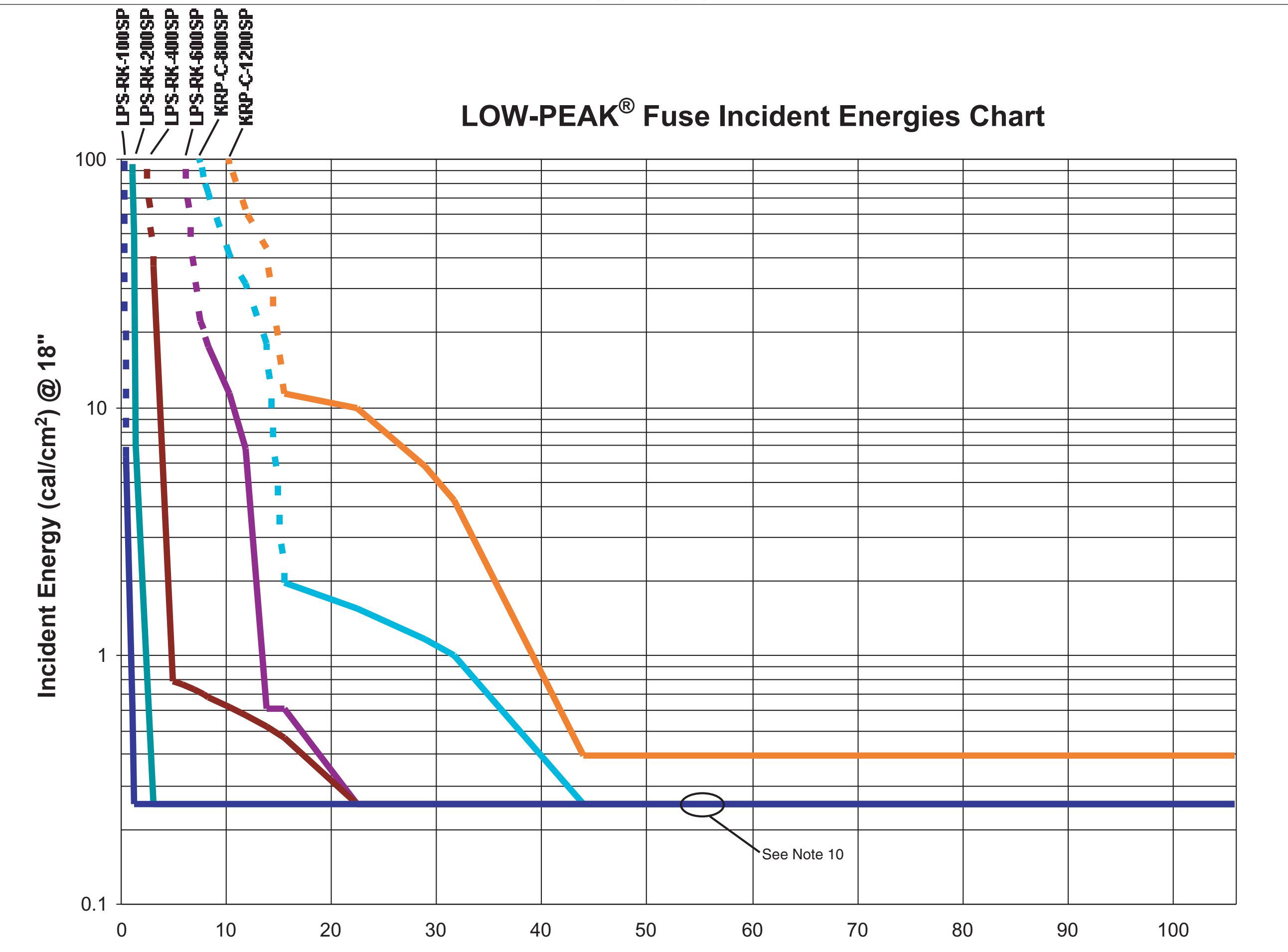



Figure 6

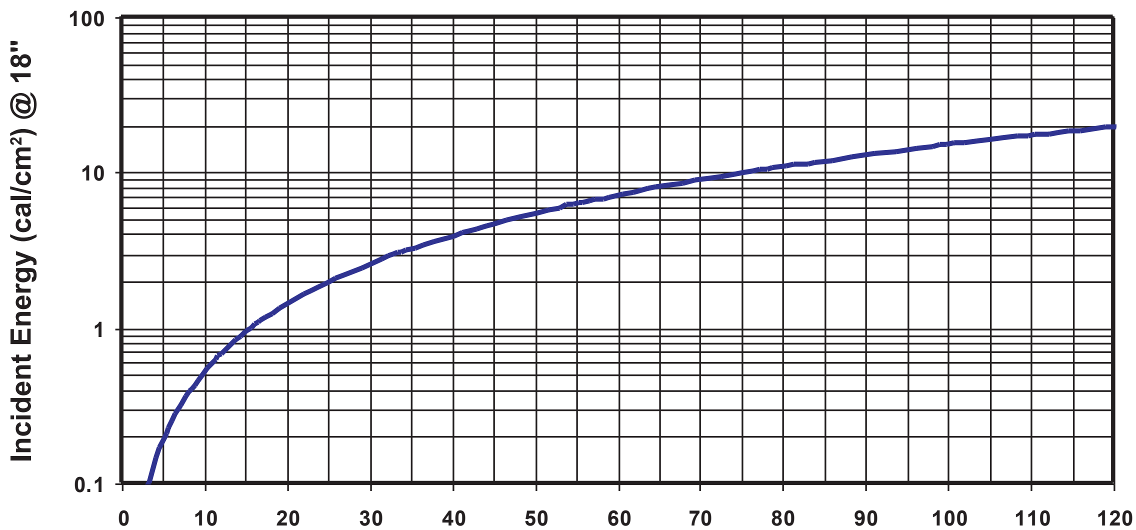



Figure 7

**Flash Hazard Analysis Tools on www.bussmann.com**

Bussmann® continues to study this topic and develop more complete data and application tools.
Visit www.bussmann.com for interactive arc-flash calculators and the most current data.

Steps necessary to conduct a Flash Hazard Analysis when using LOW-PEAK® fuses and Figures 6 and 7.

1. Determine the available bolted fault current on the line side terminals of the equipment that will be worked upon.
2. Identify the amperage of the LOW-PEAK® fuse upstream that is protecting the panel where work is to be performed.
3. Consult the LOW-PEAK® Fuse Incident Energy Chart, Figure 6, to determine the Incident Energy Exposure available.
4. Determine the Flash Protection Boundary that will require PPE based upon the incident energy. This can also be simplified by using the chart for Flash Protection Boundary in Figure 7.
5. Identify the minimum requirements for PPE when work is to be performed inside of the FPB by consulting the requirements found in NFPA 70E.

**Notes for Flash Hazard Analysis Charts**

**General Notes for fuses and circuit breakers:**

Note 1: The data in these charts (Figures 6 and 7) and procedures used for determining incident energy and flash protection boundary in Example 1 and 2 are based upon IEEE *Guide for Arc Flash Hazard Analysis,* P1584. The methods for determining incident energy from this standard were created so that the PPE selected from the calculated incident energy would be adequate for 95% of arc-flash incidents. In up to 5% of incidents, incurable burns to the body and torso could result. This was based upon PPE with standard ATPVs of 1.2, 8, 25, 40 and 100 cal/cm$^2$. PPE with intermediate ATPV values can be utilized, but at the next lower standard ATPV rating.

Note 2: First and foremost, this information is not to be used as a recommendation to work on energized equipment. This information is to help assist in determining the proper PPE to help safeguard a worker from the burns that can be sustained from an arc flash incident. This information does not take into account the effects of pressure, shrapnel, molten metal spray, or the toxic copper vapor resulting from an arc fault.

Note 3: PPE should be utilized any time that work is to be performed on or near energized electrical equipment or equipment that could become energized. Voltage testing while completing the lockout/tagout procedure (putting the equipment in a safe work condition) is considered as working on energized parts per OSHA 1910.333(b). As a general work practice, for the lowest Hazard/Risk Categories (0 & 1), it is suggested utilizing a minimum of voltage rated gloves with leathers, long sleeve cotton shirt, pants, a face shield, safety glasses and hard hat, in addition to the recommendations from NFPA 70E (even though NFPA 70E requirements do not require all these items for the lower Hazard/Risk Categories).

Note 4: To use these methods the available bolted short-circuit current must be calculated at each point in the system that is to be analyzed. In some cases, using conservatively high bolted short-circuit currents may result in lower incident energy than what is possible. This is dependent upon the time-current characteristics of the overcurrent protective devices.

Note 5: This information is not intended to promote workers working on or near exposed energized parts. The intent is for those situations such as taking voltage measurement during the lockout/tagout procedures where arc flash analysis must be performed and the worker must utilize adequate PPE.

Note 6: The data for Figure 7 is from IEEE *Guide for Arc Flash Hazard Analysis*, P1584. It is based on 1.2 cal/cm$^2$ at 18" working distance, 32mm (1¼") electrode spacing, 3Ø system, and 20" by 20" by 20" box.

**Fuse Notes:**

Note 7: The fuse information is based upon extensive tests that were conducted at various fault currents for each Bussmann® KRP-C_SP, Class L, and LPS-RK_SP, Class RK1, fuse indicated in the charts. For KRP-C_SP Fuses greater than 1200A, consult Bussmann®. Parameters for these tests were selected to achieve what was considered to be the worst-case results based upon the latest testing as reported in IEEE papers available at the time. For example, an arc-flash inside of a box will achieve a higher incident energy than an arc-flash in open air. This is because the sides of the box will focus the arc-flash energy towards the opening, whereas open air will allow the energy to dissipate in all directions. The parameters for the tests were 600V, 3Ø, ungrounded system using a 20" by 20" by 20" box and a spacing of electrodes of 32mm (1¼ in.). Actual results from incidents could be different for a number of reasons, including different (1) system voltage, (2) short-circuit power factor, (3) distance from the arc, (4) arc gap, (5) enclosure size, (6) fuse manufacturer, (7) fuse class, (8) orientation of the worker and (9) grounding scheme. 100 ampere LPS-RK_SP, Class RK1 fuses were the smallest fuses tested. So the data for the fuses smaller than that is based upon the 100 ampere data. Arc-flash values for actual 30 and 60 ampere fuses would be considerably less than 100 ampere fuses, however, it does not matter since the values for the 100 ampere fuses are already so low.

Note 8: The incident energy derived from this chart for the fuse curves is based upon a working distance of 18 inches from the arc fault source.

Note 9: To create the fuse incident energy charts, worst-case values were used. For the solid part of the lines, worst case data from actual test results were used. Actual values from these tests in most cases were found to be much lower than what is listed on the chart. For example to have a smooth curve, in one test at 15.7 kA, the highest result for incident energy was 1.1 cal/cm$^2$ but the number plotted for the chart was 2 cal/cm$^2$. For the dashed part of the line, worst case values were used based on an equation from IEEE *Guide for Arc Flash Hazard Analysis,* P1584 using the opening time from the published total clearing time current curves of these fuses.

Note 10: The fuse incident energy curves were drawn not to go below 0.25 cal/cm$^2$ even though many actual values were below .25 cal/cm$^2$. The minimum FPB of 6 inches, or incident energy exposure of 0.25 cal/cm$^2$, was chosen to keep from encouraging workers to work on energized equipment without PPE because of a low FPB. For example, due to the tremendous energy limitation of the LOW-PEAK® fuses, some of the tests resulted in a FPB of less than 2 inches. While the resulting flash may not be very large for this situation, molten metal may still be experienced, and PPE should be utilized any time that work is to be done on live electrical equipment which includes voltage testing during the lockout/tagout procedure..

Note 11: Fuse incident energy charts in this section take into account the translation from available 3Ø bolted fault current to the arcing fault current.

Note 12: The actual tests were conducted with Bussmann® LPS-RK-(amp)SP and KRP-C-(amp)SP fuses. These charts can also be used for LPJ-(amp)SP, JJS-(amp), and LP-CC-(amp) fuses to determine the incident energy available and flash protection boundary. This is due to the current limiting ability of these fuses yielding lower values of let-through current as well as opening in less time than that of the LPS-RK-(amp)SP fuses. Lower let-through values together with a lower arcing time result in a lower amount of arc-flash energy.

**Method For Other Type Fuses**

The chart in Figure 6 is applicable for LOW-PEAK® and TRON® Fuses (see Note 12). To determine the flash protection boundary and incident energy for applications with other fuses, use the equations in IEEE *Guide for Arc Flash Hazard Analysis,* P1584 or NFPA 70E-2000. The following are the formulas in NFPA 70E - 2000 for calculating the flash protection boundary and incident energy. It is significant to note that the flash protection boundary is dependent upon the available bolted short-circuit current (incorporated in $MVA_{bf}$) (or the let-through current if the overcurrent protective device is current-limiting) and the opening time of the overcurrent protective device (t).

Note, the results from these calculations may differ from the results obtained from the simple chart method just covered. These formulas were derived from a broad base of empirical test data and were state of the art when introduced. The simple chart method (Figures 6 & 7) has some artificially conservative assumptions as stated in the notes. (See Note 9 and 10.)

***Flash Protection Boundary Calculation***

$D_C = (2.65 \times MVA_{bf} \times t)^{1/2}$
$D_f = (1.96 \times MVA_{bf} \times t)^{1/2*}$

where

$D_C$ = distance in feet for a "just curable" burn
$D_f$ = distance in feet for an "incurable burn"*
$MVA_{bf}$ = bolted three phase MVA at point of short-circuit
= 1.73 × $VOLTAGE_{L-L}$ × AVAILABLE SHORT-CIRCUIT CURRENT × $10^{-6}$
t = time of exposure in seconds

*Not included in NFPA 70E.

NFPA 70E – 2000 Appendix B-5 of Part II provides equations for calculating incident energy under some common circumstances. For instance, the incident energy equation for an arcing fault contained in a cubic box (20 inches on each side, opened on one end), on 600V or less systems, with available bolted short-circuit currents of between 16,000 to 50,000 amperes is as follows:

***Incident Energy Calculation (20" cubic box)***

$$E_{MB} = 1038.7\, D_B^{-1.4738} t_A [0.0093F^2 - .3453F + 5.9675] \text{ cal/cm}^2$$

Where: $E_{MB}$ = Incident Energy (cal/cm²)
$D_B$ = Distance, (in.) [*for Distances ≥ 18 inches*]
$t_A$ = Arc Duration, (sec.)
F = Bolted Fault Short Circuit Current kA [16kA to 50kA]

**Example 2: Flash Hazard Analysis using Circuit Breakers**

The first thing that must be done when attempting to calculate the incident energy available when using a circuit breaker is to determine the circuit breaker type, ampere rating and its characteristics (settings). For example, the equations for circuit breakers vary depending upon whether a molded case circuit breaker (MCCB), insulated case circuit breaker (ICCB), or low voltage power circuit breaker (LVPCB) is utilized. Other variables that must be considered are the sensing mechanism of the circuit breaker and whether or not short time delay settings are being used. Most MCCBs, either thermal magnetic CBs or magnetic only CBs, are used without the use of short time delay settings. ICCBs and LVPCBs are most often used with electronic trip units with short-time delay features. Thermal magnetic (TM) and magnetic only (M) trip units result in lower values of incident energy exposure than that of electronic trip (E) units with short-time delay because the short time delay features increase the amount of time that the arcing current will flow, thereby increasing the incident energy exposure. After determining the necessary circuit breaker characteristics, the available 3Ø bolted fault current must be used to determine one of two equations that can be used to determine the incident energy exposure.

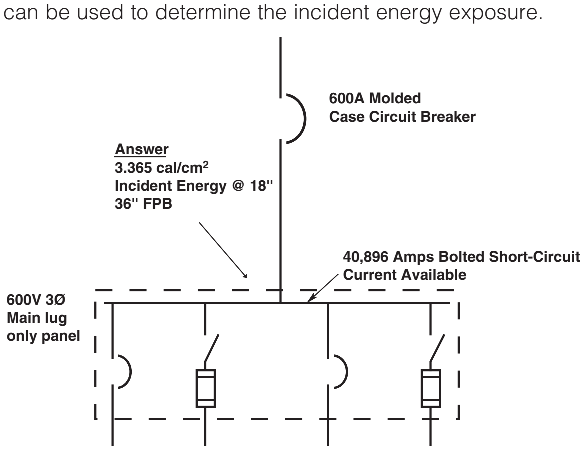



**Figure 8**

For the example one line in Figure 8, the feeder device is a 600A molded case circuit breaker (MCCB 600A) with thermal magnetic (TM) sensing properties and 40,896 amps available at the panel to be protected. Keep in mind that using this type of trip unit will result in the lowest incident energy exposure for a circuit breaker since it does not incorporate short time delay features. To determine which one of the two equations can be used (from IEEE *Guide for Arc Flash Hazard Analysis*, P1584), the following parameters must be determined. The available 3Ø bolted fault current must be between 700A and 106,000A, which 40,896A is, and must meet the following condition, $I_1 < I_{bf} < I_2$. $I_{bf}$ is the available 3Ø bolted fault current, $I_2$ is the interrupting rating of the circuit breaker, and $I_1$ is the point where the calculated arcing current ($I_a$) is just high enough to trip the circuit breaker at its instantaneous setting (See Note CB5). For this example, assume that the interrupting rating of the 600A MCCB is 65kA. The calculated arcing current ($I_a$) is determined from an equation in IEEE *Guide for Arc Flash Hazard Analysis,* P1584, based on test data. For 40,896A, the resulting arcing current $I_a$ from the equation in IEEE *Guide for Arc Flash Hazard Analysis,* P1584 is 26,810A. Then the instantaneous trip must be compared to this value of arcing current to determine $I_1$. The instantaneous trip must be evaluated at its maximum setting so as to determine the worst case. For this MCCB, assume the instantaneous trip is 10X, therefore the instantaneous trip pickup would begin at approximately 6000A.

However, instantaneous trip settings have a tolerance that can be as high as 25%. To account for this tolerance, the arcing current must also be calculated at 85% of the original calculated arcing current $I_a$. The arc energy is then compared using both values (both Ia and 85% of $I_a$) with the higher resulting value of incident energy being used. For this example, 85% of 26,810A would result in a value of 22,789A. This is above the point that the instantaneous trip setting (6000A) will detect the arcing current. Now that both parameters have been established, an equation from IEEE *Guide for Arc Flash Hazard Analysis*, P1584 can be used to calculate the incident energy based upon the available 3Ø bolted fault current. As mentioned before, these equations vary based upon the type of circuit breaker and the sensing element used. In this example, the equation for this molded case circuit breaker with a thermal magnetic trip unit would yield an incident energy value of 3.37 cal/cm² at 18 inches from the arc fault source.

If the circuit breaker in question is a power circuit breaker with short time delay feature (no instantaneous trip), the equation changes and the incident energy calculation will increase. For example, with a short time delay feature set at 30 cycles the incident energy at this available fault current could be as high as 67.6 cal/cm² at 18 inches from the arc fault source.

The next step in the flash hazard analysis is to determine the FPB. For the typical molded case circuit breaker example using a thermal magnetic trip unit, the incident energy was 3.365 cal/cm². Using the chart in Figure 5, the FPB is approximately 36 inches. For the circuit breaker utilizing a short time delay that resulted in an incident energy of 67.59 cal/cm², the FPB would be off the chart in Figure 5. In fact, any incident energy greater than 20 cal/cm² would result in a FPB of over 10 feet per the chart in Figure 5.

Let's summarize the steps necessary to conduct a Flash Hazard Analysis when using circuit breakers.

1. Determine the available 3Ø bolted fault current on the line side terminals of the equipment that will be worked upon.
2. Determine the type of upstream circuit breaker to be used along with the type of trip unit that will be used.
3. Determine the ampacity of the upstream circuit breaker.
4. Verify that the 3Ø bolted fault current meets the parameter of $I_1 < I_{bf} < I_2$, where $I_{bf}$ is the available 3Ø bolted fault current, $I_2$ is the interrupting rating of the breaker, and $I_1$ is the point where the calculated arcing current $I_a$ is just high enough to trip the circuit breaker at its instantaneous setting $I_t$.
5. To establish $I_1$ from step 4, calculate the arcing current $I_a$.
6. Calculate 85% of the arcing current $I_a$, calculated in step 5.
7. Determine the instantaneous trip setting $I_t$ of the upstream circuit breaker. If the circuit breaker does not have an instantaneous setting due to a short time delay, use the short time pickup for $I_t$.
8. Use the 85% of $I_a$ value along with $I_t$ to determine $I_1$.
9. Determine which equation from IEEE *Guide for Arc Flash Hazard Analysis,* P1584 should be used to calculate the incident energy exposure.
10. Determine the Flash Protection Boundary that will require PPE based upon the incident energy. This can also be simplified by using the chart for Flash Protection Boundary in Figure 7.
11. Identify the minimum requirements for PPE when work is to be performed inside of the FPB by consulting the minimum requirements found in NFPA 70E. See Note CB 1.

**Circuit Breaker Method Notes:**

See the General Notes under the Simple Fuse Chart Notes.

Note CB 1: The source for the method and data used in Example 2 Circuit Breaker Flash Hazard Analysis is from the IEEE *Guide for Arc Flash Hazard Analysis,* P1584. The circuit breaker information comes from theoretical equations that are based upon how circuit breakers operate and arc-flash equations. These arc-flash equations were created so that PPE chosen as a result of the equations would be adequate for 95% of arc-flash incidents. In up to 5% of incidents, incurable burns to the body and torso could result. This was based upon PPE with standard ATPVs of 1.2, 8, 25, 40 and 100 cal/cm$^2$. PPE with intermediate ATPV values can be used, but at the next lower standard ATPV rating.

Note CB2: As discussed in the IEEE *Guide for Arc Flash Hazard Analysis,* P1584, to calculate the incident energy for the circuit breakers, the available 3Ø bolted fault current must be between 700A and 106,000 amps. The available 3Ø bolted fault current must also be within the range of $I_1 < I_{bf} < I_2$. Where $I_2$ is the interrupting rating of the circuit breaker and $I_1$ is the lowest current where the available 3Ø bolted fault current generates an arcing current large enough to be picked up by the instantaneous trip of the circuit breaker.

Note CB3: The calculated arcing current is determined from an equation based upon test data. Actual results of arcing current may be higher or lower than calculated.

Note CB4: When the 3Ø bolted fault current is below $I_1$ for the circuit breaker, the arcing current must be used in conjunction with two incident energy equations, found in IEEE *Guide for Arc Flash Hazard Analysis,* P1584.

Note CB5: 85% of the arcing current must be used to determine $I_1$. This adjusted value of arcing current is used with the incident energy equations as in Note CB1, and the higher value of incident energy must be used.

Note CB6: Instantaneous trip settings for circuit breakers should be assumed to be at their maximum setting. If calculations are done based upon the minimum setting and the maximum setting is used, results may be extremely inaccurate.

**Flash Protection Boundary Comparison for Test 3 and Test 4**

Refer back to the pictures for Test 3 and Test 4 on a previous page in this section.

Using the charts in Figures 6 and 7 (which are derived from IEEE *Guide for Arc Flash Hazard Analysis,* P1584), the circuit in Test 3, protected by a KRP-C-601SP fuse, had an incident energy exposure of 1.5 cal/cm$^2$ and a FPB of approximately 20 inches. Based upon the equations from IEEE *Guide for Arc Flash Hazard Analysis,* P1584, the circuit in Test 4, protected by a 640 amp circuit breaker with a short time delay setting, had an incident energy exposure of 37.6 cal/cm$^2$, a FPB greater than 10 feet. NFPA 70E gives requirements for PPE that would have minimized the potential for the worker to sustain life-threatening injuries due to burns from the arc-flash. However, the PPE that is currently available may not protect against the pressures and shrapnel from the resulting arc-blast in these two incidents. Sensors on the chest of the mannequin in Test 3 measured a pressure of 504 lbs/ft$^2$, which is below the threshold for eardrum rupture of 720 lbs/ft$^2$. The pressure sensors in Test 4 however, measured a pressure that exceeded 2160 lbs/ft$^2$, which is greater than the threshold for lung damage. Not only could these pressures cause injury to the worker, both tests may have thrown the worker across the room or subjected the worker to the dangers of falling when working in an elevated space.

**Personal Protective Equipment (PPE)**

Employees must wear and be trained in the use of appropriate protective equipment for the possible electrical hazards with which they may face. Examples of equipment could include a hard hat, face shield, flame resistant neck protection, ear protectors, Nomex™ suit, insulated rubber gloves with leather protectors, and insulated leather footwear. All protective equipment must meet the requirements as shown in Table 3-3.8 of NFPA 70E-2000. Protective equipment, sufficient for protection against an electrical flash, would be required for any part of the body, which could be within 3 feet of the fault in Example 2. The selection of the required thermal rated PPE depends on the incident energy level at the point of work.

As stated previously, the common distance used for most of the low voltage incident energy measurement research and testing is at 18 inches from the arcing fault source. So what energy does a body part experience that is closer to the arc fault than 18 inches? The closer to the arcing fault the higher the incident energy and blast hazard. This means that when the flash protection analysis results in relatively high incident energies at 18 inches from the arc fault source, the incident energy and blast energy at the point of the arc fault can be considerably greater. Said in another way, even if the body has sufficient PPE for an 18" working distance, severe injury can result for any part of the body closer than 18" to the source of the arc.

**Exposure Time**

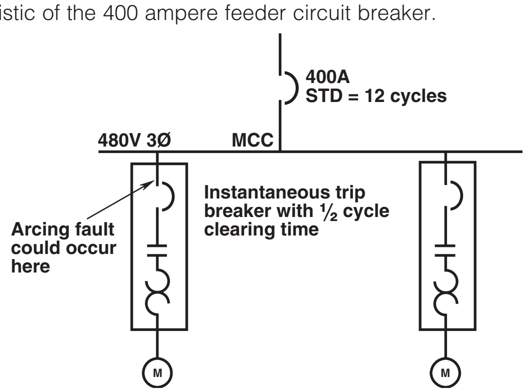
As the previous sections have illustrated, the interruption time of overcurrent protective devices is a major factor in the severity of an arc flash. Following is a table for some general minimum overcurrent protective device interruption times that can be used for the FBP and incident energy calculations if this data is not available from the manufacturer. "STD Setting" refers to the short time delay setting if a circuit breaker has this feature; typical STDs settings could be 6, 12, 18, 24, or 30 cycles.

| Type of Device | Minimum Time (Seconds)* |
|---|---|
| Current-limiting fuse | .004 |
| Circuit Breaker (5KV & 15KV) | .1 |
| Standard molded case circuit breakers (600V & below) | |
| without short-time-delay (STD) | .0083-.0167 |
| with short-time-delay (STD) | STD Setting |
| Insulated case circuit breakers (600V & below) | |
| without short-time-delay | .033 |
| with short-time-delay | STD Setting |
| Low voltage power (air frame) circuit breakers (600V & below) | |
| without-short-time-delay | .05 |
| with short-time-delay | STD Setting |
| Current-limiting molded case circuit breaker (600V & below) | .004 |

* These are approximate times for short-circuit currents within the current-limiting range of a fuse or within the instantaneous region of circuit breakers. Lower current values may cause the overcurrent device to operate more slowly. Arc-flash energy may actually be highest at lower levels of available short-circuit current. This requires that arc flash energy calculations be completed for the range of sustainable arcing currents. Where equivalent RMS let-through data (this is reduced let-through current due to current-limitation) is available, it can be used in the flash distance and incident energy formulae on page 164. Where data is unavailable, the full available short-circuit must be used.

### Expect the Worst Case

If planning to work on a piece of equipment, it is necessary to do the flash hazard analysis for the worst-case situation that could occur if an incident occurred. For instance, in the diagram below, if the combination controller door were to be opened, the worst-case arc flash hazard in the enclosure would be on the line-side of the branch-circuit circuit breaker. If an arcing fault occurred in the enclosure, on the line side of the of the branch-circuit circuit breaker, the 400 ampere feeder circuit breaker is the protective device intended to interrupt. So the flash hazard analysis for this combination motor controller enclosure must be determined using the characteristic of the 400 ampere feeder circuit breaker.




### Other Arc Fault Hazards

An arcing fault may create such enormous explosive forces that there is a huge blast wave and shrapnel expelled toward the worker. Neither NFPA 70E – 2000 nor IEEE P1584 account for the pressures and shrapnel that can result due to an arcing fault. There is little or no information on protecting a worker for these risks. On a somewhat positive note, because the arc pressure blows the worker away, it tends to reduce the time that the person is exposed to the extreme heat of the arc. The greater the fault current let-through, the greater the explosive forces. It is important to know that product standards do not evaluate a product for a worker's exposure to arc flash and blast hazards with the door(s) open. Equipment listed to a Nationally Recognized Testing Laboratory product standard is not evaluated for arc flash or arc blast protection (with the door(s) open) because the equipment is tested with the doors closed. Once a worker opens the doors, the parameters under the evaluation testing and listing do not apply.

Caution: (1) A worker using PPE with adequate cal/cm$^2$ ratings for high incident energy arc flash hazards may still incur severe injury or death due to the arc blast or shrapnel. For instance, review the results for Test 4 on page 159. Generally, the higher the incident energy, the higher the blast energy that will result. (2) For systems 600V and less, NFPA 70E – 2000 has some simpler methods to find the flash protection boundary (four foot default) and PPE selection (using two tables – a. hazard risk category by tasks table and b. PPE and tools for each hazard risk category table). Although, these methods can be simpler, there are very important qualifiers and assumptions in the tables' notes and legends. It is possible for a specific situation to be beyond the assumptions of these tables and therefore, in these situations, the tables are not to be used. Some of this information may change in NFPA 70E-2003.

### Summary About the Risks From Arc Faults

Arc faults can be an ominous risk for workers. And an uneducated eye can not identify whether the risk is low, medium or high just by looking at the equipment. Current-limiting overcurrent protection may reduce the risk. In other words, if an incident does occur, current-limiting overcurrent protective devices may reduce the probability of a severe arc flash. In many cases, using current-limiting protective devices greatly reduces the arc flash energy that might occur for the range of arc fault currents that are likely. However, current-limiting overcurrent protective devices do not mitigate the potential hazard in all situations. This is especially true as the overcurrent protective devices get into the larger ampere sizes. But all things being equal, systems with protective devices that have a high degree of current-limitation generally lower the risks. But it is still necessary to follow all the requirements of NFPA 70E and other safe work practices.

### General Recommendations For Electrical Safety Relative to Overcurrent Protection

(1) **Finger-safe products and terminal covers:** utilize finger-safe overcurrent protective devices such as the CUBEFuse™ or insulating covers over the overcurrent protective devices, disconnect terminals and all terminations.

(2) **Proper interrupting rating:** be absolutely sure to use overcurrent protective devices that have adequate interrupting ratings at their point of application. An overcurrent protective device that attempts to interrupt a fault current beyond its interrupting rating can violently rupture. Consideration for interrupting rating should be for the life of the system. All too often, transformers are replaced or systems are upgraded and the available short-circuit currents increase. Modern fuses have interrupting ratings of 200,000 and 300,000 amperes, which virtually eliminates this hazard contributor.

(3) **Current-limiting overcurrent protection:** use the most current-limiting overcurrent protective devices possible. There are a variety of choices in the market for overcurrent protective devices. Many are not marked as current-limiting and therefore can not be considered current-limiting. And then for those that are marked current-limiting, there are different degrees of current-limitation to consider. For Bussmann®, the brand to use for 600V and less, electrical distribution applications and general equipment circuit protection is LOW-PEAK® fuses. The LOW-PEAK® family of fuses is the most current-limiting type fuse family for general protection and motor circuit protection.

(4) **Upgrade existing fuse systems:** if the electrical system is an existing fusible system, consider replacing the existing fuses with the LOW-PEAK® family of fuses. If the existing fuses in the clips are not the most current-limiting type fuses, upgrading to the LOW-PEAK® family of fuses can reduce the hazards associated with arc flash. www.bussmann.com has a service for the LOW-PEAK® upgrade.

(5) **Install current-limiting overcurrent protection for actual loads:** if the actual maximum full load current on an existing main, feeder or branch circuit is significantly below its designed circuit ampacity, replace the existing fuses with lower ampere rated LOW-PEAK® fuses. Or, if the OCPD is a circuit breaker, put a fused disconnect with LOW-PEAK® fuses in series with the circuit breaker. For instance, an industrial found that many of their 800 ampere feeders to their MCCs were lightly loaded; so for better arc flash protection they installed 400 and 600 amp current-limiting fuses and switches in the feeders.

(6) **Reliable overcurrent protection:** use overcurrent protective devices that are reliable and do not require maintenance to assure performance per the original specifications. Modern fuses are reliable and retain their ability to react quickly under fault conditions. When a fuse is replaced, a new factory calibrated fuse is put into service – the circuit has reliable protection with performance equal to the original specifications. If mechanical overcurrent protective devices are utilized, be sure to perform the manufacturer's recommended periodic exercise, maintenance, testing and possible replacement. When an arc fault or overcurrent occurs, the overcurrent protective device must be able to operate as intended. Thus, for mechanical overcurrent protective devices, this may require testing, maintenance, and possible replacement before resetting the device after a fault interruption.

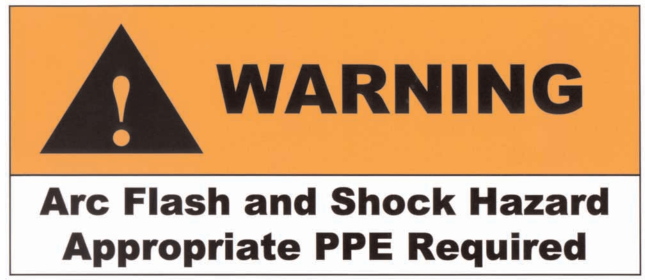
(7) **Within sight motor disconnects:** install HP rated disconnects (with permanently installed lockout provision) within sight and within 50 feet of every motor or driven machine. This measure fosters safer work practices and can be used for an emergency disconnect if there is an incident.

**Flash Protection Field Marking: New NEC® Requirement**

> **110.16 Flash Protection**
> Switchboards, panelboards, industrial control panels, and motor control centers in other than dwelling occupancies, that are likely to require examination, adjustment, servicing, or maintenance while energized, shall be field marked to warn qualified persons of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.
>
> FPN No. 1: NFPA 70E-2000, *Electrical Safety Requirements for Employee Workplaces,* provides assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment.
>
> FPN No. 2: ANSI Z535.4-1998, *Product Safety Signs and Labels*, provides guidelines for the design of safety signs and labels for application to products.
>
> Reprinted from NEC® 2002

This new requirement is intended to reduce the occurrence of serious injury or death due to arcing faults to workers who work on or near energized electrical equipment. The warning label should remind a qualified worker who intends to open the equipment for analysis or work that a serious hazard exists and that the worker should follow appropriate work practices and wear appropriate personal protective equipment (PPE) for the specific hazard (a non-qualified worker must not be opening or be near open energized equipment).

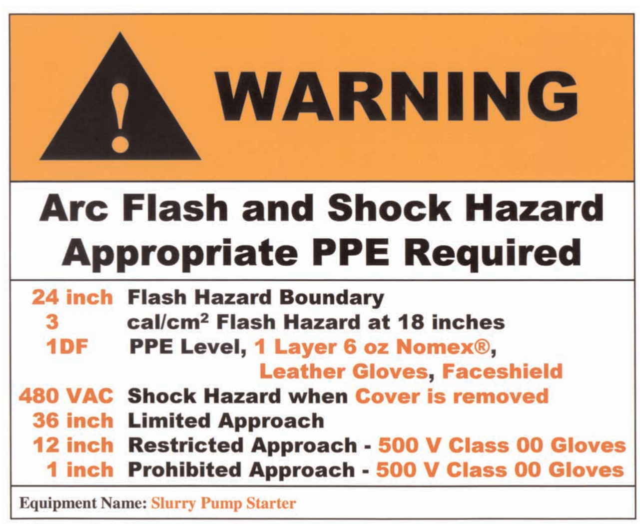
110.16 only requires that this label state the existence of an arc flash hazard.




Courtesy E.I. du Pont de Nemours & Co.

It is suggested that the party responsible for the label include more information on the specific parameters of the hazard. In this way the qualified worker and his/her management can more readily assess the risk and better insure proper work practices, PPE and tools. The example label following includes more of the vital information that fosters safer work practices. The specific additional information that should be added to the label includes:

Available 3Ø Short-Circuit Current
Flash Protection Boundary
Incident energy at 18 inches expressed in cal/cm$^2$
PPE required
Voltage shock hazard
Limited shock approach boundary
Restricted shock approach boundary
Prohibited shock approach boundary




Courtesy E.I. du Pont de Nemours & Co.