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;

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.

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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.

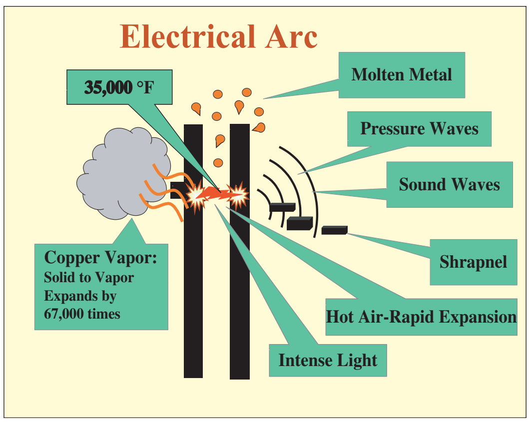

Figure 1. Electrical Arc Model

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:

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.

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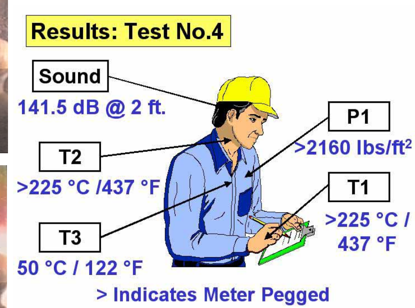
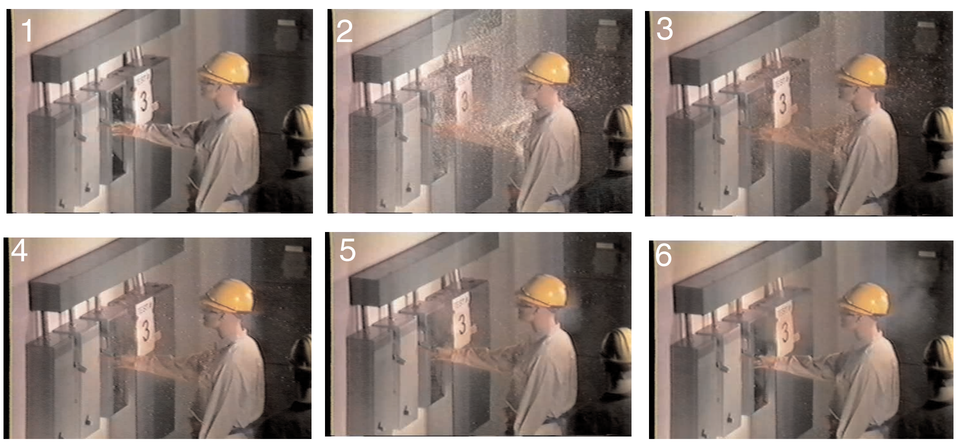
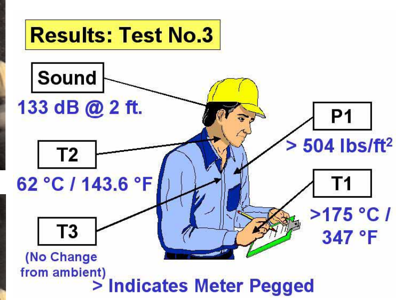
Following are the results recorded from the various sensors on the mannequin closest to the arcing fault. T1 and T2 recorded the temperature on the bare hand and neck respectively. The hand with T1 sensor was very close to the arcing fault. T3 recorded the temperature on the chest under the cotton shirt. 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.

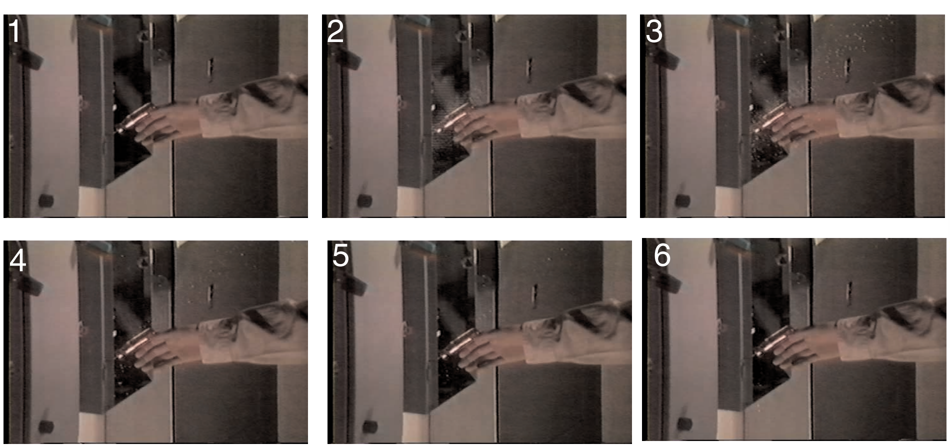


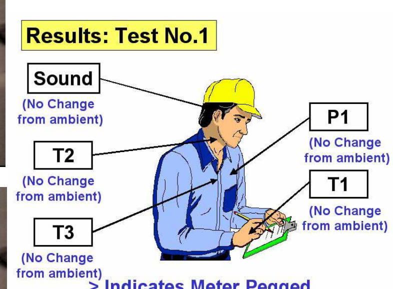
Photos and results Test 4: Staged test protected by circuit breaker with short-time delay (not a current-limiting overcurrent protective device). Short-time delay intentionally delayed opening for six cycles (.1 second). Note: Unexpectedly, there was an additional fault in the wireway and the blast caused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

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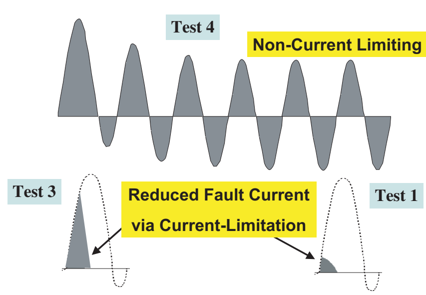
A couple of conclusions can be drawn from this testing.

(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.

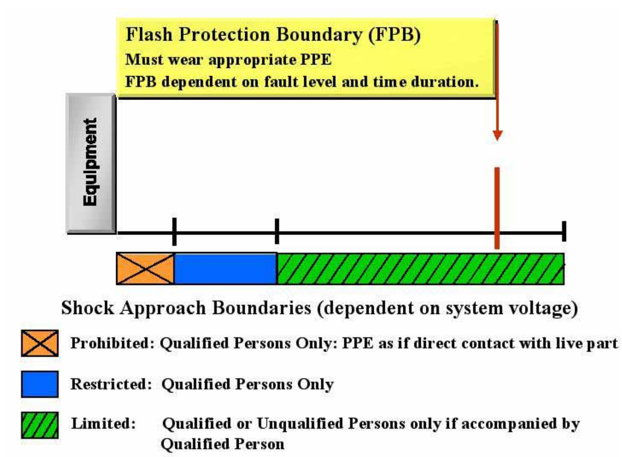


Figure 2

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.

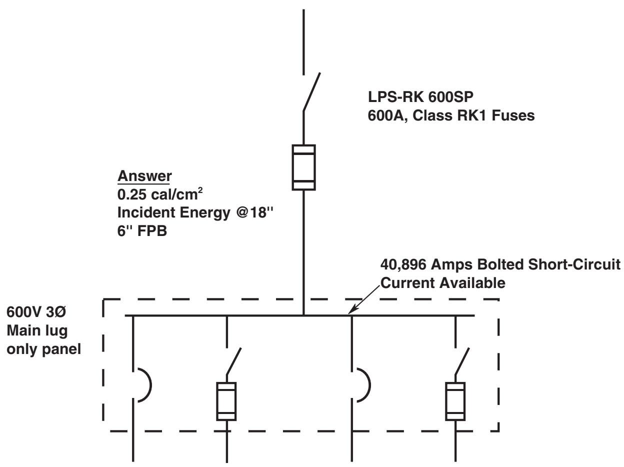


Figure 3

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.

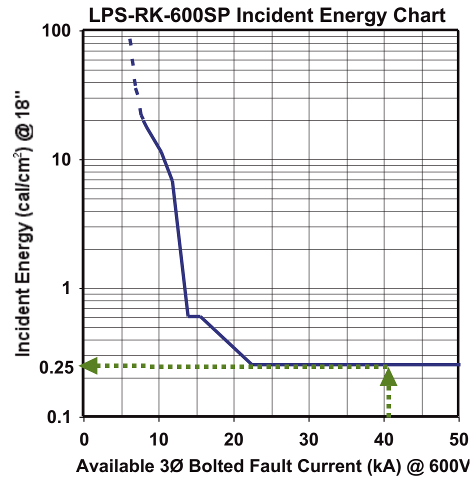


Figure 4 Important: for proper use of this curve, see Figure 6 and associated notes.

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/cm². 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/cm² 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.

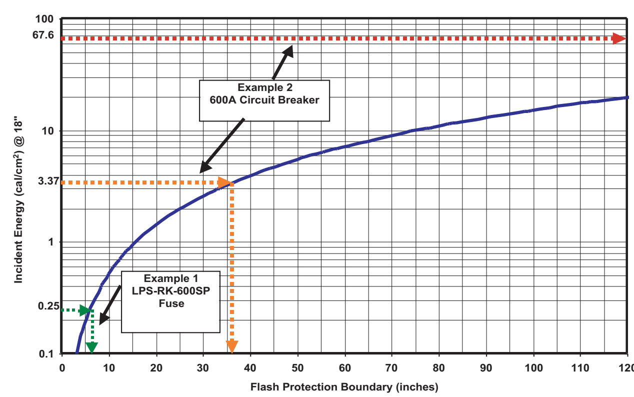


Figure 5 Important: for proper use, see notes.

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.

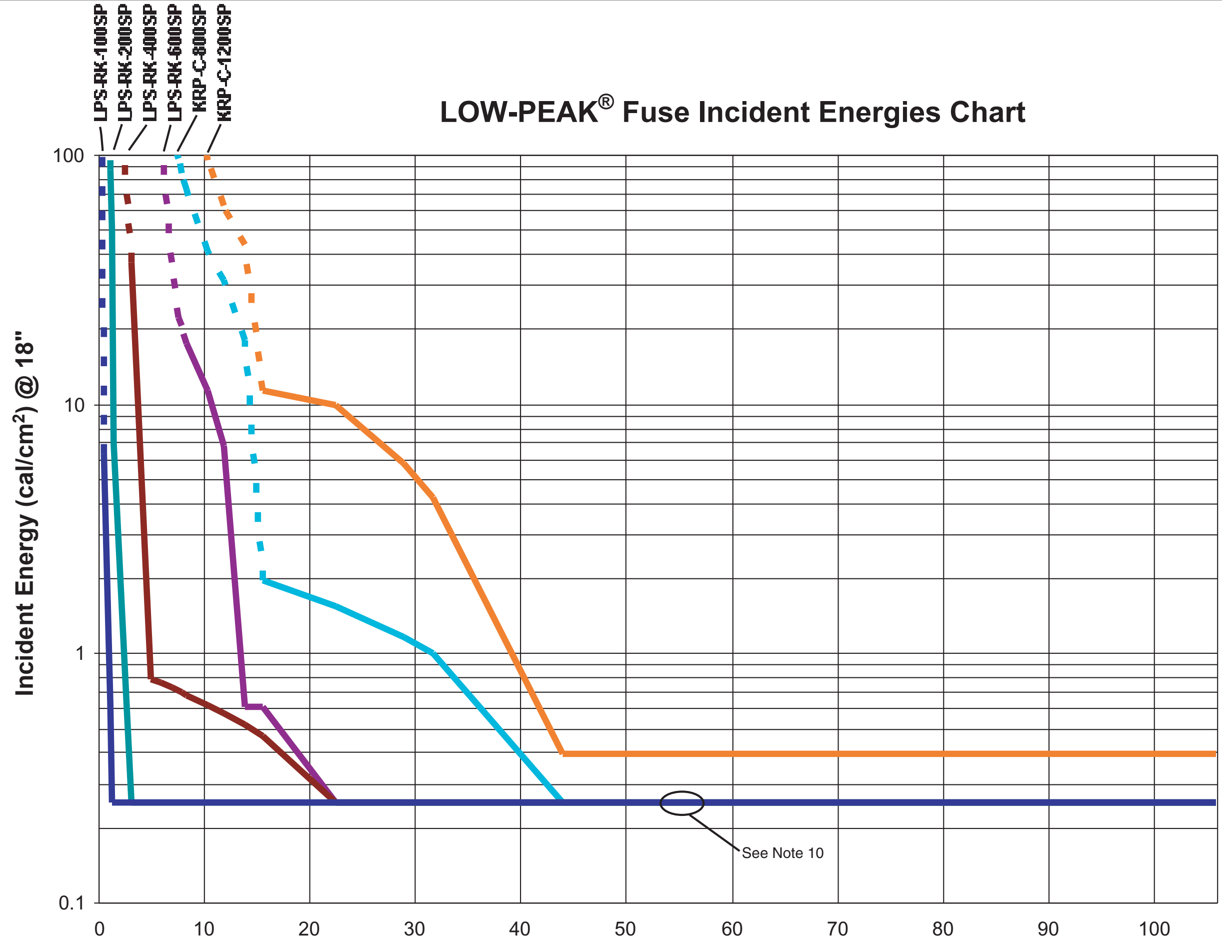


Figure 6

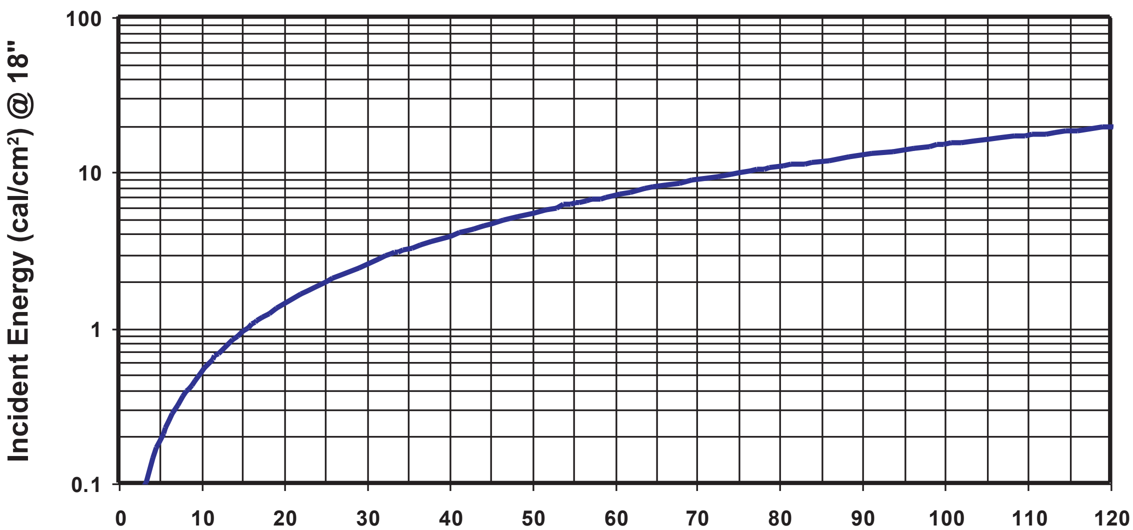


Figure 7

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.

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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.)

Electrical Safety & Arc Flash Protection

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
= $1.73 \times VOLTAGE_{L\text{-}L} \times$ AVAILABLE SHORT-CIRCUIT CURRENT $\times 10^{-6}$
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)

$E_{MB} = 1038.7\ D_B^{-1.4738} t_A [0.0093F^2 - .3453F + 5.9675]$ cal/cm²

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.

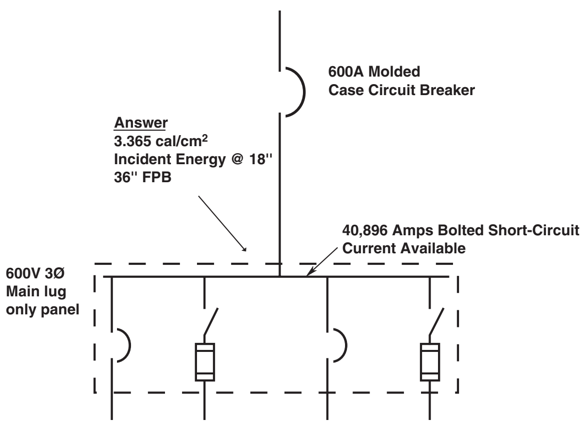

Figure 8

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.

Electrical Safety & Arc Flash Protection

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.

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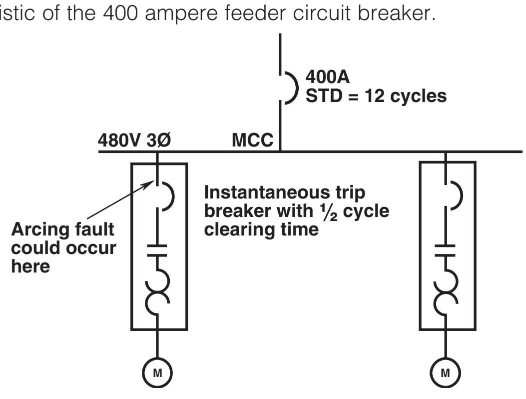
Type of Device	Minimum Time (Seconds)*
Current-limiting fuse	.004
Circuit Breaker (5KV & 15KV)	.1
Standard molded case circuit breakers (600V & below)	
without short-time-delay (STD)	.0083-.0167
with short-time-delay (STD)	STD Setting
Insulated case circuit breakers (600V & below)	
without short-time-delay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

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(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.

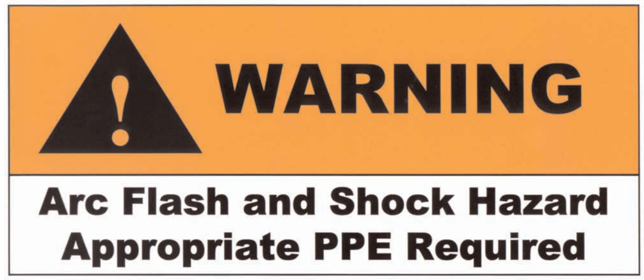
(7) **Within sight motor disconnects:** install HP rated disconnects (with permanently installed lockout provision) within sight and within 50 feet of every motor or driven machine. This measure fosters safer work practices and can be used for an emergency disconnect if there is an incident.

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).

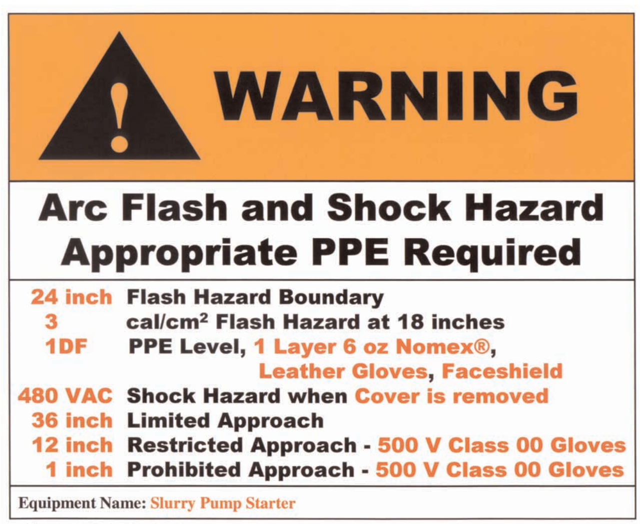
110.16 only requires that this label state the existence of an arc flash hazard.



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.

110.16 Flash Protection

Switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers that are in other than dwelling occupancies and 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.

This requirement was added in the 2002 *Code*. Field marking that warns electrical workers of potential electrical arc flash hazards is now required because significant numbers of electricians have been seriously burned or killed by accidental electrical arc flash while working on ``hot" (energized) equipment. Most of those accidents could have been prevented or their severity significantly reduced if electricians had been wearing the proper type of protective clothing. Requiring switchboards, panelboards, and motor control centers to be individually field marked with proper warning labels will raise the level of awareness of electrical arc flash hazards and thereby decrease the number of accidents.

Exhibit 110.7 shows an electrical employee working inside the flash protection boundary and in front of a large-capacity service-type switchboard that has not been de-energized and that is not under the lockout/tagout procedure. The worker is wearing personal protective equipment (PPE) considered appropriate flash protection clothing for the flash hazard involved. Suitable PPE appropriate to a particular hazard is described in NFPA 70E, *Standard for Electrical Safety in the Workplace*.

Exhibit 110.7 Electrical worker clothed in personal protective equipment (PPE) appropriate for the hazard involved.

Exhibit 110.8 displays one example of a warning sign required by 110.16.

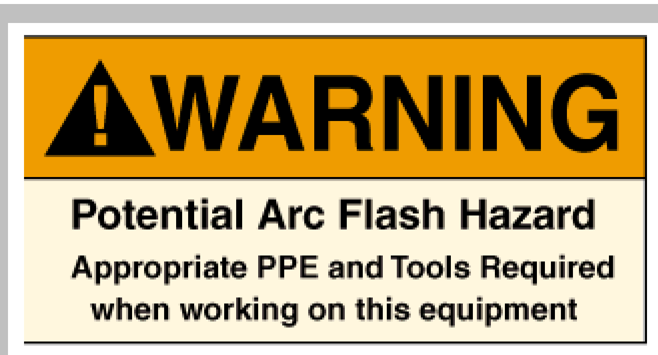


Exhibit 110.8 One example of an arc flash warning sign required by 110.16.

Accident reports continue to confirm the fact that workers responsible for the installation or maintenance of electrical equipment often do not turn off the power source before working on the equipment. Working electrical equipment energized is a major safety concern in the electrical industry. The real purpose of this additional code requirement is to alert electrical contractors, electricians, facility owners and managers, and other interested parties to some of the hazards of working on or near energized equipment and to emphasize the importance of turning off the power before working on electrical circuits.

The information in fine print notes is not mandatory. Employers can be assured that they are providing a safe workplace for their employees if safety-related work practices required by NFPA 70E have been implemented and are being followed. (See also the commentary following the definition of *qualified person* in Article 100.)

In addition to the standards referenced in the fine print notes and their individual bibliographies, additional information on this subject can be found in the 1997 report ``Hazards of Working Electrical Equipment Hot,'' published by the National Electrical Manufacturers Association.

FPN No. 1: NFPA 70E-2004, *Standard for Electrical Safety in the Workplace*, 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.

10 110.16 Flash Protection Warning

Switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers in commercial and industrial occupancies that are likely to require examination, adjustment, servicing, or maintenance while energized must be field marked to warn qualified persons of the danger associated with an arc flash from line-to-line or ground faults. The field marking must be clearly visible to qualified persons before they examine, adjust, service, or perform maintenance on the equipment. Figure 110–34

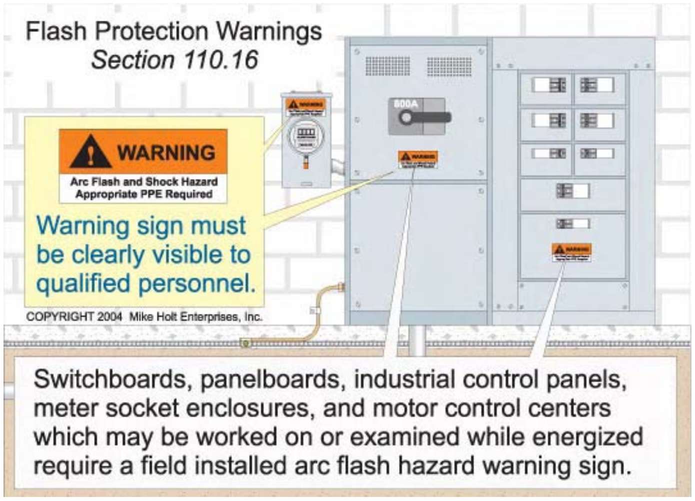


Figure 110–34

AUTHOR'S COMMENTS:

- See Article 100 for the definitions of "Panelboard" and "Qualified Persons."
- This rule is meant to warn qualified persons who work on energized electrical systems that an arc flash hazard exists so they will select proper personal protective equipment (PPE) in accordance with industry accepted safe work practice standards.

FPN No. 1: NFPA 70E, *Standard for Electrical Safety in the Workplace*, provides assistance in determining the severity of potential exposure, planning safe work practices, and selecting personal protective equipment.

AUTHOR'S COMMENT: In some installations, the use of current-limiting protection devices may significantly reduce the degree of arc flash hazards. For more information about flash protection, visit http://bussmann.com/safetybasics. Figure 110–35

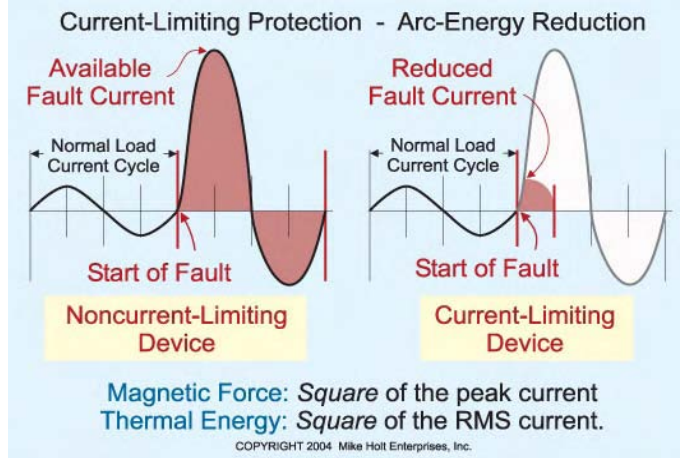


Figure 110–35

11 110.26 Spaces About Electrical Equipment

For the purpose of safe operation and maintenance of equipment, sufficient access and working space must be provided. Enclosures housing electrical apparatus that are controlled by locks are considered accessible to qualified persons who require access. Figure 110–37

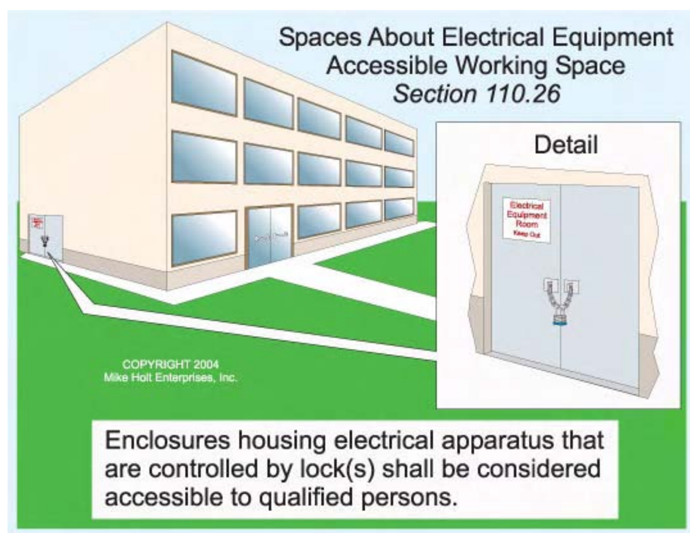


Figure 110–37

AUTHOR'S COMMENTS:

- See Article 100 for the definition of "Accessible" as it applies to equipment.
- It might be unwise to use an electrically operated lock, if it locks in the de-energized condition!

(j) Accountability for Personnel. A method shall be identified in the procedure to account for all persons who could be exposed to hazardous energy during the lockout/tagout.

(k) Lockout/Tagout Application. The procedure shall clearly identify when and where lockout applies, in addition to when and where tagout applies, and shall address the following:

(1) Lockout shall be defined as installing a lockout device on all sources of hazardous energy such that operation of the disconnecting means is prohibited and forcible removal of the lock is required to operate the disconnect means.
(2) Tagout shall be defined as installing a tagout device on all sources of hazardous energy, such that operation of the disconnect means is prohibited. The tagout device shall be installed in the same position available for the lockout device.
(3) Where it is not possible to attach a lock to existing disconnecting means, the disconnecting means shall not be used as the only means to put the circuit in an electrically safe work condition.
(4) The use of tagout procedures without a lock shall be permitted only in cases where equipment design precludes the installation of a lock on a energy isolation device(s). When tagout is employed, at least one additional safety measure shall be employed. In such cases, the procedure shall clearly establish responsibilities and accountability for each person who might be exposed to electrical hazards.

(l) Removal of Lockout/Tagout Devices. The procedure shall identify the details for removing locks or tags when the installing individual is unavailable. When locks or tags are removed by other than the installer, the employer shall attempt to locate the person prior to removing the lock or tag. When the lock or tag is removed because the installer is unavailable, the installer shall be informed prior to returning to work.

(m) Release for Return to Service. The procedure shall identify steps to be taken when the job or task requiring lockout/tagout is completed. Before electric circuits or equipment are reenergized, appropriate tests and visual inspections shall be conducted to verify that all tools, mechanical restraints and electrical jumpers, shorts, and grounds have been removed, so that the circuits and equipment are in a condition to be safely energized. Where appropriate, the employees responsible for operating the machines or process shall be notified when circuits and equipment are ready to be energized, and such employees shall provide assistance as necessary to safely energize the circuits and equipment. The procedure shall contain a statement requiring the area to be inspected to ensure that nonessential items have been removed. One such step shall ensure that all personnel are clear of exposure to dangerous conditions resulting from reenergizing the service and that blocked mechanical equipment or grounded equipment is cleared and prepared for return to service.

(n) Temporary Release for Testing/Positioning. The procedure shall clearly identify the steps and qualified persons' responsibilities when the job or task requiring lockout/tagout is to be interrupted temporarily for testing or positioning of equipment; then the steps shall be identical to the steps for return to service. See 110.9 and 130.4 for requirements when using test instruments and equipment.

120.3 Temporary Protective Grounding Equipment.

(A) Placement. Temporary protective grounds shall be placed at such locations and arranged in such a manner as to prevent each employee from being exposed to hazardous differences in electrical potential.

(B) Capacity. Temporary protective grounds shall be capable of conducting the maximum fault current that could flow at the point of grounding for the time necessary to clear the fault.

(C) Equipment Approval. Temporary protective grounding equipment shall meet the requirements of ASTM F 855, *Standard Specification for Temporary Protective Grounds to be Used on De-energized Electric Power Lines and Equipment,* 1997.

(D) Impedance. Temporary protective grounds shall have an impedance low enough to cause immediate operation of protective devices in case of accidental energizing of the electric conductors or circuit parts.

ARTICLE 130
Working On or Near Live Parts

130.1 Justification for Work. Live parts to which an employee might be exposed shall be put into an electrically safe work condition before an employee works on or near them, unless the employer can demonstrate that deenergizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations. Energized parts that operate at less than 50 volts to ground shall not be not required to be deenergized if there will be no increased exposure to electrical burns or to explosion due to electric arcs.

FPN No. 1: Examples of increased or additional hazards include, but are not limited to, interruption of life support equipment, deactivation of emergency alarm systems, and shutdown of hazardous location ventilation equipment.

FPN No. 2: Examples of work that might be performed on or near exposed energized electrical conductors or circuit parts because of infeasibility due to equipment design or operational limitations include performing diagnostics and testing (e.g., start-up or troubleshooting) of electric circuits that can only be performed with the circuit energized and work on circuits that form an integral part of a continuous process that would otherwise need to be completely shut down in order to permit work on one circuit or piece of equipment.

FPN No. 3: For voltages of less than 50 volts, the decision to deenergize should include consideration of the capacity of the source and any overcurrent protection between the energy source and the worker.

(A) Energized Electrical Work Permit.

(1) Where Required. If live parts are not placed in an electrically safe work condition (i.e., for the reasons of increased or additional hazards or infeasibility per 130.1), work to be performed shall be considered energized electrical work and shall be performed by written permit only.

(2) Elements of Work Permit. The energized electrical work permit shall include, but not be limited to, the following items:

(1) A description of the circuit and equipment to be worked on and their location
(2) Justification for why the work must be performed in an energized condition (130.1)
(3) A description of the safe work practices to be employed [110.8(B)]
(4) Results of the shock hazard analysis [110.8(B)(1)(a)]
(5) Determination of shock protection boundaries [130.2(B) and Table 130.2(C)]
(6) Results of the flash hazard analysis (130.3)
(7) The Flash Protection Boundary [130.3(A)]
(8) The necessary personal protective equipment to safely perform the assigned task [130.3(B), 130.7(C)(9), and Table 130.7(C)(9)(a)]
(9) Means employed to restrict the access of unqualified persons from the work area [110.8(A)(2)]
(10) Evidence of completion of a job briefing, including a discussion of any job-specific hazards [110.7(G)]
(11) Energized work approval (authorizing or responsible management, safety officer, or owner, etc.) signature(s)

(3) Exemptions to Work Permit. Work performed on or near live parts by qualified persons related to tasks such as testing, troubleshooting, voltage measuring, etc., shall be permitted to be performed without an energized electrical work permit, provided appropriate safe work practices and personal protective equipment in accordance with Chapter 1 are provided and used.

FPN: For an example of an acceptable energized electrical work permit, see Annex J.

130.2 Approach Boundaries to Live Parts.

(A) Shock Hazard Analysis. A shock hazard analysis shall determine the voltage to which personnel will be exposed, boundary requirements, and the personal protective equipment necessary in order to minimize the possibility of electric shock to personnel.

(B) Shock Protection Boundaries. The shock protection boundaries identified as Limited, Restricted, and Prohibited Approach Boundaries are applicable to the situation in which approaching personnel are exposed to live parts. See Table 130.2(C) for the distances associated with various system voltages.

FPN: In certain instances, the Flash Protection Boundary might be a greater distance from the exposed live parts than the Limited Approach Boundary.

(C) Approach to Exposed Live Parts Operating at 50 Volts or More. No qualified person shall approach or take any conductive object closer to exposed live parts operating at 50 volts or more than the Restricted Approach Boundary set forth in Table 130.2(C), unless any of the following apply:

(1) The qualified person is insulated or guarded from the live parts operating at 50 volts or more (insulating gloves or insulating gloves and sleeves are considered insulation only with regard to the energized parts upon which work is being performed), and no uninsulated part of the qualified person's body crosses the Prohibited Approach Boundary set forth in Table 130.2(C).
(2) The live part operating at 50 volts or more is insulated from the qualified person and from any other conductive object at a different potential.
(3) The qualified person is insulated from any other conductive object as during live-line bare-hand work.

(D) Approach by Unqualified Persons. Unqualified persons shall not be permitted to enter spaces that are required under 400.16(A) to be accessible to qualified employees only, unless the electric conductors and equipment involved are in an electrically safe work condition.

(1) Working At or Close to the Limited Approach Boundary. Where one or more unqualified persons are working at or close to the Limited Approach Boundary, the designated person in charge of the work space where the electrical hazard exists shall cooperate with the designated person in charge of the unqualified person(s) to ensure that all work can be done safely. This shall include advising the unqualified person(s) of the electrical hazard and warning him or her to stay outside of the Limited Approach Boundary.

Table 130.2(C) Approach Boundaries to Live Parts for Shock Protection. (All dimensions are distance from live part to employee.)

(1) Nominal System Voltage Range, Phase to Phase	(2) Limited Approach Boundary[1]: Exposed Movable Conductor	(3) Limited Approach Boundary[1]: Exposed Fixed Circuit Part	(4) Restricted Approach Boundary[1]; Includes Inadvertent Movement Adder	(5) Prohibited Approach Boundary[1]
Less than 50	Not specified	Not specified	Not specified	Not specified
50 to 300	3.05 m (10 ft 0 in.)	1.07 m (3 ft 6 in.)	Avoid contact	Avoid contact
301 to 750	3.05 m (10 ft 0 in.)	1.07 m (3 ft 6 in.)	304.8 mm (1 ft 0 in.)	25.4 mm (0 ft 1 in.)
751 to 15 kV	3.05 m (10 ft 0 in.)	1.53 m (5 ft 0 in.)	660.4 mm (2 ft 2 in.)	177.8 mm (0 ft 7 in.)
15.1 kV to 36 kV	3.05 m (10 ft 0 in.)	1.83 m (6 ft 0 in.)	787.4 mm (2 ft 7 in.)	254 mm (0 ft 10 in.)
36.1 kV to 46 kV	3.05 m (10 ft 0 in.)	2.44 m (8 ft 0 in.)	838.2 mm (2 ft 9 in.)	431.8 mm (1 ft 5 in.)
46.1 kV to 72.5 kV	3.05 m (10 ft 0 in.)	2.44 m (8 ft 0 in.)	965.2 mm (3 ft 2 in.)	635 mm (2 ft 1 in.)
72.6 kV to 121 kV	3.25 m (10 ft 8 in.)	2.44 m (8 ft 0 in.)	991 mm (3 ft 3 in.)	812.8 mm (2 ft 8 in.)
138 kV to 145 kV	3.36 m (11 ft 0 in.)	3.05 m (10 ft 0 in.)	1.093 m (3 ft 7 in.)	939.8 mm (3 ft 1 in.)
161 kV to 169 kV	3.56 m (11 ft 8 in.)	3.56 m (11 ft 8 in.)	1.22 m (4 ft 0 in.)	1.07 m (3 ft 6 in.)
230 kV to 242 kV	3.97 m (13 ft 0 in.)	3.97 m (13 ft 0 in.)	1.6 m (5 ft 3 in.)	1.45 m (4 ft 9 in.)
345 kV to 362 kV	4.68 m (15 ft 4 in.)	4.68 m (15 ft 4 in.)	2.59 m (8 ft 6 in.)	2.44 m (8 ft 0 in.)
500 kV to 550 kV	5.8 m (19 ft 0 in.)	5.8 m (19 ft 0 in.)	3.43 m (11 ft 3 in.)	3.28 m (10 ft 9 in.)
765 kV to 800 kV	7.24 m (23 ft 9 in.)	7.24 m (23 ft 9 in.)	4.55 m (14 ft 11 in.)	4.4 m (14 ft 5 in.)

Note: For Flash Protection Boundary, see 130.3(A).
[1]See definition in Article 100 and text in 130.2(D)(2) and Annex C for elaboration.

(2) Entering the Limited Approach Boundary. Where there is a need for an unqualified person(s) to cross the Limited Approach Boundary, a qualified person shall advise him or her of the possible hazards and continuously escort the unqualified person(s) while inside the Limited Approach Boundary. Under no circumstance shall the escorted unqualified person(s) be permitted to cross the Restricted Approach Boundary.

130.3 Flash Hazard Analysis. A flash hazard analysis shall be done in order to protect personnel from the possibility of being injured by an arc flash. The analysis shall determine the Flash Protection Boundary and the personal protective equipment that people within the Flash Protection Boundary shall use.

(A) Flash Protection Boundary. For systems that are 600 volts or less, the Flash Protection Boundary shall be 4.0 ft, based on the product of clearing times of 6 cycles (0.1 second) and the available bolted fault current of 50 kA or any combination not exceeding 300 kA cycles (5000 ampere seconds). For clearing times and bolted fault currents other than 300 kA cycles, or under engineering supervision, the Flash Protection Boundary shall alternatively be permitted to be calculated in accordance with the following general formula:

$$D_c = \left[2.65 \times MVA_{bf} \times t\right]^{1/2}$$

or

$$D_c = \left[53 \times MVA \times t\right]^{1/2}$$

where:

D_c = distance in feet from an arc source for a second-degree burn
MVA_{bf} = bolted fault capacity available at point involved (in mega volt-amps)
MVA = capacity rating of transformer (mega volt-amps). For transformers with MVA ratings below 0.75 MVA, multiply the transformer MVA rating by 1.25
t = time of arc exposure (in seconds)

At voltage levels above 600 volts, the Flash Protection Boundary is the distance at which the incident energy equals 5 J/cm^2(1.2 cal/cm^2). For situations where fault-clearing time is 0.1 second (or faster), the Flash Protection Boundary is the distance at which the incident energy level equals 6.24 J/cm^2(1.5 cal/cm^2).

(B) Protective Clothing and Personal Protective Equipment for Application with a Flash Hazard Analysis. Where it has been determined that work will be performed within the Flash Protection Boundary by 130.3(A), the flash hazard analysis shall determine, and the employer shall document, the incident energy exposure of the worker (in calories per square centimeter). The incident energy exposure level shall be based on the working distance of the employee's face and chest areas from a prospective arc source for the specific task to be performed. Flame-resistant (FR) clothing and personal protective equipment (PPE) shall be used by the employee based on the incident energy exposure associated with the specific task. Recognizing that incident energy increases as the distance from the arc flash decreases, additional PPE shall be used for any parts of the body that are closer than the distance at which the incident energy was determined As an alternative, the PPE requirements of 130.7(C)(9) shall be permitted to be used in lieu of the detailed flash hazard analysis approach described in 130.3(A).

FPN: For information on estimating the incident energy, see Annex D.

130.4 Test Instruments and Equipment Use. Only qualified persons shall perform testing work on or near live parts operating at 50 volts or more.

130.5 Work On or Near Uninsulated Overhead Lines.

(A) Uninsulated and Energized. Where work is performed in locations containing uninsulated energized overhead lines that are not guarded or isolated, precautions shall be taken to prevent employees from contacting such lines directly with any unguarded parts of their body or indirectly through conductive materials, tools, or equipment. Where the work to be performed is such that contact with uninsulated energized overhead lines is possible, the lines shall be deenergized and visibly grounded at the point of work, or suitably guarded.

(B) Deenergizing or Guarding. If the lines are to be deenergized, arrangements shall be made with the person or organization that operates or controls the lines to deenergize them and visibly ground them at the point of work. If arrangements are made to use protective measures, such as guarding, isolating, or insulation, these precautions shall prevent each employee from contacting such lines directly with any part of his or her body or indirectly through conductive materials, tools, or equipment.

(C) Employer and Employee Responsibility. The employer and employee shall be responsible for ensuring that guards or protective measures are satisfactory for the conditions. Employees shall comply with established work methods and the use of protective equipment.

(D) Approach Distances for Unqualified Persons. When employees without electrical training are working on the ground or in an elevated position near overhead lines, the location shall be such that the employee and the longest conductive object the employee might contact cannot come closer to any unguarded, energized overhead power line than the Limited Approach Boundary. If the voltage on the line exceeds 50 kV, the distance shall be 3.04 m (10 ft) plus 100 mm (4 in.) for every 10 kV over 50 kV.

FPN: Objects that are not insulated for the voltage involved should be considered to be conductive.

(E) Vehicular and Mechanical Equipment.

(1) Elevated Equipment. Where any vehicle or mechanical equipment structure will be elevated near energized overhead lines, they shall be operated so that the Limited Approach Boundary distance of Table 130.2(C), Column 2, is maintained. However, under any of the following conditions, the clearances shall be permitted to be reduced:

(1) If the vehicle is in transit with its structure lowered, the Limited Approach Boundary to overhead lines in Table 130.2(C), Column 2, shall be permitted to be reduced by 1.83 m (6 ft). If insulated barriers, rated for the voltages involved, are installed and they are not part of an attachment to the vehicle, the clearance shall be permitted to be reduced to the design working dimensions of the insulating barrier.
(2) If the equipment is an aerial lift insulated for the voltage involved, and if the work is performed by a qualified person, the clearance (between the uninsulated portion of the aerial lift and the power line) shall be permitted to be reduced to the Restricted Approach Boundary given in Table 130.2(C), Column 4.

(2) Equipment Contact. Employees standing on the ground shall not contact the vehicle or mechanical equipment or any of its attachments, unless either of the following conditions apply:

(1) The employee is using protective equipment rated for the voltage.
(2) The equipment is located so that no uninsulated part of its structure (that portion of the structure that provides a conductive path to employees on the ground) can come closer to the line than permitted in 130.5(E)(1).

(3) Equipment Grounding. If any vehicle or mechanical equipment capable of having parts of its structure elevated near energized overhead lines is intentionally grounded, employees working on the ground near the point of grounding shall not stand at the grounding location whenever there is a possibility of overhead line contact. Additional precautions, such as the use of barricades or insulation, shall be taken to protect employees from hazardous ground potentials (step and touch potential), which can develop within a few feet or more outward from the grounded point.

130.6 Other Precautions for Personnel Activities.

(A) Alertness.

(1) When Hazardous. Employees shall be instructed to be alert at all times when they are working near live parts operating at 50 volts or more and in work situations where unexpected electrical hazards might exist.

(2) When Impaired. Employees shall not knowingly be permitted to work in areas containing live parts operating at 50 volts or more or other electrical hazards while their alertness is recognizably impaired due to illness, fatigue, or other reasons.

(B) Blind Reaching. Employees shall be instructed not to reach blindly into areas that might contain exposed live parts where an electrical hazard exists.

(C) Illumination.

(1) General. Employees shall not enter spaces containing live parts unless illumination is provided that enables the employees to perform the work safely.

(2) Obstructed View of Work Area. Where lack of illumination or an obstruction precludes observation of the work to be performed, employees shall not perform any task near live parts operating at 50 volts or more or where an electrical hazard exists.

(D) Conductive Articles Being Worn. Conductive articles of jewelry and clothing (such as watchbands, bracelets, rings, key chains, necklaces, metalized aprons, cloth with conductive thread, metal headgear, or metal frame glasses) shall not be worn where they present an electrical contact hazard with exposed live parts.

(E) Conductive Materials, Tools, and Equipment Being Handled.

(1) General. Conductive materials, tools, and equipment that are in contact with any part of an employee's body shall be handled in a manner that prevents accidental contact with live parts. Such materials and equipment include, but are not limited to, long conductive objects, such as ducts, pipes and tubes, conductive hose and rope, metal-lined rules and scales, steel tapes, pulling lines, metal scaffold parts, structural members, bull floats, and chains.

(2) Approach to Live Parts. Means shall be employed to ensure that conductive materials approach exposed live parts no closer than that permitted by Table 130.2(C).

(F) Confined or Enclosed Work Spaces. When an employee works in a confined or enclosed space (such as a manhole or vault) that contains exposed live parts operating at 50 volts or more or an electrical hazard exists, the employer shall provide, and the employee shall use, protective shields, protective barriers, or insulating materials as necessary to avoid inadvertent contact with these parts. Doors, hinged panels, and the like shall be secured to prevent their swinging into an employee and causing the employee to contact exposed live parts operating at 50 volts or more or where an electrical hazard exists.

(G) Housekeeping Duties. Where live parts present an electrical contact hazard, employees shall not perform housekeeping duties inside the Limited Approach Boundary where there is a possibility of contact, unless adequate safeguards (such as insulating equipment or barriers) are provided to prevent contact. Electrically conductive cleaning materials (including conductive solids such as steel wool, metalized cloth, and silicone carbide, as well as conductive liquid solutions) shall not be used inside the Limited Approach Boundary unless procedures to prevent electrical contact are followed.

(H) Occasional Use of Flammable Materials. Where flammable materials are present only occasionally, electric equipment capable of igniting them may not be used, unless measures are taken to prevent hazardous conditions from developing. Such materials include, but are not limited to, flammable gases, vapors, or liquids; combustible dust; and ignitible fibers or flyings.

FPN: Electrical installation requirements for locations where flammable materials are present on a regular basis are contained in Article 440.

(I) Anticipating Failure. When there is evidence that electric equipment could fail and injure employees, the electric equipment shall be deenergized unless the employer can demonstrate that deenergizing introduces additional or increased hazards or is infeasible because of equipment design or operational limitation. Until the equipment is deenergized or repaired, employees shall be protected from hazards associated with the impending failure of the equipment.

(J) Routine Opening and Closing of Circuits. Load-rated switches, circuit breakers, or other devices specifically designed as disconnecting means shall be used for the opening, reversing, or closing of circuits under load conditions. Cable connectors not of the load-break type, fuses, terminal lugs, and cable splice connections shall not be permitted to be used for such purposes, except in an emergency.

(K) Reclosing Circuits After Protective Device Operation. After a circuit is deenergized by a circuit protective device, the circuit shall not be manually reenergized until it has been determined that the equipment and circuit can be safely energized. The repetitive manual reclosing of circuit breakers or reenergizing circuits through replaced fuses shall be prohibited. When it is determined from the design of the circuit and the overcurrent devices involved that the automatic operation of a device was caused by an overload rather than a fault condition, examination of the circuit or connected equipment shall not be required before the circuit is reenergized.

130.7 Personal and Other Protective Equipment.

(A) General. Employees working in areas where electrical hazards are present shall be provided with, and shall use, protective equipment that is designed and constructed for the specific part of the body to be protected and for the work to be performed.

(B) Care of Equipment. Protective equipment shall be maintained in a safe, reliable condition. The protective equipment shall be visually inspected before each use.

FPN: Specific requirements for periodic testing of electrical protective equipment are given in 130.7(C)(8) and 130.7(F).

(C) Personal Protective Equipment.

(1) General. When an employee is working within the Flash Protection Boundary he/she shall wear protective clothing and other personal protective equipment in accordance with 130.3.

(2) Movement and Visibility. When flame-resistant (FR) clothing is worn to protect an employee, it shall cover all ignitible clothing and shall allow for movement and visibility.

(3) Head, Face, Neck, and Chin Protection. Employees shall wear nonconductive head protection wherever there is a danger of head injury from electric shock or burns due to contact with live parts or from flying objects resulting from electrical explosion. Employees shall wear nonconductive protective equipment for the face, neck, and chin whenever there is a danger of injury from exposure to electric arcs or flashes or from flying objects resulting from electrical explosion.

FPN: See 130.7(C)(13)(b) for arc flash protective requirements.

(4) Eye Protection. Employees shall wear protective equipment for the eyes whenever there is danger of injury from electric arcs, flashes, or from flying objects resulting from electrical explosion.

(5) Body Protection. Employees shall wear FR clothing wherever there is possible exposure to an electric arc flash above the threshold incident-energy level for a second-degree burn, 5 J/cm^2 (1.2 cal/cm^2).

Exception: For incident-energy exposures 8.36 J/cm^2 (2 cal/cm^2) and below, employees may wear non-melting clothing described in Hazard/Risk Category 0 in Table 130.7(C)(11).

FPN: Such clothing can be provided as shirt and trousers, or as coveralls, or as a combination of jacket and trousers, or, for increased protection, as coveralls with jacket and trousers. Various weight fabrics are available. Generally, the higher degree of protection is provided by heavier weight fabrics and/or by layering combinations of one or more layers of FR clothing. In some cases one or more layers of FR clothing are worn over flammable, non-melting clothing. Non-melting, flammable clothing, used alone, can provide protection at low incident energy levels of 8.36 J/cm^2 (2.0 cal/cm^2) and below.

(6) Hand and Arm Protection. Employees shall wear rubber insulating gloves where there is danger of hand and arm injury from electric shock due to contact with live parts. Hand and arm protection shall be worn where there is possible exposure to arc flash burn. The apparel described in 130.7(C)(13)(c) shall be required for protection of hands from burns. Arm protection shall be accomplished by apparel described in 130.7(C)(5).

(7) Foot and Leg Protection. Where insulated footwear is used as protection against step and touch potential, dielectric overshoes shall be required. Insulated soles shall not be used as primary electrical protection.

(8) Standards for Personal Protective Equipment. Personal protective equipment shall conform to the standards given in Table 130.7(C)(8).

FPN: Non-FR or flammable fabrics are not covered by a standard in Table 130.7(C)(8). See 130.7(C)(14)(a), 130.7(C)(14)(b), and 130.7(C)(15).

Table 130.7(C)(8) Standards on Protective Equipment

Subject	Number and Title
Head protection	ANSI Z89.1, *Requirements for Protective Headwear for Industrial Workers*, 1997
Eye and face protection	ANSI Z87.1, *Practice for Occupational and Educational Eye and Face Protection*, 1998
Gloves	ASTM D 120-02, *Standard Specification for Rubber Insulating Gloves*, 2002
Sleeves	ASTM D 1051-02, *Standard Specification for Rubber Insulating Sleeves*, 2002
Gloves and sleeves	ASTM F 496-02, *Standard Specification for In-Service Care of Insulating Gloves and Sleeves*, 2002
Leather protectors	ASTM F 696-02, *Standard Specification for Leather Protectors for Rubber Insulating Gloves and Mittens*, 2002
Footwear	ASTM F 1117-98, *Standard Specification for Dielectric Overshoe Footwear*, 1998 ANSI Z41, *Standard for Personnel Protection, Protective Footwear*, 1999
Visual inspection	ASTM F 1236-01, *Standard Guide for Visual Inspection of Electrical Protective Rubber Products*, 2001
Apparel	ASTM F 1506-02a, *Standard Performance Specification for Textile Material for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards*, 2002a
Raingear	ASTM F 1891-02a, *Standard Specification for Arc and Flame Resistant Rainwear*, 2002a
Face protective products	ASTM F 2178-02, *Standard Test Method for Determining the Arc Rating of Face Protective Products*, 2002

(9) Selection of Personal Protective Equipment.

(a) When Required for Various Tasks. When selected in lieu of the flash hazard analysis of 130.3(A), Table 130.7(C)(9)(a) shall be used to determine the hazard/risk category for a task. The assumed short-circuit current capacities and fault clearing times for various tasks are listed in the text and notes to Table 130.7(C)(9)(a). For tasks not listed, or for power systems with greater than the assumed short-circuit current capacity or with longer than the assumed fault clearing times, a flash hazard analysis shall be required in accordance with 130.3.

FPN No. 1: Both larger and smaller available short-circuit currents could result in higher available arc-flash energies. If the available short-circuit current increases without a decrease in the opening time of the overcurrent protective device, the arc-flash energy will increase. If the available short-circuit current decreases, resulting in a longer opening time for the overcurrent protective device, arc-flash energies could also increase.

FPN No. 2: Energized parts that operate at less than 50 volts are not required to be de-energized to satisfy an "electrically safe work condition." Consideration should be given to the capacity of the source, any overcurrent protection between the energy source and the worker, and whether the work task related to the source operating at less than 50 volts increases exposure to electrical burns or to explosion from an electric arc.

Table 130.7(C)(9)(a) Hazard/Risk Category Classifications

Task (Assumes Equipment Is Energized, and Work Is Done Within the Flash Protection Boundary)	Hazard/ Risk Category	V-rated Gloves	V-rated Tools
Panelboards Rated 240 V and Below — Notes 1 and 3			
Circuit breaker (CB) or fused switch operation with covers on	0	N	N
CB or fused switch operation with covers off	0	N	N
Work on energized parts, including voltage testing	1	Y	Y
Remove/install CBs or fused switches	1	Y	Y
Removal of bolted covers (to expose bare, energized parts)	1	N	N
Opening hinged covers (to expose bare, energized parts)	0	N	N
Panelboards or Switchboards Rated >240 V and up to 600 V (with molded case or insulated case circuit breakers) — Notes 1 and 3			
CB or fused switch operation with covers on	0	N	N
CB or fused switch operation with covers off	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
600 V Class Motor Control Centers (MCCs) — Notes 2 (except as indicated) and 3			
CB or fused switch or starter operation with enclosure doors closed	0	N	N
Reading a panel meter while operating a meter switch	0	N	N
CB or fused switch or starter operation with enclosure doors open	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
Work on control circuits with energized parts 120 V or below, exposed	0	Y	Y
Work on control circuits with energized parts >120 V, exposed	2*	Y	Y
Insertion or removal of individual starter "buckets" from MCC — Note 4	3	Y	N
Application of safety grounds, after voltage test	2*	Y	N
Removal of bolted covers (to expose bare, energized parts)	2*	N	N
Opening hinged covers (to expose bare, energized parts)	1	N	N

Table 130.7(C)(9)(a) *Continued*

Task (Assumes Equipment Is Energized, and Work Is Done Within the Flash Protection Boundary)	Hazard/ Risk Category	V-rated Gloves	V-rated Tools
600 V Class Switchgear (with power circuit breakers or fused switches) — Notes 5 and 6			
CB or fused switch operation with enclosure doors closed	0	N	N
Reading a panel meter while operating a meter switch	0	N	N
CB or fused switch operation with enclosure doors open	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
Work on control circuits with energized parts 120 V or below, exposed	0	Y	Y
Work on control circuits with energized parts >120 V, exposed	2*	Y	Y
Insertion or removal (racking) of CBs from cubicles, doors open	3	N	N
Insertion or removal (racking) of CBs from cubicles, doors closed	2	N	N
Application of safety grounds, after voltage test	2*	Y	N
Removal of bolted covers (to expose bare, energized parts)	3	N	N
Opening hinged covers (to expose bare, energized parts)	2	N	N
Other 600 V Class (277 V through 600 V, nominal) Equipment — Note 3			
Lighting or small power transformers (600 V, maximum)	—	—	—
Removal of bolted covers (to expose bare, energized parts)	2*	N	N
Opening hinged covers (to expose bare, energized parts)	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
Application of safety grounds, after voltage test	2*	Y	N
Revenue meters (kW-hour, at primary voltage and current)	—	—	—
Insertion or removal	2*	Y	N
Cable trough or tray cover removal or installation	1	N	N
Miscellaneous equipment cover removal or installation	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
Application of safety grounds, after voltage test	2*	Y	N
NEMA E2 (fused contactor) Motor Starters, 2.3 kV Through 7.2 kV			
Contactor operation with enclosure doors closed	0	N	N
Reading a panel meter while operating a meter switch	0	N	N
Contactor operation with enclosure doors open	2*	N	N
Work on energized parts, including voltage testing	3	Y	Y
Work on control circuits with energized parts 120 V or below, exposed	0	Y	Y
Work on control circuits with energized parts >120 V, exposed	3	Y	Y
Insertion or removal (racking) of starters from cubicles, doors open	3	N	N
Insertion or removal (racking) of starters from cubicles, doors closed	2	N	N
Application of safety grounds, after voltage test	3	Y	N
Removal of bolted covers (to expose bare, energized parts)	4	N	N
Opening hinged covers (to expose bare, energized parts)	3	N	N

Table 130.7(C)(9)(a) ***Continued***

Task (Assumes Equipment Is Energized, and Work Is Done Within the Flash Protection Boundary)	Hazard/ Risk Category	V-rated Gloves	V-rated Tools
Metal Clad Switchgear, 1 kV and Above			
CB or fused switch operation with enclosure doors closed	2	N	N
Reading a panel meter while operating a meter switch	0	N	N
CB or fused switch operation with enclosure doors open	4	N	N
Work on energized parts, including voltage testing	4	Y	Y
Work on control circuits with energized parts 120 V or below, exposed	2	Y	Y
Work on control circuits with energized parts >120 V, exposed	4	Y	Y
Insertion or removal (racking) of CBs from cubicles, doors open	4	N	N
Insertion or removal (racking) of CBs from cubicles, doors closed	2	N	N
Application of safety grounds, after voltage test	4	Y	N
Removal of bolted covers (to expose bare, energized parts)	4	N	N
Opening hinged covers (to expose bare, energized parts)	3	N	N
Opening voltage transformer or control power transformer compartments	4	N	N
Other Equipment 1 kV and Above			
Metal clad load interrupter switches, fused or unfused	—	—	—
Switch operation, doors closed	2	N	N
Work on energized parts, including voltage testing	4	Y	Y
Removal of bolted covers (to expose bare, energized parts)	4	N	N
Opening hinged covers (to expose bare, energized parts)	3	N	N
Outdoor disconnect switch operation (hookstick operated)	3	Y	Y
Outdoor disconnect switch operation (gang-operated, from grade)	2	N	N
Insulated cable examination, in manhole or other confined space	4	Y	N
Insulated cable examination, in open area	2	Y	N

Note:

V-rated Gloves are gloves rated and tested for the maximum line-to-line voltage upon which work will be done.

V-rated Tools are tools rated and tested for the maximum line-to-line voltage upon which work will be done.

2* means that a double-layer switching hood and hearing protection are required for this task in addition to the other Hazard/Risk Category 2 requirements of Table 130.7(C)(10).

Y = yes (required)

N = no (not required)

Notes:

1. 25 kA short circuit current available, 0.03 second (2 cycle) fault clearing time.
2. 65 kA short circuit current available, 0.03 second (2 cycle) fault clearing time.
3. For < 10 kA short circuit current available, the hazard/risk category required may be reduced by one number.
4. 65 kA short circuit current available, 0.33 second (20 cycle) fault clearing time.
5. 65 kA short circuit current available, up to 1.0 second (60 cycle) fault clearing time.
6. For < 25 kA short circuit current available, the hazard/risk category required may be reduced by one number.

(10) Protective Clothing and Personal Protective Equipment Matrix. Once the Hazard/Risk Category has been identified, Table 130.7(C)(10) shall be used to determine the required personal protective equipment (PPE) for the task. Table 130.7(C)(10) lists the requirements for protective clothing and other protective equipment based on Hazard/Risk Category numbers 0 through 4. This clothing and equipment shall be used when working on or near energized equipment within the Flash Protection Boundary.

FPN No. 1: See Annex H for a suggested simplified approach to ensure adequate PPE for electrical workers within facilities with large and diverse electrical systems.

FPN No. 2: The PPE requirements of this section are intended to protect a person from arc-flash and shock hazards. While some situations could result in burns to the skin, even with the protection described in Table 130.7(C)(10), burn injury should be reduced and survivable. Due to the explosive effect of some arc events, physical trauma injuries could occur. The PPE requirements of this section do not provide protection against physical trauma other than exposure to the thermal effects of an arc flash.

(11) Protective Clothing Characteristics. Table 130.7(C)(11) lists examples of protective clothing systems and typical characteristics including the degree of protection for various clothing. The protective clothing selected for the corresponding hazard/risk category number shall have an arc rating of at least the value listed in the last column of Table 130.7(C)(11).

FPN: The arc rating for a particular clothing system can be obtained from the FR clothing manufacturer.

(12) Factors in Selection of Protective Clothing. Clothing and equipment that provide worker protection from shock and arc flash hazards shall be utilized. Clothing and equipment required for the degree of exposure shall be permitted to be worn alone or integrated with flammable, nonmelting apparel. If FR clothing is required, it shall cover associated parts of the body as well as all flammable apparel while allowing movement and visibility. All personal protective equipment shall be maintained in a sanitary and functionally effective condition. Personal protective equipment items will normally be used in conjunction with one another as a system to provide the appropriate level of protection.

FPN: Protective clothing includes shirts, pants, coveralls, jackets, and parkas worn routinely by workers who, under normal working conditions, are exposed to momentary electric arc and related thermal hazards. Flame-resistant rainwear worn in inclement weather is included in this category of clothing.

(a) Layering. Nonmelting, flammable fiber garments shall be permitted to be used as underlayers in conjunction with FR garments in a layered system for added protection. If nonmelting, flammable fiber garments are used as underlayers, the system arc rating shall be sufficient to prevent breakopen of the innermost FR layer at the expected arc exposure incident energy level to prevent ignition of flammable underlayers.

FPN: A typical layering system might include cotton underwear, a cotton shirt and trouser, and a FR coverall. Specific tasks might call for additional FR layers to achieve the required protection level.

(b) Outer Layers. Garments worn as outer layers over FR clothing, such as jackets or rainwear, shall also be made from FR material.

(c) Underlayers. Meltable fibers such as acetate, nylon, polyester, polypropylene, and spandex shall not be permitted in fabric underlayers (underwear) next to the skin.

Exception: An incidental amount of elastic used on nonmelting fabric underwear or socks shall be permitted.

FPN No. 1: FR garments (e.g., shirts, trousers, and coveralls) worn as underlayers that neither ignite nor melt and drip in the course of an exposure to electric arc and related thermal hazards generally provide a higher system arc rating than nonmelting, flammable fiber underlayers.

FPN No. 2: FR underwear or undergarments used as underlayers generally provide a higher system arc rating than nonmelting, flammable fiber underwear or undergarments used as underlayers.

(d) Coverage. Clothing shall cover potentially exposed areas as completely as possible. Shirt sleeves shall be fastened at the wrists, and shirts and jackets shall be closed at the neck.

(e) Fit. Tight-fitting clothing shall be avoided. Loose-fitting clothing provides additional thermal insulation because of air spaces. FR apparel shall fit properly such that it does not interfere with the work task.

(f) Interference. The garment selected shall result in the least interference with the task but still provide the necessary protection. The work method, location, and task could influence the protective equipment selected.

(13) Arc Flash Protective Equipment.

(a) Flash Suits. Flash suit design shall permit easy and rapid removal by the wearer. The entire flash suit, including the hood's face shield, shall have an arc rating that is suitable for the arc flash exposure. When exterior air is supplied into the hood, the air hoses and pump housing shall be either covered by FR materials or constructed of nonmelting and nonflammable materials.

(b) Face Protection. Face shields shall have an arc rating suitable for the arc flash exposure. Face shields without an arc rating shall not be used. Eye protection (safety glasses or goggles) shall always be worn under face shields or hoods.

FPN: Face shields made with energy-absorbing formulations that can provide higher levels of protection from the radiant energy of an arc flash are available, but these shields are tinted and can reduce visual acuity. Additional illumination of the task area might be necessary when these types of arc protective face shields are used.

Table 130.7(C)(10) Protective Clothing and Personal Protective Equipment (PPE) Matrix

Protective Clothing and Equipment	Protective Systems for Hazard/Risk Category					
Hazard/Risk Category Number	**−1 (Note 3)**	**0**	**1**	**2**	**3**	**4**
Non-melting (according to ASTM F 1506-00) or Untreated Natural Fiber						
a. T-shirt (short-sleeve)	X			X	X	X
b. Shirt (long-sleeve)		X				
c. Pants (long)	X	X	X (Note 4)	X (Note 6)	X	X
FR Clothing (Note 1)						
a. Long-sleeve shirt			X	X	X (Note 9)	X
b. Pants			X (Note 4)	X (Note 6)	X (Note 9)	X
c. Coverall			(Note 5)	(Note 7)	X (Note 9)	(Note 5)
d. Jacket, parka, or rainwear			AN	AN	AN	AN
FR Protective Equipment						
a. Flash suit jacket (multilayer)						X
b. Flash suit pants (multilayer)						X
c. Head protection						
1. Hard hat			X	X	X	X
2. FR hard hat liner					AR	AR
d. Eye protection		—	—	—	—	—
1. Safety glasses	X	X	X	AL	AL	AL
2. Safety goggles				AL	AL	AL
e. Face and head area protection		—	—	—	—	—
1. Arc-rated face shield, or flash suit hood				X (Note 8)		
2. Flash suit hood					X	X
3. Hearing protection (ear canal inserts)				X (Note 8)	X	X
f. Hand protection			—	—	—	—
Leather gloves (Note 2)			AN	X	X	X
g. Foot protection						
Leather work shoes			AN	X	X	X

AN = As needed
AL = Select one in group
AR = As required
X = Minimum required
Notes:
1. See Table 130.7(C)(11). Arc rating for a garment is expressed in cal/cm^2.
2. If voltage-rated gloves are required, the leather protectors worn external to the rubber gloves satisfy this requirement.
3. Hazard/Risk Category Number "−1" is only defined if determined by Notes 3 or 6 of Table 130.7(C)(9)(a).
4. Regular weight (minimum 12 oz/yd^2 fabric weight), untreated, denim cotton blue jeans are acceptable in lieu of FR pants. The FR pants used for Hazard/Risk Category 1 shall have a minimum arc rating of 4.
5. Alternate is to use FR coveralls (minimum arc rating of 4) instead of FR shirt and FR pants.
6. If the FR pants have a minimum arc rating of 8, long pants of non-melting or untreated natural fiber are not required beneath the FR pants.
7. Alternate is to use FR coveralls (minimum arc rating of 4) over non-melting or untreated natural fiber pants and T-shirt.
8. A faceshield with a minimum arc rating of 8, with wrap-around guarding to protect not only the face, but also the forehead, ears, and neck (or, alternatively, a flash suit hood), is required.
9. Alternate is to use two sets of FR coveralls (the inner with a minimum arc rating of 4 and outer coverall with a minimum arc rating of 5) over non-melting or untreated natural fiber clothing, instead of FR coveralls over FR shirt and FR pants over non-melting or untreated natural fiber clothing.

Table 130.7(C)(11) Protective Clothing Characteristics

Hazard/Risk Category	Typical Protective Clothing Systems: Clothing Description (Typical number of clothing layers is given in parentheses)	Required Minimum Arc Rating of PPE [$J/cm^2(cal/cm^2)$]
0	Non-melting, flammable materials (i.e., untreated cotton, wool, rayon, or silk, or blends of these materials) with a fabric weight at least 4.5 oz/yd^2 (1)	N/A
1	FR shirt and FR pants or FR coverall (1)	16.74 (4)
2	Cotton underwear — conventional short sleeve and brief/shorts, plus FR shirt and FR pants (1 or 2)	33.47 (8)
3	Cotton underwear plus FR shirt and FR pants plus FR coverall, or cotton underwear plus two FR coveralls (2 or 3)	104.6 (25)
4	Cotton underwear plus FR shirt and FR pants plus multilayer flash suit (3 or more)	167.36 (40)

Note: Arc rating is defined in Article 100 and can be either ATPV or E_{BT}. ATPV is defined in ASTM F 1959-99 as the incident energy on a fabric or material that results in sufficient heat transfer through the fabric or material to cause the onset of a second-degree burn based on the Stoll curve. E_{BT} is defined in ASTM F 1959-99 as the average of the five highest incident energy exposure values below the Stoll curve where the specimens do not exhibit breakopen. E_{BT} is reported when ATPV cannot be measured due to FR fabric breakopen.

(c) Hand Protection. Leather or FR gloves shall be worn where required for arc flash protection. Where insulating rubber gloves are used for shock protection, leather protectors shall be worn over the rubber gloves.

FPN: Insulating rubber gloves and gloves made from layers of flame-resistant material provide hand protection against the arc flash hazard. Heavy-duty leather (e.g., greater than 12 oz/yd^2) gloves provide protection suitable up to Hazard/Risk Category 2. The leather protectors worn over insulating rubber gloves provide additional arc flash protection for the hands. During high arc flash exposures leather can shrink and cause a decrease in protection.

(d) Foot Protection. Heavy-duty leather work shoes provide some arc flash protection to the feet and shall be used in all tasks in Hazard/Risk Category 2 and higher.

(14) Clothing Material Characteristics. FR clothing shall meet the requirements described in 130.7(C)(14)(a) through 130.7(C)(15).

FPN: FR materials, such as flame-retardant treated cotton, meta-aramid, para-aramid, and poly-benzimidazole (PBI) fibers, provide thermal protection. These materials can ignite but will not continue to burn after the ignition source is removed. FR fabrics can reduce burn injuries during an arc flash exposure by providing a thermal barrier between the arc flash and the wearer. In aramid and PBI blends, para-aramid adds strength to a fabric to prevent the fabric from breaking open due to the blast shock wave and high thermal energy of the arc.

(a) Melting. Clothing made from flammable synthetic materials that melt at temperatures below 315°C (600°F), such as acetate, nylon, polyester, polypropylene, and spandex, either alone or in blends, shall not be used.

FPN: These materials melt as a result of arc flash exposure conditions, form intimate contact with the skin, and aggravate the burn injury.

Exception: Fiber blends that contain materials that melt, such as acetate, nylon, polyester, polypropylene, and spandex, shall be permitted if such blends in fabrics meet the requirements of ASTM F 1506, Standard Performance Specification for Textile Material for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards, and if such blends in fabrics do not exhibit evidence of a melting and sticking hazard during arc testing according to ASTM F 1959 [see also 130.7(C)(15)].

(b) Flammability. Clothing made from nonmelting flammable natural materials, such as cotton, wool, rayon, or silk, shall be permitted for Hazard/Risk Categories 0 and −1 considered acceptable if it is determined by flash hazard analysis that the exposure level is 8.36 J/cm^2 (2.0 cal/cm^2) or less, and that the fabric will not ignite and continue to burn under the arc exposure hazard conditions to which it will be exposed (using data from tests done in accordance with ASTM F 1958.) See also 130.7(C)(12)(a) for layering requirements.

FPN No. 1: Non-FR cotton, polyester-cotton blends, nylon, nylon-cotton blends, silk, rayon, and wool fabrics are flammable. These fabrics could ignite and continue to burn on the body, resulting in serious burn injuries.

FPN No. 2: Rayon is a cellulose-based (wood pulp) synthetic fiber that is a flammable but nonmelting material.

(15) Clothing Not Permitted. Clothing made from materials that do not meet the requirements of 130.7(C)(14)(a) regarding melting, or made from materials that do not meet the flammability requirements of 130.7(C)(14)(b), shall not be permitted to be worn.

FPN: Some flame-resistant fabrics, such as non-FR modacrylic and nondurable flame-retardant treatments of cotton, are not recommended for industrial electrical or utility applications.

Exception: Non-melting, flammable (non-FR) materials shall be permitted to be used as underlayers to FR clothing, as described in 130.7(C)(14)(a) and also shall be permitted to be used for Hazard/Risk Category 0 and −1 as described in Table 130.7(C)(10).

(16) Care and Maintenance of FR Clothing and FR Flash Suits.

(a) Inspection. FR apparel shall be inspected before each use. Work clothing or flash suits that are contaminated, or damaged to the extent their protective qualities are impaired, shall not be used. Protective items that become contaminated with grease, oil, or flammable liquids or combustible materials shall not be used.

(b) Manufacturer's Instructions. The garment manufacturer's instructions for care and maintenance of FR apparel shall be followed.

(D) Other Protective Equipment.

(1) Insulated Tools and Equipment. Employees shall use insulated tools and/or handling equipment when working inside the Limited Approach Boundary of exposed live parts where tools or handling equipment might make accidental contact. Insulated tools shall be protected from damage to the insulating material.

FPN: See 130.2(B) for working on exposed live parts.

(a) Requirements for Insulated Tools. The following requirements shall apply to insulated tools:

(1) Insulated tools shall be rated for the voltages on which they are used.
(2) Insulated tools shall be designed and constructed for the environment to which they are exposed and the manner in which they are used.

(b) Fuse or Fuse Holding Equipment. Fuse or fuse holder handling equipment, insulated for the circuit voltage, shall be used to remove or install a fuse if the fuse terminals are energized.

(c) Ropes and Handlines. Ropes and handlines used near exposed live parts operating at 50 volts or more, or used where an electrical hazard exists, shall be nonconductive.

(d) Fiberglass-Reinforced Plastic Rods. Fiberglass-reinforced plastic rod and tube used for live line tools shall meet the requirements of ASTM F 711, *Standard Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used; in Live Line Tools*, 1989 (R 1997).

(e) Portable Ladders. Portable ladders shall have nonconductive side rails if they are used where the employee or ladder could contact exposed live parts operating at 50 volts or more or where an electrical hazard exists. Nonconductive ladders shall meet the requirements of ANSI standards for ladders listed in Table 130.7(F).

(f) Protective Shields. Protective shields, protective barriers, or insulating materials shall be used to protect each employee from shock, burns, or other electrically related injuries while that employee is working near live parts that might be accidentally contacted or where dangerous electric heating or arcing might occur. When normally enclosed live parts are exposed for maintenance or repair, they shall be guarded to protect unqualified persons from contact with the live parts.

(g) Rubber Insulating Equipment. Rubber insulating equipment used for protection from accidental contact with live parts shall meet the requirements of the ASTM standards listed in Table 130.7(F).

(h) Voltage Rated Plastic Guard Equipment. Plastic guard equipment for protection of employees from accidental contact with live parts, or for protection of employees or energized equipment or material from contact with ground, shall meet the requirements of the ASTM standards listed in Table 130.7(F).

(i) Physical or Mechanical Barriers. Physical or mechanical (field fabricated) barriers shall be installed no closer than the restricted approach distance given in Table 130.2(C). While the barrier is being installed, the restrictive approach distance specified in Table 130.2(C) shall be maintained, or the live parts shall be placed in an electrically safe work condition.

(E) Alerting Techniques.

(1) Safety Signs and Tags. Safety signs, safety symbols, or accident prevention tags shall be used where necessary to warn employees about electrical hazards that might endanger them. Such signs and tags shall meet the requirements of ANSI Standard Z535 given in Table 130.7(F).

(2) Barricades. Barricades shall be used in conjunction with safety signs where it is necessary to prevent or limit employee access to work areas containing live parts. Conductive barricades shall not be used where it might cause an electrical hazard. Barricades shall be placed no closer than the Limited Approach Boundary given in Table 130.2(C).

(3) Attendants. If signs and barricades do not provide sufficient warning and protection from electrical hazards, an attendant shall be stationed to warn and protect employees. The primary duty and responsibility of an attendant providing manual signaling and alerting shall be to keep unqualified employees outside a work area where the unqualified employee might be exposed to electrical hazards. An attendant shall remain in the area as long as there is a potential for employees to be exposed to the electrical hazards.

(F) Standards for Other Protective Equipment. Other protective equipment required in 130.7(D) shall conform to the standards given in Table 130.7(F).

Table 130.7(F) Standards on Other Protective Equipment

Subject	Number and Title
Ladders	ANSI A14.1, *Safety Requirements for Portable Wood Ladders,* 1994 ANSI A14.3, *Safety Requirements for Fixed Ladders,* 2002 ANSI A14.4, *Safety Requirements for Job-Made Ladders,* 1992 ANSI A14.5, *Safety Requirement for Portable Reinforced Plastic Ladders,* 2000
Safety signs and tags	ANSI Z535, *Series of Standards for Safety Signs and Tags,* 1998
Blankets	ASTM D 1048, *Standard Specification for Rubber Insulating Blankets,* 1999
Covers	ASTM D 1049, *Standard Specification for Rubber Covers,* 1998
Line hoses	ASTM D 1050, *Standard Specification for Rubber Insulating Line Hoses,* 1990
Line hoses and covers	ASTM F 478, *Standard Specification for In-Service Care of Insulating Line Hose and Covers,* 1999
Blankets	ASTM F 479, *Standard Specification for In-Service Care of Insulating Blankets,* 1995
Fiberglass tools/ ladders	ASTM F 711, *Standard Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used; in Line Tools,* 1989 (R 1997)
Plastic guards	ASTM F 712, *Standard Test Methods for Electrically Insulating Plastic Guard Equipment for Protection of Workers,* 1995
Temporary grounding	ASTM F 855, *Standard Specification for Temporary Protective Grounds to Be Used on De-energized Electric Power Lines and Equipment,* 1997
Insulated hand tools	ASTM F 1505, *Standard Specification for Insulated and Insulating Hand Tools,* 2001

IEEE Standards

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Abstract: This amendment provides additions and corrections to IEEE Std 1584-2002.
Keywords: arc fault currents, arc-flash hazard, arc-flash hazard analysis, arc-flash hazard marking, arc in enclosures, arc in open air, bolted fault currents, electrical hazard, flash protection boundary, incident energy, personal protective equipment, protective device coordination study, short-circuit study, working distances

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Introduction

(This introduction is not part of IEEE Std 1584a-2004, IEEE Guide for Performing Arc-Flash Hazard Calculations—Amendment 1.)

This amendment to IEEE Std 1584-2002 offers guidelines on how to apply the document based on experience gained by users since its publication.

As defined by the IEEE operating procedures, a guide is a document in which alternative approaches to good practice are suggested, but no clear-cut recommendations are made. This guide is intended to be used only by qualified people. The complexities of electrical power system configurations and equipment dictate that, like short-circuit studies and protective-device coordination studies, an arc-flash hazard study should only be undertaken by experienced electrical power system engineers or other well-trained professionals. Those who are not this qualified are encouraged to use a table method to select personal protective equipment (PPE).

A set of cautions and disclaimers is provided in the guide and reproduced in the spreadsheet calculator to help users understand the limitations in the technology. Proper PPE based on arc-flash hazard calculations or tables is the last line of defense against arc-flash hazards. Other mitigation techniques, as in the following list, provide a much better defense. A facility owner and employees working on equipment should be aware of all the limitations. The warning labels in rated PPE help to do this. However, users should recognize that following codes, standards, guides, and recommended practices does not guarantee that all arc-flash injuries will be avoided.

De-energizing remains the first choice as a means of achieving an electrically safe working condition and reducing the possibility of injury, but that is not always possible. Also, incidents have occurred during the action of de-energizing equipment to create the safe working condition and during switching to reestablish power. For these occasions, an arc-flash hazard analysis and the institution of a PPE program provide great value in reducing the likelihood of injuries in an arc flash.

These studies may identify equipment where the possible incident energy levels are so high that PPE is not available or not recommended. In those cases, operating procedure or engineering design changes may need to be considered to reduce the exposure or incident energy levels. Developing these changes is an important part of implementing a study's results. Examples of some of these changes include the following:

- Changing operating procedures to eliminate or minimize the time that two sources of power are tied together
- Resetting or replacing existing protective devices to get faster fault clearing times
- Adding fast operating relays or current-limiting devices to reduce fault clearing times
- Adding remote racking and operating capability
- Installing arc-resistant switchgear

Notice to users

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: http://standards.ieee.org/reading/ieee/updates/errata/index.html. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: http://standards.ieee.org/reading/ieee/interp/index.html.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents or patent applications for which a license may be required to implement an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Participants

When the IEEE 1584 Working Group approved this amendment, it had the following membership:

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The following members of the individual balloting committee voted on this amendment. Balloters may have voted for approval, disapproval, or abstention.

Alonza W Ballard
Louis A Barrios
James E Bowen
Frederick Bried
Kristine K Buchholz
Donanld Colaberardino
Gary DiTroia
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George Gregory
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Danny Liggett
Bruce McClung
Michael McNeil
Daleep Mohla
William Moylan
Paul Myers
Tom Neal
Daniel Neeser
John Nelson
Art Neubauer
T W Olsen
David Pace
Lorraine Padden
Giuseppe Parise
John Propst
Melvin Sanders
Vincent Saporita
Mary Capelli Schellpfef-fer
Dennis Thonsgard
Michael Toney
Michael Wactor
Craig Wellman
Donald W. Zipse

When the IEEE-SA Standards Board approved this amendment on 23 September 2004, it had the following membership:

Contents

IEEE Guide for Performing Arc-Flash Hazard Calculations—Amendment 1

NOTE—The editing instructions contained in this amendment define how to merge the material contained herein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make small corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strikethrough~~ (to remove all old material) and <u>underscore</u> (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make large changes in existing text, subclauses, tables, or figures by removing existing material and replacing it with new material. Editorial notes will not be carried over into future editions because the changes will be incorporated into the base standard.

5. Model for incident energy calculations

5.2 Arcing current

Change the last paragraph in 5.2 to the following:

<u>For applications with a system voltage under 1000 V,</u> calculate a second arc current equal to 85% of I_a, so that a second arc duration can be determined (see 9.10.4).

5.6 Current-limiting fuses

Insert the following sentence as the third sentence:

Where applicable, these formulae should be used as opposed to the formulae in 5.2 and 5.3.

5.7 Low-voltage circuit breakers

Add a sentence at the end of the first paragraph:

Where the time-current curves are available, the equations in 5.2 and 5.3 are preferred.

Where the time-current curves are available, the equations in 5.2 and 5.3 are preferred.

7. Comparison of arc-flash calculation methods

7.1 Table method in NFPA 70E-2004

Change 7.1, as shown in the following text:

~~The simplest~~ One method for determining PPE requirements for arc-flash protection is to use the tables in NFPA 70E-2004. These tables ~~give instant answers and require almost no field data~~ provide guidance for determination of hazard risk categories and PPE requirements for various common tasks. It should be noted that these tables are for specific fault currents and specific clearing times as stipulated in notes at the end of the tables. ~~and the tables do not cover all applications or installations of electrical equipment. While these tables are intended to be conservative for most applications, they may not enable the user to select adequate protection.~~

Arc-flash calculator (provided with IEEE Std 1584-2002 as a separate file embedded in a spreadsheet program)

Change the formula in the I24 cell of the data-normal sheet in the arc-flash calculator to the following, then repeat the change down the column for each row:

=IF(AND(B24<1,O24=0),(E24/C24)*POWER(10,X24),"Not required")

The formula, which found 85% of the arcing current, did not reflect the possible reduced current in the protective device. The ratio E24/C24 was missing.

Article II

The Other Electrical Hazard: Electric Arc Blast Burns

The Other Electrical Hazard Electric Arc Blast Burns

Ralph H. Lee

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Abstract

Electric arc burns make up a substantial portion of the injuries from electrical malfunctions. The extremely high temperatures of these arcs, about four times as high as that of the sun's surface, can cause fatal burns at up to about five feet (152 cm.), and major burns at up to about ten feet (305 cm) distance. In this paper are developed information for evaluation of the degree of hazard involved with various voltages and capacity ratings of equipment, and outline of the required precautions and protective means to avoid injury from this source.

Introduction

Almost everyone is aware that electrical shock can be a hazard to life, although the minor shocks that many have experienced with no dire consequences tend to make one somewhat careless of this. There is another hazard which few appreciate, which we do not even need to touch to incur injury. This is the radiation burn from the fierce fire of electric arcs, due to short circuit developing from poor electrical contact or failure of insulation. The electric arc between metals is, next to the laser, the hottest thing on earth, or about four times as hot as the sun's surface. Where high arc currents are involved, burns from such arcs can be fatal where the victim is even several feet from the arc, and debilitating burns at distances of ten feet are common. Clothing is ignited at distances of several feet; this itself can cause fatal burns, because the clothing cannot be removed or extinguished quickly enough to prevent serious burns over much of the body skin area.

So all that is necessary is to be within about five feet or so from a severe power arc with bare skin or flammable clothing, to incur serious or fatal injuries. Electrical workers are frequently within these distances of energized parts, which can become involved in arc, so it is only the relative infrequency of such arcs which really prevents more injuries than now occur. Examples of this exposure are hook stick operation of medium voltage fuses, testing of cable terminals before grounding, or grounding before testing, or work in manholes near still energized cables.

Electric arcing is the term applied to the passage of substantial electric currents through what had previously been air. But air is not the conductor; current passage is through the vapor of the arc terminal material, usually a conductor metal or carbon. Contrasted with current flow through low pressure gases such as neon, arcing involves high temperatures of up to or beyond 20,000 K (35,000°F) at the arc terminals. These temperatures are not withstandable by any materials known on earth; all are not only melted, but vaporized. Actually, 20,000°K is about four times as hot as the surface temperature of the sun.

Nature of Arcs

Subsequent to its initiation, by flashover or from the introduction of some conductive material, an arc is the flow of current through a path consisting of the vapor of the terminal material. This vapor has substantially higher resistance than the solid metal, to the extent that voltage drop in the arc ranges between 75 and 100 volts per inch, several thousand times its drop in a solid conductor. Since the inductance of the arc path is not appreciably different from that of a solid conductor of the same length, the arc current path is substantially resistive in nature, yielding unity power factor. (Voltage drop in a faulted large solid or stranded conductor is about 0.5 to 1 volt per foot, 0.16 to 0.32 V/cm.)

For low voltage circuits, the arc, at 75 to 100 V/in. length, consumes a substantial portion of the available voltage, leaving only the difference between source voltage and arc voltage to force the fault current through the total system impedance, including that of the arc. This is the reason for the "stabilization" of arc current on 277/480 volt circuits when the arc length is of the order of four inches (bus spacing, etc.)

For higher voltages, the arc lengths can be substantially greater, say 1 in. (2.54 cm) per 100 volts of supply, before the system impedance starts to regulate or limit the fault current. Note that the arc voltage drop and the source voltage drop add in quadrature, the former resistive, the latter substantially reactive. Thus, the length, or size, of arcs in the higher voltage systems, can be greater, so can readily bridge the gap from energized parts to ground or other polarities with little drop in fault current.

The Arc as a Source of Heat

The electric arc is widely recognized as a very high level source of heat. Common uses are arc welding and electric arc furnaces, even electric cauterizing of wounds to seal against infection while deeper parts are healing. The temperatures of metal terminals are extraordinarily high, being reliably reported to be 20,000°K (about 35,000°F). (1) One investigator reports temperatures as high as 34,000°K, and special types of arcs can reach 50,000°K. The only higher temperature source known on earth is the laser, which can produce 100,000°K.

The intermediate (plasma) part of the arc, the portion away from the terminals, the "shank" of the dog-bone, figuratively, is reported as having a temperature of 13,000°K. In comparison, the surface temperature of the sun is about 5,000°K, so the terminal and plasma portions are four and 2-1/2 times, respectively, as hot as the sun's surface. (Temperature below the surface of the sun is, of course, much higher, such as 10,000,000°K at the center.)

Heat transfer from a hotter to a cooler object is a function of the difference between the fourth powers of their absolute temperatures:

$h = C \times 3.68\,(T_e^4 - T_a^4) \times 10^{-11}$ - Eq. 1 (2)

where h = heat transfer, w/sq. in.
w/6.45 sq. cm
C = absorption coeff. of absorbing surface
T_e = absolute temp. of emitting surface, °K
T_a = absolute temp. of absorbing surface, °K

This relationship is useful when the two bodies are large in extent, and relatively close together, so that little heat is lost from edge effects. It is much more useful for purposes of this study to separate this into two elements:

1. The total heat emanating from the source.
2. The proportion of this heat absorbed by unit area of the absorbing object. This is inversely proportional to the square of the distance of separation, similar to light from a central source.

The heat generated by a source per unit of surface area is:

$h = 3.68 \times T^4 \times 10^{-11}$ w/sq. in - Eq. 2 (2)

$= 0.571 \times T^4 \times 10^{-11}$ w/sq. cm

The temperature is known, but not the area of the source; this will be developed subsequently.

To find the heat received by an object, per unit area, we need to know:

Q_s = heat emitted from the source, per unit area
A_s = total surface area of the source
r = distance from center of source to object
A_o = projected surface area of the object along a plane normal to the source-to-object direction
Q_o = heat absorbed by projected surface of object

From these, the following relationship is obtained:

$Q_o = [(Q_s A_s)/(4\Pi r^2_s)][A_o]$

Figure 1 is useful in visualizing this relationship. In English, this is saying that the heat received per unit projected area of the object is the heat radiated per unit area of the source times the surface area of the source, divided by 4∏ times the square of the radius from source to object. This is the same

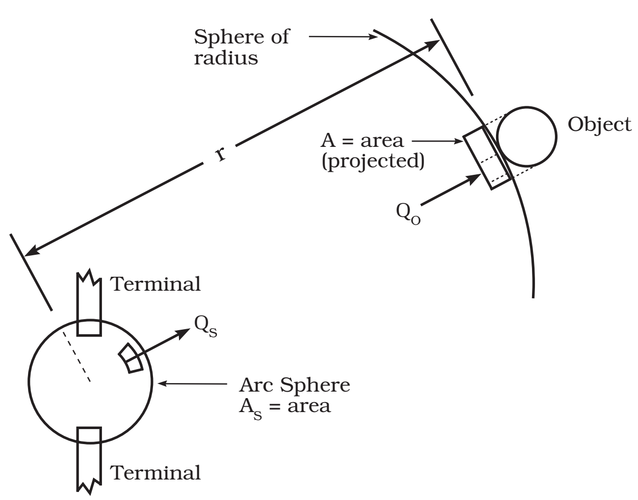


Figure 1
Illustration of Arc Source
and heat-receiving object.

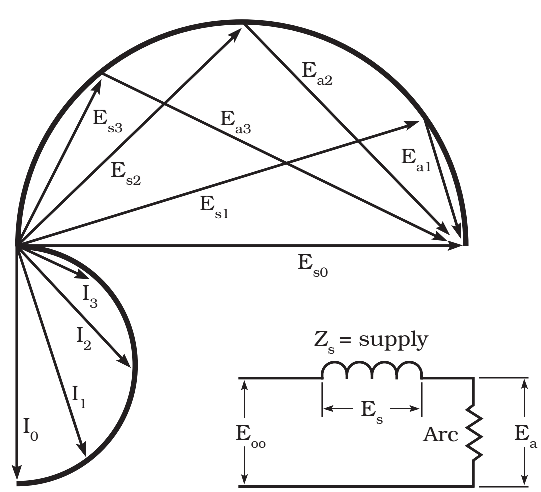


Figure 2
Vector Diagram of
Voltages and Currents, with
division between
Source Arc Drops as
Arc Length is Varied.

as saying the heat received by the earth from the sun is the total heat output of the sun times the earth's projected surface area on a sphere of radius equal to the sun-to-earth distance. The absorption coefficients enter into these relationships.

For portions of the receiving object which are not at right angles to the source-object radius, the surface heat density needs to be multiplied by the cosine of the angle between the surface and the direction of the source. (For 90°, this multiple is 1.)

Whether the surface is a number of channels or any other shape is not important, only that it has the required area. For simplicity, we will consider it is a sphere, and will have a diameter which gives the specific surface area. Thus, the diameter of the sphere will be a function of the square root of the arc wattage.

Development of Arc Size

In a bolted fault, there is no arc, so there will be little heat generated there. Should there be appreciable resistance at the fault point, temperature there could rise to the melting and boiling point of the metal, and an arc would be started. The longer the arc becomes, the more of the available system voltage will be consumed in it, so there will be less voltage available to overcome the supply impedance, and the total current will decrease.

This is illustrated in Figure 2. The system has rated voltage E_{oo}, and total impedance to the fault of Z_s. Four arc conditions are shown, one of zero length (bolted fault), one of short length (sub. 1), one of moderate length (sub. 2) and one of greater length, (sub. 3). Since the arc impedance is almost purely resistive, and that of the supply system almost purely inductive, the voltage drops across arc and supply system are in quadrature for all arc lengths. The locus of the intersection of the vectors of supply voltage drop (E_s) and arc voltage drop (E_a) is a semicircle with diameter of E_{so}, the supply system drop for a bolted fault, also equal to E_{oo}. For this range or arc lengths, the total current is represented by current vectors I_o, I_1, I_2, and I_3, all at right angles to the corresponding E_s's. The magnitude of the I vectors is proportional to that of the E_s vectors, since they are related by the constant Z_s, ($I = E_s/Z_s$).

The total energy in the arc, then, is the product of E_a and I. This is zero for the bolted fault, appreciable for condition 1,very substantial for sub. 2, then decreasing for condition sub. 3, where the arc voltage increases only moderately while the current decreases substantially. Also, somewhere in the region of sub. 2 - sub. 3, the length of the arc may become so long that the arc is self-extinguishing, or at least self-stabilizing at a low current level. This would be the condition in burn-down of 480/277 V buses with wide spacing, where the arc current stabilizes at about 1500 A for 4" (10 cm) p-g spacing at 277 V.

Table I
Maximum Power in 3Ø arc, MW

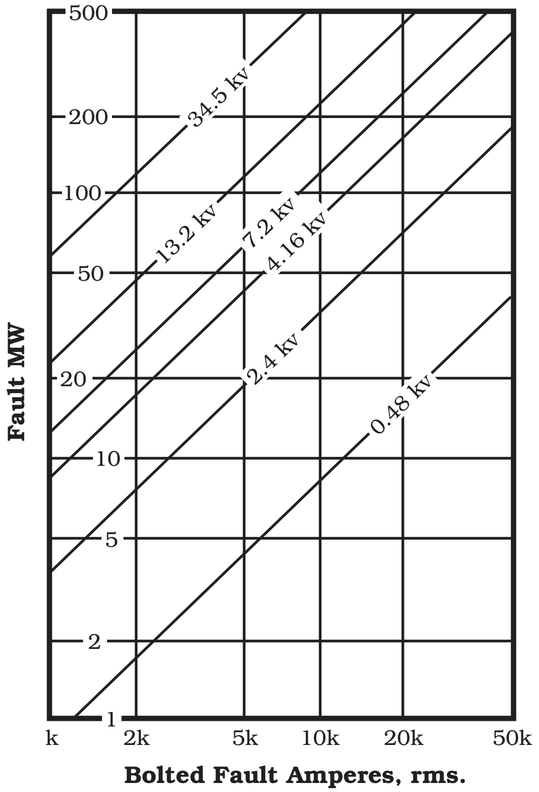
Bolted Fault kA	System Voltage, kV					
	0.48	2.4	4.2	7.2	13.2	34.5
1	0.42	2.0	3.6	6.3	11.4	29.8
2	0.83	4.2	7.2	12.5	22.8	59.6
3	1.25	6.2	10.8	18.7	34.8	91.0
5	2.08	10.3	18.0	31.2	57.1	149.2
10	4.15	20.8	36.0	62.3	114.2	295.5
15	6.23	31.1	54.0	93.4	171.3	447.7
20	8.3	41.5	72.0	120.5	228.3	596.7
30	12.5	62.2	108.0	186.8		
40	16.6	83.0	144.0			
50	20.8	103.8	180.0			

Table II
Diameter of Arc Sphere re; arc Power

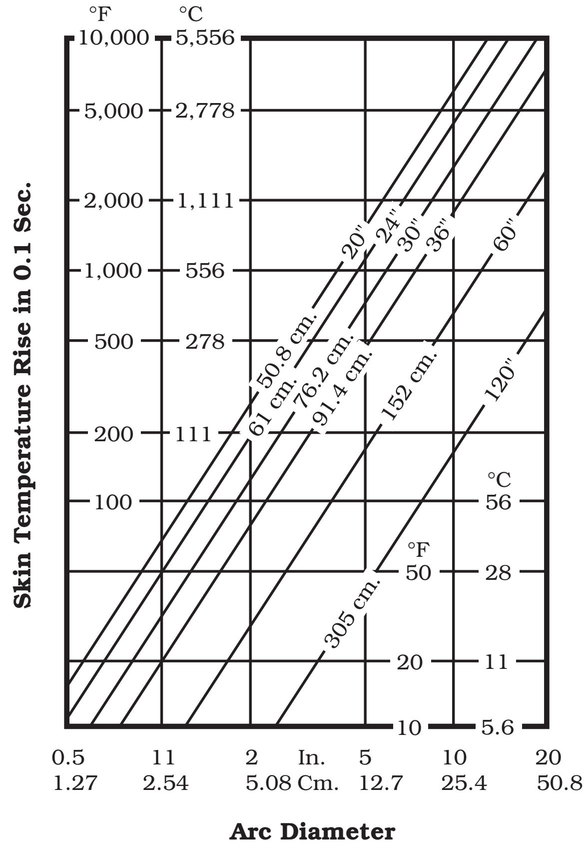
Arc Power MW	Surface Area Sq. In.	Sphere Dia.	
		In.	cm.
0.25	0.415	0.363	0.922
0.5	0.829	0.514	1.308
1.0	1.65	0.725	1.84
2.5	4.15	1.14	2.90
5.0	8.29	1.62	4.11
7.5	12.44	1.99	5.05
12.5	20.73	2.57	6.55
25	41.46	3.63	9.22
50	82.92	5.14	13.06
75	124.38	6.29	15.98
100	165.84	7.27	18.47
150	248.76	8.88	22.56
250	414.60	11.49	29.18
500	829.20	16.1	40.89

Table III
Temperature Rise in Skin in 0.1 Sec.

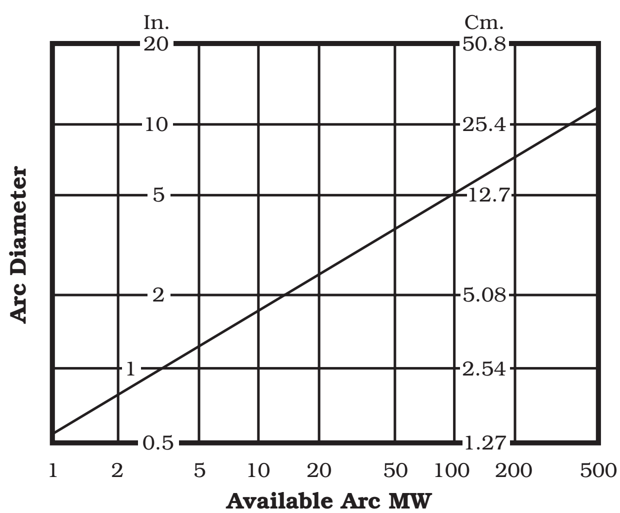
Arc Sphere Diameter		Distance from Center					
In.	cm	20" 50.8 cm	24" 61	30" 76.2	36" 91.4	60" 152	120" 305 cm
1	2.54	34°C 63°F	24 43	15 27	11 19	4 7	1°C 2°F
2	5.08	138°C 249°F	96 173	61 111	43 77	16 28	4°C 7°F
3	7.62	310°C 557°F	215 387	138 248	96 172	34 62	9°C 16°F
4	10.2	549°C 988°F	381 686	244 439	170 305	61 110	15°C 28°F
6	15.2	1230°C 2214°F	854 1537	547 983	380 633	137 245	34°C 62°F
8	20.3	2196°C 3953°F	1525 2745	976 1756	678 1220	244 439	61°C 110°F
10	25.4	3425°C 6167°F	2379 4282	1523 2739	1058 1903	381 695	95°C 172°F
12	30.5	4941°C 8894°F	3431 6176	2196 3951	1526 2745	549 987	137°C 248°F
16	40.6	8740°C 15733°F	6069 10925	3885 6989	2699 4840	971 1745	242°C 439°F



Curve 1
Bolted Fault Amperes, Rms



Curve 3
Skin Temp. Rise in 0.1 Sec.
for Various Distances



Curve 2
Arc Diameter Determination

It has been found that condition 2, where the arc voltage drop equals the supply system drop, yields the maximum arc wattage condition. Here, the arc voltage drop is 70.7% of the supply voltage, and the current is 70.7% of the bolted fault level. These are in phase, so the product is pure power, even though the system power factor is 45° lagging at the time, due to the supply system impedance of 0 pf. Under these conditions the maximum arc wattage is 0.707^2 of 0.5 times the maximum kVA bolted fault capability of the system at that point.

Thus, it may be seen that the maximum arc energy in watts is 0.5 times the maximum bolted fault VA at a given point. There will be lower arc energies than this, but there is no way to predict them. Just as in shock hazard, one must base arc blast hazard possibility on the maximum possible conditions. So a judgement on the wattage of a possible arc will be the system voltage times one-half the maximum bolted fault current. Our hazard possibility then, is readily calculable for the complete range of system voltages and available bolted fault currents, determining the arc wattage, the size sphere this represents, and the temperature rise per unit time in a unit surface at the full range of distances from the arc. These calculations have been carried out in preparation of Tables I, II, and III, and Curves 1, 2, and 3. These do not take into account the heat which is reflected from the flesh, as dependent on the coefficient of absorption of skin. When white skin is light-colored and clean, this absorption coefficient is about 0.5, but when it is dirty or dark, the coefficient is nearly unity. Also, the calculations do not take into account heat reflected from surfaces near the arc; this additional heat from reflection from other surfaces plus the likelihood that the skin may be dirty or dark is the reason for omitting this factor.

This reflectance factor is useful in choosing personnel protective equipment; if this equipment is colored very white, it will reflect about 90% of the radiant heat of this nature it is exposed to, so will absorb a much smaller quantity for conduction to the wearer. Note that this is for radiant heat from sources above 3500°K only, however, not the normal flame type heat sources. Even with non-heat-protective clothing, then lighter colors will absorb less heat, and will therefore give more protection.

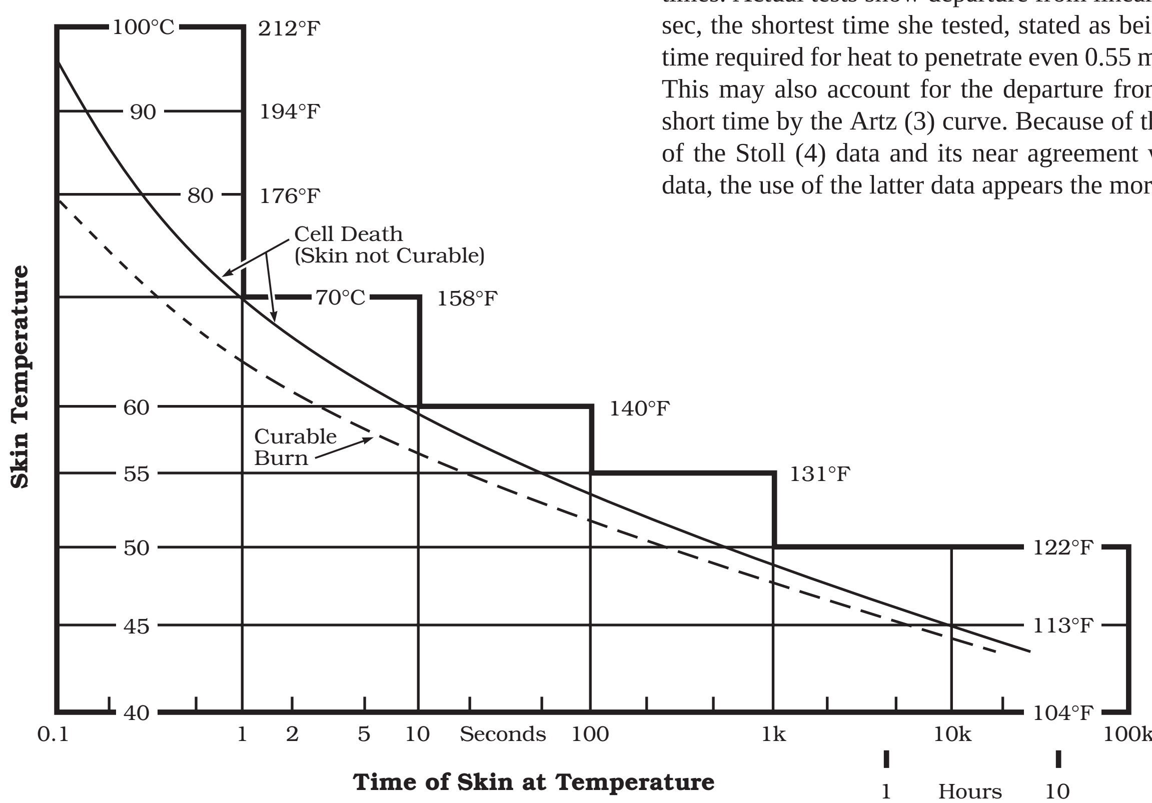
This could also be done without regard to the “Sphere and the Arc” concept and dimension. By considering the total power in the arc to be absorbed by a layer of human epidermis at the respective surface of a sphere at the various radii, the results would be calculable by determining the temperature rise of a hollow sphere of wall thickness of 1/16" (the average skin thickness) and a radius of the respective distances from the center of the source, for the range of arc power being considered.

Effect of Temperature on Human Tissue and Clothing

The human animal can exist in only a relatively narrow range close to normal blood temperature, 97.7°F of 36.5°C. Much below this level requires insulation with clothing, and slightly above this level can be compensated for by perspiration. Artz (3) shows that at as low skin temperature as 44°C, 110°F, the body temperature equilibrium mechanism begins to break down in about six hours, so cell damage can occur beyond six hours at that temperature. Between 44 and 51°C, the rate of cell destruction doubles for each 1°C temperature rise, and above 51°C the rate is extremely rapid. At 70°C, only one second duration is sufficient to cause total cell destruction. Curve 4 shows the relationship between time to cell death and temperature, according to Artz (3). A second, lower line in Curve 4 shows the time-temperature curve of a curable burn. The extrapolation of available data to times below 1 sec indicates that any tissue temperature of 96°C and above for 0.1 second will cause incurable burns.

Stoll (4) agrees quite well in the region from 44 to 50°C, but uses the rate applicable to this interval to extrapolate linearly on log-log scales for higher temperatures and shorter times. Actual tests show departure from linearity at about 6 sec, the shortest time she tested, stated as being due to the time required for heat to penetrate even 0.55 mm or 1/50 in. This may also account for the departure from linearity in short time by the Artz (3) curve. Because of the limitations of the Stoll (4) data and its near agreement with the Artz data, the use of the latter data appears the more reasonable.

Curve 4
Time - Temperature Relationship
Human Tissue Tolerance



So the portion of Curve 3 above 96°C, 205°F represents total destruction of the tissue directly exposed. Re-casting the intercepts of that line back into Curve 1, it is seen that the danger points for 36 in (91 cm) spacing (radius) of the various voltages are:

Table IV
Max Transformer Ratings for Non-fatal
Skin Burn, Various Voltages, 36“ Rad.

Transformer kV	Bolted Fault Cur. Avail.	Std. Transf. Rating, MVA
0.48	40,000 A	1.9
2.4	8,000	1.83
4.2	4,200	1.75
7.2	2,600	1.75
13.2	1,400	1.75
34.5	536	1.75

Table V
Distance-Capacity of Source
for Hazardous Burn at 0.1 Second.

Distance		MVA Rating of Source all Voltages
In	Cm	
20	50.8	0.54
24	61.0	0.78
30	76.2	1.21
36	91.4	1.75
60	152.4	4.86
120	304.8	19.4

The uniformity of capacity rating for the range of voltages is most interesting. It should be remembered that this is applicable to the uniform separation distance of 36", 91.4 cm, and will vary directly with the square of the separation distance ratio to that distance. Normally, the customary spacing varies directly with the voltage of the equipment. One would approach a 480 volt equipment much more closely than one of 34.5 kV. However, the burn hazard is proportional to arc KW (source kVA), so we can interrelate kVA of source with distance at which hazardous burning could occur as in Table V.

Table VI

Critical Burn Distances from Transformer Secondary Lines

Expanding on equations 5 and 7 of the original technical paper, Table V, the reverse of Table IV interrelates transformer MVA rating and distances for just curable and just fatal burns.

Transformer MVA	Distance for Burn From 0.1 Sec. Arc — Just Curable		Just Fatal	
	D_c Ft.	D_c In.	D_f Ft.	D_f In.
0.3	1.01	12.12	0.82	9.8
0.5	1.30	15.6	1.06	12.7
0.75	2.00	23.0	1.63	19.5
1.0	2.30	27.6	1.87	22.5
1.5	2.82	33.8	2.29	27.5
2.0	3.26	39.1	2.65	32
3.0	3.99	48	3.24	39
5.0	5.15	62	4.18	50
10	7.28	87	5.91	71

For times other than 0.1 seconds, the distance should be multiplied by the square root of the ratio of actual time to 0.1 second.

No specific criteria exist for relating D_C to 1° and 2° burns, but distance ratios of 6 and 3 for these two "grades" may be estimated.

Arc Flash Users Guide

This chapter examines the calculation procedures used in the PTW Arc Flash Study.

The Arc Flash Study module follows the guidelines and procedures outlined in the NFPA 70E-2004 and IEEE 1584-2002. It is recommended that you purchase and reference the NFPA 70E and IEEE 1584 Standards prior to performing and interpreting Arc Flash Calculations.

This guide includes:

- Engineering Methodology
- Terminology and Symbols
- Assumptions and Equations
- PTW Applied Methodology
- Examples

TABLE OF CONTENTS

ARC FLASH USERS GUIDE

1.1 Cautions and Disclaimers

This Users Guide outlines methods for conducting an arc-flash hazard analysis. Following the suggestions contained in this guide does not guarantee worker safety from arc flash events. Professional judgment must be used in the development of the system model, interpretation of the results and the selection of adequate PPE.

The information contained herein should be used in conjunction with the IEEE 1584 standard and NFPA 70E guidelines regarding Arc Flash Analysis.

This guide does not imply that work on energized equipment with exposure to live parts is an acceptable practice. OSHA 29 CRF Subpart S.1910.333 limits the situations in which work is performed near energized equipment or circuits.

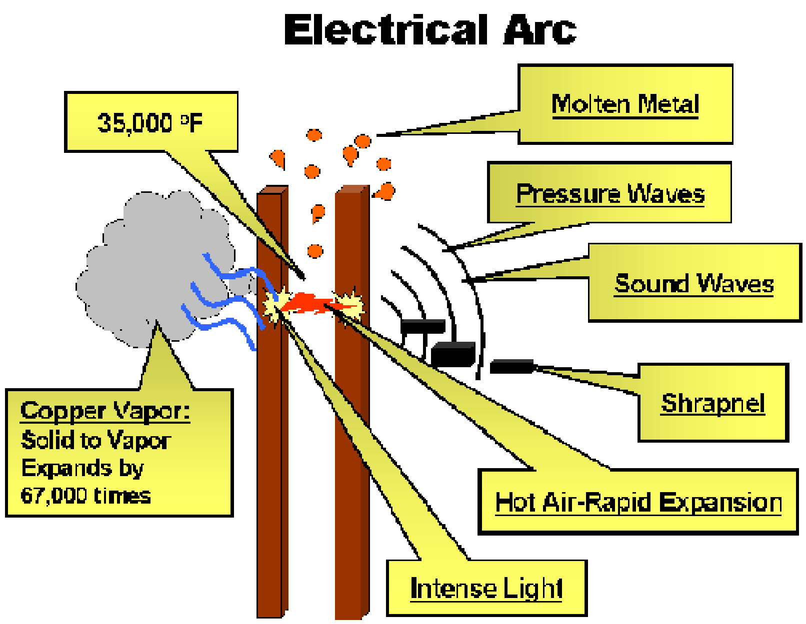
“Live parts to which an employee may be exposed shall be de-energized before the employee works on or near them, unless the employer can demonstrate that de-energizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations.”

Incident Energy is the result of short circuit current and clearing time under arcing fault conditions. Small changes in arcing fault current and trip settings can significantly affect the amount of incident energy.

This guide is based on technical data documented in the IEEE 1584-2002 standard and is intended for use by qualified personnel experienced in power system studies. The equations documented in the IEEE 1584-2002 and referenced in this guide were generated from tests performed at multiple test labs. Differences in environmental conditions between your facility and the test labs may affect the results. These equations may not produce conservative results when applied to your facility. SKM Systems Analysis, Inc. makes no warranty concerning the accuracy or application of the study results.

1.2 What is an Arc Flash Study?

Arc Flash Studies estimate incident energy exposure from potential arc sources. To understand the purpose of an Arc Flash Study, it is important to understand the difference between a traditional fault and an arcing fault. A bolted 3-phase, phase to phase, or phase to ground fault creates high current that flows through the network and the current is contained within the network. Traditional fault studies are used to select equipment that can withstand and interrupt these short circuit currents. Arcing faults occur when the current passes through vapor between two conducting materials. These high-temperature arcs can cause fatal burns even when standing several feet from the arc. The electrical arcs also shower droplets of molten material in the surrounding area, causing further hazard. The arcing fault current is smaller than a traditional bolted fault current because the vapor acts as impedance between the conducting materials.



The PTW Arc Flash Study, herein referred to as Arc Flash, follows the NFPA 70E 2004 and IEEE 1584 2002 methods for determining the arc-flash hazard distance and the incident energy that workers may be exposed to when working on or near electrical equipment. Electrical arc burns account for a large percentage of electrical injuries.

An arc flash study combines short circuit calculations, empirical equations and protective device operating times to estimate incident energy and protective clothing requirements at typical working distances.

1.3 Introduction to Arc Flash Studies

1.3.1 Causes of Electrical Arc Flash Events

- Contact with live parts typically from dropping tools or loose parts.
- Insulation failure
- Over-voltages
- Dust
- Corrosion
- Condensation

1.3.2 Why Perform Arc Flash Studies?

- Prevent worker injury or death
- Avoid litigation expense
- Minimize equipment damage
- Minimize system down time
- Comply with codes and safety regulations (OSHA, NFPA, NEC).
- Insurance requirements

1.4 Engineering Methodology

For Arc Flash calculations, a thorough understanding of the IEEE 1584 standard, fault analysis principles and protective coordination is required.

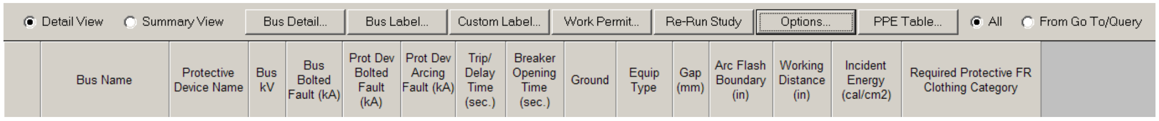
1.4.1 IEEE Standard 1584

The IEEE 1584 standard provides a procedure to determine incident energy to which a worker may be exposed. The equations used in the 1584 standard were developed from tests of arc flash incidents initiated in a lab environment. While it's not feasible to include every combination of environmental factors in the tests, the tests and resulting empirical equations provide the best means of estimating arc flash hazard levels available today. It's still important to understand the limitations of the tests and use engineering judgment when interpreting the calculations. Significant variations in incident energy can result from relatively small changes in the power system model. It's important to understand where these sensitive areas exit and how to make changes that will provide more conservative results. Refer to the IEEE 1584 standard and the following chapters to gain a better understanding of the assumptions, limitations and application guidelines for arc flash analysis.

You should think of Arc Flash calculations as a sensitivity study rather than a single fixed calculation. Since the incident energy is based on a combination fault current and trip time, it is not possible to predict whether a higher fault current or a lower fault current will produce the worst-case incident energy. The arcing fault current is often below the instantaneous trip setting and for these cases a lower fault current will result in a longer trip time and more energy release.

The intent of this guide is to describe how the PTW Arc Flash module calculates and reports the incident energy and flash boundary values, and to understand the terminology and assumptions used in the software. This guide is a supplement and not a substitute for a complete understanding of the IEEE 1584 standard.

1.4.2 Arc Flash Report Definitions



Bus Name
Fault location for bus report. For line side and load side report options the bus refers to the equipment where the line side and load side protective devices are connected.

Protective Device Name
Refers to the protective device that clears the arcing fault or portion of the total arcing fault current.

Bus Bolted Fault Current (kA)
The current flowing to a bus fault that occurs between two or more conductors or bus bars, where the impedance between the conductors is zero.

Protective Device Bolted Fault Current (kA)
The portion of the total bolted fault current, that flows through a given protective device.

Protective Device Arcing Fault Current (kA)
The arcing current flowing through each protective device feeding the electric arc fault. Note that the total arc fault current may flow through several parallel sources to the arc location.

Trip / Delay Time
The time required for the protective device to operate for the given fault condition. In the case of a relay, the breaker opening time is entered separately from the relay trip time. For low voltage breakers and fuses, the trip time is assumed to be the total clearing curve or high tolerance of the published trip curve.

Breaker Opening Time
The time required for a breaker to open after receiving a signal from the trip unit to operate. The combination of the Trip/Delay time and the Breaker Opening time determines the total time required to clear the fault. For low voltage circuit breakers, the total clearing time displayed on the Manufacturer’s drawing is assumed to include the breaker opening time.

Ground
Indicates whether the fault location includes a path to ground. Systems with high-resistance grounds are assumed to be ungrounded in the Arc Flash calculations.

In Box
Identifies whether the fault location is in an enclosure or in open air. In open air the arc energy will radiate in all directions whereas an enclosure will focus the energy toward the enclosure opening. The In Box / Air selection is available when the NFPA 70E study option is selected. For the IEEE 1584 study selection the In Box or In Air is determined automatically from the Equipment Type specification.

Equipment Type
Used only in the IEEE 1584 method to indicate whether the equipment is Switchgear, Panel, Cable or Open Air. The equipment type provides a default Gap value and a distance exponent used in the IEEE incident energy equations.

Gap
Defines the spacing between bus bars or conductors at the arc location.

Arc Flash Boundary
The distance from exposed live parts within which a person could receive a 2nd degree burn.

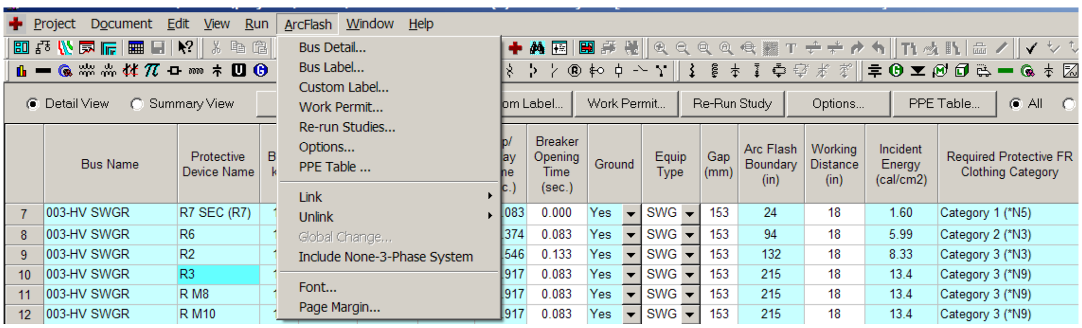
Working Distance
The distance between the arc source and the worker’s face or chest

Incident Energy
The amount of energy on a surface at a specific distance from a flash

Required Protective FR Clothing Class (PPE)
Indicates the Personal Protective Equipment (PPE) required to prevent an incurable burn at the working distance during an arcing fault.

1.4.3 Arc Flash Menu Options

The Arc Flash study module has several menu options. With the Arc Flash application window active, the following menu items are available:



Bus Label	The Bus Label provides a summary of the flash boundary, incident energy and PPE classification at each bus. The NFPA shock hazard Limited, Restricted and Prohibited Approach boundaries are also listed based on the nominal system voltage at the bus.
Bus Detail	Generates a detailed label including the protective device settings, arcing fault current, incident energy at multiple working distances, and clothing class for the primary working distance. You can also enter the client information and job #, etc. Bus Detail can be used on a single bus or for a selected group of buses. The description information entered will be re-used for all buses.
Work Permit	Generates a work permit required for working on energized equipment per NFPA 70E 2004.
Re-run Studies	Refreshes the Arc Flash display to reflect updated short circuit values caused by system changes made since the last arc flash study was run.
Options	Displays Option menu for Arc Flash Study
PPE Table	Displays PPE Table where Personal Protective Equipment descriptions are assigned to ranges of incident energy. The PPE classes, descriptions and label color for each class are user-definable.
Link/Unlink with Fault Study	You can highlight a bus or multiple buses from the Arc Flash table and select the Unlink with Fault Study option to allow you to enter user-defined values for bolted fault current. Remember to re-link the rows if you want fault currents to be updated from the project database.
Link/Unlink with TCC	You can highlight a bus or multiple buses from the Arc Flash table and select the Unlink with TCC option to allow you to enter user-defined Trip Times for the protective device. Remember to re-link the rows if you want the trip times to be updated from the project database.

Link/Unlink with Ground	You can highlight a bus or multiple buses from the Arc Flash table and select the Unlink Ground option to allow you to enter “yes” or “no” in Ground column.
Link/Unlink Gap	You can highlight a bus or multiple buses from the Arc Flash table and select the Unlink Gap option to allow you to enter user-defined values for Gap.
Link/Unlink Equipment Type	You can highlight a bus or multiple buses from the Arc Flash table and select the Unlink Equipment Type option to allow you to select your own equipment type from the list.
Link/Unlink Working Distance	You can highlight a bus or multiple buses from the Arc Flash table and select the working distance to allow you to enter user-defined values for working distance.
Global Change	You can highlight column or a group of fields in a column and select the Global Change option to change all selected entries to a new value. A sample use is to change the working distance from one value to another for a group of buses. Note that white fields are editable and cyan/blue fields are linked or calculated fields that are not editable.
Font, Page Margin	You can change font, page margin, and page number display for printing. You can also print or preview the results.
Include non 3-phase system	Includes non 3-phase system buses to the Arc Flash display and report

The same menu items are available by clicking the Right Mouse button.

1.4.4 Arc Flash Study Procedure

The Arc Flash study requires an accurate short circuit and coordination study for the different modes in which the system may operate.

The general arc flash study procedure outlined in the IEEE 1584 standard includes:

1. Collect field data sufficient to perform a short-circuit and coordination study.
2. Identify the possible system operating modes including tie-breaker positions, parallel generation, etc.
3. Calculate the bolted fault current at each fault location.
4. Calculate the arcing fault current flowing through each branch for each fault location.
5. Determine the time required to clear the arcing fault current using the protective device settings and associated trip curves.
6. Select the working distances based on system voltage and equipment class.
7. Calculate the incident energy at each fault location.
8. Calculate the flash protection boundary at each fault location.

1.4.5 Arc Flash Modeling Assumptions

It’s important to understand the assumptions made by the PTW Arc Flash module.

The following assumptions are applied

- Arc Flash searches the entire system topology, starting from the faulted bus out, to find the first protective device with an over-current trip curve. When the first device is located, the search is discontinued (i.e. assumes coordination with upstream branches). The next upstream protective device may be included in the search by selecting the “Check upstream devices for mis-coordination” option. If there are multiple contributions to the faulted bus, the search process will be repeated until each contribution is cleared by it’s protective device, or the search reaches the end of the topology. Protection functions with a name of “Ground”, “Earth”, or “AF_EX” will be excluded from the protective device search and the next upstream device is used instead. Upstream refers to the flow of power from the primary sources of power to the faulted location from the perspective of standing at the fault location.

- The trip time is determined for all protective devices located in the branch that contains the first trip device and the device with the fastest trip time for the given arcing fault current is used.

- Worker is stationary during the entire arc flash incident (constant working distance).

- Induction motors contribute continuous sub-transient current until removed at user specified time ‘x’, unless they are specifically excluded from the arc flash study.

- When applying generic current-limiting fuse representation, the current-limiting range is assumed to start where fuse clearing curve drops below 0.01 sec.

- When applying generic current-limiting fuse representation, fuses operating in the current limiting range are assumed to clear in ½ cycle for currents 1 to 2 times the current where the current-limiting range begins, and ¼ cycle for currents higher than 2 times the current where the current-limiting range begins.

- Interrupting device is rated for the available short circuit current (no equipment damage is considered).

- Upstream branch devices are properly coordinated with downstream branch devices. The next upstream protective device may be included in the search by selecting the "Check upstream devices for mis-coordination" option. The device that clears the arcing fault fastest is used.

- Ground fault and motor over load devices are not included.

- For multi-function protective devices, only the first f unction is used to determine the trip time.

- Reports only the larger incident energy based on low or high tolerances applied to the calculated arcing fault current.

- When the total fault current cleared is less than the threshold percent specified in the study setup, or no protective device is found, the bus is labeled as Dangerous and the incident energy and flash boundary are not reported.

- If the trip time obtained from the time current curve is larger than the maximum protection trip time defined in the study setup, the maximum protection trip time is used.

1.4.6 Arc Flash Equations

IEEE 1584 Standard – 2002

Arcing Fault Current at the bus (I_a) and through each protective device ($I_{a\ br}$) for bus voltages less than 1 kV and bolted fault current between 700Amps and 106,000 Amps.

$$lg\ (I_a) = K + 0.662\ lg\ (I_B) + 0.0966\ V + 0.000526\ G + 0.5588\ V\ lg\ (I_B) - 0.00304\ G\ lg\ (I_B)$$

lg	*is* log_{10}
Ia	is arcing fault current at the bus in kA
K	*is -0.153 for open configuration and*
	is -0.097 for box configuration
I_B	*is bolted fault current – 3phase sym rms kA at the bus*
V	*is bus voltage in kV*
G	*is bus bar gap between conductors in mm*

Arcing Fault Current at the bus (I_a) and through each protective device ($I_{a\ br}$) for bus voltages greater than or equal to 1 kV and bolted fault current between 700Amps and 106,000 Amps.

$$lg\ (I_a) = 0.00402 + 0.983\ lg\ (I_B)$$

Therefore, $I_a = 10^{\ lg\ (Ia)}$

$I_{a\ br} = I_a * I_{B\ br} / I_B$

$I_{B\ br}$ is the Bolted Fault Current through each protective device in kA.
$I_{a\ br}$ is the arcing fault current through each protective device in kA.

*Note: For IEEE 1584-2002 - Section 5.2, a second arcing fault current is calculated at 85% of the original. The Trip Time and Incident Energy at both the 85% and 100% arcing fault currents are calculated and the larger of the two Incident Energy values is displayed with the associated Trip Time. PTW allows a user-defined arc fault tolerance. The default tolerance is -15% as described in the IEEE 1584 - 2002 standard. For additional information refer to section 1.5.10.

Normalized Incident Energy

$$lg\ (En) = K1 + K2 + 1.081\ lg\ (Ia) + 0.0011\ G$$

En *is incident energy (J/cm2) normalized for a arcing duration of 0.2s and working distance of 610mm*

K1 *is -0.792 for open configuration and*
is -0.555 for box configuration (switchgear, panel, cable)

K2 *is 0 for ungrounded and high resistance grounded systems and*
is -0.113 for grounded systems

G *is the gap between bus bar conductors in mm*

solve $En = 10 \wedge lg\ En$

Incident Energy converted from normalized:

E = 4.184 Cf En (t/0.2) (610^X / D^X)

E	*is incident energy (J/cm2)*
Cf	*is 1.0 for voltage above 1 kV and*
	is 1.5 for voltage at or below 1 kV
t	*is arcing duration in seconds*
D	*is the working distance in mm*
x	*is the distance exponent*

Default distance exponent x based on the voltage level and equipment type

x	*Equipment Type*	*kV*
1.473	*Switchgear*	*≤ 1*
1.641	*Panel*	*≤ 1*
0.973	*Switchgear*	*> 1*
2	*all others*	

Arc Flash Boundary (DB)

DB = [4.184 Cf En (t/0.2) (610^X / EB)] ^ 1/x

DB	*is the arc flash boundary in mm at incident energy of EB*
EB	*is the limit for a second-degree bare skin burn. EB = 5.0 (J/cm2)*
x	*is the distance exponent*

Default distance exponent x based on the voltage level and equipment type

x	*Equipment Type*	*kV*
1.473	*Switchgear*	*≤ 1*
1.641	*Panel*	*≤ 1*
0.973	*Switchgear*	*> 1*
2	*all others*	

NFPA 70E - 2004

The NFPA 7E – 2004 follows the same procedure as IEEE 1584 – 2002 with the following exceptions:

Flash Protection Boundary for buses less than 600 Volts:

$D_c = [2.65 \text{ x } MVA_{bf} \text{ x } t]^{1/2}$

$D_c = [53 \text{ x } MVA \text{ x } t]^{1/2}$

Where

D_c = distance in feet from an arc source for a second-degree burn

MVA_{bf} = bolted fault capacity available at bus in MVA

MVA = capacity rating of transformer. For transformers less than 0 .75 MVA, multiply the transformer MVA by 1.25.

t = arc exposure in seconds.

Flash Protection Boundary for buses above 600 volts:

for Clearing Time of 0.1 second or less,
calculate boundary distance where incident energy = 1.5 cal/cm2

for Clearing Time longer than 0.1 second,
calculate boundary distance where incident energy = 1.2 cal/cms2

1.4.7 Default Values

Equipment Categories and Gap

Equipment Category contains	Gap (mm)	Equip Type	kV
Switchgear	32	Panel	≤ 1
Cable	13	Cable	≤ 1
Air	32	Open Air	≤ 1
* all others	25	Panel	≤ 1
Cable	13	Cable	1-5
Air	102	Open Air	1-5
* all others	25	Switchgear	1-5
Cable	13	Cable	> 5
Air	153	Open Air	> 5
* all others	153	Switchgear	> 5

Working Distances

Default the working distance based on the voltage level and equipment type

Working Distance	Equipment Type	kV
24 inches (610mm)	Switchgear	<= 1
18 inches (455mm)	Panel	<=1
36 inches (910mm)	Switchgear	> 1 & < 35
72 inches (1829mm)	Switchgear	> 35
18 inches (455mm)	all others	

1.4.8 Determination of Grounded/Ungrounded Bus

The PTW Arc Flash study performs a calculation for both 3 phase and single-line-to-earth faults. The single-line-to-earth fault is only used to determine whether the bus should be considered as grounded or ungrounded. Since the IEEE 1584 standard includes resistance grounded conditions as ungrounded, the PTW arc flash module compares the single-line-to-earth value with the three-phase value to determine the grounded/ungrounded state. If the single-line-to-earth fault value is less than 5% of the three-phase value, the fault bus is considered to be ungrounded. The 5% threshold is a default value that can be adjusted.

1.4.9 Relationship Between 3-Phase Fault and Arcing Fault

The equations used to calculate the magnitude of an arcing fault are relative to the available 3-phase bolted fault current. Single-line to ground and line-to-line faults are not directly considered when calculating arcing fault or incident energy. While it’s recognized that many arcing faults are initiated by a line to ground fault, the arc flash equations in the IEEE 1584 standard are relative to the available bolted-3-phase fault current for the following reasons:

a) 3-phase faults give the highest possible short circuit energy in AC equipment.
b) Arcing faults that begin as line-to-line or line-to-ground faults quickly escalate into 3-phase faults as the air ionizes across the phases. The high-speed video photography of arc flash tests show the arc rotating between the phases and the metal box. The tests were performed on grounded and ungrounded systems and the arc fault equation includes a grounded/ungrounded variable.

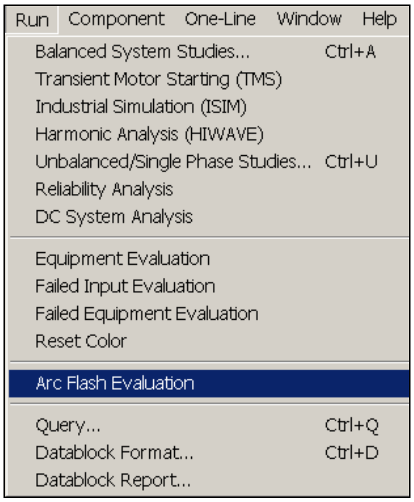
1.5 PTW Applied Methodology

1.5.1 Running the Arc Flash Study

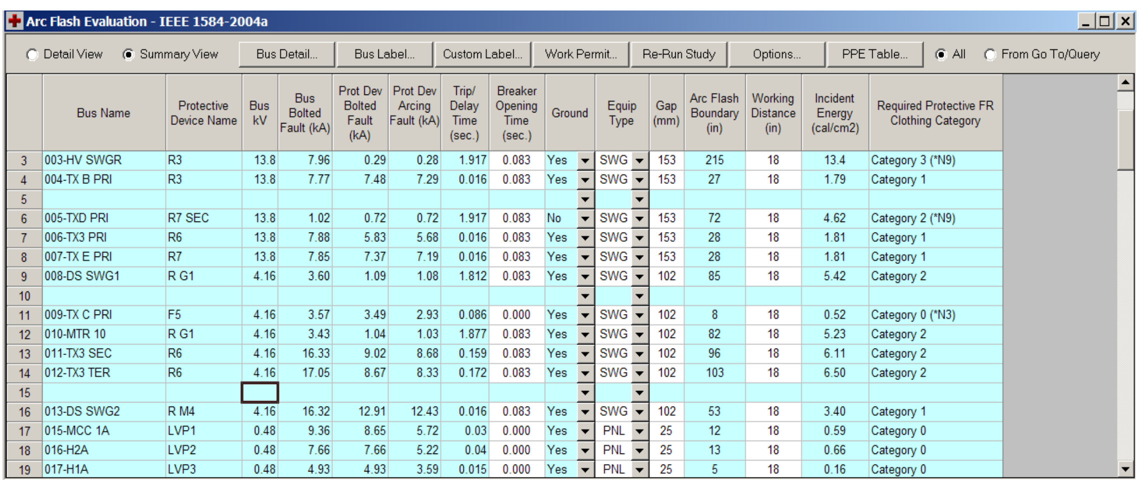
You can run the Study from any screen in PTW, and it always runs on the active project.

To run the Arc Flash Study

1. From the Run menu, choose Arc Flash Evaluation.



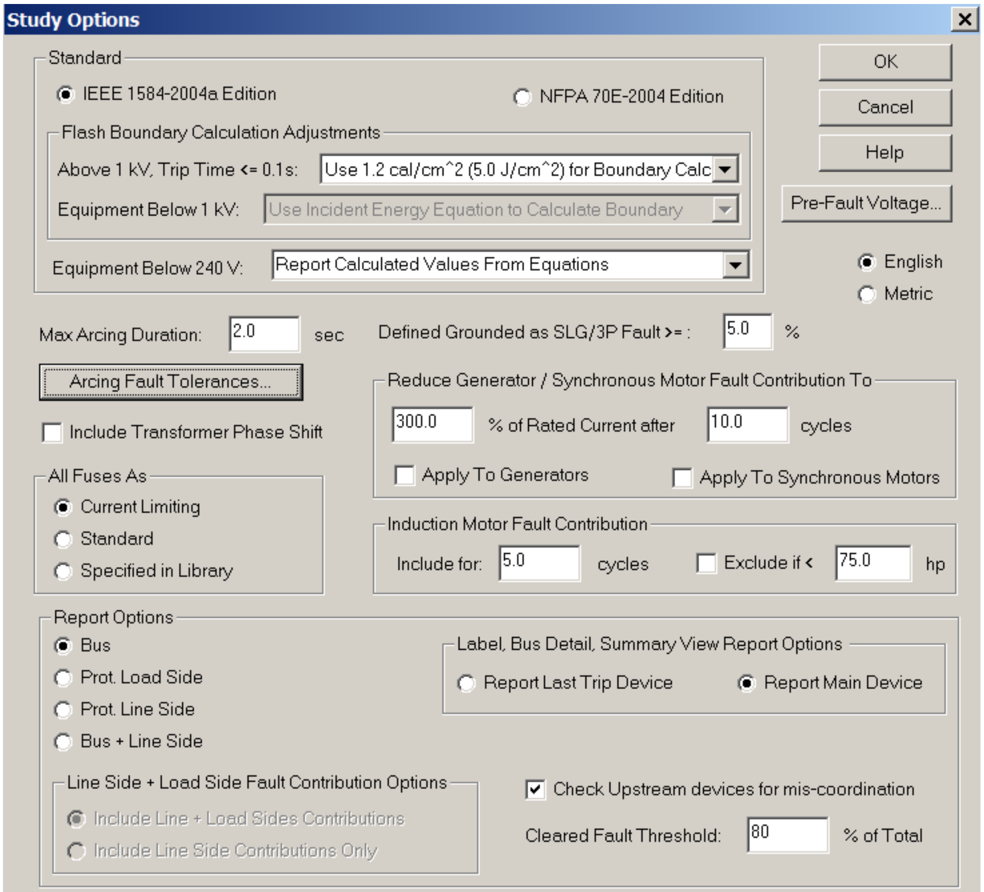
The Arc Flash Study produces a display that lists each bus in the system, protective devices that clear the arcing fault, trip times, incident energy, flash boundary and PPE clothing class.



	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Category
3	003-HV SWGR	R3	13.8	7.96	0.29	0.28	1.917	0.083	Yes	SWG	153	215	18	13.4	Category 3 (*N9)
4	004-TX B PRI	R3	13.8	7.77	7.48	7.29	0.016	0.083	Yes	SWG	153	27	18	1.79	Category 1
5															
6	005-TXD PRI	R7 SEC	13.8	1.02	0.72	0.72	1.917	0.083	No	SWG	153	72	18	4.62	Category 2 (*N9)
7	006-TX3 PRI	R6	13.8	7.88	5.83	5.68	0.016	0.083	Yes	SWG	153	28	18	1.81	Category 1
8	007-TX E PRI	R7	13.8	7.85	7.37	7.19	0.016	0.083	Yes	SWG	153	28	18	1.81	Category 1
9	008-DS SWG1	R G1	4.16	3.60	1.09	1.08	1.812	0.083	Yes	SWG	102	85	18	5.42	Category 2
10															
11	009-TX C PRI	F5	4.16	3.57	3.49	2.93	0.086	0.000	Yes	SWG	102	8	18	0.52	Category 0 (*N3)
12	010-MTR 10	R G1	4.16	3.43	1.04	1.03	1.877	0.083	Yes	SWG	102	82	18	5.23	Category 2
13	011-TX3 SEC	R6	4.16	16.33	9.02	8.68	0.159	0.083	Yes	SWG	102	96	18	6.11	Category 2
14	012-TX3 TER	R6	4.16	17.05	8.67	8.33	0.172	0.083	Yes	SWG	102	103	18	6.50	Category 2
15															
16	013-DS SWG2	R M4	4.16	16.32	12.91	12.43	0.016	0.083	Yes	SWG	102	53	18	3.40	Category 1
17	015-MCC 1A	LVP1	0.48	9.36	8.65	5.72	0.03	0.000	Yes	PNL	25	12	18	0.59	Category 0
18	016-H2A	LVP2	0.48	7.66	7.66	5.22	0.04	0.000	Yes	PNL	25	13	18	0.66	Category 0
19	017-H1A	LVP3	0.48	4.93	4.93	3.59	0.015	0.000	Yes	PNL	25	5	18	0.16	Category 0

1.5.2 Arc Flash Study Options

The Arc Flash Options dialog box lets you select options for running the Study.



Following is a list of the available Study options.

Standard allows the choice of NFPA 70E or IEEE 1584 methods. If NFPA 70E method is selected, the equations published in NFPA 70E – 2004 Annex D.6 will be used to calculate the incident energy and flash boundary. If the IEEE 1584 method is selected, the equations published in the IEEE 1584 2002 and NFPA 70E – 2004 Annex D.8 will be used to calculate the arcing fault current, incident energy, and flash boundary. The IEEE 1584 method is based on more recent and expanded test data, and is the preferred method. Since IEEE 1584 method is also part of the NFPA 70E 2004, using the IEEE 1584 method could be considered as comply with NFPA 70E as well.

Flash Boundary Calculation Adjustments - The Flash Boundary is normally calculated by setting the incident energy to 1.2 cal/cm^2 and use the incident energy equation to reverse calculate the flash boundary. An option to use 1.5 cal/cm^2 for equipments above 1 kV and trip time < 0.1 seconds is provided here. This is recommended by NFPA 70E – 2004.

An option to use equation: sqrt (2.65 * 3-Phase MVA * t) to calculate the flash boundary when the voltage level is equal or below 1 kV is also provided. Refer to NFPA 70E – 2004 Article 130.3 for more detail.

Equipment Below 240 Volts Options:

- Report as Category 0 if Bolted Fault Current < 10 kA, recommended by NFPA 70E – 2004.
- Report as Category 0 if Transformer Size < 125 kVA, recommended by IEEE 1584 – 2002.
- Report as Category 0 if < 10 kA and TX Size < 125 kVA.
- Report Calculated Values From Equations.

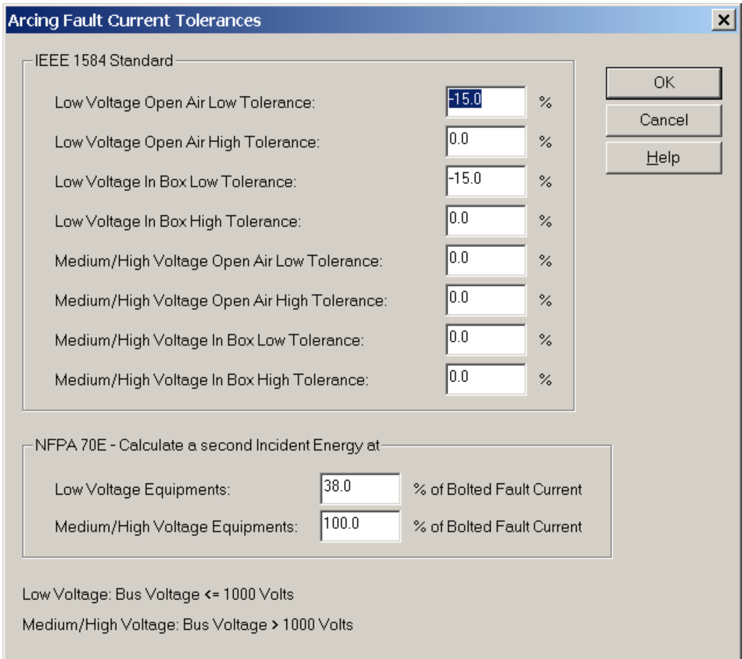
If option 1, 2, or 3 is selected, and the calculated incident energy is smaller than 1.2 cal/cm^2, the calculated value will be reported and used to calculate the flash boundary.

English or Metric Units – For both NFPA 70E - 2004 and IEEE 1584 - 2002 standards, we allow the choice of English or Metric units. For English units the distances are expressed in Inches and energy values are expressed in Calories/cm^2. For metric units the distances re expressed in mm and energy values are expressed in Joules/cm^2.

Maximum Arcing Duration allows you to specify a maximum (Trip Time + Breaker Time) for the incident energy and flash boundary calculations. IEEE 1584 Annex B.1.2 stated that *"If the time is longer than two seconds, consider how long a person is likely to remain in the location of the arc flash. It is likely that the person exposed to arc flash will move away quickly if it is physically possible and two seconds is a reasonable maximum time for calculations. A person in a bucket truck or a person who has crawled into equipment will need more time to move away."*

The default for the Maximum Arcing Duration in PTW is set to 2 seconds, if the Trip Time read from the TCC plus the Breaker Time is bigger than the Maximum Arcing Duration, the Trip Time will be set to the Maximum Arcing Duration – Breaker Time.
Sound engineering judgment is always required when making reasonable arc flash energy estimates.

Arcing Fault Tolerances… - For the IEEE 1584 standard, specify a low and high tolerance for arcing fault current calculations. For example, enter a –15% low and +10% high tolerances means the program will calculate two incident energies one at 0.85* arcing fault current, and another at 1.1* arcing fault current. For the NFPA 70E standard, specify the percentage of bolted fault current used to calculate the second incident energy. For example, enter a 38% bolted fault current means the program will calculate two incident energies one at 100% of the bolted fault current and another at 38% of the bolted fault current.



The arcing fault current magnitude is a function of the voltage and arc impedance. Since a small change in arcing fault current can produce substantially different trip times and incident energy, it is prudent to account for arcing fault current variability through reasonable tolerances. The IEEE 1584 standard uses a 15% low tolerance for arcing fault current calculations, and the NFPA 70E suggests using a 38% bolted fault current. The incident energy is calculated at the low and high tolerance specified and the largest incident energy is reported. For cases where both the low and high tolerance values result in the same trip time, the high tolerance will always produce the highest incident energy. For cases where the low tolerance results in longer trip times, which is often the case, the incident energy is typically higher at the longer trip time. In the arc flash table, the value is labeled with (*3) when the low tolerance arc fault value is used

Defined Ground as SLG/3P Fault in % - enter the single line to ground fault current / 3-phase fault current at the bus in percentage. If the calculated SLG / 3P fault current at the bus is higher than the value specified by the user, the bus is considered grounded. IEEE 1584 recommended different incident energy equation parameters based on whether a bus is grounded or not.

All Fuses as Current Limiting, Standard Fuses, or Specified in Library -- When Standard Fuses are selected, the arc duration is read from the total clearing curve at the arcing fault current. When Current Limiting Fuses are assumed, arc duration is reduced when the arc current is within the current-limiting range. The user can alternatively specify fuses as current limiting in the protective device library by checking the check box "Current Limiting, Use Manufacturer's Equipment-specific Incident Energy Equations" in the Device page. If the manufacturer's equations are entered in the Arc Flash page, PTW will use these equations instead of the standard incident energy equations from the IEEE 1584 or NFPA 70E. If no manufacturer's equipment-specific equations are entered or could be matched with the cartridge and bolted fault current range, the fuse will be treated as a current limiting fuse without using the manufacturer's equations.

If the check box "Current Limiting…" check box in the library is unchecked and the "Specified in Library" option is selected, the fuses will be treated as standard fuses without having the current limiting feature.

For breakers, manufacturers could also provide equipment-specific equations to represent faster trip time when the fault current reach a certain level, but they are not current limiting in natural.

For all current limiting fuses and breakers, if the trip time of the TCC clearing curve at the branch arcing fault current is less than ½ cycles, and the curve is defined below 0.01 seconds, the defined clearing time is used. Otherwise, the arcing fault current (I_a) is compared to the current (I_L) where the total clearing curve drops below 0.01 seconds, and the trip time is based on the following table:

Trip/Delay Time	Condition
Read from clearing curve	$I_a < I_L$
1/2 cycle	$I_L \leq I_a \leq 2\, I_L$
1/4 cycle	$I_a > 2\, I_L$

For fuses with only the average melting time curve available, and the time read from the average melting curve at the arcing fault current Trips less or equate to 0.03 seconds, add 15% to Tr. If Tr is above 0.03 seconds, add 10% to determine the total clearing time. If the arcing fault current is above the total clearing time at the bottom of the curve (0.01 seconds), use 0.01 seconds for the time. (IEEE_P1584/D10 4.6 Step5)

The protective device library alternatively allows you to enter current limiting equations for fuses at each bolted fault current range. Arc Flash uses these equations to calculate the Incident Energy and Flash Boundary instead of the standard IEEE1584 equations.

Equipment-Specific Incident Energy Equations on the Arc Flash Tab - If manufacturers of low voltage breakers have their equipment-specific incident energy equations published, these equations can be entered in the Arc Flash tab of the Protective Device Library. The user must check the "Use Equipment-Specific Incident Energy Equations on the Arc Flash Tab" check box in order for the equations to be used in the Arc Flash calculations.

If the "Use Equipment-Specific Incident Energy Equations on the Arc Flash Tab" check box is checked, but no equation on the Arc Flash tab has a bolted fault current range that covers the calculated bolted fault current through the device, the Equipment-Specific equation will not be used. Instead, the device will be treated as current limiting a the following way:

If the trip time of the TCC clearing curve at the branch arcing fault current is less than ½ cycles and the curve is defined below 0.01 seconds, the defined clearing time is used. Otherwise, the arcing fault current (Ia) is compared to the current (IL) where the total clearing curve drops below 0.01 seconds, and the trip time is based on the following table:

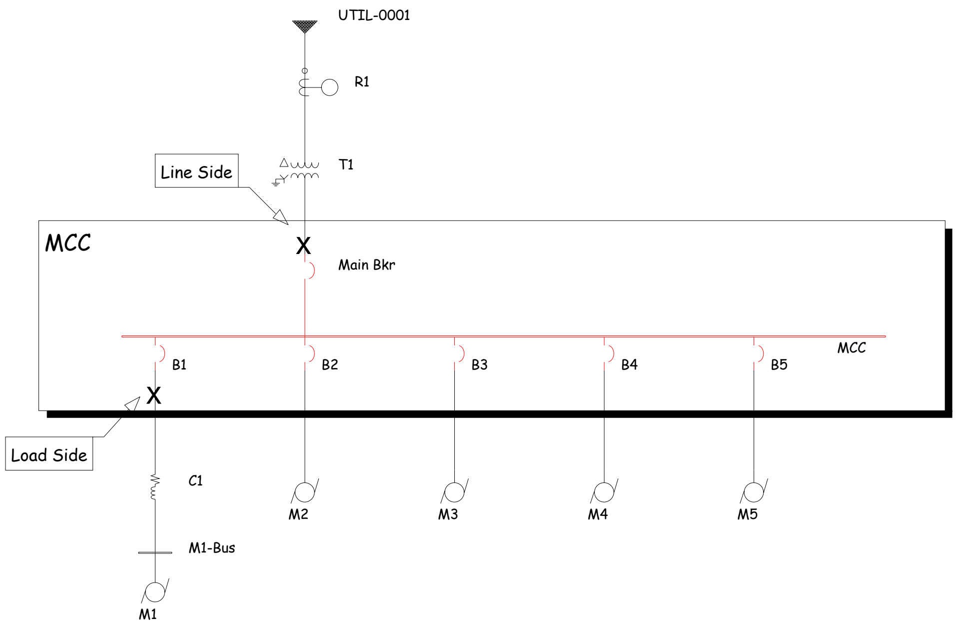
Trip/Delay Time	Condition
Read from clearing curve	$I_a < I_L$
1/2 cycle	$I_L \leq I_a \leq 2\, I_L$
1/4 cycle	$I_a > 2\, I_L$

Reduce Generator / Synchronous Motor Fault Contribution To – Generators and synchronous motors do not supply the same amount of fault current after a certain number of cycles following the fault. For example, the fault current may be reduced from the initial 1000% of the Rated Current (10 per unit) to 300% after 10 cycles. Enter the percentage of the Rated Current and the number of cycles after which to reduce the fault current to. PTW assumes a step change from the initial fault current to the reduced value and incident energy will be calculated using the initial fault current and the number of cycles specified, then accumulated with rest of the incident energy calculated using the reduced fault current and the duration at which the protective device trips. The Apply To Generator check box controls whether the reduction of contribution should be applied to generators. If unchecked, generator contribution will be the same as the initial fault for the entire arcing duration. Similarly, the Apply To Synchronous Motors check box controls whether synchronous motor contribution should be reduced after the number of cycles.

Induction Motor Fault Contribution – Specify the number of cycles to include the induction motor contributions. PTW assumes a step change from the initial fault current with induction motor contributions to the reduced fault current without induction motor contributions. To include induction motors all the time, enter a large value as the cycles. To ignores all induction motor fault contributions from the arcing fault current and the incident energy calculations, enter 0 cycles. You can enter a specific induction motor hp size and check or uncheck the Exclude if <??? hp independently to exclude motors less than the given hp.

Report Option

Three different report options are available. The report options are named Bus, Protective Load Side, and Protective Line Side. The Bus report is the normal selection however the load side and line side reports may be useful in specific situations. Refer to the following diagram and descriptions.



- **Bus option** – The bus report assumes that the fault occurs at the equipment bus. If the bus has multiple contributions, the devices that trip each branch contribution will be listed in the order they trip, and incident energy will be accumulated until a significant percentage of the fault current has tripped. The significant portion is defined by the "Cleared Fault Threshold" percentage you specify.

- **Protective Device Load Side option** – The load side report applies a fault at the load side (To End) of each protective device whose line side (From End) is connected directly to a bus without having an impedance device between the bus and the protective device. The protective device being evaluated is the one that clears the fault. The fault current through the device will be used to calculate the arcing fault current and obtain the trip time from the TCC. You can then select to include Line + Load Sides Contributions (to represent both ends hot) in calculating the incident energy, or to include Line Side Contributions only in which case the load side contributions are not included (now working as if the load side is disconnected).

- **Protective Device Line Side option** – The line side report applies a fault at the line side (From End) of each protective device whose load side (To End) is connected directly to a bus without having an impedance device between the bus and the protective device. You can then selected to include Line + Load Sides Contributions or to include Line Side Contributions only. The first case represent both ends hot, this occur if the main breaker failed to open, and the next upstream device is the one that must clear the fault. If there is more than one contribution when there is a fault at the line side, incident energy will be accumulated up to the fault contribution percentage specified. If Line Side Contributions Only is selected, the load side contributions are not included and it is now working as if the load side is disconnected.

  Note: In the above discussion of Load Side (To End) and Line Side (From End),we assumed that the power flows from the From End to the To End. If the direction of power is opposite to our assumption, the devices that would be listed in the Load Side report under normal power flow direction will be listed in the Line Side report instead.

- **Bus + Line Side option** – This option combines the bus report option and the line side report option into one report. Calculated result for the bus and line side will be listed next to each other for easier comparison of worse case scenario. A special custom label is supplied by PTW to put both bus and line side results in one single label.

- **Report Last Trip Device vs. Report Main Device –** The last device is the one after whose tripping, the percentage of fault current cleared reaches the Cleared Fault Threshold; The main device is the one that carries the biggest percentage of the fault current contribute to the bus. This option is applicable for the Bus Report option only and it affects the device reported in the Summary View, Bus Detail and Bus Label.

Check Upstream devices for mis-coordination, evaluates trip times for backup protective devices beyond the branch containing the first protective device. Two conditions must be satisfied for the upstream backup protective device to be reported instead of the immediate protective device:

Condition 1: The immediate protective device must carry 5% or more of the Cleared Fault Threshold value (default as 80%) multiplied by the total bus fault current.

Condition 2: The upstream backup protective device must trip faster and carry a fault current that is bigger or equal to the Cleared Fault Threshold value multiplied by the fault current through the immediate device.

Upstream mis-coordination is checked by branch, all devices within the branch containing the immediate protective device will be evaluated and the fastest one will be used to compare with the fastest device in the upstream branch. If the first valid protective device is found in an upstream branch and the trip time is slower than the immediate device, the search stops there and the immediate device will be reported.

The definition of a valid device is one with a trip curve that is not a Ground Fault type and the protection function name does not include "Ground", "Earth", "Neutral" or "AF_EX".

If the upstream mis-coordination is not checked, all devices within the branch containing the first protective device will still be evaluated, and the one with the fastest trip time will be used in the Arc Flash calculation.

Cleared Fault Threshold determines the portion of the Total Arcing Fault current at the Bus that needs to be interrupted by protective devices to extinguish the arc. Therefore the remaining portion of Arcing Fault current, if any, can not sustain the arc and will not be considered in the accumulated incident energy. Enter a value in percent of the total bus fault current, the default value is 80%, which means that the final arc fault trip time is based on when 80% or more of the total fault current at the bus has been cleared. In the Summary View, the last device to trip that reaches the cleared fault threshold is the only protective device that will be listed under the bus, and the data from the device will be used in the Bus Detail report and Bus Label. The cleared fault threshold value is also used to determine which branches are searched for mis-coordination.

There isn't any recommendation in the NFPA or IEEE1584 for the "Fault Clear Threshold". But the assumption comes from the fact that when certain percentage of fault (like 80%) is interrupted by the protective devices then the remaining bolted/arcing fault percentage/current can not sustain the arc and naturally can not be added to the accumulated energy. Since the last 5% - 15% of the contribution may take a very long time to trip (a small current takes a long delay time), then it is not practical to accumulate the energy up to 100%, because the calculated incident energy would be much bigger than reality. If the user is setting a "Maximum Protection Trip Time" in the Arc Flash Options to a realistic number (2 second for example), then the "Fault Clear Threshold" becomes less of an issue, the user could set it to 100% and we will only accumulate the energy up to 2 seconds anyway.

Pre-Fault Voltage options
Specify the pre-fault voltage options for the short circuit study.

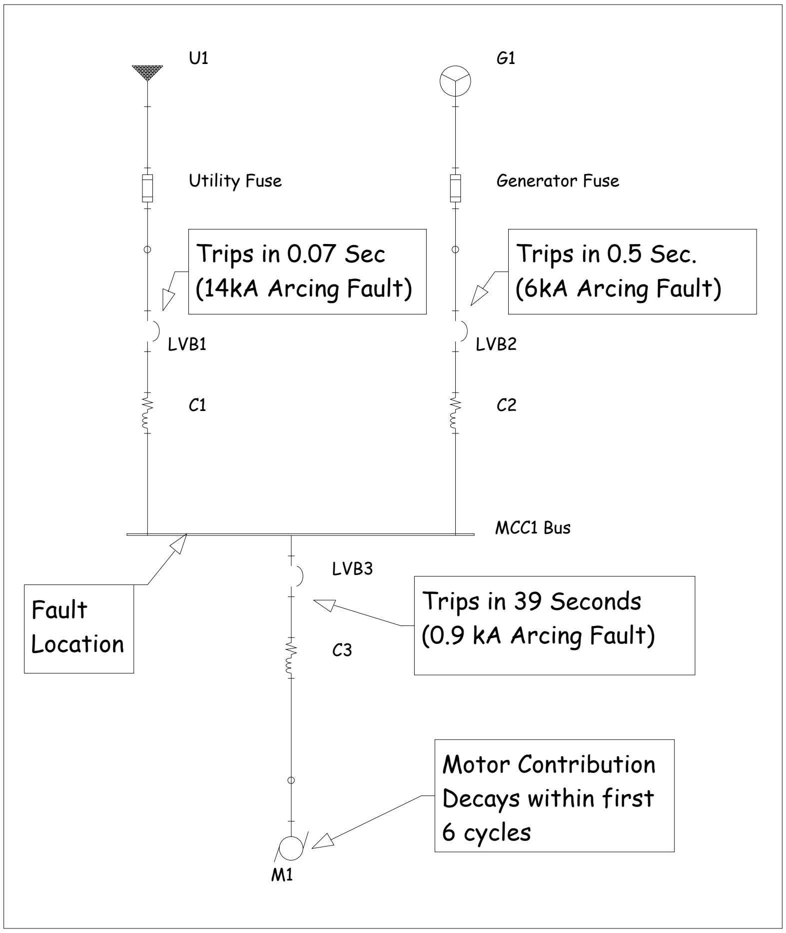
Load Flow
If the Load Flow option is selected, the load flow voltage at each bus will be used to calculate the bus and branch fault current when apply a fault to the bus.

PU Voltage for All Buses
If the PU Voltage for All Buses option is selected, the user can enter one single value for the per unit pre-fault voltage to be used for all bus in the system.

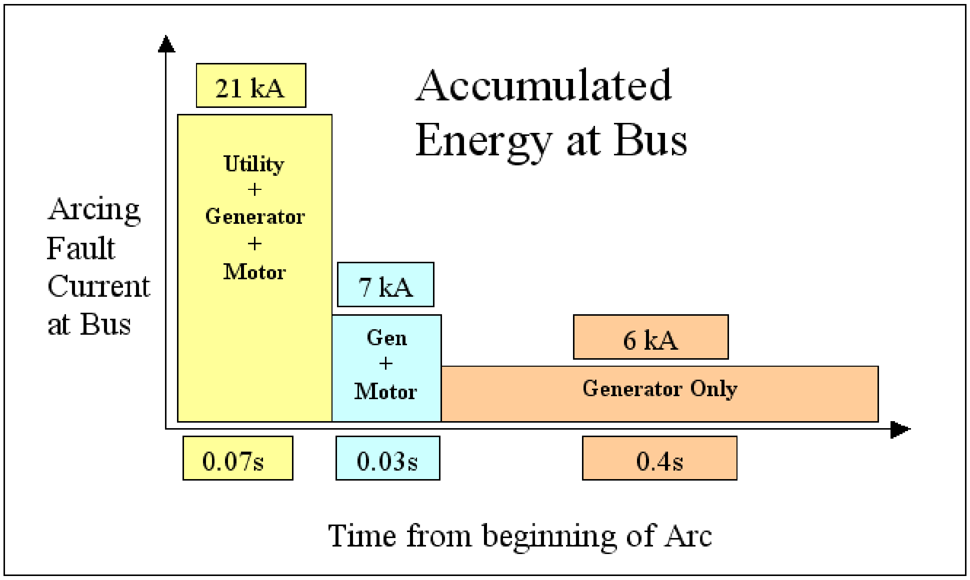
PU Voltage Enter for Each Bus
If the PU Voltage Enter for Each Bus option is selected, the user can enter the per unit pre-fault voltage to be used at each individual bus and the per unit voltage will be used to calculate the bus and branch fault current when apply a fault to that bus.

No Load with Tap
If the No Load with Tap option is selected, the per unit pre-fault voltage is calculated by the program starting from the Initial Operating Voltage from the utility or Swing Bus generator. Transformer Tap and Phase Shift will be included in the calculation of the pre-fault voltage if the options are checked in the Calculation Model. This is the default option.

Accumulated Energy
The concept of accumulated energy is based on conditions where parallel contributions feed a single fault location. Referring to the following diagram, a fault at Bus MCC1 is fed from three parallel contributions (Utility, Generator, Motor). Each contribution will trip at a different time and the worker will be exposed to a varying amount of energy as each branch trips.



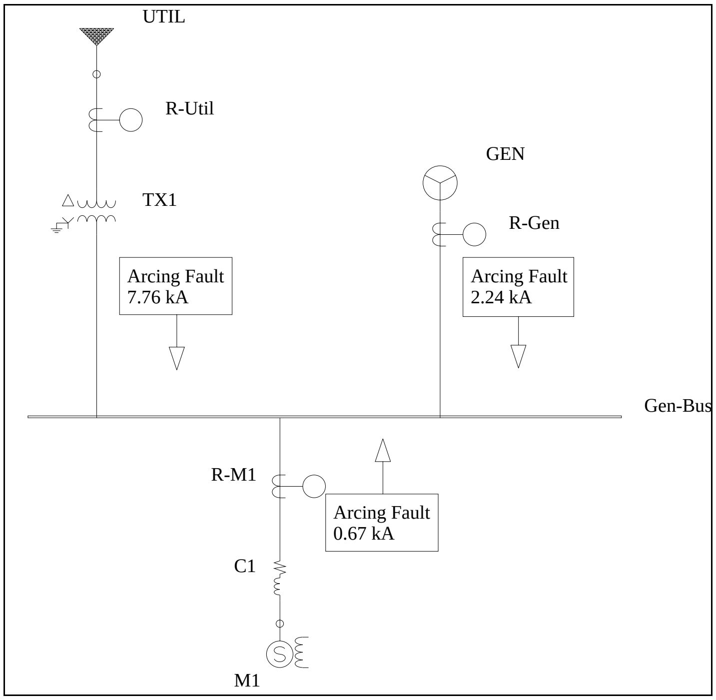
For this example, the worker is exposed to all three contributions for the first 0.07 seconds, the motor and generator for the next 0.03 seconds, and the generator contribution by itself for another 0.4 sec.



The Arc Flash study reports the accumulated energy from all three contributions. If the Utility had been the only significant contribution, the energy would have been accumulated only for the first 0.07 seconds, the time when the utility contribution was cleared. In this case, the utility is 67% of the total and the generator contribution was 28% of the total. Therefore both the utility and generator were both determined to be significant contributions as defined by the 80% "Cleared Fault Threshold" percentage specified. Both the Utility and the Generator must trip before the 80% Cleared Fault Threshold is reached.

Detail View versus Summary View

The detail view in the arc flash report lists all parallel contributions and the accumulated energy as each contribution is cleared. The summary view lists only the last branch that clears the significant contribution as defined by the "Cleared Fault Threshold" percentage specified. In the following example, 3 parallel branches contribute current to the fault.



The Detail View for the bus report lists all 3 contributions, the trip time for each branch, and the cumulative energy when each branch clears. For this example, the Utility Contribution clears in 0.234 seconds, the Generator Contribution clears in 1.12 seconds, and the Synchronous Motor clears in 5.57 seconds (assuming no AC decay), but displays the 2 second maximum time specified in the study setup. When the Utility branch clears, the incident energy is 2.83 cal/cm2 (Class 1). When the Generator Branch clears 0.68 seconds later, the accumulated energy is 4.91 cal/cm2 (Class 1).

Arc Flash Evaluation - IEEE 1584-2004a

Detail View | Summary View | Bus Detail... | Bus Label... | Custom Label... | Work Permit... | Re-Run Study | Options... | PPE Table... | All | From Go To/Query

	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Category
1	Gen-Bus	R-Util	4.16	11.00	8.01	7.76	0.15	0.083	Yes	SWG	102	87	36	2.82	Category 1
2	Gen-Bus	R-Gen	4.16	11.00	2.31	2.24	1.032	0.083	Yes	SWG	102	173	36	5.51	Category 2
3	Gen-Bus	R-M1	4.16	11.00	0.69	0.67	1.917	0.083	Yes	SWG	102	191	36	6.07	Category 2 (*N9)

The Utility contribution is 73% and the generator is 21% of the total arcing fault current at Gen-Bus. With the Cleared Fault Threshold option set to 80%, the Summary display and Labels will report the energy accumulated up to the time when at least 80% of the total fault current is cleared. This occurs when the Generator contribution is cleared. The Summary View lists only the generator branch since when the generator trips, 94% of the fault current has cleared.

Arc Flash Evaluation - IEEE 1584-2004a

Detail View | Summary View | Bus Detail... | Bus Label... | Custom Label... | Work Permit... | Re-Run Study | Options... | PPE Table... | All | From Go To/Query

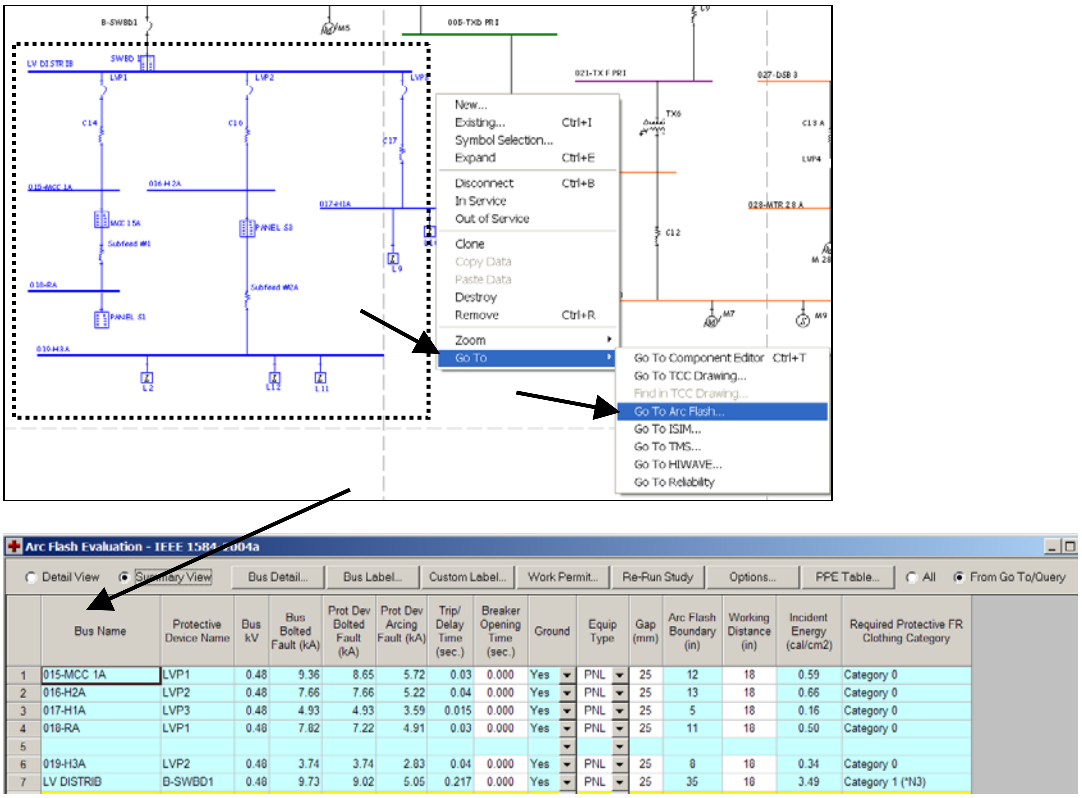
	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Category
1	Gen-Bus	R-Gen	4.16	11.00	2.31	2.24	1.032	0.083	Yes	SWG	102	173	36	5.51	Category 2

Selecting Buses for Display in Arc Flash Report

By default, all buses are displayed in the arc flash report. To display only selected buses, use the Query or Go-To functions as described below:

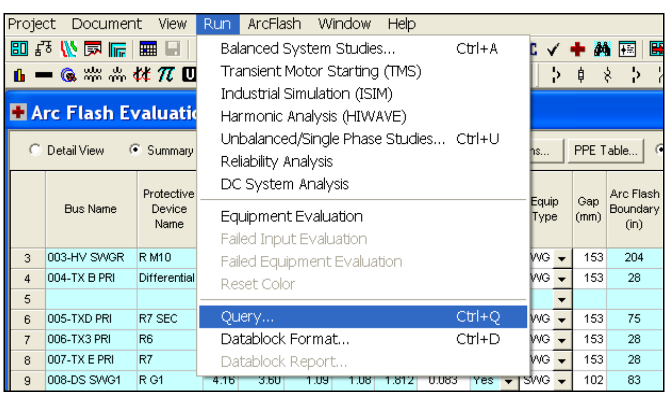
Go-To-Arc Flash

From the one-line diagram, select the buses you want to display and use the Window > Go-To-Arc Flash menu item (or use the Right Mouse Button menu). The Go-To-Arc Flash option will open the Arc Flash report and list only the bus or buses selected on the one-line.



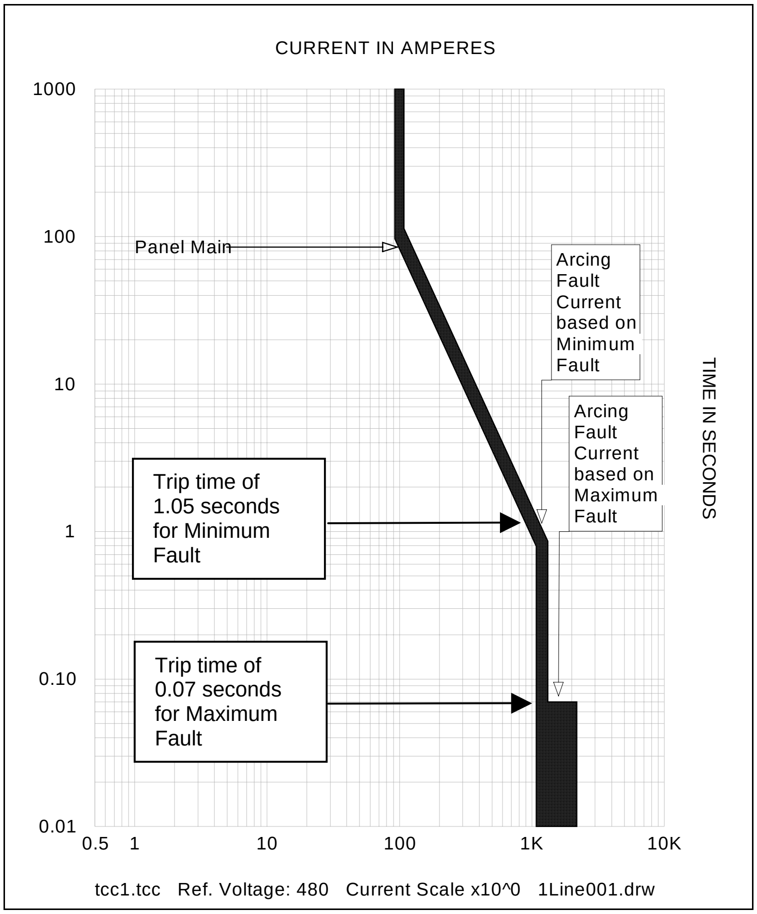
Query

Alternatively, you can display selected buses by using a query. For example, you can query on buses where the voltage is equal to 480 Volts. To run a query, select the Run Query Menu. Refer to the on-line help, PTW Tutorial or PTW Users Guide for more information on creating new queries.



Minimum and Maximum Faults

It's important to consider both minimum and maximum fault conditions when performing arc flash calculations. The reason why both are important is illustrated below:



Notice on the TCC drawing that for a maximum arcing fault that the trip time remains in the instantaneous trip region (0.07 seconds). Using a smaller minimum fault current and lower pre-fault voltage results in a lower fault current that takes slightly more than one second to trip (1.05 seconds). Using the maximum fault current, the incident energy is 1.22 J/cm2 resulting in a Class 0 FR Clothing Class. Using the minimum fault current, the incident energy is 11.9 J/cm2 resulting in a Class 1 FR Clothing Class. For this case, the lower fault current results in a longer trip time producing higher incident energy exposure to the worker. Making conservative assumptions regarding both the minimum and maximum fault currents will provide higher certainty in specifying the proper clothing class and selecting conservative protective device settings.

	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (J/cm2)	Required Protective FR Clothing Category
1	Panel Bus	Panel Main	0.48	2.18	2.18	1.78	0.071	0.000	No	PNL	25	260	610	1.24	Category 0

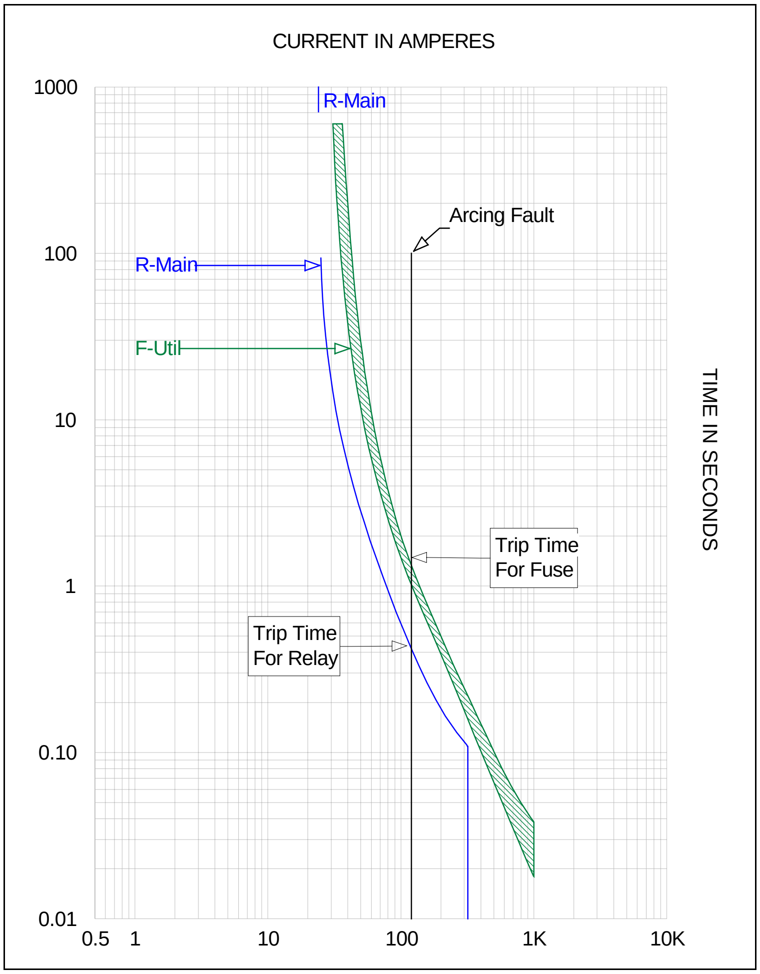
	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (mm)	Working Distance (mm)	Incident Energy (J/cm2)	Required Protective FR Clothing Category
1	Panel Bus	Panel Main	0.48	1.35	1.35	1.19	1.057	0.000	No	PNL	25	1031	610	11.8	Category 1

1.5.3 Determining Trip Time

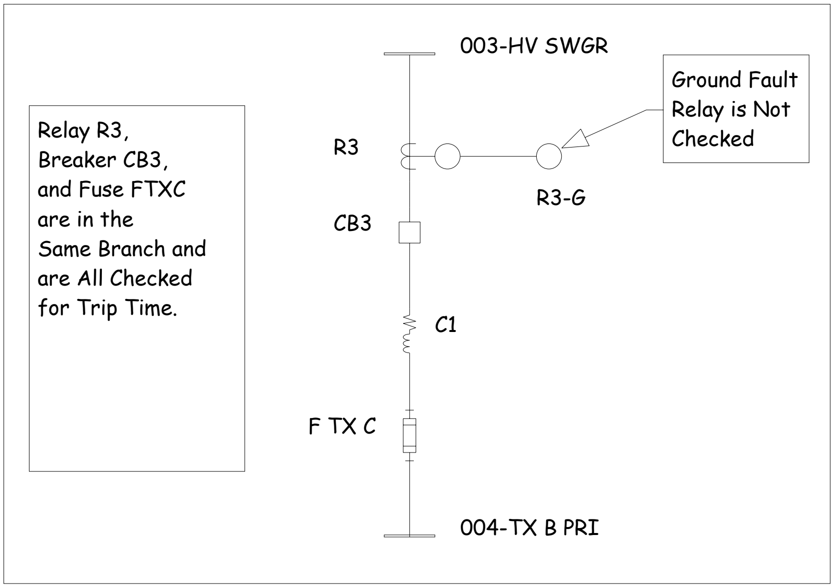
The protective device arcing fault current is used to determine the trip time for both IEEE 1584 and NFPA 70E Methods within the specified range of voltage and available fault current.

Ground Fault devices are not included. For multi-function devices, only the trip time of the first function is checked. Functions named Ground, Earth and AF_EX are excluded.

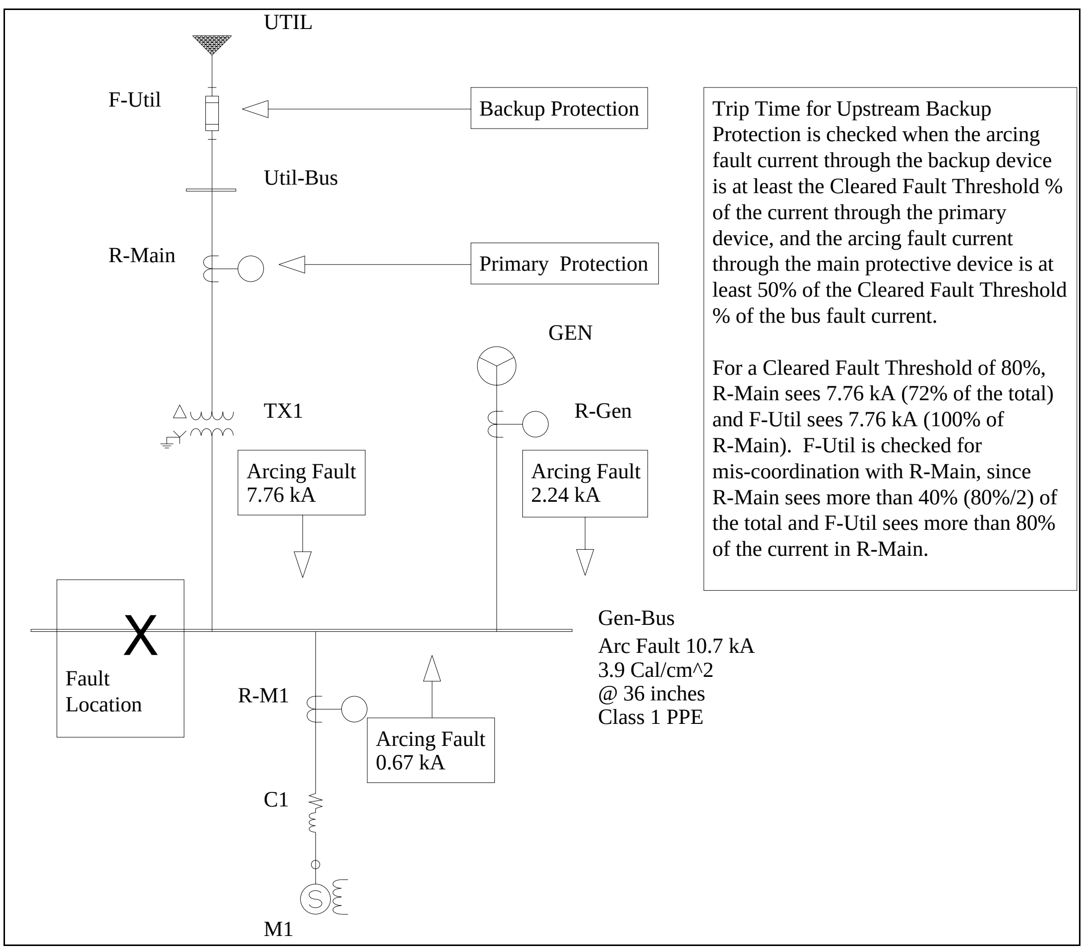
The clearing time is used for trip curves that have a tolerance.



The trip time for all devices in a branch are checked. The device with the fasted trip time for the arcing fault current is used.



The trip time for the first upstream backup device is checked for primary contributions. Only the first backup device is checked and only if the branch fault current is significant.



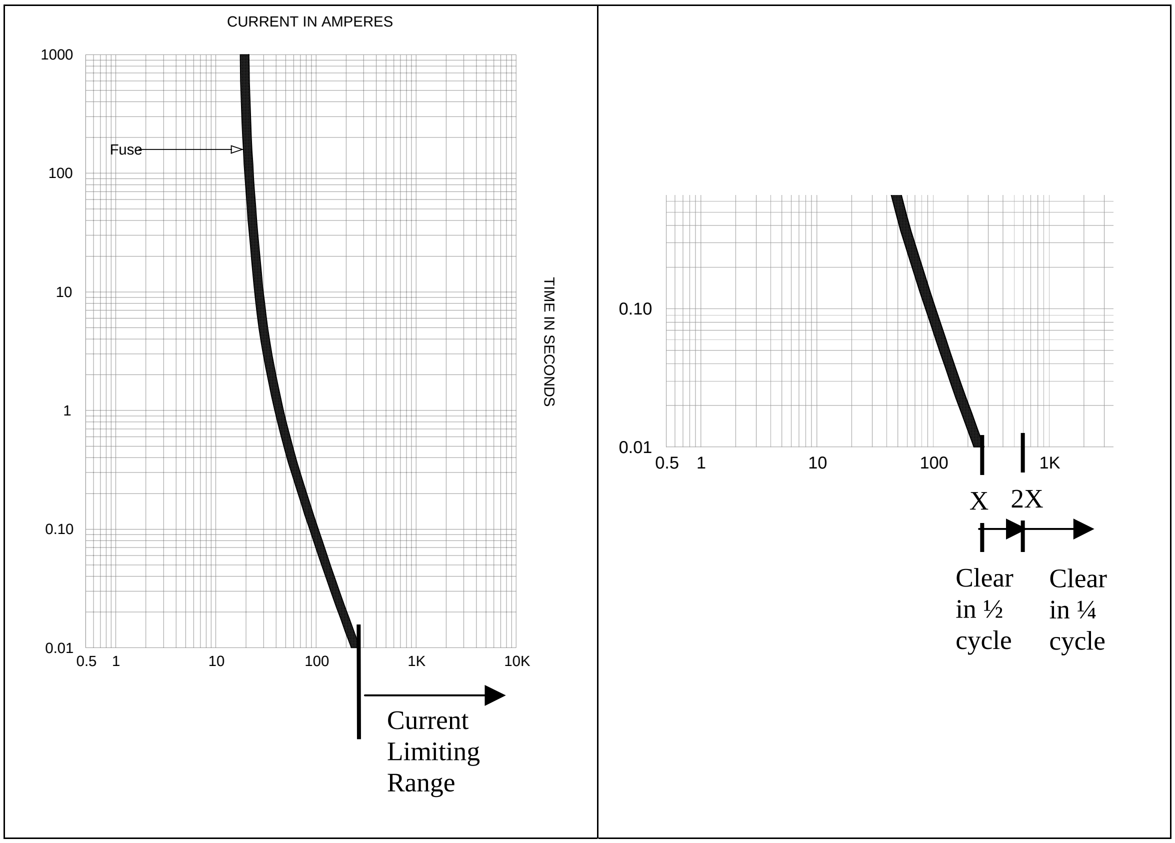
1.5.4 Current-Limiting Devices

There are two common methods to approximate current-limiting devices in Arc Flash calculations:

1) Use faster clearing times to conservatively simulate current-limiting devices when the arcing fault current is in the current-limiting range;

2) Use empirical equations from equipment tests to calculate incident energy and flash boundaries.

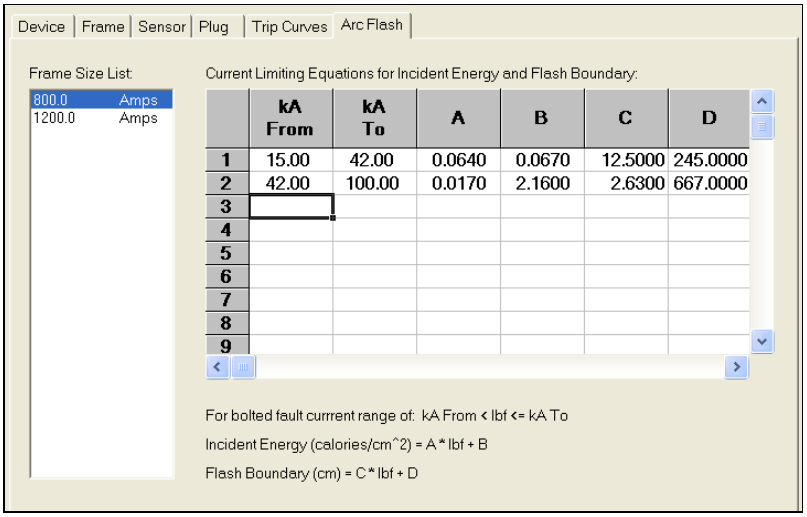
Note that it is difficult to determine where the current-limiting range begins. Published data assumes a specific X/R ratio, whereas your system X/R may be different. The dynamic X/R seen under an Arcing Fault condition further complicates the issue. PTW assumes that the current limiting range begins at X, where the clearing curve of the protective device crosses 0.01 seconds.



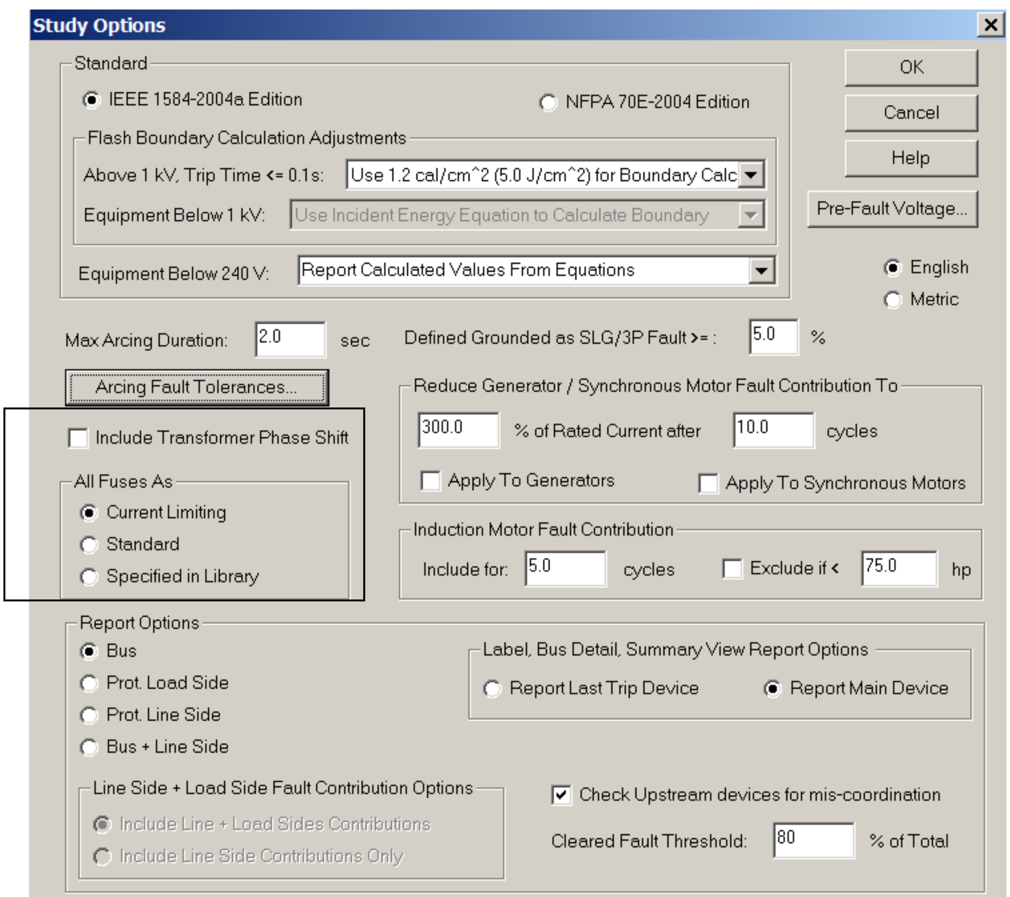
For arcing fault currents greater than X but less than 2X, the ½ cycle clearing time is used. For arcing fault currents 2X and larger, a ¼ cycle clearing time is used.

Alternatively, the trip curves can be extended below the 0.01 second when data is published.

For current-limiting devices with published empirical equations for incident energy and flash boundary calculations, the equation parameters can be defined in the library as a function of bolted fault current.



The Arc Flash Study Options menu controls how current-limiting fuses are treated in the calculations. Current-limiting effects for circuit breakers must be defined in the library by extending the clearing times below 0.01 seconds, or by entering the empirical equations for the current-limiting device. A choice to represent all fuses as current-limiting, standard, or as specified in the library is available.



1.5.5 Reports

The arc flash report options include a standard spreadsheet report, datablock report, Crystal report, detailed label, summary label, and datablock display on one-line:

Standard Report: The standard report is generated directly from the main arc flash application screen. You can use the Document>Print, or Document>Save-As menu functions.

Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Category
023-MTR 23	R TX F	0.48	19.87	15.67	9.30	0.145	0.050	Yes	PNL	25	54	18	7.20	Category 2
025-MTR 25	R7 SEC	4.16	6.73	4.78	3.97	1.426	0.083	Yes	SWG	102	198	18	12.3	Category 3 (*N3)
026-TX G PRI	R7 SEC	4.16	6.84	4.89	4.06	1.376	0.083	Yes	SWG	102	195	18	12.2	Category 3 (*N3)
027-DSB 3	F TX G SEC	0.48	32.17	24.28	11.42	0.697	0.000	Yes	PNL	25	118	18	26.2	Category 4 (*N3)
028-MTR 28 A	LVP4	0.48	21.94	18.26	10.68	0.05	0.000	Yes	PNL	25	26	18	2.17	Category 1
028-MTR 28 B	LVP5	0.48	21.94	18.26	10.68	0.05	0.000	Yes	PNL	25	26	18	2.17	Category 1
029-TX D SEC	R7 SEC	4.16	6.70	4.81	4.00	1.412	0.083	Yes	SWG	102	198	18	12.3	Category 3 (*N3)
BLDG 115 SERV	R7 SEC	4.16	7.01	5.03	4.18	1.312	0.083	Yes	SWG	102	192	18	11.9	Category 3 (*N3)
LV DISTRIB	B-SWBD1	0.48	9.73	9.02	5.05	0.217	0.000	Yes	PNL	25	35	18	3.49	Category 1 (*N3)
Category 0: Untreated Cotton														(*N3) - Arcing Current Low Tolerances Used
Category 1: FR Shirt & Pants														
Category 2: Cotton Underwear + FR Shirt & Pants														
Category 3: Cotton Underwear + FR Shirt & Pant + FR Coverall														
Category 4: Cotton Underwear + FR Shirt & Pant + Multi Layer Flash Suit														IEEE 1584-2004a Bus Report (80% Cleared Fault Threshold, include Ind. Motors for 5.0 Cycles), mis-coordination checked

Bus Detail: The Bus Detail option generates a detailed label including a listing of the protective device settings and energy at several different working distances. The Bus Detail label is generated by clicking on the Bus Detail button.

WARNING - Arc Flash Hazard

Client	SKM Systems Analysis, Inc.							
Location	Main Plant							
Job #	SAMPLE	**Date**	08/05/02		**Engineer**	SKM		
Bus	020-DS SWG3			**Category**				
Rated Volts	4160	**Rated Amps**		**Mf/Ty/Desc**				
Main Device	R SWG3		**Device Settings**					
WESTINGHOUSE, CO-8		**Phase**	Tap	Time Dials	INST (High)			
50/51			2.0 (480A)	9.75	12 (2880A)			
Frame	**Sensor**	**Plug**						

Arc Flash Calculation Data Sheet

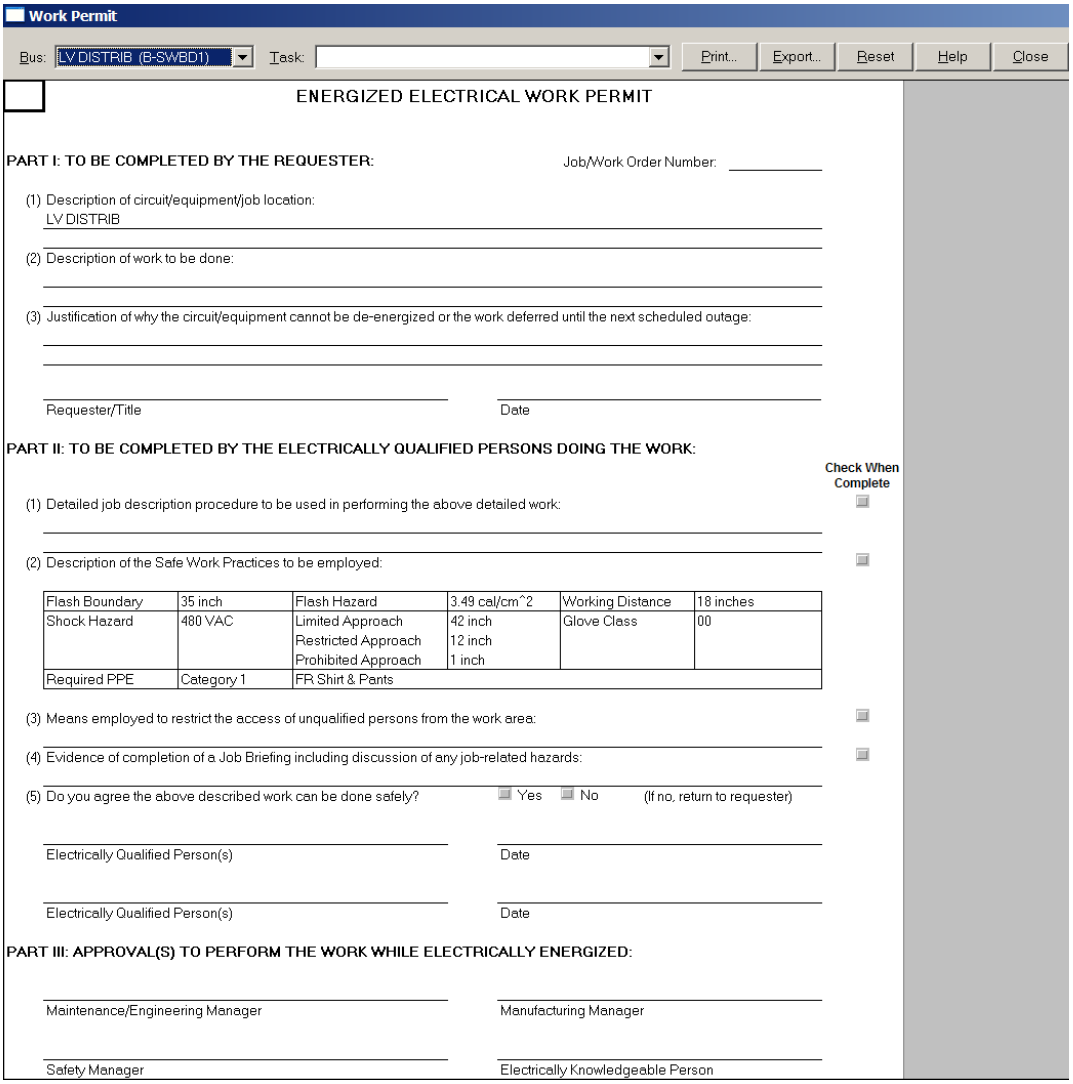
Bolted Short Circuit Fault	17.0 kA 3Phase	**Trip/Delay**	**Breaker Open**	**Arcing Duration**			
Arcing Fault in Protective Device	10.5 kA 3Phase	0.016 s	0.083 s	0.099 s			
Arc/Equipment Type	Switchgear	Gap: 102	Grounded				
Arc Flash Boundary	56 inches	**@ 1.2 cal/cm2 - 2nd Degree Burn Boundary of Bare Skin**					
Working Distance	18 inches		21	24	30	48	
Incident Energy	3.57 cal/cm^2		3.08	2.70	2.17	1.38	
PPE Clothing Class	Class 1 - FR Shirt & Pants						

Personnel Protection Equipment Table

Description	Class	Weight (oz/yd^2)	ATPV (cal/cm^2)	Notes
Untreated Cotton	0	4.5-7	N/A	
FR Shirt & Pants	1	4.5-8	5	
Cotton Underwear + FR Shirt & Pants	2	9-12	8	
Cotton Underwear + FR Shirt & Pant + FR Coverall	3	16-20	25	
Cotton Underwear + FR Shirt & Pant + Double Layer Switching	4	24-30	40	

Proper Protective Equipment Required

Work Permit: The work permit button generates a work permit form required by NFPA 70E 2004. Standard tasks may be selected from the task list and the equipment location and flash hazard study results are automatically displayed on the form.



Work Permit

Bus: LV DISTRIB (B-SWBD1) Task: Print... Export... Reset Help Close

ENERGIZED ELECTRICAL WORK PERMIT

PART I: TO BE COMPLETED BY THE REQUESTER: Job/Work Order Number:

(1) Description of circuit/equipment/job location:
LV DISTRIB

(2) Description of work to be done:

(3) Justification of why the circuit/equipment cannot be de-energized or the work deferred until the next scheduled outage:

Requester/Title Date

PART II: TO BE COMPLETED BY THE ELECTRICALLY QUALIFIED PERSONS DOING THE WORK:

Check When Complete

(1) Detailed job description procedure to be used in performing the above detailed work:

(2) Description of the Safe Work Practices to be employed:

Flash Boundary	35 inch	Flash Hazard	3.49 cal/cm^2	Working Distance	18 inches
Shock Hazard	480 VAC	Limited Approach Restricted Approach Prohibited Approach	42 inch 12 inch 1 inch	Glove Class	00
Required PPE	Category 1	FR Shirt & Pants			

(3) Means employed to restrict the access of unqualified persons from the work area:

(4) Evidence of completion of a Job Briefing including discussion of any job-related hazards:

(5) Do you agree the above described work can be done safely? Yes No (If no, return to requester)

Electrically Qualified Person(s) Date

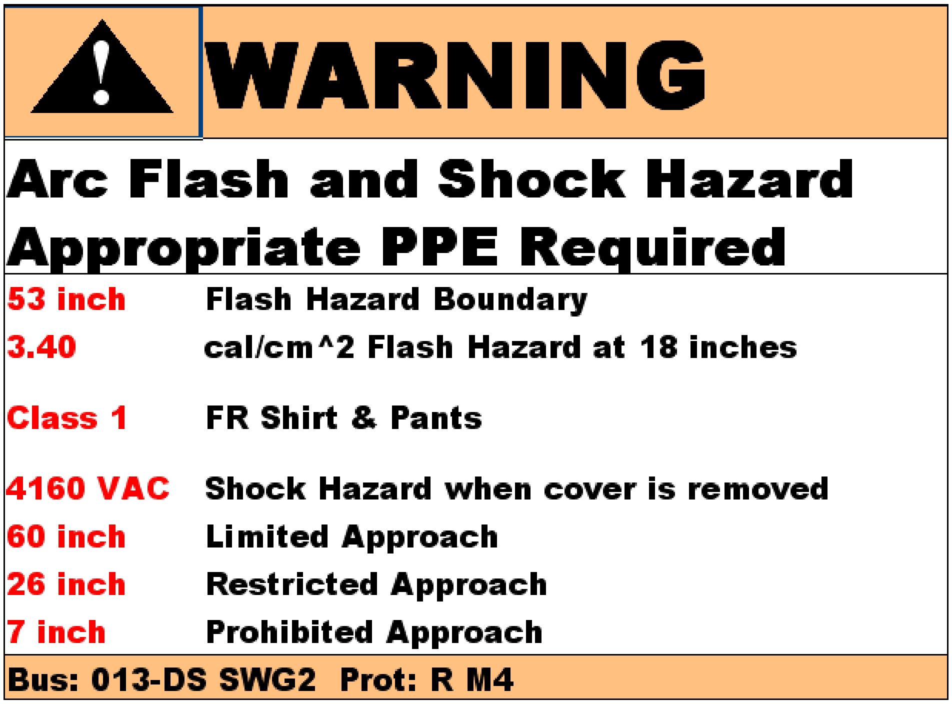
Electrically Qualified Person(s) Date

PART III: APPROVAL(S) TO PERFORM THE WORK WHILE ELECTRICALLY ENERGIZED:

Maintenance/Engineering Manager Manufacturing Manager

Safety Manager Electrically Knowledgeable Person

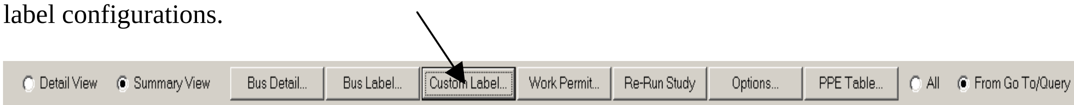
Bus Label: The Bus Label provides a summary of the flash boundary, incident energy and PPE classification at each bus. The NFPA shock hazard Limited, Restricted and Prohibited Approach boundaries are also listed based on the nominal system voltage at the bus. To generate the Bus Label, click on the Bus Label button. The header and footer are color coded according to the color specified for each Class in the PPE Table.



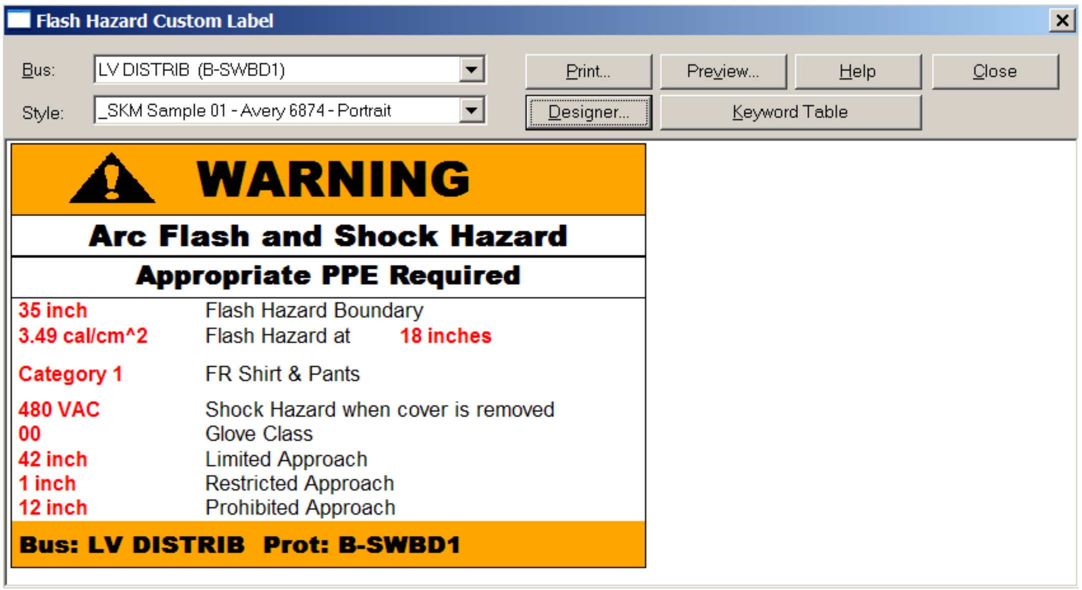
Arc Flash Custom Label

PTW provides an Arc Flash Custom Label Designer for you to specify the Page Size, Label Size, Page Margins, Orientation, Rows and Columns of the labels and Spacing between labels. The available fields could be selected from the list, and the size and position of each field is defined in the Field Layout Settings. You can also create your own Text field, Date field, or place a picture anywhere in the label and specify the background color and font size for the user defined text fields and input in your own local language.

Click on the “Custom Label” button on top of the Arc Flash spread sheet table to defined custom label configurations.



The following window will appear:



Bus List - allows you to select or scroll through (using the arrow Up or Down keys) to preview the final look of the label specific to the selected bus.

Style List - all custom labels created by SKM or by your own are listed here. The SKM labels have a Style name of "_SKM Sample …" for those that are completely defined. The ones with "… - Template" at the end of the style name only define the width and height of the label and leave the rest for your customization.

Print - allows you to select the buses to be printed.

Preview - allows you to select to preview the selected bus.

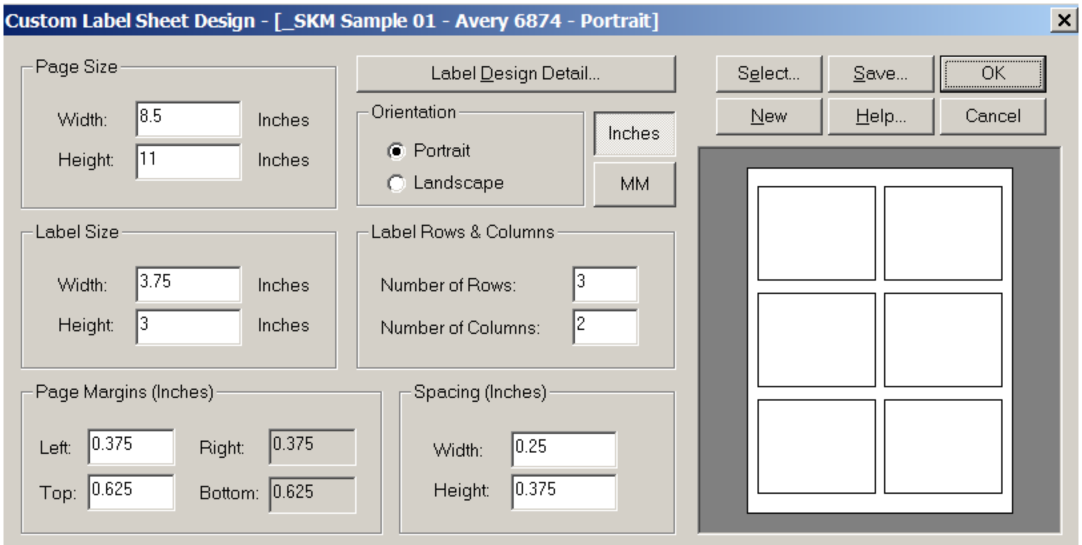
Designer - allows you modify and existing label or create and design a new one.

Keyword Table - allows you to map the standard keywords displayed on the label to your own preference, or your own local language.

Custom Label Sheet Design

Click on the “Designer” button show the “Custom Label Sheet Design” window.

The Arc Flash Custom Label layout page allow you to specify the Page Size, Label Size, Page Margins, Orientation, Rows and Columns of labels and Spacing between labels.



The “Select” button allows you to select an existing custom label design.

The “Save” button allows you to save what you have modified to the same Style name, or overwrite an existing Style, or save as an new Style name.

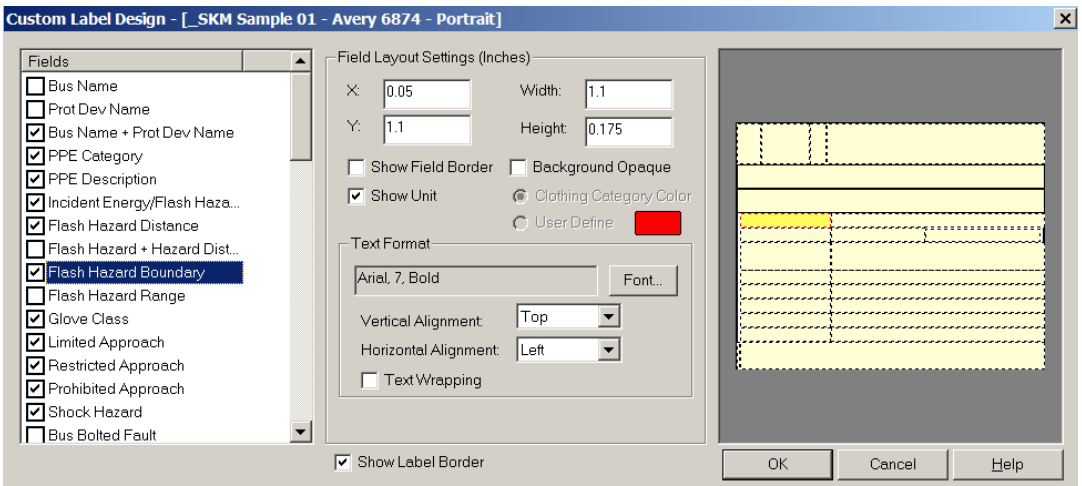
The “New” button allows you to create a new label style.

Label Design Detail

Press the “Label Design Detail” button to view/modify the detail of a label.

The available fields are selected from the list on the left, and the size and position of each field is defined in the Field Layout Settings. You can select any existing Arc Flash data field listed on the left by clicking on the field. Check the box next to the field to display the field on the Label. In order to see the field show up on the view area at the right hand side, make sure the field coordinate is within the label area, and either of the width or height is not zero.

You can create you own Text field, Date field, or place a picture anywhere in the label. Enter the X, Y positions and the width and height for the field, you can also specify the background color and font size for the user defined text fields and input in your own local language.



Show Label Border - Display a thin line of rectangle border around the label area.

Show Unit - Select to display the unit along with the result value or not. This selection is only available in some fields that have a unit to display.

X - The coordinate X of the top-left corner of the field

Y - The coordinate Y of the top-left corner of the field

Width - The width of the field

Height - The height of the field

Show Field Border - Draw a thin line of rectangle border around the field area.

Background Opaque - Select to apply background color to the field. If the user’s printer is B&W, this function will not generate a good result.

Clothing Category Color - Background color use the pre-defined SKM Clothing Category Color Table and it will be changed dynamically according to the result warning level. (Note: Red for the dangerous Category and orange for the warning classes)

Text Format

Font - Click the font button to bring up a font select dialog. Choose the font, font style, font size, font effects, and the font color.

Vertical Alignment - Choose to display the text to locate on the top, center or bottom of the field area.

Horizontal Alignment - choose to display the text to align on the left side, right side, or in the horizontal center of the field area.

Text Wrapping - Wrap the text to next line when it hits the right end of the field area.

Text - The content of the text field. (This is only available to the regular text field.)

Picture Format - Available in picture field only.

Scale - The scaling of the picture.

Best Fit - the picture will be scratched to the exact size of the field area, in order to fit both of the height and the width.

Actual Size - The picture will be shown in the exact number of pixels.

Fit to Width - The picture will be scratched to fit the width.

Fit to Height - The picture will be scratched to fit the height.

Path: the path of the picture file (BMP file only). User can use the browse button to select from a file dialog, or type in manually. If a user chooses to type in manually, make sure the path is correct.

Custom Field Selections and Descriptions

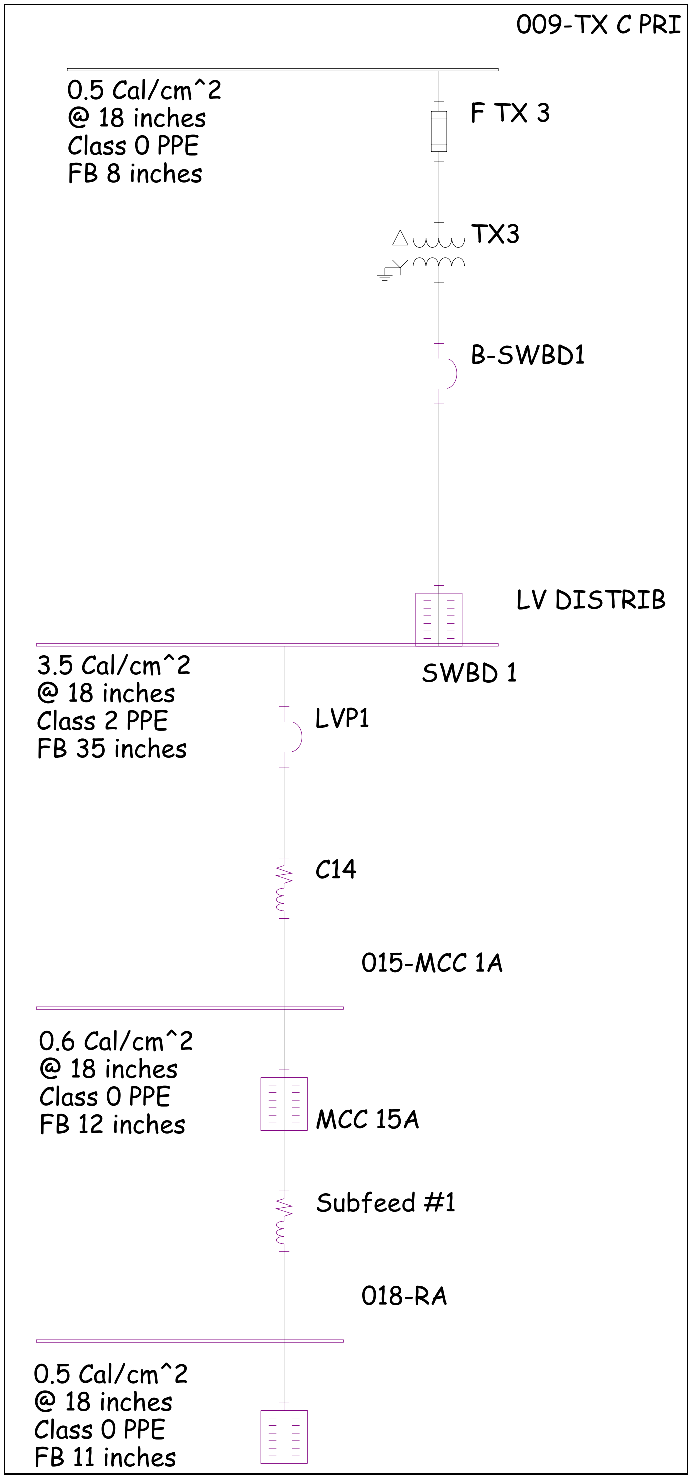
Choose the fields from the left-hand-side field list to modified the specific field. Check the box next to the field to display the field. In order to see the field show up on the view area at the right hand side, make sure the field coordinate is within the label area, and either of the width or height is not zero.

Bus Name	The name of the equipment bus and the bus description entered in the Component Editor.
Prot Dev Name	The name of the protective device after its tripping, the "Fault Clear Threshold" percentage will be cleared (if the Arc Flash Option is set to Report Last Trip Device, or the name of the protective device that trips the largest percentage of the fault contribution at the bus (if the Report Main Device is the selected option).
Bus Name + Prot Dev Name	The name of the equipment bus, the bus description, and the name of the protective device.

Clothing Category / PPE Category	Indicates the Personal Protective Equipment (PPE) required to prevent an incurable burn at the working distance during an arcing fault.
Clothing Category / PPE Category Description	Provides a description of the clothing required to meet the reported Clothing Category.
Flash Hazard / Incident Energy	The amount of energy on a surface at a specific distance from a flash
Flash Hazard Distance / Working Distance	The distance between the arc source and the worker's face or chest
Flash Hazard Boundary	The distance from an arcing fault within which unprotected skin could receive a 2nd degree burn. Generally considered the distance where the incident energy equals 1.2 cal/cm2.
Glove Class	Provides the glove class required based on the design voltage at the fault location.Glover Class
Limited Approach	An approach limit at a distance from an exposed live part within which a shock hazard exists. Defined in NFPA 70E based on design voltage at the fault location.
Prohibited Approach	An approach limit at a distance from an exposed live part within which work is considered the same as making contact with the live part. Defined in NFPA 70E based on design voltage at the fault location.
Restricted Approach	A shock protection boundary to be crossed by only qualified persons (at a distance from a live part) which, due to its proximity to a shock hazard, requires the use of shock protection techniques and equipment when crossed. Defined in NFPA 70E based on design voltage at the fault location.
SKM Label Title 1	SKM supplied text "WARNING" or "DANGER" can be displayed on the printed labels.
SKM Label Title 2	SKM supplied text "Arc Flash and Shock Hazard" or "NO PPE AVAILABLE" can be displayed on the printed labels.

SKM Label Title 3	SKM supplied text "Appropriate PPE Required" or "ENERGGIZED WORK PROHIBITED" can be displayed on the printed labels.
Today’s Date	A smart field that reads the system date from the computer and displays it on the printed label.
Label Title 1 – Label Title 3	3 user-defined text fields that can be displayed on the printed labels.
Text1 – Text8	8 user-defined text fields that can be displayed on the printed labels.
Picture1 – Picture3	3 user-defined bit-map pictures that can be displayed on the printed labels.

Datablock Display: The datablock display is activated from the Run>Datablock Format menu item. You can modify the datablock formats to include any combination of data fields including: Incident Energy, Working Distance, PPE Class, Flash Boundary (as shown below), Arcing Fault, Breaker Time, Gap, Grounded Indicator, PPE Description, Trip time, and Shock Boundaries. The Arc Flash datablock, like any other datablock, can be applied to One-lines, TCCs and the Component Editor.



Datablock Report: The datablock report can be generated from the Component Editor or the One-line diagrams. As with a datablock display, any combination of fields can be reported. The Datablock report may be printed, saved as a text file or saved as an Excel file.

Bus	Isc (kA)	Protection	IE (Cal/cm^2)	Work Dist (inches)	PPE Class	Boundary (inches)
003-HV SWGR	8	R M10	12.7	18	3	204
004-TX B PRI	8	R3	1.8	18	1	27
005-TXD PRI	1	R7 SEC	4.8	18	2	75
006-TX3 PRI	8	R6	1.8	18	1	28
007-TX E PRI	8	R7	1.8	18	1	28
008-DS SWG1	4	R G1	5.3	18	2	83
009-TX C PRI	4	F5	0.5	18	0	8
010-MTR 10	3	R G1	5.3	18	2	82
011-TX3 SEC	16	R6	6.1	18	2	96
012-TX3 TER	17	R6	6.5	18	2	103
013-DS SWG2	16	R M4	3.4	18	1	53
015-MCC 1A	9	LVP1	0.6	18	0	12
016-H2A	8	LVP2	0.7	18	0	13
017-H1A	5	LVP3	0.2	18	0	5
018-RA	8	LVP1	0.5	18	0	11
019-H3A	4	LVP2	0.3	18	0	8
020-DS SWG3	17	R SWG3	3.6	18	1	56
021-TX F PRI	14	R TX F	1.5	36	1	45
022-DSB 2	21	R TX F	7.0	18	2	53
023-MTR 23	20	R TX F	7.1	18	2	53
025-MTR 25	7	R7 SEC	12.3	18	3	198
026-TX G PRI	7	R7 SEC	12.2	18	3	195
027-DSB 3	32	F TX G SEC	26.2	18	4	118
028-MTR 28 A	22	LVP4	2.2	18	1	26
028-MTR 28 B	22	LVP5	2.2	18	1	26
029-TX D SEC	7	R7 SEC	12.3	18	3	198
BLDG 115 SERV	7	R7 SEC	11.9	18	3	192
LV DISTRIB	10	B-SWBD1	3.5	18	1	35

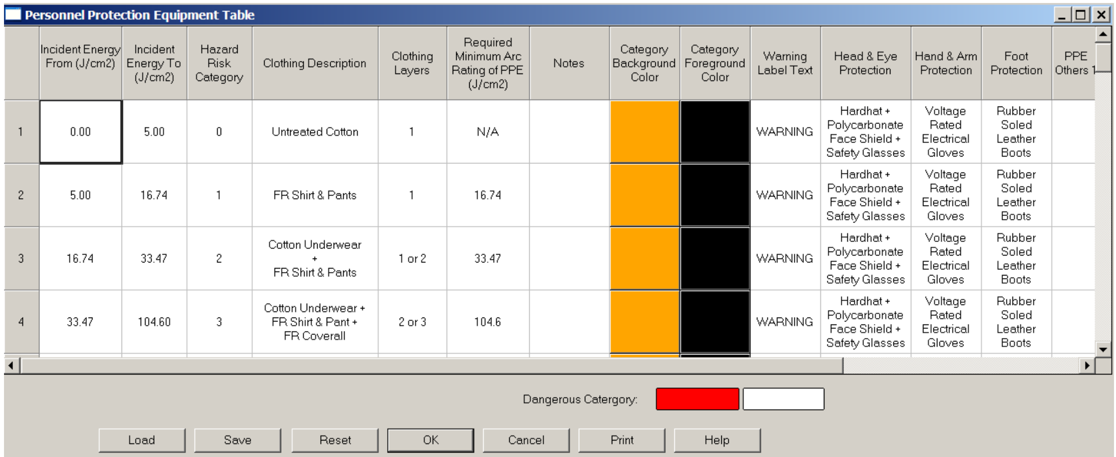
1.5.6 Selecting Buses for Arc Flash Report

By default, all buses are included in the arc flash report. To limit the buses displayed in the arc flash report, any of the following methods may be used:

- Bus Nodes versus Buses. Bus Nodes are excluded from the Arc Flash report automatically.
- Energized State: Buses that are de-energized or out-of-service may be excluded from the Arc Flash report using the Arc Flash>Hide De-Energized menu option.
- Query: A query can be used to customize the bus list. For example, you can query to only display only above Class 2 PPE, above 208 Volts, or any other user-defined criteria.
- Go-To Selection: From the one-line, you can select the area of interest and use the Go-To-Arc Flash option. Only the items selected on the one-line will be displayed in the Arc Flash Table. The Go-To function is also available from TCC drawings and the Component Editor. From the TCC, only the buses attached to the components on the TCC will be displayed in the Arc Flash table. From the Component Editor, only the selected bus will be displayed in the Arc Flash table.

1.5.7 PPE Table

The PPE table defines the Personal Protective Equipment Categories and clothing descriptions used in the reports and labels. Different label colors may be assigned for each PPE Category, the Bus Detail and Arc Flash Label will apply the colors based on the PPE Categories calculated.



	Incident Energy From (J/cm2)	Incident Energy To (J/cm2)	Hazard Risk Category	Clothing Description	Clothing Layers	Required Minimum Arc Rating of PPE (J/cm2)	Notes	Category Background Color	Category Foreground Color	Warning Label Text	Head & Eye Protection	Hand & Arm Protection	Foot Protection	PPE Others 1
1	0.00	5.00	0	Untreated Cotton	1	N/A				WARNING	Hardhat + Polycarbonate Face Shield + Safety Glasses	Voltage Rated Electrical Gloves	Rubber Soled Leather Boots	
2	5.00	16.74	1	FR Shirt & Pants	1	16.74				WARNING	Hardhat + Polycarbonate Face Shield + Safety Glasses	Voltage Rated Electrical Gloves	Rubber Soled Leather Boots	
3	16.74	33.47	2	Cotton Underwear + FR Shirt & Pants	1 or 2	33.47				WARNING	Hardhat + Polycarbonate Face Shield + Safety Glasses	Voltage Rated Electrical Gloves	Rubber Soled Leather Boots	
4	33.47	104.60	3	Cotton Underwear + FR Shirt & Pant + FR Coverall	2 or 3	104.6				WARNING	Hardhat + Polycarbonate Face Shield + Safety Glasses	Voltage Rated Electrical Gloves	Rubber Soled Leather Boots	

The PPE table defines the Personal Protective Equipment Categories and clothing descriptions used in the reports and labels. Different label colors may be assigned for each PPE Category, the Bus Detail and Arc Flash Label will apply the colors based on the PPE Categories calculated.

The data supplied as default is taken from NFPA 70E, 2004 edition, Page-61. Four default Categories of FR Clothing are defined based on the applicable range of the incident energy. Modify these values or add new Categories to this table if needed.

The Notes, Head & Eye Protection, Hand & Arm Protection, Foot Protection, PPE Others 1, …, 5 provides user defined additional protections for each category. The Warning Label Text could be user defined as well. All user defined additional protection fields are available in the Custom Label.

You can also choose a background and a foreground color for each of the PPE Category. These colors will be used as the background and foreground color for the SKM Label Title 1, 2, and 3 in the Arc Flash Label.

"Dangerous" is a special category, the user can choose the background and foreground colors for the Dangerous category.

Reset
If you make changes to this table and don’t want to keep them, use the Reset button to re-store the defaults from the NFPA 70E, 2004 edition, Page-61.

Print
Use the Print button to print out this table.

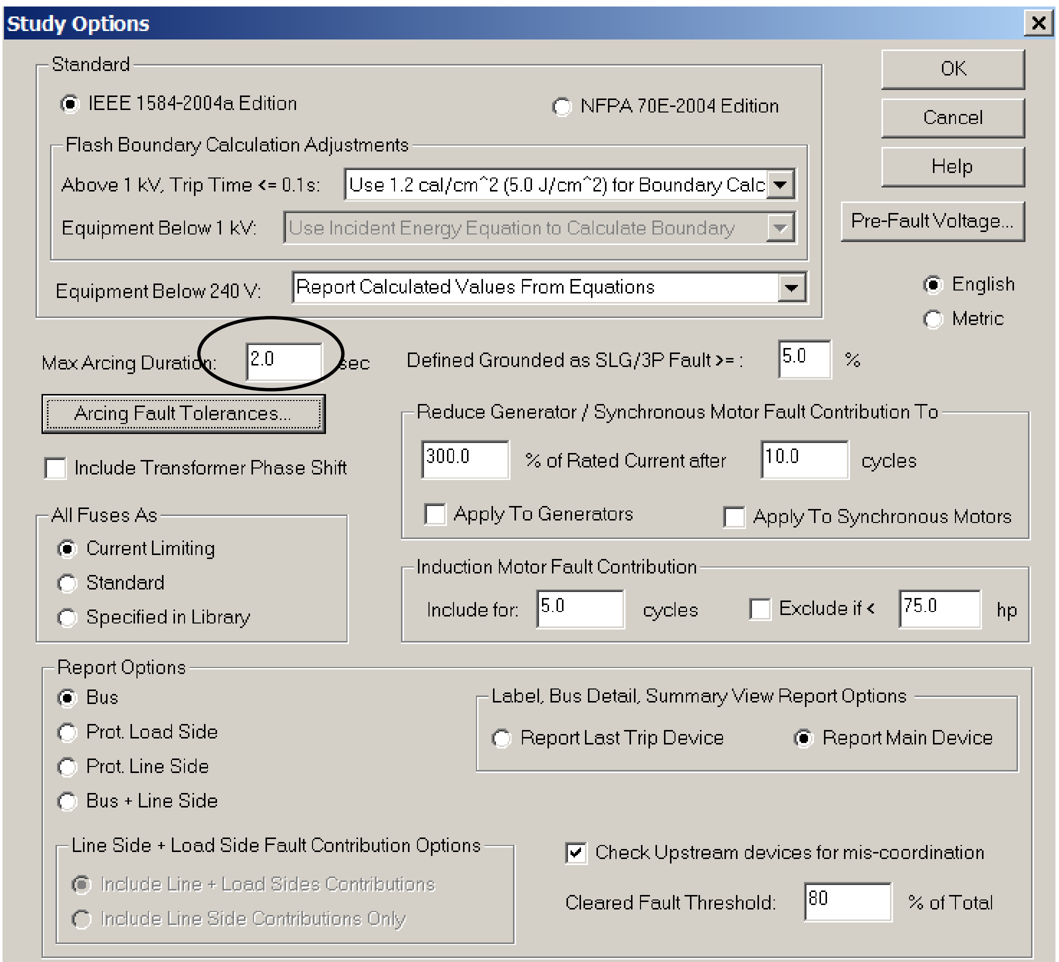
Save
If you had customized this table and want to keep the changes, use the save button to save the changes you made to a *.PPE file.

Load
If you want to load your customized PPE table, use the load button to load your customized PPE table.

1.5.8 Long Trip Times

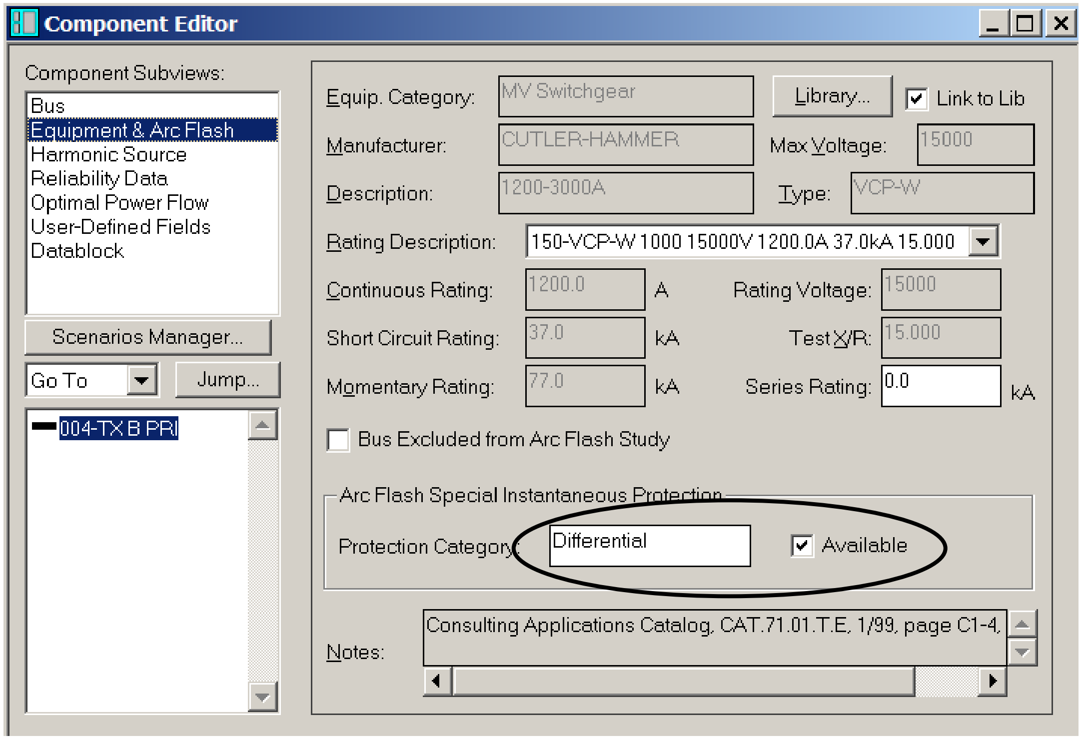
Long trip times will result in high incident energy values. The IEEE 1584-2002 equations do not include a time limit or variable working distance. It's important to understand why the trip time is long and the behavior of the fault source. Often the trip time is long when the fault current is relatively small. For these cases, if the workers are properly clothed to withstand the initial few seconds of flash energy, it is likely they will be able to move further away from the arc source than the stated working distance.

To evaluate the effect of faster trip times or limited arc duration for an existing system, use the Maximum Protection Trip Time field in the Arc Flash Study Options dialog.



1.5.9 Differential Protection

Differential Protection, and other special protection schemes, can be represented by entering a Protection Category description for the Bus and checking the available check box.



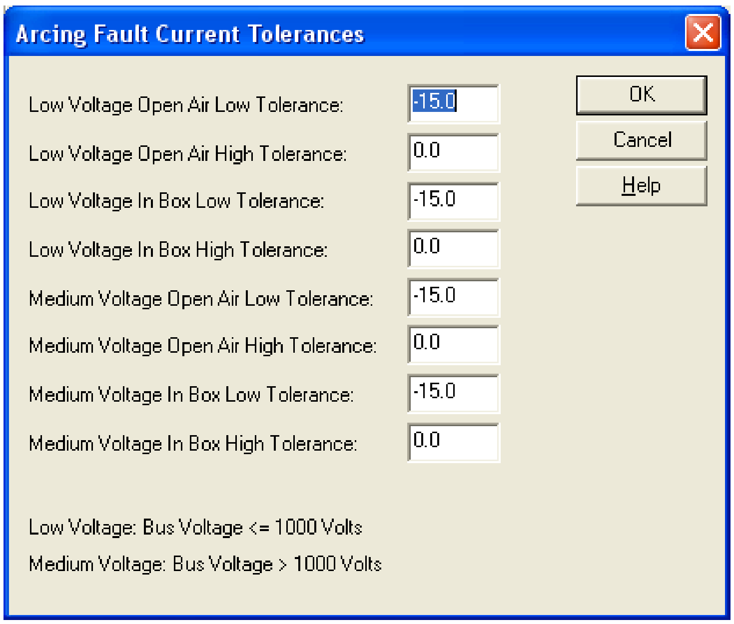
The trip time for the Differential protection is entered directly in the Arc Flash table

Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Category
003-HV SWGR	R3	13.8	7.96	0.29	0.28	1.917	0.083	Yes	SWG	153	215	18	13.4	Category 3 (*N9)
004-TX B PRI	Differential	13.8	7.77	7.77	7.5	0.016	0.083	Yes	SWG	153	27	18	1.79	Category 1 (*N6)

The Special Instantaneous Protection specification can be used for differential, zone interlocking, optical sensors, and other protection methods. If special protection is not defined for the bus, the traditional time-over current protection method is used.

1.5.10 Arcing Fault Tolerances

There is on-going discussion regarding the use of arcing fault tolerance in determining trip times during an arcing fault. The IEEE 1584 2002 standard uses a 15% low tolerance for arcing fault current due to variations found in the test results. We know that the arc current is greater than zero and less than the bolted 3-phase fault, however variations in arc impedance due to temperature, humidity, dust content, altitude or other factors may create some variability beyond what was documented in the test results. To follow the IEEE 1584-2002 standard, a 15% low tolerance should be used. If a higher degree of safety is desired, larger tolerances may be specified. The low tolerance values may result in longer trip times and higher incident energy. If both the low tolerance and high tolerance values result in the same trip time, the high tolerance value will produce the highest incident energy. Separate tolerance values for low voltage and medium voltage are available since variations in arc impedance will have more effect on arcing fault current at lower voltages.



1.5.11 Reducing Incident Energy

The following design modifications may be used to reduce incident energy from arc flash events:

1) Clear the arcing fault faster
   a) Reduce Existing Pickup and Delay Settings wherever possible.
   b) Enable Instantaneous Functions or Retro-fit with Instantaneous Functions
   c) Reduce Fuse Sizes wherever possible.
   d) Use Current-limiting breakers or fuses for high arcing fault currents
   e) Add Differential Protection
   f) Use Temporary Instantaneous Trip Settings when work is being performed
   g) Add optical sensors to trip when flash occurs

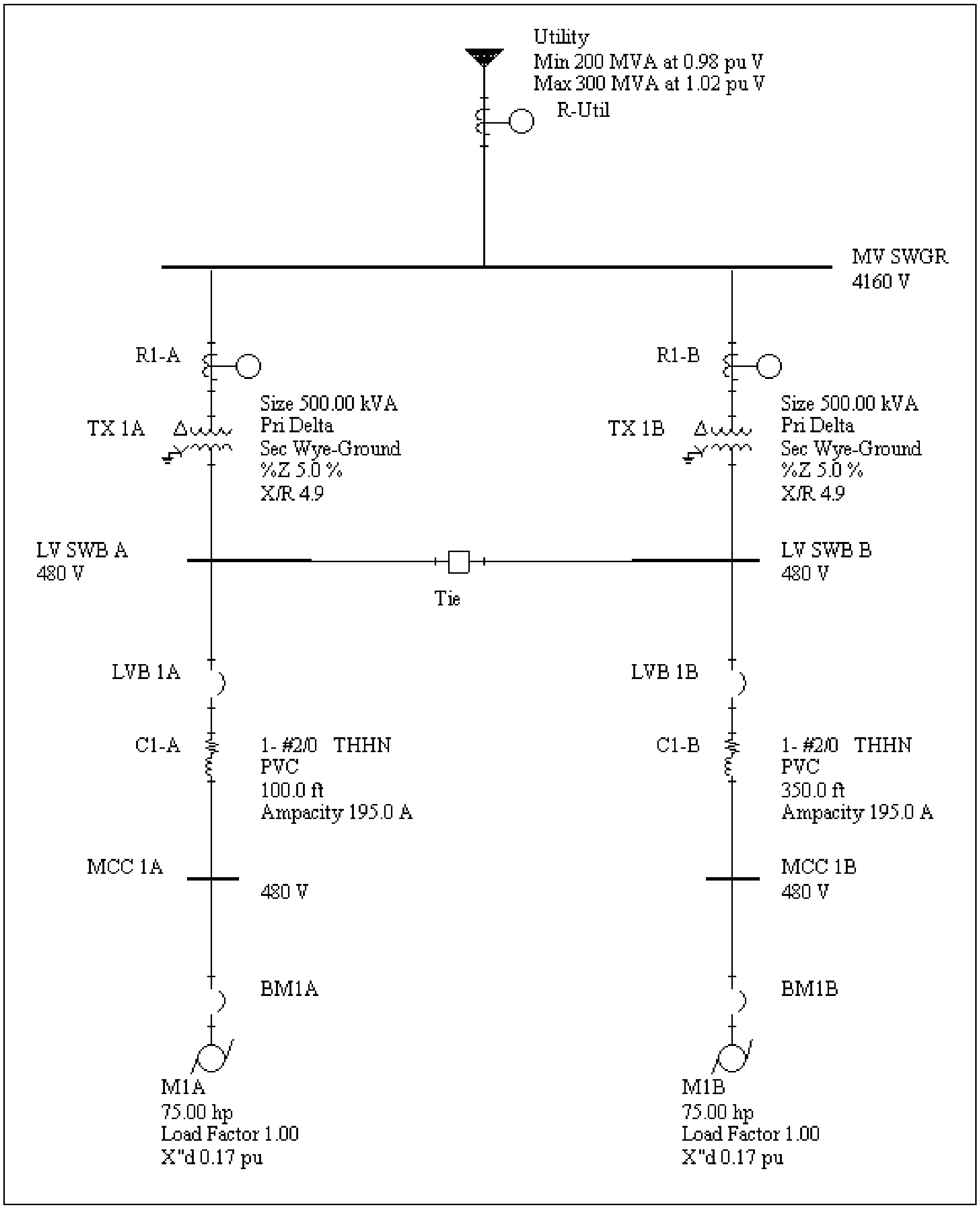
2) Reduce the fault level*
   a) Use Current-limiting breakers or fuses
   b) Use Current-limiting reactors
   c) Block paralleling capabilities

*Note that reducing the fault level results in reduced incident energy only when the reduced current does not increase the trip time.

1.6 Application Example

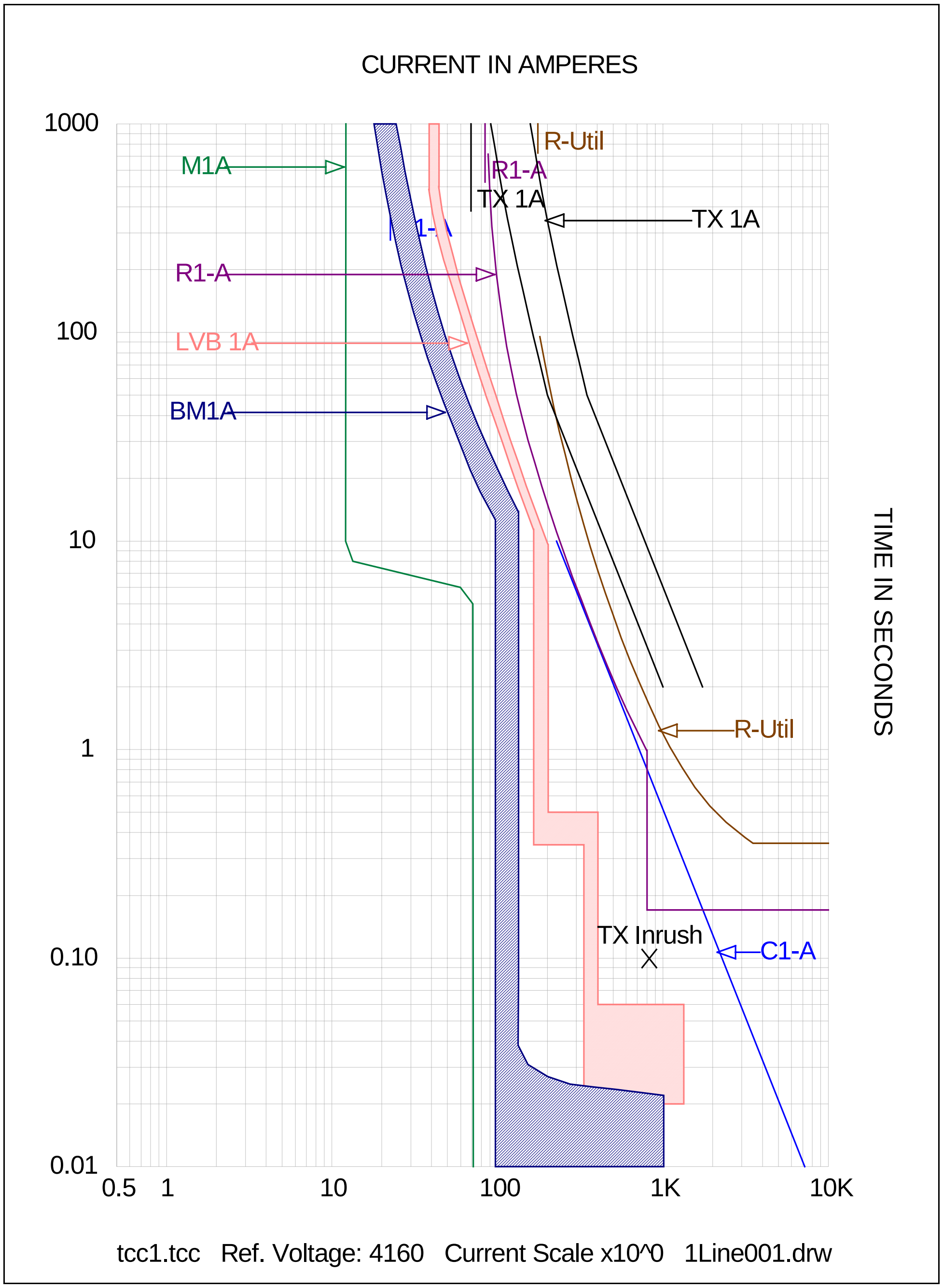
1.6.1 Sample Arc Flash Study

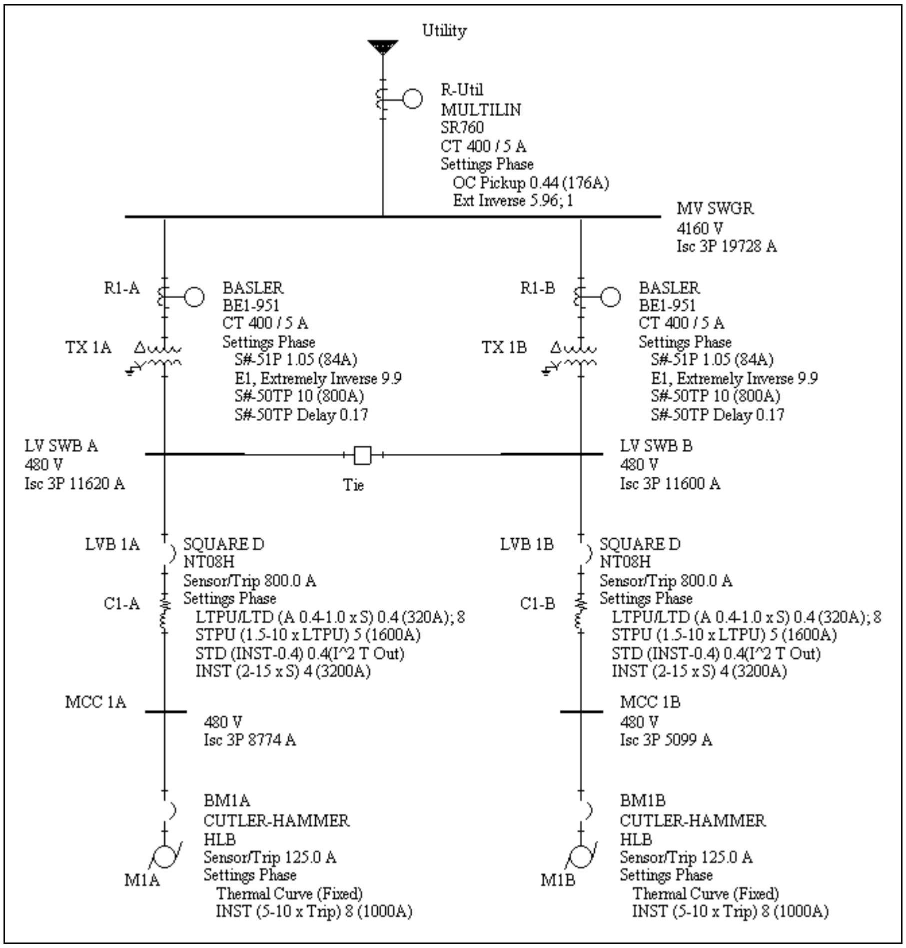
The following example highlights the steps required for an arc flash study.



Step 1: Enter data sufficient to perform Short Circuit study. The required data includes component connections, bus voltages, transformer impedance, cable impedance, and utility, generator, and motor fault contributions.

Step 2: Enter data sufficient to perform a time over-current coordination study. The required information includes protective devices and their associated trip settings.

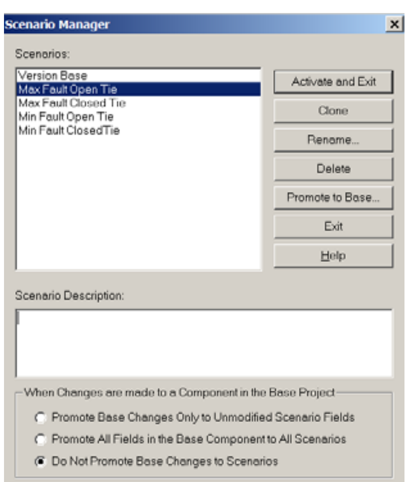




Step 3: Identify Operating Modes. For this example, the operating modes include:

1) Maximum Utility fault of 300 MVA at a pre-fault voltage of 1.02 per unit.
2) Minimum Utility fault of 200 MVA at a pre-fault voltage of 0.98 per unit.
3) Tie breaker open and closed.

Using the Scenario Manager in PTW, the Base Project can be duplicated and the different operating modes can be saved for comparison.



A summary table comparing the 4 scenarios in the PTW Version Manager Data Visualizer follows:

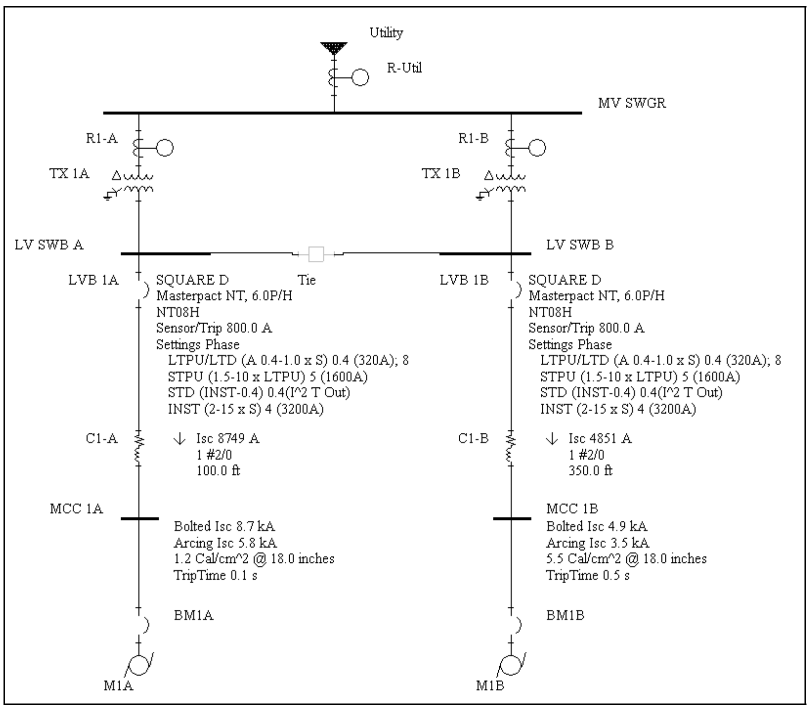
Component	Field	Max Fault Open Tie	Max Fault Closed Tie	Min Fault Open Tie	Min Fault Closed Tie
LV SWB A	Energy (Cal/cm^2)	5.52	50.75	5.25	51.98
LV SWB B	Energy (Cal/cm^2)	5.52	50.75	5.24	51.98
MCC 1A	Energy (Cal/cm^2)	1.18	1.71	1.13	1.63
MCC 1B	Energy (Cal/cm^2)	5.48	0.82	5.26	0.79
MV SWGR	Energy (Cal/cm^2)	28.99	28.99	18.06	18.06

From the summary table, the highest incident energy for each bus follows:

LV SWB A Minimum Fault with Closed Tie
LV SWB1B Minimum Fault with Closed Tie
MCC 1A Maximum Fault with Closed Tie
MCC 1B Maximum Fault with Open Tie
MV SWGR Maximum Fault

The important thing to note is that you can't predict which operating scenario will result in the highest incident energy without evaluating all of the scenarios. The highest incident energy at some locations occurs with minimum fault and others with maximum fault, some with the tie closed and others with the tie open. The incident energy is affected by both the fault current and the trip time. The trip time is fixed for some levels of fault current and varies inversely at others. Using the arcing fault current rather than the bolted fault current also makes general predictions difficult.

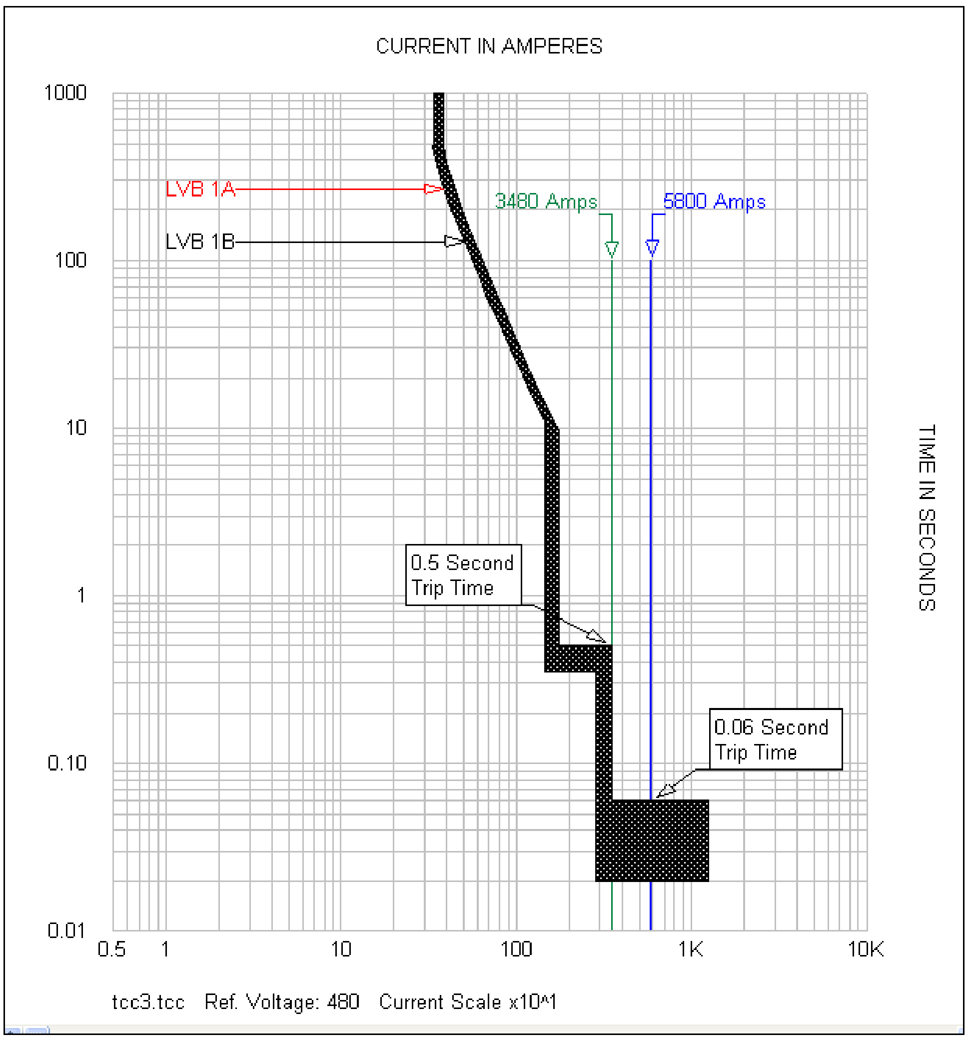
For a better understanding, lets look at why the results are higher for MCC 1B than they are for MCC 1A using the Maximum Fault with Bus Tie Open scenario.



Reviewing the datablock display on the one-line, you can see that the primary protection has the same settings for MCC 1A and MCC 1B. The only input difference is that cable C1-A is 100 feet long, whereas cable C1-B is 350 feet long. The cable length difference results in a smaller fault current at bus MCC 1B. Although the fault current is smaller, the incident energy is higher. To understand this situation, review of the coordination drawing is required.

Viewing the Arcing Fault current values on the following coordination drawing indicates the associated trip time for MCC 1A and MCC 1B. MCC 1A trips in 0.5 Seconds, whereas MCC 1B trip in 0.06 seconds. MCC 1A has less fault current but the longer trip time results in the release of more energy.

Notice that the TCC curve identifies 5800 Amps which is the calculated arcing fault current through breaker LVB 1A for a fault at MCC 1A. It also identifies 3480 Amps, which is the arcing fault current through breaker LVB 1B for a fault at MCC 1B. 5800 Amps results in a trip time of 0.06 seconds, whereas 3480 Amps results in a trip time of 0.5 seconds. Due to variations in the test data for arcing faults, the IEEE 1584 also recommends calculating the trip time and incident energy using both 100% and 85% of the calculated arcing fault current. In this case the 100% value produces a higher incident energy since the trip time for both 100% and 85% are the same. Quite often, the 85% arc fault produces higher incident energy if the trip time is longer for the lower fault current.



Bus Name	Protective Device Name	kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Class
MCC 1A	LVB 1A	0.48	9.34	8.75	5.80	0.06	0.000	Yes	PNL	25	18	18	1.18	Class 0
MCC 1B	LVB 1B	0.48	5.36	4.85	3.48	0.5	0.000	Yes	PNL	25	46	18	5.48	Class 2

Arcing Fault

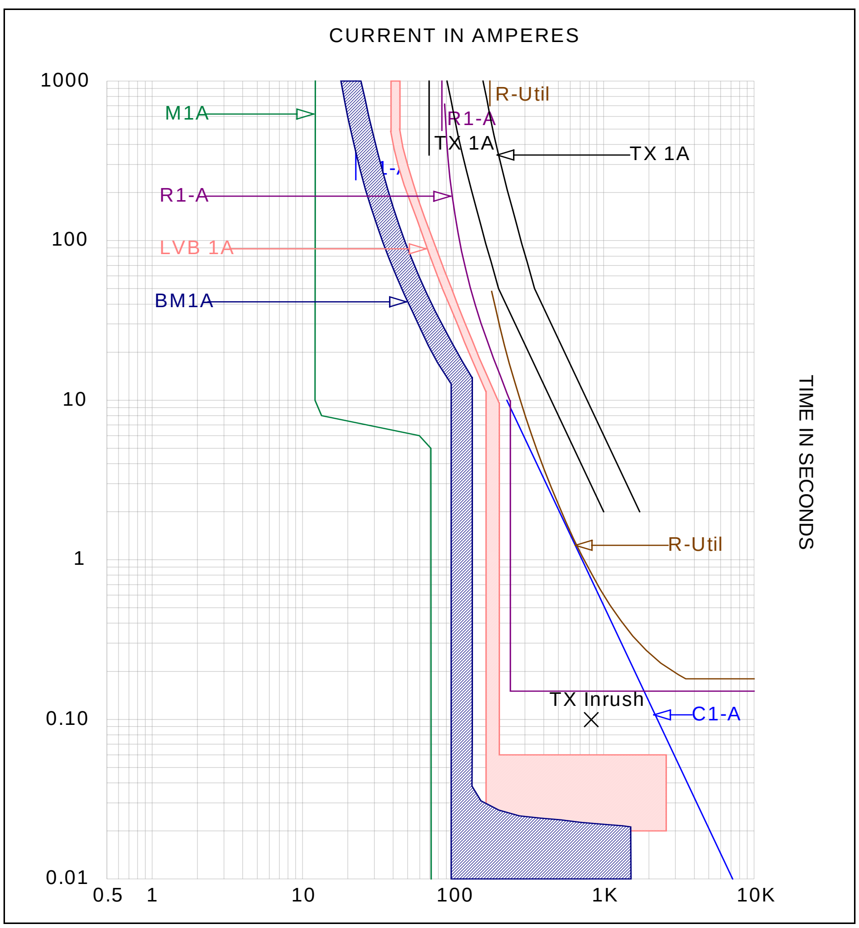
Trip Time

Incident Energy

The incident energy at bus MCC 1A is calculated to be 1.18 Calories/cm2 whereas the incident energy at bus MCC 1B is calculated to be 5.48 Calories/cm2. MCC1B has a lower arcing fault current (3.48 kA versus 5.8 kA) but the longer trip time (0.5sec. versus 0.06 sec.) results in higher incident energy.

The next step is to improve safety wherever possible. This means to clear the arcing faults as fast as possible and to document appropriate clothing requirements.

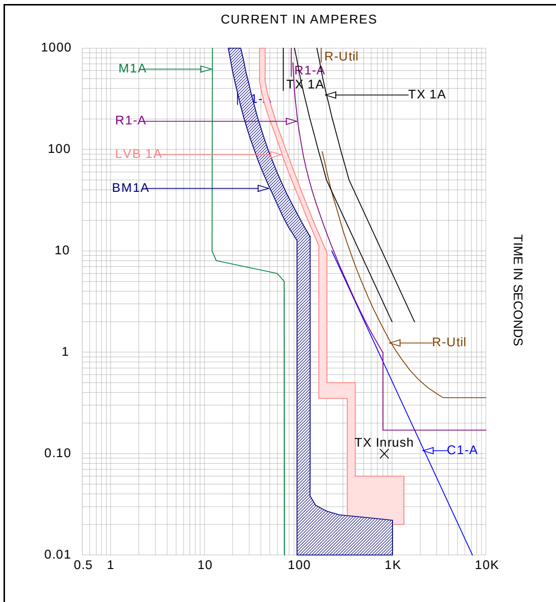
By reducing the instantaneous settings for breakers LVB 1A and LVB 2A, and by reducing the instantaneous time delay for relays R1-A and R1-B, as shown on the following TCC drawing, the trip times for the arcing fault currents are reduced significantly.



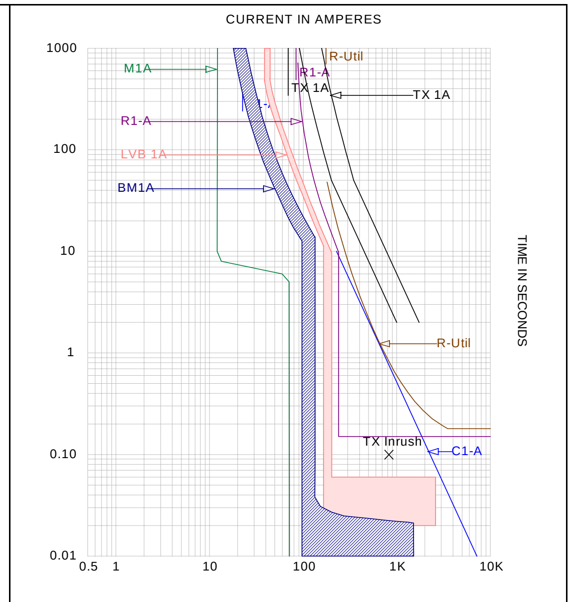
Arc Flash results after adjustments to protective device settings.

	Bus Name	Protective Device Name	kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Class
1	LV SWB A	R1-A	0.48	12.49	11.87	7.54	0.15	0.050	Yes	PNL	25	43	18	5.03	Class 2
2	LV SWB B	R1-B	0.48	12.47	11.87	7.54	0.15	0.050	Yes	PNL	25	43	18	5.03	Class 2
3	MCC 1A	LVB 1A	0.48	9.34	8.75	5.80	0.06	0.000	Yes	PNL	25	18	18	1.18	Class 0
4	MCC 1B	LVB 1B	0.48	5.36	4.85	3.48	0.06	0.000	Yes	PNL	25	13	18	0.71	Class 0
5															
6	MV SWGR	R-Util	4.16	42.60	42.47	40.21	0.179	0.083	No	SWG	102	562	36	17.3	Class 3

Comparison of protective device settings before and after changes.



BEFORE



AFTER

Comparison of Arc Flash Results for all scenarios using the PTW Scenario Data Visualizer.

BEFORE

Component	Field	Max Fault Open Tie	Max Fault Closed Tie	Min Fault Open Tie	Min Fault Closed Tie
LV SWB A	Energy (Cal/cm^2)	5.52	50.75	5.25	51.98
LV SWB B	Energy (Cal/cm^2)	5.52	50.75	5.24	51.98
MCC 1A	Energy (Cal/cm^2)	1.18	1.71	1.13	1.63
MCC 1B	Energy (Cal/cm^2)	5.48	0.82	5.26	0.79
MV SWGR	Energy (Cal/cm^2)	28.99	28.99	18.06	18.06

AFTER

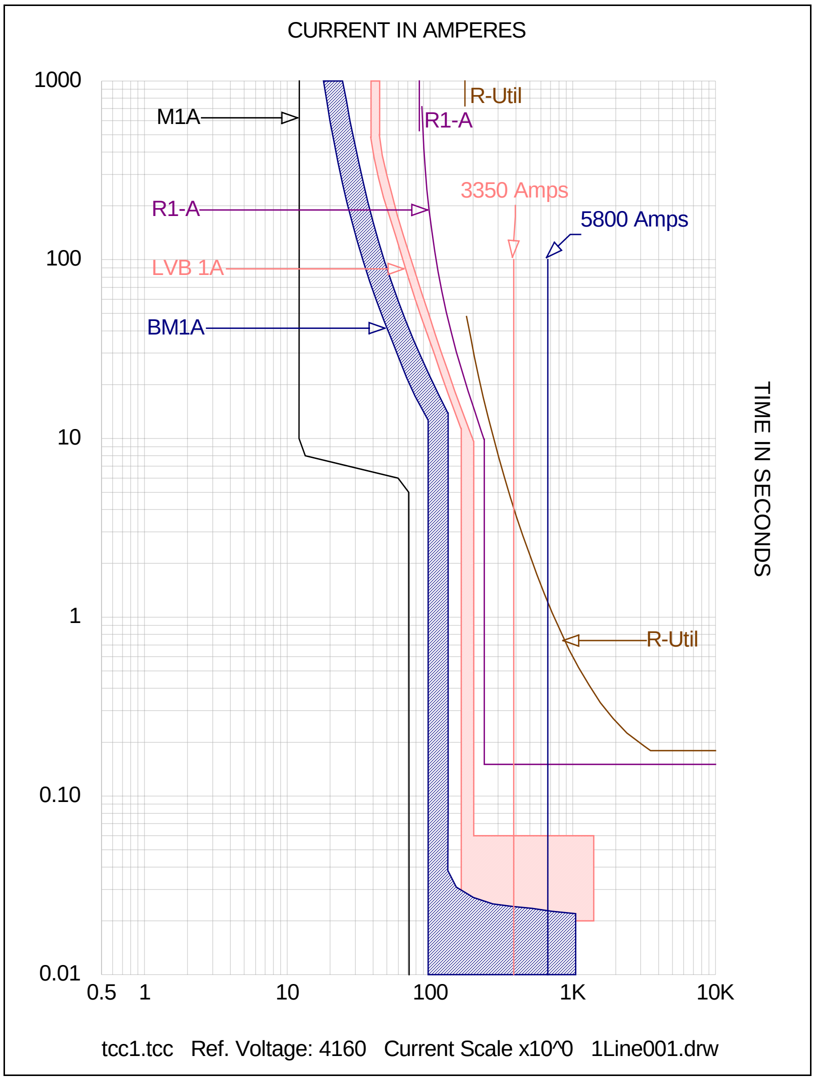
Component	Field	Max Fault Open Tie	Max Fault Closed Tie	Min Fault Open Tie	Min Fault Closed Tie
LV SWB A	Energy (Cal/cm^2)	5.03	9.27	4.78	8.69
LV SWB B	Energy (Cal/cm^2)	5.03	9.27	4.77	8.69
MCC 1A	Energy (Cal/cm^2)	1.18	1.71	1.13	1.63
MCC 1B	Energy (Cal/cm^2)	0.71	0.82	0.68	0.79
MV SWGR	Energy (Cal/cm^2)	17.33	17.33	10.80	10.80

Summary of Worst Case Before and After Protection Setting Changes

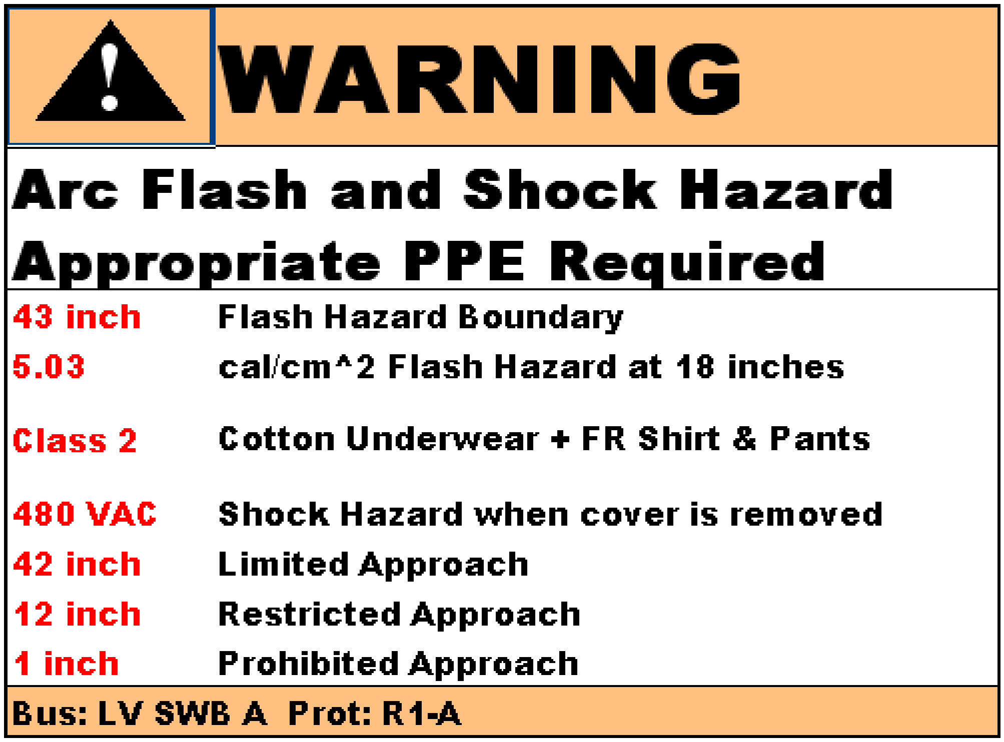
	BEFORE	AFTER
LV SWB A	51.98 cal/cm2	9.27 cal/cm2
LV SWB B	51.98 cal/cm2	9.27 cal/cm2
MCC 1A	1.71 cal/cm2	1.71 cal/cm2
MCC 1B	5.48 cal/cm2	0.82 cal/cm2
MV SWGR	28.99 cal/cm2	17.33 cal/cm2

After adjusting the protective device settings so that all of the devices operate in the instantaneous region for all configurations, the largest incident energy now occurs for the Maximum Fault with the Tie Closed, as expected.

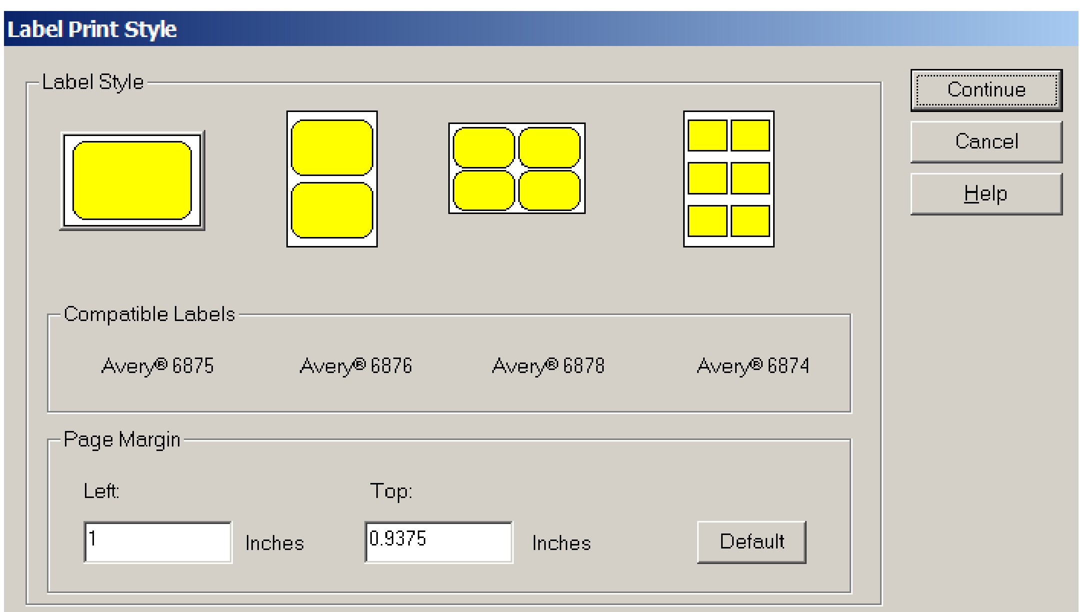
Given the same arcing fault current, the faster you can clear the fault, the lower your incident energy will be. This is why small changes in protective device settings can have a significant impact on the incident energy values, and a tolerance is recommended for available fault current and the estimated arcing fault values.



Once you're satisfied with the study results, you can print reports and labels.



You can print labels to plain paper or to label sheets in a variety of sizes.



A common practice is to print to plain paper and laminate.

Articles of Interest

Article II

The Other Electrical Hazard:
Electric Arc Blast Burns

Article II

The Other Electrical Hazard: Electric Arc Blast Burns

The Other Electrical Hazard
Electric Arc Blast Burns

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Abstract

Electric arc burns make up a substantial portion of the injuries from electrical malfunctions. The extremely high temperatures of these arcs, about four times as high as that of the sun's surface, can cause fatal burns at up to about five feet (152 cm.), and major burns at up to about ten feet (305 cm) distance. In this paper are developed information for evaluation of the degree of hazard involved with various voltages and capacity ratings of equipment, and outline of the required precautions and protective means to avoid injury from this source.

Introduction

Almost everyone is aware that electrical shock can be a hazard to life, although the minor shocks that many have experienced with no dire consequences tend to make one somewhat careless of this. There is another hazard which few appreciate, which we do not even need to touch to incur injury. This is the radiation burn from the fierce fire of electric arcs, due to short circuit developing from poor electrical contact or failure of insulation. The electric arc between metals is, next to the laser, the hottest thing on earth, or about four times as hot as the sun's surface. Where high arc currents are involved, burns from such arcs can be fatal where the victim is even several feet from the arc, and debilitating burns at distances of ten feet are common. Clothing is ignited at distances of several feet; this itself can cause fatal burns, because the clothing cannot be removed or extinguished quickly enough to prevent serious burns over much of the body skin area.

So all that is necessary is to be within about five feet or so from a severe power arc with bare skin or flammable clothing, to incur serious or fatal injuries. Electrical workers are frequently within these distances of energized parts, which can become involved in arc, so it is only the relative infrequency of such arcs which really prevents more injuries than now occur. Examples of this exposure are hook stick operation of medium voltage fuses, testing of cable terminals before grounding, or grounding before testing, or work in manholes near still energized cables.

Electric arcing is the term applied to the passage of substantial electric currents through what had previously been air. But air is not the conductor; current passage is through the vapor of the arc terminal material, usually a conductor metal or carbon. Contrasted with current flow through low pressure gases such as neon, arcing involves high temperatures of up to or beyond 20,000 K (35,000°F) at the arc terminals. These temperatures are not withstandable by any materials known on earth; all are not only melted, but vaporized. Actually, 20,000°K is about four times as hot as the surface temperature of the sun.

Nature of Arcs

Subsequent to its initiation, by flashover or from the introduction of some conductive material, an arc is the flow of current through a path consisting of the vapor of the terminal material. This vapor has substantially higher resistance than the solid metal, to the extent that voltage drop in the arc ranges between 75 and 100 volts per inch, several thousand times its drop in a solid conductor. Since the inductance of the arc path is not appreciably different from that of a solid conductor of the same length, the arc current path is substantially resistive in nature, yielding unity power factor. (Voltage drop in a faulted large solid or stranded conductor is about 0.5 to 1 volt per foot, 0.16 to 0.32 V/cm.)

For low voltage circuits, the arc, at 75 to 100 V/in. length, consumes a substantial portion of the available voltage, leaving only the difference between source voltage and arc voltage to force the fault current through the total system impedance, including that of the arc. This is the reason for the "stabilization" of arc current on 277/480 volt circuits when the arc length is of the order of four inches (bus spacing, etc.)

For higher voltages, the arc lengths can be substantially greater, say 1 in. (2.54 cm) per 100 volts of supply, before the system impedance starts to regulate or limit the fault current. Note that the arc voltage drop and the source voltage drop add in quadrature, the former resistive, the latter substantially reactive. Thus, the length, or size, of arcs in the higher voltage systems, can be greater, so can readily bridge the gap from energized parts to ground or other polarities with little drop in fault current.

The Arc as a Source of Heat

The electric arc is widely recognized as a very high level source of heat. Common uses are arc welding and electric arc furnaces, even electric cauterizing of wounds to seal against infection while deeper parts are healing. The temperatures of metal terminals are extraordinarily high, being reliably reported to be 20,000°K (about 35,000°F). (1) One investigator reports temperatures as high as 34,000°K, and special types of arcs can reach 50,000°K. The only higher temperature source known on earth is the laser, which can produce 100,000°K.

The intermediate (plasma) part of the arc, the portion away from the terminals, the "shank" of the dog-bone, figuratively, is reported as having a temperature of 13,000°K. In comparison, the surface temperature of the sun is about 5,000°K, so the terminal and plasma portions are four and 2-1/2 times, respectively, as hot as the sun's surface. (Temperature below the surface of the sun is, of course, much higher, such as 10,000,000°K at the center.)

Heat transfer from a hotter to a cooler object is a function of the difference between the fourth powers of their absolute temperatures:

$h = C \times 3.68\ (T_e^4 - T_a^4) \times 10^{-11}$ - Eq. 1 [2]

where h = heat transfer, w/sq. in.
w/6.45 sq. cm
C = absorption coeff. of absorbing surface
T_e = absolute temp. of emitting surface, °K
T_a = absolute temp. of absorbing surface, °K

This relationship is useful when the two bodies are large in extent, and relatively close together, so that little heat is lost from edge effects. It is much more useful for purposes of this study to separate this into two elements:

1. The total heat emanating from the source.
2. The proportion of this heat absorbed by unit area of the absorbing object. This is inversely proportional to the square of the distance of separation, similar to light from a central source.

The heat generated by a source per unit of surface area is:

$h = 3.68 \times T^4 \times 10^{-11}$ w/sq. in - Eq. 2 [2]

$= 0.571 \times T^4 \times 10^{-11}$ w/sq. cm

The temperature is known, but not the area of the source; this will be developed subsequently.

To find the heat received by an object, per unit area, we need to know:

Q_s = heat emitted from the source, per unit area
A_s = total surface area of the source
r = distance from center of source to object
A_o = projected surface area of the object along a plane normal to the source-to-object direction
Q_o = heat absorbed by projected surface of object

From these, the following relationship is obtained:

$Q_o = [(Q_s A_s)/(4\pi r_s^2)][A_o]$

Figure 1 is useful in visualizing this relationship. In English, this is saying that the heat received per unit projected area of the object is the heat radiated per unit area of the source times the surface area of the source, divided by 4π times the square of the radius from source to object. This is the same

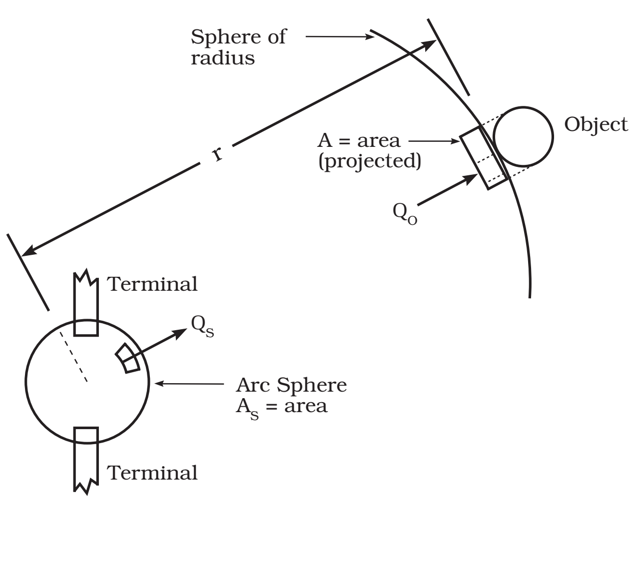


Figure 1
Illustration of Arc Source
and heat-receiving object.

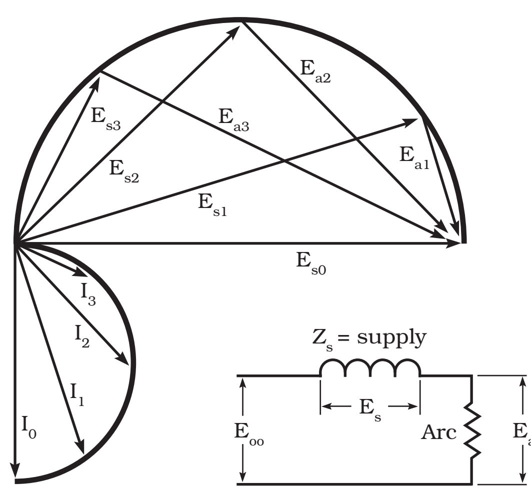


Figure 2
Vector Diagram of
Voltages and Currents, with
division between
Source Arc Drops as
Arc Length is Varied.

as saying the heat received by the earth from the sun is the total heat output of the sun times the earth's projected surface area on a sphere of radius equal to the sun-to-earth distance. The absorption coefficients enter into these relationships.

For portions of the receiving object which are not at right angles to the source-object radius, the surface heat density needs to be multiplied by the cosine of the angle between the surface and the direction of the source. (For 90°, this multiple is 1.)

Whether the surface is a number of channels or any other shape is not important, only that it has the required area. For simplicity, we will consider it is a sphere, and will have a diameter which gives the specific surface area. Thus, the diameter of the sphere will be a function of the square root of the arc wattage.

Development of Arc Size

In a bolted fault, there is no arc, so there will be little heat generated there. Should there be appreciable resistance at the fault point, temperature there could rise to the melting and boiling point of the metal, and an arc would be started. The longer the arc becomes, the more of the available system voltage will be consumed in it, so there will be less voltage available to overcome the supply impedance, and the total current will decrease.

This is illustrated in Figure 2. The system has rated voltage E_{oo}, and total impedance to the fault of Z_s. Four arc conditions are shown, one of zero length (bolted fault), one of short length (sub. 1), one of moderate length (sub. 2) and one of greater length, (sub. 3). Since the arc impedance is almost purely resistive, and that of the supply system almost purely inductive, the voltage drops across arc and supply system are in quadrature for all arc lengths. The locus of the intersection of the vectors of supply voltage drop (E_s) and arc voltage drop (E_a) is a semicircle with diameter of E_{so}, the supply system drop for a bolted fault, also equal to E_{oo}. For this range or arc lengths, the total current is represented by current vectors I_o, I_1, I_2, and I_3, all at right angles to the corresponding E_s's. The magnitude of the I vectors is proportional to that of the E_s vectors, since they are related by the constant Z_s, ($I = E_s/Z_s$).

The total energy in the arc, then, is the product of E_a and I. This is zero for the bolted fault, appreciable for condition 1,very substantial for sub. 2, then decreasing for condition sub. 3, where the arc voltage increases only moderately while the current decreases substantially. Also, somewhere in the region of sub. 2 - sub. 3, the length of the arc may become so long that the arc is self-extinguishing, or at least self-stabilizing at a low current level. This would be the condition in burn-down of 480/277 V buses with wide spacing, where the arc current stabilizes at about 1500 A for 4" (10 cm) p-g spacing at 277 V.

Table I
Maximum Power in 3Ø arc, MW

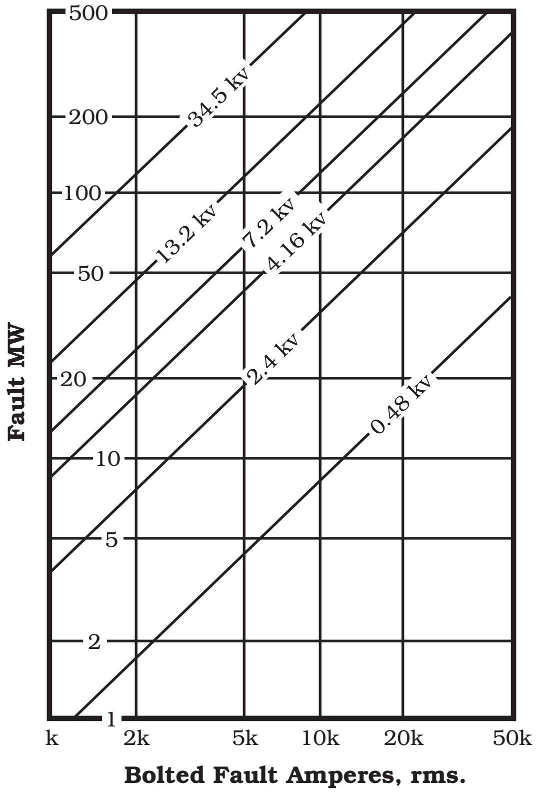
Bolted Fault kA	System Voltage, kV					
	0.48	2.4	4.2	7.2	13.2	34.5
1	0.42	2.0	3.6	6.3	11.4	29.8
2	0.83	4.2	7.2	12.5	22.8	59.6
3	1.25	6.2	10.8	18.7	34.8	91.0
5	2.08	10.3	18.0	31.2	57.1	149.2
10	4.15	20.8	36.0	62.3	114.2	295.5
15	6.23	31.1	54.0	93.4	171.3	447.7
20	8.3	41.5	72.0	120.5	228.3	596.7
30	12.5	62.2	108.0	186.8		
40	16.6	83.0	144.0			
50	20.8	103.8	180.0			

Table II
Diameter of Arc Sphere re; arc Power

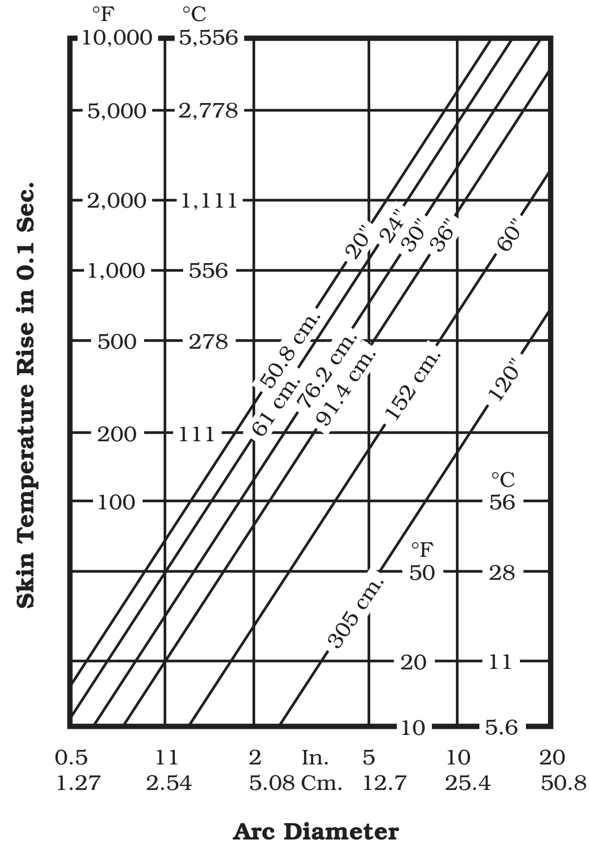
Arc Power MW	Surface Area Sq. In.	Sphere Dia.	
		In.	cm.
0.25	0.415	0.363	0.922
0.5	0.829	0.514	1.308
1.0	1.65	0.725	1.84
2.5	4.15	1.14	2.90
5.0	8.29	1.62	4.11
7.5	12.44	1.99	5.05
12.5	20.73	2.57	6.55
25	41.46	3.63	9.22
50	82.92	5.14	13.06
75	124.38	6.29	15.98
100	165.84	7.27	18.47
150	248.76	8.88	22.56
250	414.60	11.49	29.18
500	829.20	16.1	40.89

Table III
Temperature Rise in Skin in 0.1 Sec.

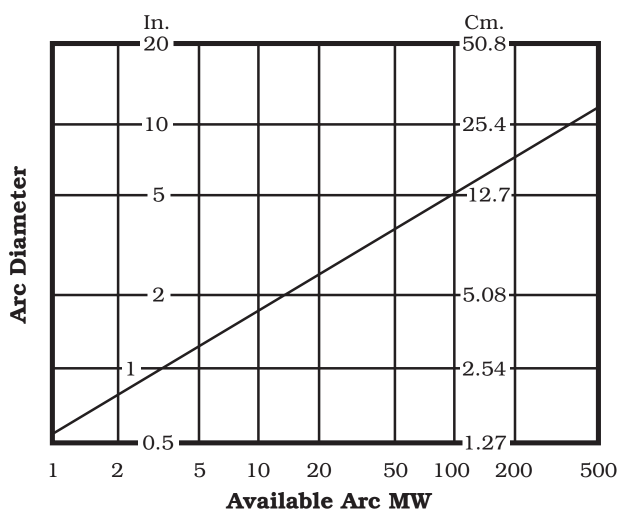
Arc Sphere Diameter		Distance from Center					
In.	cm	20" 50.8 cm	24" 61	30" 76.2	36" 91.4	60" 152	120" 305 cm
1	2.54	34°C 63°F	24 43	15 27	11 19	4 7	1°C 2°F
2	5.08	138°C 249°F	96 173	61 111	43 77	16 28	4°C 7°F
3	7.62	310°C 557°F	215 387	138 248	96 172	34 62	9°C 16°F
4	10.2	549°C 988°F	381 686	244 439	170 305	61 110	15°C 28°F
6	15.2	1230°C 2214°F	854 1537	547 983	380 633	137 245	34°C 62°F
8	20.3	2196°C 3953°F	1525 2745	976 1756	678 1220	244 439	61°C 110°F
10	25.4	3425°C 6167°F	2379 4282	1523 2739	1058 1903	381 695	95°C 172°F
12	30.5	4941°C 8894°F	3431 6176	2196 3951	1526 2745	549 987	137°C 248°F
16	40.6	8740°C 15733°F	6069 10925	3885 6989	2699 4840	971 1745	242°C 439°F



Curve 1
Bolted Fault Amperes, Rms



Curve 3
Skin Temp. Rise in 0.1 Sec.
for Various Distances



Curve 2
Arc Diameter Determination

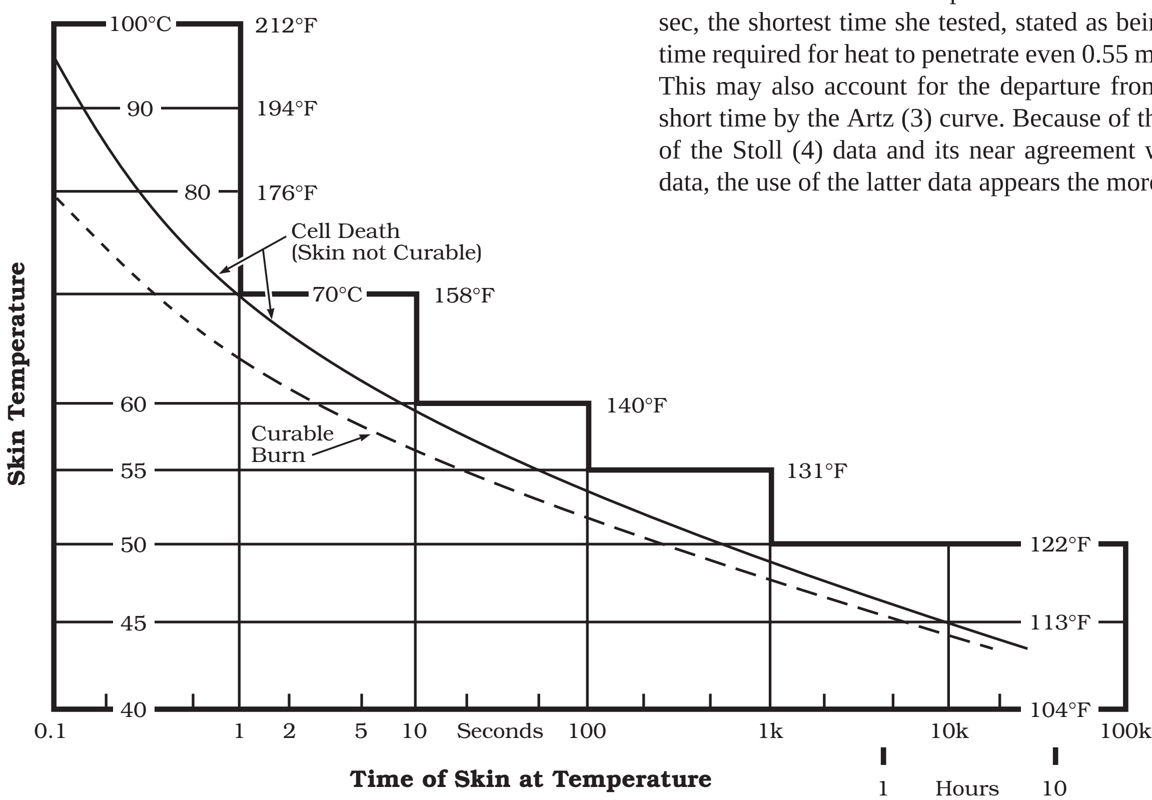
It has been found that condition 2, where the arc voltage drop equals the supply system drop, yields the maximum arc wattage condition. Here, the arc voltage drop is 70.7% of the supply voltage, and the current is 70.7% of the bolted fault level. These are in phase, so the product is pure power, even though the system power factor is 45° lagging at the time, due to the supply system impedance of 0 pf. Under these conditions the maximum arc wattage is 0.707^2 of 0.5 times the maximum kVA bolted fault capability of the system at that point.

Thus, it may be seen that the maximum arc energy in watts is 0.5 times the maximum bolted fault VA at a given point. There will be lower arc energies than this, but there is no way to predict them. Just as in shock hazard, one must base arc blast hazard possibility on the maximum possible conditions. So a judgement on the wattage of a possible arc will be the system voltage times one-half the maximum bolted fault current. Our hazard possibility then, is readily calculable for the complete range of system voltages and available bolted fault currents, determining the arc wattage, the size sphere this represents, and the temperature rise per unit time in a unit surface at the full range of distances from the arc. These calculations have been carried out in preparation of Tables I, II, and III, and Curves 1, 2, and 3. These do not take into account the heat which is reflected from the flesh, as dependent on the coefficient of absorption of skin. When white skin is light-colored and clean, this absorption coefficient is about 0.5, but when it is dirty or dark, the coefficient is nearly unity. Also, the calculations do not take into account heat reflected from surfaces near the arc; this additional heat from reflection from other surfaces plus the likelihood that the skin may be dirty or dark is the reason for omitting this factor.

This reflectance factor is useful in choosing personnel protective equipment; if this equipment is colored very white, it will reflect about 90% of the radiant heat of this nature it is exposed to, so will absorb a much smaller quantity for conduction to the wearer. Note that this is for radiant heat from sources above 3500°K only, however, not the normal flame type heat sources. Even with non-heat-protective clothing, then lighter colors will absorb less heat, and will therefore give more protection.

This could also be done without regard to the "Sphere and the Arc" concept and dimension. By considering the total power in the arc to be absorbed by a layer of human epidermis at the respective surface of a sphere at the various radii, the results would be calculable by determining the temperature rise of a hollow sphere of wall thickness of 1/16" (the average skin thickness) and a radius of the respective distances from the center of the source, for the range of arc power being considered.

Curve 4
Time - Temperature Relationship
Human Tissue Tolerance



Effect of Temperature on Human Tissue and Clothing

The human animal can exist in only a relatively narrow range close to normal blood temperature, 97.7°F of 36.5°C. Much below this level requires insulation with clothing, and slightly above this level can be compensated for by perspiration. Artz (3) shows that at as low skin temperature as 44°C, 110°F, the body temperature equilibrium mechanism begins to break down in about six hours, so cell damage can occur beyond six hours at that temperature. Between 44 and 51°C, the rate of cell destruction doubles for each 1°C temperature rise, and above 51°C the rate is extremely rapid. At 70°C, only one second duration is sufficient to cause total cell destruction. Curve 4 shows the relationship between time to cell death and temperature, according to Artz (3). A second, lower line in Curve 4 shows the time-temperature curve of a curable burn. The extrapolation of available data to times below 1 sec indicates that any tissue temperature of 96°C and above for 0.1 second will cause incurable burns.

Stoll (4) agrees quite well in the region from 44 to 50°C, but uses the rate applicable to this interval to extrapolate linearly on log-log scales for higher temperatures and shorter times. Actual tests show departure from linearity at about 6 sec, the shortest time she tested, stated as being due to the time required for heat to penetrate even 0.55 mm or 1/50 in. This may also account for the departure from linearity in short time by the Artz (3) curve. Because of the limitations of the Stoll (4) data and its near agreement with the Artz data, the use of the latter data appears the more reasonable.

So the portion of Curve 3 above 96°C, 205°F represents total destruction of the tissue directly exposed. Re-casting the intercepts of that line back into Curve 1, it is seen that the danger points for 36 in (91 cm) spacing (radius) of the various voltages are:

Table IV
Max Transformer Ratings for Non-fatal
Skin Burn, Various Voltages, 36“ Rad.

Transformer kV	Bolted Fault Cur. Avail.	Std. Transf. Rating, MVA
0.48	40,000 A	1.9
2.4	8,000	1.83
4.2	4,200	1.75
7.2	2,600	1.75
13.2	1,400	1.75
34.5	536	1.75

Table V
Distance-Capacity of Source
for Hazardous Burn at 0.1 Second.

Distance		MVA Rating of Source all Voltages
In	Cm	
20	50.8	0.54
24	61.0	0.78
30	76.2	1.21
36	91.4	1.75
60	152.4	4.86
120	304.8	19.4

The uniformity of capacity rating for the range of voltages is most interesting. It should be remembered that this is applicable to the uniform separation distance of 36", 91.4 cm, and will vary directly with the square of the separation distance ratio to that distance. Normally, the customary spacing varies directly with the voltage of the equipment. One would approach a 480 volt equipment much more closely than one of 34.5 kV. However, the burn hazard is proportional to arc KW (source kVA), so we can interrelate kVA of source with distance at which hazardous burning could occur as in Table V.

Table VI

Critical Burn Distances from Transformer Secondary Lines

Expanding on equations 5 and 7 of the original technical paper, Table V, the reverse of Table IV interrelates transformer MVA rating and distances for just curable and just fatal burns.

Transformer MVA	Distance for Burn From 0.1 Sec. Arc — Just Curable		Just Fatal	
	D_c Ft.	D_c In.	D_f Ft.	D_f In.
0.3	1.01	12.12	0.82	9.8
0.5	1.30	15.6	1.06	12.7
0.75	2.00	23.0	1.63	19.5
1.0	2.30	27.6	1.87	22.5
1.5	2.82	33.8	2.29	27.5
2.0	3.26	39.1	2.65	32
3.0	3.99	48	3.24	39
5.0	5.15	62	4.18	50
10	7.28	87	5.91	71

For times other than 0.1 seconds, the distance should be multiplied by the square root of the ratio of actual time to 0.1 second.

No specific criteria exist for relating D_C to 1° and 2° burns, but distance ratios of 6 and 3 for these two "grades" may be estimated.

Arc Flash Specification

1.01 OBJECTIVE

A. The purpose of this project is to provide a complete arc flash program for **XYZ Company** to help protect individuals working on its premises from electrical arc flash hazards. These individuals may include any workers who inspect, maintain or operate energized electrical equipment.
B. The program shall bring **XYZ Company** into compliance with the applicable standards for new installations (NEC) and for worker safety in operating facilities (OSHA 29 CFR 1910, NFPA 70E-2004).
C. The program shall assist **XYZ Company** with improving the reliable operation of the electrical system.

1.02 PROJECT SCOPE

A. System Data

The supplier shall provide an up to date electrical system single-line diagram as required by NFPA 70E, 2004 Edition, “Standard for Electrical Safety in the Workplace”, as referenced in OSHA 29 CFR 1910 Subpart S, Appendix A. This information shall include nameplate data for electrical components (e.g. transformers, medium voltage switchgear, panelboards, switchboards, motor control centers, etc.) for all portions of the electrical system from the utility intertie through the lowest rated panel.

Cable sizes, types and lengths between electrical equipment components and up to date utility source data shall be provided for an accurate single-line representation of the electrical system. Unique characteristics of the equipment installation shall be provided which may impact the magnitude of the potential hazard (e.g. open space versus enclosure). Overcurrent device settings shall be verified.

Data collection may require removal of barriers, opening of front panels, etc. while equipment is energized. The supplier must provide proof (written documentation) that its employees working on the premises of **XYZ Company** have been properly trained in the use and application of personal protective equipment (PPE) and the hazards of working on or near energized equipment. The supplier must provide its own PPE protection with a minimum arc thermal performance rating (ATPV) of 40 calories/cm^2.

B. System Analysis

A comprehensive analysis of **XYZ Company**’s electrical system shall be performed for all equipment 480 volt and higher and 240 volt served by a 125kVA or larger transformer based on the up to date single-line diagram provided from “Section A”. This analysis shall include the following:

1. Short Circuit Study – A short circuit analysis shall be performed in accordance with ANSI standard C37 and IEEE standard 141-1993 (Red Book) for each electrical component as defined in “Section A. “
2. Coordination Study – A coordination study shall be performed in accordance with IEEE 242-2001 “Buff” to determine the proper overcurrent device settings that will balance system reliability through selective coordination while minimizing the magnitude of an electrical arc flash hazard incident.
3. Incident Energy Study – An incident energy study shall be done in accordance with the IEEE 1584-2004a, ”IEEE Guide for Performing Arc Flash Hazard Calculations” as referenced in NFPA 70, “Standard for Electrical Safety in the Workplace”, 2004 Revision, in order to quantify the hazard for selection of personal protective equipment (PPE). Tables that assume fault current levels and clearing time for proper PPE selection are not acceptable.

The supplier shall assist **XYZ Company** in selecting appropriate combinations of PPE prior to the final analysis and preparation of equipment labels.

C. Design Review

The supplier shall assist **XYZ Company** with system design adjustments to optimize the results of the study as it relates to safety and reliable electrical system operation (e.g. overcurrent device settings, working distances, current limiting devices). This includes mitigation, where possible, of incident energy levels that exceed 40 calories/cm^2. A qualified engineer with power systems design experience shall provide this assistance.

D. Study Report

The supplier shall supply a comprehensive report that includes:

- Report summary with analysis methodology, findings and recommendations
- Summary of input data for utility source, equipment and cables
- Available fault current at each equipment location with comparison to equipment rating
- Overcurrent device settings (e.g. pick-up, time delay, curve), “as found” and “as recommended”
- Incident energy level (calories/cm^2) for each equipment location and recommended PPE
- Overcurrent device coordination curves including related section of the single-line diagram
- Complete system single-line diagram for the system analyzed

E. Labels

Based on the results of the incident energy study, the supplier shall produce and install a warning label (orange $\leq$40 cal/cm^2) or danger label (red > 40 cal/cm^2) for each piece of equipment as specified in “Section A” in accordance with ANSI Z535.4-2002. The label must be readable in both indoor and outdoor environments for at least 3 years and contain the following information:

- Arc hazard boundary (inches)
- Working distance (inches)
- Arc flash incident energy at the working distance (calories/ cm^2)
- PPE category and description including the glove rating
- Voltage rating of the equipment
- Limited approach distance (inches)
- Restricted approach distance (inches)
- Prohibited approach distance (inches)
- Equipment/bus name
- Date prepared
- Supplier name and address

F. Equipment Verification/Operation

The validity of the arc flash study and incident energy readings is in part based on proper setting of overcurrent device trip times and the proper operation of the overcurrent devices and breakers themselves. The supplier shall verify proper operation of overcurrent devices and breakers at the request of **XYZ Company** using InterNational Electrical Testing Association (NETA) qualified technicians.

The supplier shall be capable of adjustment, maintenance, repair or replacement of overcurrent devices or breakers as required to support the performance of the electrical system in line with the expectations of the system study.

G. Safety Training

The supplier shall provide **XYZ Company** one day of arc flash safety training that contains the requirements referenced in OSHA 1910.269, OSHA 1910 Subpart S and NFPA 70E. This shall include:

- Proper use of the system analysis data

- Interpretation of hazard labels
- Selection and utilization of personal protective equipment
- Safe work practices and procedures

The supplier shall provide **XYZ Company** an outline of the one day training course including training materials at time of quotation. **XYZ Company** at its discretion may require additional training customized to its specific needs. The supplier shall be capable of developing and presenting customized training for approval as required.

The supplier shall provide a training certificate to record satisfactory completion by **XYZ Company** employees for continuing education credits and re-licensing requirements. Satisfactory completion is defined as the student obtaining a minimum of 70% on the post training examination and the ability to work safely if a hands on performance evaluation is provided

H. Safety Documentation/Policy

At the request of **XYZ Company**, the supplier shall integrate the results of the system study and design review into the safety manual of **XYZ Company** in compliance with OSHA CFR 29 1910.333. The supplier shall assist **XYZ Company** at its request to develop a safety policy with corresponding documentation and procedures including information gained in the system analysis. This includes electrical safety, procedures for mitigation of arc hazards, PPE selection based on specific equipment of **XYZ Company**, task and training requirements.

1.03 QUALITY ASSURANCE

A. The supplier shall provide all necessary material, equipment, labor, and technical supervision to perform the arc flash hazard analysis as described herein.

B. The supplier shall utilize engineers and technicians that are experienced and regularly perform electrical power system testing.

C. Personnel performing the arc flash analysis shall be trained and experienced in accordance with NETA Training Specifications concerning the apparatus and systems being evaluated. These individuals shall be capable of conducting the tasks of the analysis in a safe manner and with complete knowledge of the hazards involved.

1.04 SAFETY AND PROCEDURAL REQUIREMENTS

A. The supplier must provide proof (written documentation) that its employees working on the premises of **XYZ Company** have been properly trained in the use and application of personal protective equipment (PPE) and the hazards of working on or near energized equipment. The supplier must provide its own PPE protection with a minimum arc thermal performance rating (ATPV) of 40 calories/cm^2.

B. Safety practices that shall be followed include, but are not limited to, the following:
- Occupational Safety and Health Act
- *Accident Prevention Manual for Industrial Operations*, National Safety Council
- Applicable state and local safety operating procedures
- Owner’s safety practices

C. Perform all work in accordance with the applicable codes and standards of the following agencies except as provided otherwise herein:
1. InterNational Electrical Testing Association – NETA ATS latest Edition: Acceptance Testing Specifications, and/or NETA MTS latest Edition: Maintenance Testing Specifications.
2. National Fire Protection Association – NFPA
   a. ANSI/NFPA 70: National Electrical Code
   b. ANSI/NFPA 70B: Recommended Practice for Electrical Equipment Maintenance
   c. NFPA 70E: Electrical Safety Requirements for Employee Workplaces

Arc Flash Hazard
Design, Maintenance and Operation Process Checklist

				Yes	No	Don't Know
1-1 DESIGN						
1-1.1	Arc Flash Design Review	1-1.1.1	Has a design review been conducted to identify potential areas to reduce hazards including fault levels, exposure times, remote operations, remote racking, and system grounding?	❑	❑	❑
		1-1.1.2	Have protective devices been tested/checked to verify performance per study?	❑	❑	❑
		1-1.1.3	Is there a procedure in place to assure studies are updated and testing is performed when system or utility supply changes are made?	❑	❑	❑
1-1.2	Documentation	1-1.2.1	Is your Arc Flash Hazard plan documented? Does the documentation include the results of the arc flash analysis, updated single-line diagrams, signs and labels on equipment and at hazardous areas? Do all labels include the type, name/ID, incident energy at working distances, flash protection boundary, hazard/risk category, and arc flash training?	❑	❑	❑
		1-1.2.2	Are all single-line diagrams up-to-date reflecting any modification or expansions to your electrical distribution system or any changes in the electric utility system?	❑	❑	❑
		1-1.2.3	Do you have a documented method for maintaining required Personal Protective Equipment?	❑	❑	❑
2-1 OPERATIONS						
2-1.1	Safety	2-1.1.1	Does your safety program include a certified training program including awareness of electrical hazards?	❑	❑	❑
		2-1.1.2	Does your safety program identify hazard / risk evaluation procedures, electrically safe work procedures, tools and PPE, and electrical safety principles?	❑	❑	❑
		2-1.1.3	Do you have appropriate safety procedures in place to minimize dangers where exposure cannot be avoided?	❑	❑	❑
		2-1.1.4	Do you have a formal record keeping process for documenting accidents and near misses?	❑	❑	❑
		2-1.1.5	Is there a process in place that ensures actions will be taken to update procedures or take other corrective action when an accident or near miss occurs?	❑	❑	❑
		2-1.1.6	Do workers comply with manual procedures?	❑	❑	❑
		2-1.1.7	Is there a periodic audit of workers to confirm compliance with safety manual procedures?	❑	❑	❑
2-1.2	Training	2-1.2.1	Do you have an effective arc flash training program? Does it provide workers the knowledge and understanding of the existence, nature, causes, and methods to prevent electrical hazards?	❑	❑	❑
		2-1.2.2	Does your arc flash training program include training on arc flash awareness, standards and codes, understanding of arc flash quantities, selection and use of appropriate PPE, reading and following warning signs and labels, methods to reduce risk while working on live exposed parts, and arc flash hazard assessment?	❑	❑	❑

				Yes	No	Don't Know
2-1 Operations						
2-1.2	Training	2-1.2.3	Is there a process in place that ensures the training program is periodically reviewed to identify needed changes?	❑	❑	❑
		2-1.2.4	Have all personnel working on or near energized equipment undergone specific training in the hazards of working on energized equipment, and the use and proper application of PPE?	❑	❑	❑
		2-1.2.5	Do training records exist?	❑	❑	❑
2-1.3	Labeling	2-1.3.1	Does all electrical equipment that may remain energized during maintenance or repair post a warning label in compliance with the National Electrical Code 110.16?	❑	❑	❑
2-1.4	Personal Protective Equipment	2-1.4.1	Do you have a personal protective equipment plan?	❑	❑	❑
		2-1.4.2	Does the plan address all OSHA standards regarding PPE?	❑	❑	❑
		2-1.4.3	Does the plan cover how PPE should be worn, maintained, and disposed of after the equipment life has expired?	❑	❑	❑
		2-1.4.4	Is there a process in place to ensure PPE requirements are updated when system or utility supply changes are made?	❑	❑	❑
2-1.5	Regulatory Compliance	2-1.5.1	Does your arc flash hazard program address all regulatory requirements imposed by NFPA 70E 2004, The National Electrical Code 110.16, IEEE 1584 and OSHA 1910.132(d), and 1926.28(a)?	❑	❑	❑
		2-1.5.2	Do you have an established process for updating Arc Flash Hazard programs as new information becomes available?	❑	❑	❑
3-1 MAINTENANCE						
3-1.1	Electrical Preventive Maintenance Program	3-1.1.1	Does your preventive maintenance program specifically address arc flash hazards?	❑	❑	❑
		3-1.1.2	Is the program being followed rigorously?	❑	❑	❑
		3-1.1.3	Is there a procedure in place that updates the program based on changes to plant equipment or processes?	❑	❑	❑

Item Details

Safety & Security > Arc Flash Protection > Clothing and Accessories

Hood,Arc Flash,11 Cal

Hood, Arc Flash, Size One Size Fits All, Navy Blue Color, Arc Rating 11 Cal/Cm2, Material Flame Resistant Cotton, Single Layer 9 oz/yd2, Wide Arc Rated Anti Fog Lens, Amber Lens Color, Flame Resistant Thread, Viewing Area 10 x 20 In, Standards ASTM F1506 and NFPA 70E, Provides Excellent Comfort and Mobility for Industrial and Utility Workers, Includes Universal Hard Hat Bracket

Grainger Item #	5EU30
Price (ea.)	**$240.00**
Brand	SALISBURY
Mfr. Model #	FH11BL
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	2.15
Usually Ships**	1-3 Days
Catalog Page No.	2635

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Tech Specs | Additional Information | Notes & Restrictions | MSDS | Required Accessories | Optional Accessories | Alternate Products | Repair Parts

Item	Hood
Type	Arc Flash
Garment Style	Pro-Hood (R)
Size	One Size Fits All
Color	Navy Blue
Arc Rating	11 Cal/cm sq.
Material	Flame Resistant Cotton, Single Layer 9 oz/yd2
Lens	Wide Arc Rated Anti Fog
Lens Color	Amber
Thread	Flame Resistant
Viewing Area (In.)	10 x 20
Standards	ASTM F1506 and NFPA 70E
Application	Provides Excellent Comfort and Mobility for Industrial and Utility Workers
Includes	Universal Hard Hat Bracket

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Item Details

Safety & Security > Hand Protection > Insulating Gloves, Protectors, Sleeves

GLOVE,LINEMANS,PR

Linemans Glove, Size 9, Class 0 Rubber, 11 Inches Length, 1000 VAC, Pair

Grainger Item #	4T488
Price (pr.)	**$50.40**
Brand	SALISBURY
Mfr. Model #	E011B
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	0.65
Usually Ships**	Today
Catalog Page No.	2615

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Also Consider

GLOVE,LINEMANS,PR
Brand: SALISBURY
Grainger Item #: 4T489
Price (pr.): $50.40
Qty.
Add to Order

Tech Specs | Additional Information | Notes & Restrictions | MSDS | Required Accessories | Optional Accessories | Alternate Products | Repair Parts

Item	Glove
Size	9
Material	Rubber
Length	11
Color	Solid Black
Characteristics	Cement Dipped to Protect Wearer Against Electrical Shock while Working Around Energized Systems
Test Condition	Every 6 Months in Accordance with ASTM F496
Standards	ASTM D 120

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Item Details

Safety & Security > Arc Flash Protection > Clothing and Accessories

Coverall,Arc Flash,L

Coverall, Arc Flash, Size Large, Navy Blue Color, Arc Rating 8 Cal/Cm2, Chest Size 42-44 In, Inseam 30 In, Material Flame Resistant Cotton, Flame Resistant Thread, Standards ASTM F1506 and NFPA 70E, Provides Excellent Comfort and Mobility for Industrial and Utility Workers

Grainger Item #	5EU57
Price (ea.)	**$145.95**
Brand	SALISBURY
Mfr. Model #	ACCA8BL-L
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	2.25
Usually Ships**	1-3 Days
Catalog Page No.	2635

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Qty.

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Tech Specs | Additional Information | Notes & Restrictions | MSDS | Required Accessories | Optional Accessories | Alternate Products | Repair Parts

Item	Coverall
Type	Arc Flash
Garment Style	Coveralls
Size	Large
Color	Navy Blue
Arc Rating	8 Cal/cm sq.
Chest Size (In.)	42-44
Inseam (In.)	30
Material	Flame Resistant Cotton
Thread	Flame Resistant
Standards	ASTM F1506 and NFPA 70E
Application	Provides Excellent Comfort and Mobility for Industrial and Utility Workers

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Item Details

Safety & Security > Arc Flash Protection > Clothing and Accessories

Arc Flash Kit,8 Cal,L

Arc Flash Kit, Coveralls Garmet Style, Size Large, Color Navy Blue, Arc Rating 8 Cal/cm2, Chest Size 42-44 In, Inseam 30 In, Material Flame Resistant Cotton, Polycarbonate Lens, Amber Lens Color, Ratchet Suspension, Thickness 0.06 In, Viewing Area 8 x 14 In, Standards ASTM F1506 and NFPA 70E, Includes Arc Flash Coverall, AS1000HAT Hard Hat With Arc Faceshield, AFHOOD 10 Cal/cm2, Large Nylon Storage Bag, Faceshield Canvas Storage Bag and Safety Eyewear

Grainger Item #	5EU45
Price (ea.)	**$359.00**
Brand	SALISBURY
Mfr. Model #	SKCA8L
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	7.1
Usually Ships**	1-3 Days
Catalog Page No.	2636

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Qty.

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Tech Specs | Additional Information | Notes & Restrictions | MSDS | Required Accessories | Optional Accessories | Alternate Products | Repair Parts

Item	Arc Flash Kit
Garment Style	Coveralls
Size	Large
Color	Navy Blue
Arc Rating	8 Cal/cm sq.
Chest Size (In.)	42-44
Inseam (In.)	30
Material	Flame Resistant Cotton
Lens	Polycarbonate
Lens Color	Amber
Suspension	Ratchet
Thickness (In.)	0.06
Thread	Flame Resistant
Viewing Area (In.)	8 x 14
For Use With	Insulating Rubber Gloves and Leather Protectors (Not Included)
Standards	ASTM F1506 and NFPA 70E
Application	Provides Excellent Comfort and Mobility for Industrial and Utility Workers

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Includes	Arc Flash Coverall, AS1000HAT Hard Hat With Arc Faceshield, AFHOOD 10 Cal/cm2, Large Nylon Storage Bag, Faceshield Canvas Storage Bag and Safety Eyewear

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Item Details

Safety & Security > Arc Flash Protection > Clothing and Accessories

JACKET,ARC FLASH,LARGE

Arc Flash Jacket With Hood, Size Large, Arc Rating 11Cal/Cm2, Color Navy Blue, Length 32 Inches, Chest 42-44 Inches, Closure Front Hook and Loop, Flame Resistant, Launderable, Meets ASTM F1506 and NFPA 70E

Grainger Item #	3YA92
Price (ea.)	**$125.20**
Brand	SALISBURY
Mfr. Model #	JSHV1132L
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	2.2
Usually Ships**	Today
Catalog Page No.	2635

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Qty.

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Also Consider

LEATHER PROTECTOR,PR

Brand: SALISBURY
Grainger Item #: 4T491
Price (pr.): $34.85
Qty.

Add to Order

Tech Specs | **Additional Information** | **Notes & Restrictions** | **MSDS** | **Required Accessories** | **Optional Accessories** | **Alternate Products** | **Repair Parts**

Item	Jacket
Garment Style	Jacket with Hood
Size	Large
Color	Navy Blue
Arc Rating	11 Cal/cm sq.
Length (In.)	32
Chest Size (In.)	42-44
Thread	Flame Resistant
Standards	ASTM F1506 and NFPA 70E
Application	Provides Excellent Comfort and Mobility for Industrial and Utility Workers
Includes	Hood

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