Improving Electrical Safety with Short Circuit Protection of Industrial Control Panels

PREFACE

The effort to reduce the risk of the severe injuries from electrical hazards continues to evolve with electrical equipment designs that reduce the likelihood of injury to workers that interact with that equipment.

Although standards, work practices, training and PPE are advancing to create safer workplaces, equipment designs offer a greater opportunity for safety improvements by reducing the likelihood of injury should a fault occur within or downstream of the equipment.

The goals of this document are:

- to provide a better understanding of the hazards that can arise from short circuits (faults) that may occur in the part of the power system controlled by the Industrial Control Panels (ICP).
- provide fuse protection options that reduce the risk of injury to your customers who will operate or work on the controls while energized.

This Guide addresses safety issues related to short circuits both within the ICP and downstream from the panels.

Coverage includes Arc Flash issues, Short Circuit Current Ratings (SCCR), Ampere Interrupting Ratings (AIR), Coordination of Overcurrent Protective Devices (OCPD) for Short Circuits and protection of components within the ICP from downstream faults.

The first section focuses on how equipment can be damaged by large short circuit currents and how this damage can relate to hazards. The ‘square of the current’ effect of fault currents is emphasized.

The second section reviews equipment ratings related to short circuits. The safety consequences of inadequate ratings are discussed.

The third section presents how hazards can be significantly mitigated by the current limiting ability of certain UL fuses classes.

The fourth section presents protection concepts from a system perspective to obtain safety enhancements throughout the life of the equipment with the most reliable operation of the short circuit protection.

The fifth section shows how panel SCCRs can easily be enhanced to 100kA with AJT Class J fuses and ATDR Class CC fuses. The methodology described in UL508A Supplement SB is used in the examples.

We at Mersen are committed to providing products and support that assist you in making your designs safer. We look forward to working with you.

DISCLAIMER

This guide has been written to illustrate how safety concepts can be integrated into panel designs to help customers achieve lower levels of risks when interacting with the panels. Many of these improvements can be obtained with current-limiting fuses when applied properly.

The reader should understand that standards and codes have undergone numerous changes in recent years and will likely continue to evolve.

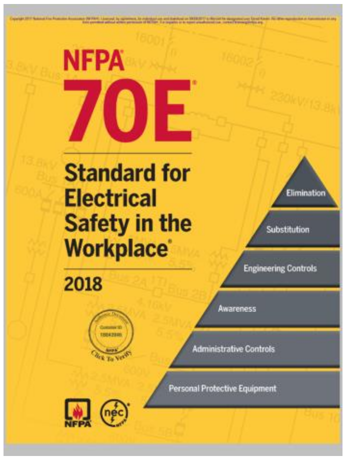
The reader is encouraged to explore the topics covered herein and remain current on the safety standards related to the design and application of Industrial Control Panels.

There will likely be interpretation disagreements among experts on these subjects. In no event will Mersen be held liable for any direct or indirect damages arising from the use of the recommendations or interpretations set forth in this paper.

CONTENTS

Introduction

In addition to requirements for performance, design goals for Industrial Control Panels (ICP) should include requirements for various aspects of safety. Protecting workers against the various hazards of short circuits is receiving even more consideration today as electrical safety standards are adopting more risk management techniques for protecting workers. As customers adopt these improved approaches to electrical safety, there will be greater interest in designs that minimize the risks to workers who install, commission, troubleshoot and use that equipment.



The pyramid on the cover of NFPA70E-2018 [1] represents a significant advance in electrical safety as more risk management principals have been incorporated into the standard in recent editions. The risk control elements shown on the pyramid are ordered in the accepted level of effectiveness in protecting people; e.g. substitution is far more effective than PPE. An example of this would be the movement from 120Vac to 24Vdc control voltages.

In general, the top 3 are most effectively accomplished during the design phase of equipment and systems.

This Guide is intended to assist you in selecting fuse options that will significantly minimize the risks associated with short circuits involving control panels. The major topics covered are:

1. *Importance of Short Circuit Ratings for Safety*. Both Short Circuit Current Ratings (SCCR) and Ampere Interrupting Ratings (AIR) are covered. Additionally, high fault current ratings are discussed as an easy means of improving an ICP's SCCR.
2. *Enhancing Short Circuit Safety with Current Limiting Fuses*. How the selection of the short circuit protection can affect the level of safety for the life of the panel is discussed. Both protection of components and people are covered.
3. *Design Concepts for Improving Safety and Reliability.* This focuses on design issues related to arc flash, coordination with the upstream power system, coordination with overload protection, optimum protection of components and improving the SCCR of the panel.

By selecting AJT Class J Fuses and ATDR Class CC fuses for the Overcurrent Protection Device (OCPD) in the panel, you are ensured that the level of protection designed into the ICP will not be compromised throughout the life of the panel. Increased system fault currents do not affect the key performance criteria of fuses that are discussed in this paper. For example:

- Incident Energy calculations remain constant (and may decrease) for larger fault currents (See page 20)
- Type 2 No-Damage protection of motor starters with fuses is typically valid for fault currents up to 100kA. (See page 21)
- Following simple guidelines, coordination between fuses extends to 200kA (See page 25)
- Many components used in ICP have high fault current ratings of 100kA when protected by AJT Class J fuses. For example, Mersen Power Distribution Block are rated 100kA when protected by AJT Class J fuses. See [13] for more examples.
- Fuse-protected ICPs typically have a SCCR of 100kA. (See page 31)
- AJT Class J fuses are single pole rated at 600V and have ampere interrupting ratings (AIR) of 200kA. (See page 17 and 50)
- ATDR Class CC fuses are single pole rated at 600V and have ampere interrupting ratings (AIR) of 200kA. (See page 17 and 50)

For more information on the additional benefits of fuse protection see [2]

Glossary

AIR (Ampere Interrupting Rating) the maximum current that an OCPD can safely interrupt.

Available Fault Current – the maximum short circuit current that can flow in an unprotected circuit.

Circuit, Control Circuit - A circuit that carries the electric signals directing the performance of a controller, but which does not carry the main power circuit. (UL508A)

Circuit, Feeder Circuit – the conductors and circuitry on the supply side of the branch circuit overcurrent protective device.

Circuit, Branch Circuit – the conductors and components following the last overcurrent protective device protecting a load.

Fuse Terms

Current-limiting fuse - "A fuse that, within a specified overcurrent range, limits the clearing time at rated voltage to an interval equal to or less that the first major symmetrical current loop duration; and limits the peak current to a value less than the available peak current." (UL 248-1)

Fast acting fuse - A term not defined in standards but which is often used to describe a fuse that is not a time-delay fuse.

Fuse - "An overcurrent protective device with a circuit-opening fusible part that is heated and severed by the passage of overcurrent through it." (NEC)

Fuse minimum melting I^2t - the minimum I^2t (energy) causing melting of the fuse element.

Fuse total clearing I^2t - the maximum I^2t (energy) passed by a fuse operating above its threshold current

Peak Let Through Current (I_p) – The maximum instantaneous current passed by a current-limiting fuse when clearing a fault current of a specified magnitude.

Threshold Current – The minimum prospective rms current at which the fuse becomes current-limiting. At this value the fuse will melt within the first 1/4 cycle and completely clear the circuit within ½ cycle.

Time Delay Fuse – A fuse that has a defined minimum clearing time for a defined overload condition. For example, a time-delay UL Class J fuse must hold 500% of its ampere rating for a minimum of 10 seconds per the UL248 standard.

UL Fuse Class – See Annex for more information.

ICP - Industrial Control Panel - Assumed to have power circuit(s) for this Guide

OCPD - Over-Current Protective Device - a fuse or a breaker used to protect downstream equipment.

Coordination, Selective (Selective Coordination) - Localization of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the selection and installation of overcurrent protective devices and their ratings or settings for the full range of available overcurrents, from overload to the maximum available fault current, and for the full range of overcurrent protective device opening times associated with those overcurrents. (NEC)

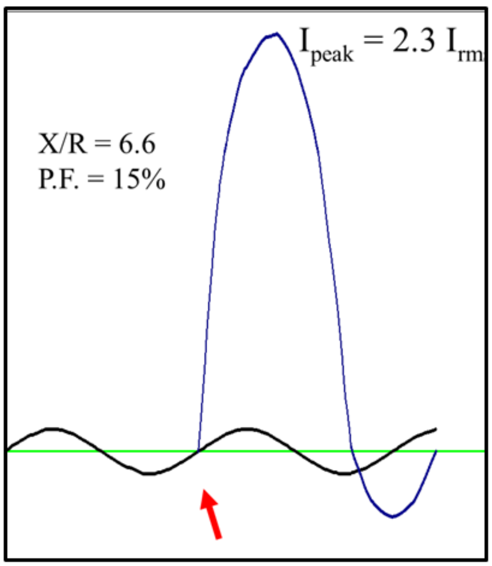
SCCR (Short Circuit Current Rating) - "The prospective symmetrical fault current at a nominal voltage to which an apparatus or system is able to be connected without sustaining damage exceeding the defined acceptance criteria." (NEC)

1. Overview of Short Circuit Hazards

Short Circuit Currents

Before discussing damage caused by short circuit currents, it is important to note that ac fault currents can have a large degree of asymmetry that is dependent on the source impedance and the phase angle at which the short circuit was initiated.

Highly inductive circuits can cause an initial offset of the current (asymmetrical) as shown in the figure below. The offset will decay to zero and the current will become symmetrical after several cycles. LV equipment is often tested with an X/R ratio near to the value shown. This can result in a first peak that is 70% higher than the normal symmetrical peak of 1.414 x I_{rms} as shown in the table and Figure 1-1.



Available Fault Current(RMS)	I_{peak}
10,000	23,000
50,000	115,000
100,000	230,000
200,000	460,000

Figure 1-1 Asymetrical fault current.

Short Circuit Damage

By first reviewing how electrical components can be damaged by large fault currents, the advantages of current limitation for short circuit protection can be more fully understood. Because this "damage" can involve explosions and fires in the equipment, this review provides insight into the safety aspects of adequate short circuit protection.

Overcurrents can cause damage to electrical components by three methods: large electromagnetic <u>forces</u>, excessive <u>heating</u> and the extreme heat energies due to <u>arcs</u>. Although these methods are examined individually, all can be present during a fault condition.

Electromagnetic force

Electromagnetic forces can be created when two currents are flowing in near proximity to each other. Although, the principle of electromagnetic force is used in proper functioning of devices like motors, this discussion focuses on how large fault currents create forces that can cause damage or destruction to equipment and result in hazardous situations.

In the example shown in figure 1-2, the current flowing out one conductor and back the parallel conductor will create a magnetic field surrounding each conductor. With the lines of magnetic flux in opposite directions between the conductors, a force is created that will repel the two conductors from each other.

$$F = \frac{\mu_o * I_1 * I_2}{2\pi d}$$

$$F = \frac{5.4 * (I_F)^2 * 10^{-7}}{d} \quad \frac{\text{lbs}}{\text{ft}}$$

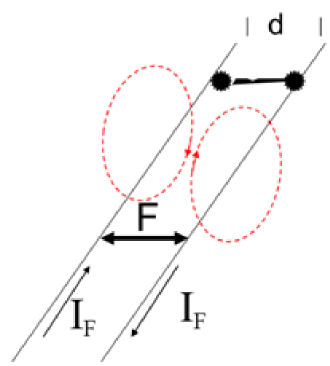


Figure 1-2. Force between conductors.

In the figure above, the amount of force predicted by the equation shown is for 2 parallel conductors. Notice 3 things about the nature of the force.

1. Most importantly, the force is proportional to the "square of the current". This means when the current is doubled, the force is quadrupled. If the current increases from 10A to 20A, the force increases 4x; if the current increases from 10A to 10,000A (1000x increase), the force increases 1000 x 1000 or 1,000,000 times.
2. 10^{-7} means 1 divided by 10,000,000; small currents will have extremely small forces associated with them.
3. The force is "inversely" proportional to the distance between the conductors. If the spacing between conductors is increased from 1 inch to 2 inches the force will decrease by one half.

As an example of how large forces can get, consider two cables spaced ½" apart that can carry the various short circuits shown in table 1-1. With an asymmetrical wave as discussed above, the peak force will occur concurrently with the peak current. For a 60Hz ac system this can occur in less than 5ms. The peak currents will be as shown in the middle column and the peak force calculated per equation (2) will be proportional to the square of the peak value in the first half cycle and is shown in the third column of the figure. Notice that for high fault currents, the force can be measured in tons.

Table 1-1 Peak Currents and Peak Forces

AMPS(rms)	AMPS(peak)	FORCE(lbs/ft)
1,000	2,300	5.7
10,000	23,000	571
50,000	115,000	14,283
100,000	230,000	57,132
200,000	460,000	228,528

Three phase ac faults will have a variation of the equation above based on the geometry of the conductors. The direction of the forces between conductors in a 3-phase fault will alternate as the current goes through its phase rotation. In figure 1-3, the C-Phase conductor is repelled from the other two phase; A- and B- phase conductors are attracted because the direction of the current flow at this point of the phase rotation is the same. As the fault progresses through the phase rotation, the conductors will alternately be attracted and repelled until the fault is cleared.

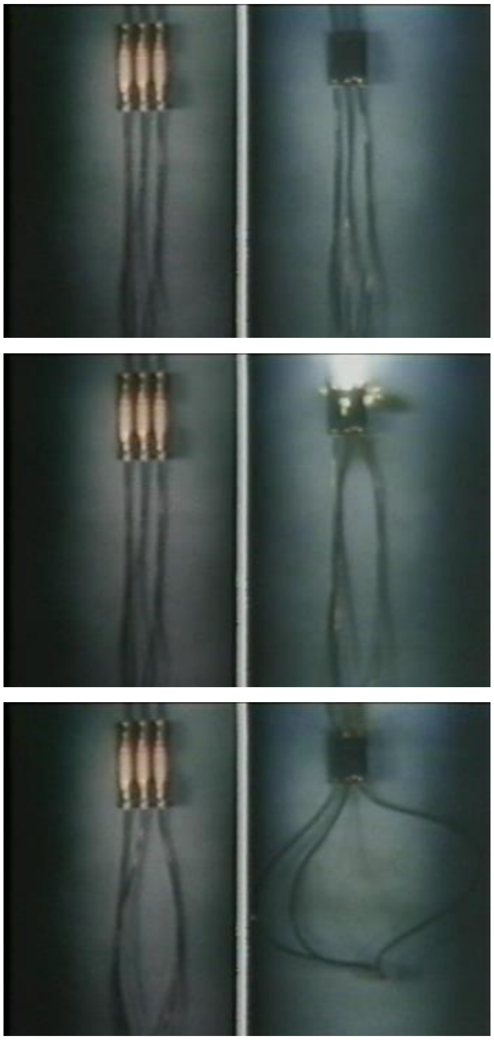


Figure 1-3. Forces from a 3-phase fault

A repulsive force between contacts is also created during a fault. If these forces become too large during the fault, the contacts will be forced apart and can create a destructive arc.

Heat

The second cause of component damage is heat. The equation below defines how the heat developed in a component is related to the current flowing through it.

$$E = I^2 R t \tag{3}$$

Notice 2 things about this equation.

1. The heat is <u>proportional to the square of the current</u>. Doubling the current in a conductor will increase the rate of heating by 4x. If the current is increased a thousand-fold (e.g. from 20A to 20,000A), the rate of heating of the conductor will be increased by 1,000,000 times (1,000 x 1,000).
2. The heat is proportional to the time that the current is present. That means heat is cumulative - the longer the current is present the greater the generation of heat within the component.

Consider a cable rated at 20A. When 10A is flowing through the conductor, heat will be generated within the copper. The rating of 20A means that under normal conditions, this heat will be eliminated through the insulation at a rate at which it is generated; i.e. the temperature stabilizes below a level that will cause damage to the insulation. If the current is quadrupled to 40A, heat would be generated in the conductor 16x as fast (4x4), which would exceed the cooling ability through the insulation - the temperature of the insulation would rise. If this overload is not removed in adequate time, the insulation could melt or burn (see figure 1-4) causing fires and short circuits in conduits and cable trays.

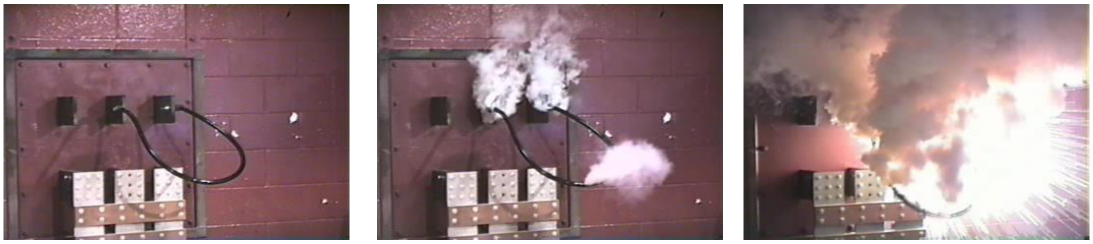


Figure 1-4. Damage caused by an overload after 15 minutes

However, if a short circuit occurred with a current of 10,000A flowing through the cable (1,000 x the 10A load current), the heating effect would increase 1,000,000 times (1,000 x 1000). Cable damage curves (and equations) are available that plot the amount of time that it takes to damage the cable's insulation versus short circuit current. Depending on the amount of current and cable size, this time can be as low as ½ cycle (8.3ms). See Figure 1-5

Figure 1-5. Cable damage caused by a short circuit of 35kA within 2 cycles.

Arc Damage and Hazards

When a high-energy arc is initiated, large amounts of electrical energy are transferred into the arc creating hazards that have been well documented [3] [4]. This energy is distributed in several ways as illustrated in figure 1-6. The surface of the metal electrodes is rapidly raised to the boiling temperature releasing molecules into the plasma jets. Both the copper vapor molecules and air molecules, drawn into the plasma jets, are disassociated and become part of a rapidly expanding plasma cloud. As the arc event persists, electrical energy is consumed in maintaining and expanding the plasma cloud. People in or near to this cloud can be exposed to immense convective and/or radiant heat energy that can ignite clothing and cause serious burns. The amount of heat transferred appears to be linear with time [5]. The rapid expansion at the initiation of an arc fault can give rise to a significant pressure wave moving away from the arc roots. Resulting sound levels near to the event will exceed levels that can damage human ears.

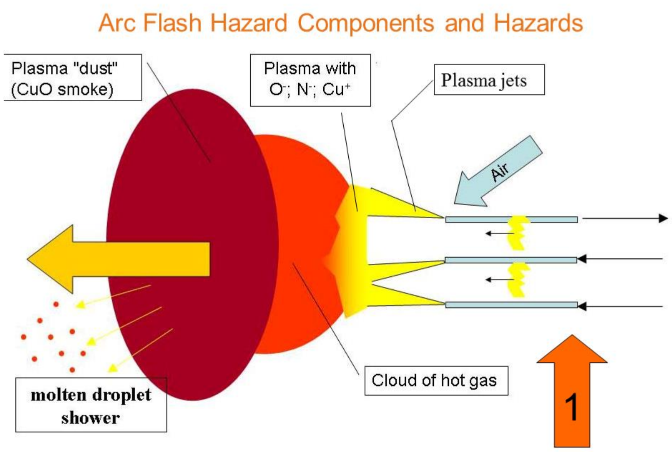


Fig. 1-6. Illustration of arc flash components

Other hazards are presented to workers as the event runs its course. As the plasma travels further from the arc it cools allowing plasma components to combine into molecules that can be toxic. These materials, such as copper oxides, are identified as plasma "dust" in Fig 1-6. Heat transferred from the electrodes into the conductors melts the metal which is then launched as molten droplets into the plasma jets. The intensity of light at the initiation of the arc the can cause immediate vision damage and increases the probability for future vision problems

The photos in figure 1-7 are from a high-speed video of an arc flash event with horizontal electrodes [6]. The three electrodes are centered at the front opening of a 20" x 20" x 20" in test box. The view of this event is represented by arrow 1 in figure 1-6. The first photo in the sequence is the first frame of the video where the arc first appeared. The second frame is 1ms later and shows the thermal expansion. The third frame, 4ms into the event, shows the plasma cloud expanding with the front approximately 18" from the opening of the enclosure. These frames show that the plasma is being electromagnetically driven away from the electrodes. The final frame shows the copper laden 'smoke' as the arc becomes fully developed.

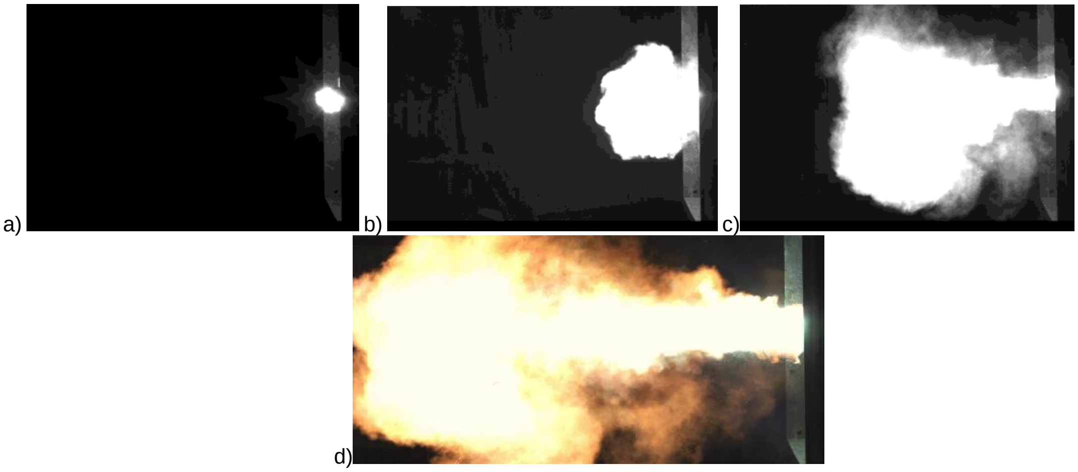


Fig. 1-7. Expanding plasma cloud with horizontal electrodes.

Summary of Arc Flash Hazards:

- The immense heat of the plasma and radiated heat
- Thermoacoustic shock wave and pressure build up within enclosures
- Ejected molten droplets of conductor material
- Shrapnel
- Large volumes of toxic smoke
- Extremely intense light
- Contact with energized components.

Figure 1-8 (l) is a photo of a bus plug switch after an arc fault. Notice the 'plasma dust' (copper oxides) that were deposited on all the components within the enclosure. When repairing equipment that experienced an internal arc fault, extreme care must be exercised to ensure this dust is properly removed from components. This coating can form conductive bridges across insulating material see Fig. 1-8(r) and help initiate a subsequent arc fault when the equipment is re-energized. Note that the dust may not be clearly visible as the dust may have been forced into other compartments of the equipment during the fault.

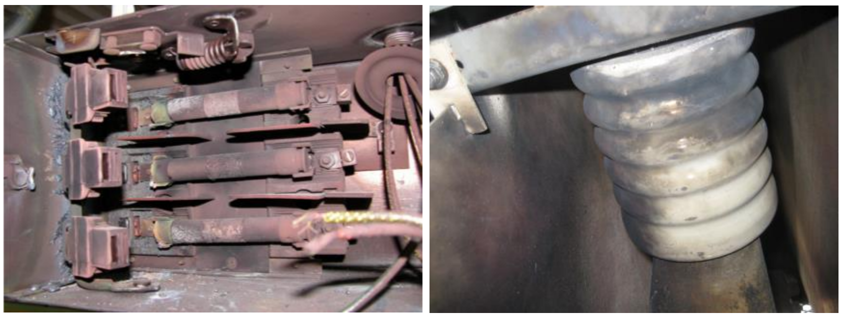


Figure 1-8 Damage from Arcing Faults

Heat Hazards

Arc flash studies have shown that heat densities at typical working distances can exceed 40 cal/cm^2. Even at lower levels, conventional clothing ignites, causing severe, even fatal, burns. Workers not in the plasma can be burned from the intense heat radiated beyond typical working distances. At typical arc fault durations of less than one second, a heat density greater than 1.2 cal/cm^2 on exposed flesh is enough to cause a second-degree burn.

Pressure Within an Enclosure

In the case of Fig 1-7, the arc behaves as if in open air because there are no obstructions to the flow of the plasma. As the plasma cloud initially begins to expand, there can be a large difference in pressure between this rapidly expanding cloud and the surrounding air. This "pressure wave" can cause personnel injury or significant damage to equipment and surroundings.

Upon initiation of an arc within an enclosure, a pressure wave will move outwards towards the enclosure walls. The magnitude of the pressure will be affected by such variables as the energy delivered to the arc in its early phases, orientation of electrodes, volume within the enclosure and reflections caused by the geometry of the enclosure and its components. If great enough, the door can be blown open (see figure 1-9) exposing a nearby worker to the well documented and serious hazards of an arc flash event. [7]

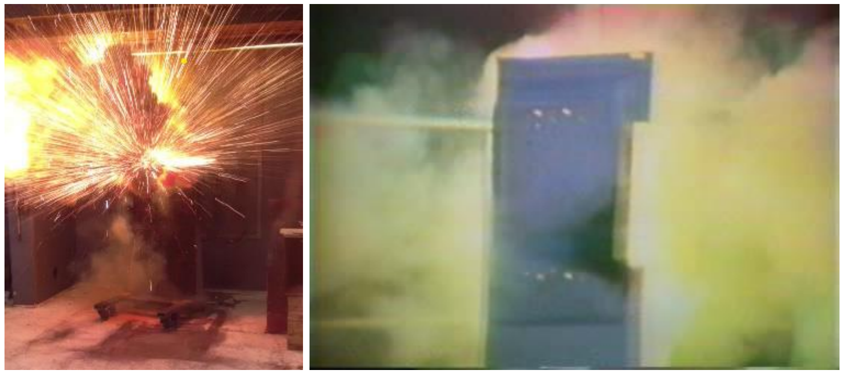


Figure 1-9 Exposed to the Arc Flash Hazard

This expansion can be seen in the photo series of Fig. 1-10. An arc fault was created at the tips of the electrodes in the 20” x 20” x 20” open test box shown in Fig. 1-10a. The first frame of the video sequence shown in Fig. 1-10b shows the initial formation of the plasma cloud. The frame in Fig. 1-10c is 3ms later and shows the rapid expansion of the cloud as the air and electrode materials are raised to very high temperatures. Note that the cloud has expanded to nearly fill the enclosure with hot gases. Careful examination of frame Fig. 1-10d shows that the impact of these gases against the side wall has caused the ⅛” thick steel plate to bow outwards. This frame is 4.9ms into the event.

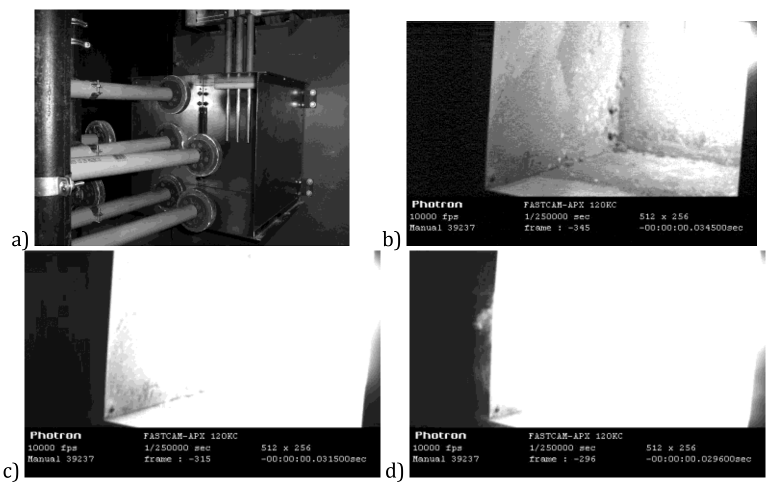


Fig. 1-10 Expanding plasma cloud within an enclosure.

Incident energy is not necessarily a good predictor of the magnitude of the initial impact of the pressure wave. This test had a 600 V source configured to deliver a bolted fault current of 23 kA to the tips of the copper conductors. Incident energy would be estimated to be less than 0.5 cal/cm^2 at the 4.9ms period shown in the photo series. For a clearing time of 100ms, the incident energy calculation would be near 4.3 cal/cm^2. For a clearing time of 200ms, the incident energy would be near 8.6 cal/cm^2. The magnitude of the initial impact against the walls would be the same for these various levels of incident energy regardless of the duration.

If the enclosure had a door limiting the evacuation of the expanding gases from the box, pressure could build to greater values. Resultant distortion of the box and door could eventually cause the door to blow open or off (Fig. 1-9). As demonstrated in the photos, this increase in pressure is quite fast. With a smaller box the pressure against the side walls would likely be greater as they are closer to the heat source that is causing the rapid expansion.

2. The Importance of Adequate Short Circuit Ratings for Safety

Short Circuit Ratings for Safety

When applying electrical equipment and components to any power system, it is imperative that all components are capable of safely handling any short circuit current to which they could be exposed. Equipment that is expected to pass the short circuit current without opening (e.g. bus duct) must have a SCCR greater than the maximum available fault current. These devices are sometimes referred to as passive devices. For those components intended to open (or break) short circuit currents, they must have an AIR greater than the maximum available fault current that they would be expected to interrupt. Section 5 discusses how the individual ratings of components found in ICP can be used per UL508A Supplement SB [8] to determine the SCCR of the panel.

SCCR - Short Circuit Current Ratings.

All electrical components have a limit as to how much electromagnetic force and heating that they withstand from a short circuit current passing through them. If these limits are exceeded, catastrophic failure of that component can occur and lead to an arc flash event. This is demonstrated in figure 2-1 when a fault current much larger than the SCCR was applied in a test at Mersen's High Power Test Lab.

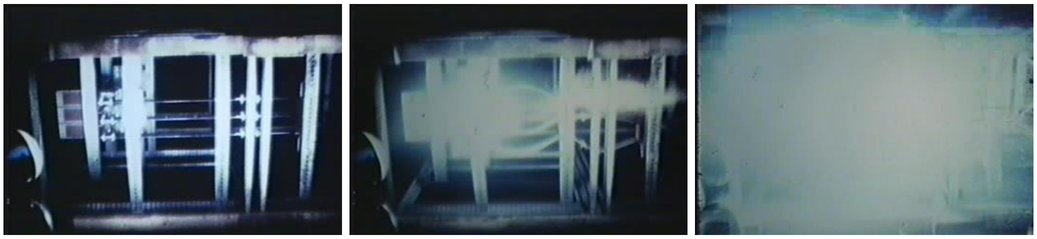


Figure 2-1. Bus bar failure due to excessive electromagnetic forces.

To prevent this from occurring, it is critical that listed components be applied according to their UL listing. The component listing requires the product to successfully pass the short circuit tests contained in the standard with the defined test circuit and duration. Table 2-1 below identifies the UL standard number for components typically contained in control panels. UL Recognized Components need to be applied according their individual UL file.

Table 2-1 List of UL standards for ICP Components

Standard	Component
UL 248	Fuses
UL 4248	Fuse Holders
UL1953	Power Distribution Blocks
UL1059	Terminal Blocks
UL 508*	Industrial Control Equipment
UL 98	Enclosed / Dead Front Switches
UL1449	SPD

* - See also UL60947

<u>Determining what SCCR is required for components</u> within an ICP <u>requires knowledge of the power system</u> to which the ICP will be connected. At the minimum, your customer needs to estimate the maximum available fault current that the ICP will be exposed to over its life. A table of sample calculations are provided in the Annex to demonstrate how the power system elements can affect the magnitude of available fault current.

High Fault Current Ratings - the key to higher Control Panel SCCR.

Supplement SB [8] allows up to three SCCR options for components used in an ICP.

1. The default SCCR rating per UL508A Table SB4.1
2. The SCCR marked on the component or instruction sheet provided with the component.
3. The SCCR based on testing with a specific overcurrent protective device

The third option is referred to as a high fault current rating and is obtained by the component manufacturer through tests defined in the standard to which the component is listed.

For example, a 16A motor controller that has a default SCCR of 5kA from table SB4.1 might be listed at 10kA by the manufacturer of the controller. The manufacturer of the controller might also list their component at 100kA when protected by a Class J fuse that is no greater than 30A. If in this example, the designer of the ICP elected to use a non-current limiting OCPD, then the SCCR of the component is 10kA. If the designer of the ICP elects to use an AJT25 Class J fuse to protect the branch circuit containing the controller, then the SCCR of the component is 100kA.

AIR - Ampere Interrupting Ratings.

When an OCPD interrupts a large fault current, an arc is initiated between two conductive elements. For a fuse, the arc will initiate between both sides of a melted notch of the fuse element as discussed in the next section. For a circuit breaker, this will be between the parting contacts.

The OCPD must withstand the heat energy and pressure created by the internal arcing. The OCPD must dissipate this energy and quickly extinguish the arc to complete the interruption of the current. The current, voltage, and clearing time determine the energy associated with the event. If an OCPD attempts to interrupt a fault current greater than its AIR, the resulting arc will overwhelm the extinguishing system's capability and will likely result in a catastrophic failure and an arc flash event as shown in figure 2-2. The resulting arc flash was not contained by the enclosure and could have exposed a worker to the arc flash hazards discussed above.

Article 110.9 is clear that the interrupting rating of all OCPD must be greater than the available fault current. Determining what AIR is required for OCPD within the ICP requires knowledge of the Power System to which the ICP will be connected.

Figure 2-2 10kAIR OCPD interrupting 25kA.

Other Considerations for a Long Reliable Life

An increase in fault currents available at the ICP can obsolete equipment selections if not considered in the design phase. Increases in available fault current may be caused by:

- Relocation of the ICP to a power system with a larger transformer.
- A new utility supply transformer.
- Replacement of the transformer supplying the ICP with a larger transformer or one with a lower impedance.
- Utility changes to the distribution system.
- Addition of a facility generator in parallel with the utility source.
- Addition of a facility tie bus for distribution reliability.

Components within the ICP may have adequate ratings when originally commissioned; however, if changes to the power system increase fault currents they can become overdutied, unsafe and would need to be replaced. If fault currents increase to values greater than the Short Circuit Current Rating (SCCR) of the ICP, the entire panel would need to be replaced.

3. Enhancing Short Circuit Safety with Current Limiting Fuses

Overview of Current Limitation

Low Voltage current limiting fuses, such as those listed to the UL Class J or CC standard, must clear a single-phase short circuit current in less than one half cycle in its current limiting range [9]. Since the fuse element must also melt in less than the first quarter cycle, it prevents the fault current from reaching its first peak. This reduction of fault current magnitude and duration can:

- Minimize (or prevent) damage to equipment in the faulted circuit by limiting the rapid heating of components and destructive electromechanical forces.
- Limit the destructive heating effects of arcing faults on electrical equipment.
- Dramatically reduce the electrical energy delivered to an arc fault as evidenced by the very low prediction of incident energy. [5][10] [11].
- Limit peak power delivered to arcing faults and its potential explosive consequences.
- Achieve <u>full</u> coordination even under short circuit conditions up to 200kA.
- Reduce the magnitude and duration of the system voltage drop caused by fault currents by quickly isolating the faulted circuit.
- Provide for 200kAIR for Class J and Class CC fuses.

The AJT Class J and ATDR Class CC family of fuses are the best choice for new specifications. The unique dimensions of the Class J make it unlikely that it will be replaced with a lesser performing fuse. When used with a Class CC rejection fuse block such as the USCC, it will be difficult to replace an ATDR fuse with a lesser rated supplemental fuse. See [2] for more information on the advantages of these fuses for safety and reliability over their lifetime.

Current Limitation

Current limiting operation. The short circuit element of a fuse is made of strips of copper or silver with regions of reduced cross-sectional area called notches (Fig. 3-1). The element is enclosed in an insulating tube filled with pure quartz sand. Designed to carry normal load currents without melting, current limiting operation begins at the initiation of a short circuit greater than its threshold current. As the short circuit current starts to rise, the temperature of the notches begins to rise very quickly. When the notches melt, internal electric arcs are produced in the notch zones. The increasing impedance of the series arcs causes the fault current to be rapidly reduced to zero and the arcs are rapidly extinguished by the sand fill.

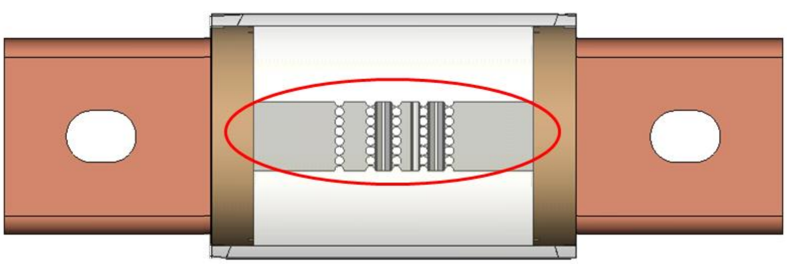


Fig. 3-1. Current limiting fuse notches

Current limiting performance. Fig. 3-2 illustrates the operation of a fuse interrupting a short circuit fault current in an ac circuit. During the pre-arcing (melting) period the current follows the prospective current wave and the voltage drop across the fuse is quite low. When the fuse element melts and internal arcing begins, the voltage across the fuse increases rapidly and the current is forced to zero well before the natural zero crossing of the available current wave as shown in the figure. Thus, the two requirements for current limitation are met; the peak instantaneous current (I_p) allowed by the fuse is less than the peak of the prospective current and the duration of the arc is less than ½ of an electrical cycle.

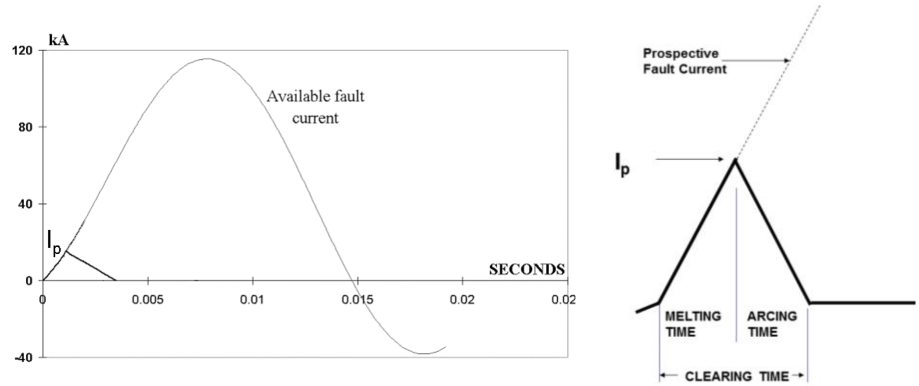


Fig. 3-2. Performance of a current limiting fuse

The degree of current limitation provided by a fuse is measured two ways — peak let-thru current (I_p) and I^2t. Maximum allowable I_p and I^2t values are specified in the UL 248 standards for all UL Listed current-limiting fuses. The let-thru information for Class J and CC is repeated in the Annex table Excerpt from Table SB4.2 of UL508A. Note that within the same UL fuse class, larger ampere ratings will 'let-through' higher currents as shown within the tables in the Annex

The I^2t determined through testing is used by fuse manufacturers for several purposes. The melting I^2t of the fuse is used to provide guidance (tables) on fuse sizing to prevent undesired openings. The clearing I^2t is a useful indicator of the amount of I^2Rt heating of a component during a short circuit and is used to provide guidance on protection of sensitive power components.

Manufacturer-published data for current limiting fuses include I_p and effective rms current. Since the measured value of let-through tests is the peak value of the resulting limited waveform, the fault current that would produce the same I_p without any current limitation is referred to as the 'effective' rms let-through current. Effective rms current is used in arc flash calculations when the fuse is in its current limiting mode [11][12]. Peak let through current can be used in UL508A Supplement SB for modifying the available fault current in some branch circuits within an ICPs.

Energy Limitation and Power Limitation

Since current limiting fuses can reduce both the magnitude and duration of a fault current, there is a dramatic reduction in the first half cycle energy delivered to an arc fault. Interruption can occur before the potential peak power of the fault is reached.

This limitation is demonstrated in Figure 3-3 where the power waveform from a 7-cycle three phase arc fault is compared to the power waveform of the same arc fault circuit when protected by an AJT400 Class J fuse.

The arc energy of the 7-cycle event (area under the power curve) was measured at 1130 kWs and the incident energy was calculated to be 10.7cal/cm².

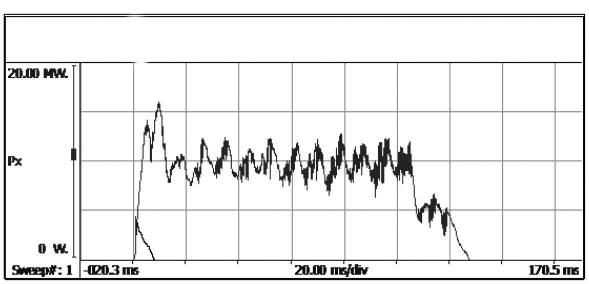


Figure 3-3. Power waveforms for arc fault tests (480V; I_{BF} 35.4kA)

Under the same test conditions, energy was limited to 19 kWs with the AJT400 Class J fuse and the calculated incident energy was less than 0.3 cal/cm². Note that although the duration of the fuse event was 1/14th of the 7-cycle event, the arc energy was significantly less than for this fuse class. The additional 75% reduction in electrical energy delivered is due to the limitation of the current as well as the duration. This dramatic reduction in arc energy makes it more likely that arc fault damage can be quickly repaired, and equipment placed back into service.

The peak power of the 7-cycle test was greater than 15MW whereas with the AJT400 test the peak power was limited to under 5MW. This reduction in peak power and arc energy released in the first half cycle of the ac fault can allow for the containment of arc flash hazards by limiting the pressure rise within enclosures as described in [7].

The advantage of this limitation is clear in the side by side comparison of arc flash tests in Figure 3-4. Both tests were performed at 600V with 44kA available fault current to both test boxes. The sequence on the left had a clearing time set for 100ms while that on the right was protected by an A6D600R UL Class RK1 fuse. The frame captures from the high-speed videos in (a) show the initiation for both arc faults 16 inches back from the opening of the enclosure. In(b), six milliseconds into the event, the arc flash gases are shown expanding violently outward from the box on the left. Since the fuses melted near 2 milliseconds into the event, the gases shown on the right in (b) have obtained their maximum reach. In (c), the fuse protected test has completely cleared in 6ms with a maximum incident energy of 0.5 cal/cm^2. The test on the left continued for another 90+ milliseconds before it was cleared by the lab breaker and resulted in incident energy in excess of 14 cal/cm^2.

(a)
(b)
(c)

Figure 3-4. Comparison of fuse protected arc flash event.

Arc Flash Safety - Protection of People and Families

Electrical safety programs must ensure that all workers who interact with electrical equipment are protected from arc flash hazards to a level of risk acceptable to their organization. Increasing concern for arc flash safety has grown to include both operators of electrical equipment as well as electrical workers. Internal arc faults can blow open doors of low voltage equipment including Industrial Control Panels ICP) that have been properly installed [7]. Should this occur when an operator is interacting with the equipment, the worker can be exposed to the hazards of arc flash. Additionally, many companies are focusing efforts to get lower incident energy levels on equipment that has frequent worker interaction with the doors open. Many are seeking the lowest values that are economically feasible.

Protecting the ICP with an upstream external AJT fuse is a great option for minimizing the likelihood of operators being exposed to the arc flash hazard when interacting with the equipment when it is properly closed. Testing in a high-power test lab, has demonstrated the possibility that ICP enclosures can contain the hazards of an internal arc flash if protected by AJT Class J fuses selected to be in their current limiting range. At this time, no standard exists to certify this level of protection. The size of the enclosures, type of latch(es) and hinges would affect the ability of the hazards to be contained.

Even if a fused-protected ICP protects workers against arc flash hazards when the door is closed, consideration should also be given to the required level of PPE worn by electrical workers who interact (e.g. troubleshooting) with the ICP while it is energized and the door open. An incident energy goal of less than 0.6 cal/cm^2 to reduce the risk of serious worker injury can usually be obtained throughout the life of the ICP with the proper selection of AJT fuses

To get the best protection for workers and equipment from AJT fuses, you should ensure that the AJT fuse is selected so that it will be current limiting for the expected arc fault current. Table 3-1 shows the minimum available fault currents (at 480V) required to drive AJT fuses into current limitation for downstream arc faults. Tests have shown that as fault currents become greater than these minimums the incident energy will less decrease or remain the same.

Table 3-1. Minimum fault currents required for AJT fuses.

FUSE	Minimum I_{bf} for Current Limitation	Minimum I_{bf} for 1.2 cal/cm^2
AJT60	2.2kA	1.5kA
AJT100	4.5kA	2.2kA
AJT200	8kA	5kA
AJT400	15kA	9.6kA
AJT600	25kA	15kA

Calculated at 480V using VCB with IEEE1584-2018 equations

For fault currents lower than those shown in the table, contact Technical Services to see how the Non-time-delay HSJ or A4J Class J fuses can be applied.

Optimum Protection of Equipment and Components

External Faults.

When a fault occurs at a load controlled by the ICP, large fault currents can flow through components of the ICP causing damage to critical parts. Many of the components used in ICP have SCCR of 10kA or less. Using the fuses identified in the component listing for high fault current tests will likely provide you with the higher component SCCR ratings needed for your designs. See for example, [13] for the high fault current ratings of Mersen's products. The SCCR ratings of Mersen FSPDB's power distribution blocks with AJT fuses are shown as an example in Table 3-2.

Table 3-2 High Fault Current Ratings of FSPDB Distribution Block

Mersen Part No.	Amps	SCCR	Line	Load	Class J (AJT, A4J, HSJ)
FSPDB1A	175	100KA	2/0-#14	2/0-#14	200A
FSPDB1C	175	100KA	2/0-#14	2/0-#14	200A
FSPDB2A	175	100KA	2/0-#14	2/0-#14	200A
FSPDB2C	175	100KA	2/0-#14	2/0-#14	200A
FSPDB3A	310	100KA	350-#6 & 2/0-#14	2/0-#14	400A
FSPDB3C	310	100KA	350-#6 & 2/0-#14	2/0-#14	400A
FSPDB4A	355	100KA	400-#6	400-#6	400
FSPDB4C	355	100KA	400-#6	400-#6	600

FSPDB5A and FSPDB5C has a 100 kA SCCR with a A4BQ800.

Small motor starters are particularly susceptible to short circuit damage of their contacts and overload elements. Under high fault current test conditions, some damage to contacts and overloads is allowed per UL508. However, most of the common starters have been tested and certified to Type 2 (no damage) levels of protection with a 100kA SCCR when the specified OCPDs (e.g. AJT Class J fuses) are used as the protection in the circuit. [14].

Figure 3-5. Type 1 protection (l) versus Type 2 protection (r)

Type 1 coordination ensures that there are no fire risks created during defined short circuit tests. Whereas Type 1 allows some damage to the controller per UL508, Type 2 goes further and requires that the controller be suitable for further use after the short circuit test. The indicators on the AJT in Figure 3-5 (r) shows that the fuses cleared before damage to the controller could occur.

The AJT and ATDR series of fuses are the best choices for achieving Type 2 protection of motor controllers <u>and</u> high fault current ratings for components used in ICP. For example, see Table 3-3 for Type 2 protection of a particular motor controller. See [15] for listing of more examples of AJT and ATDR fuses required for Type 2 protection of common motor controllers.

Table 3-3. Example of a Type 2 Selection Chart

460 Volt, Three-Phase Motors					
HP	CONTACTOR	OLR	CLASS J	CLASS CC	SCCR (kA)
1/2	LC1D09	LRD06	AJT2	ATDR5	100
3/4	LC1D09	LRD06	AJT2	ATDR5	100
1	LC1D09	LRD07	AJT5	ATDR8	100
1 1/2	LC1D09	LRD08	AJT5	ATDR12	100
2	LC1D09	LRD08	AJT5	ATDR12	100
3	LC1D09	LRD10	AJT20	ATDR30	100
5	LC1D09	LRD14	AJT20	ATDR30	100
7 1/2	LC1D12	LRD16	AJT20	ATDR30	100
10	LC1D18	LRD21	AJT25	-	100
15	LC1D25	LRD22	AJT35	-	100
15	LC1D32	LRD22	AJT40	-	100
25	LC1D40	LRD3355	AJT60	-	100
30	LC1D40	LRD3355	AJT60	-	100

Since the branch circuit fuses provide the short circuit protection for the part of the circuit external to the ICP, the magnitude of energy allowed to downstream arc faults should also be considered since it can have an effect on the ability to contain arc flash hazards from workers nearby to the controlled motors and local disconnects. In a paper by Crawford on motor terminal box (MTB) explosions, the authors recommended at least Class RK1 current limiting fuses to reduce the arc energy at the MTB to the lowest level possible for worker safety [16]. This also applies to local motor disconnects. See [7] to get more information on how the superior energy reduction ability of AJT Class J current limiting fuses has been demonstrated to greatly reduce the likelihood of enclosure failure due to arc faults within various enclosures.

Internal Faults.

If an arc fault occurred within the ICP, the amount of energy delivered to the fault could adversely impact the amount of effort required to return the equipment back to service after repairs. The greater the arc energy allowed by the upstream OCPD, the greater the damage and effort required to repair the equipment. If too much energy is transferred to the internal arc fault, extensive damage could occur and pose danger to nearby workers. The photos in Figure 3-6 shows where an arc occurred on the line side of a bus plug switch. Some researchers suggest that by limiting arc energies to less than 100kWs may ensure that only minimal damage is sustained from an internal arc fault and such damaged could be be repaired in the field. [17] [18]

Figure 3-6. Extensive damage to bus plug switch due to an internal arc fault.

4. Design Concepts to Improve Reliability of the Short Circuit Protection System

Introduction

For purposes of discussion, each OCPD associated with the ICP depicted in Figure 4-1 is assigned a zone of protection with a number. Reliability of the short circuit system requires that:

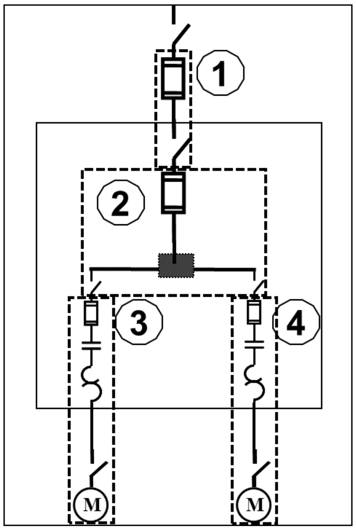


Figure 4-1 Simple Control panel

1. OCPD must provide acceptable levels of overload and short circuit protection for all components in their zone.
2. If there is an overload protection device and a short circuit device, it is desirable that the short circuit protection not open for overloads.
3. OCPD should open for all over-currents in their zone. That is, the OCPD should not operate for overloads *and* short circuits outside of their zone. Referred to as Full Selective Coordination.

The zone of protection discussion applies to protection of components but it does not necessarily apply for the protection of people. Although AJT fuses applied in zones ②③ and ④ would provide excellent energy limitation for arc faults within their zone, they are not considered in the determination of the arc flash hazard anywhere within the ICP. Only the external fuse ① is considered for this protection.

The key to obtaining all the benefits associated with current limiting fuses starts with selection of the branch circuit fuses. By optimizing the choice of AJT Class J time-delay fuses or ATDR Class CC time-delay fuses, the selection of upstream fuses can be more effective. Careful selection of fuses for motor circuits and transformers are critical for accomplishing these goals for the ICP.

Arc Flash Considerations.

The tripping characteristics of the upstream feeder overcurrent protection device will determine the incident energy at the ICP. As discussed in the previous section, using very current limiting Class J or CC fuses in the ICP branches allows for faster opening times of the feeder OCPD for short circuits without compromising coordination. It is easy to select Class J feeder fuses to be fully coordinated with Class J branch fuses while still yielding incident energy calculations of less than 1.0 cal/cm^2 at the ICP when properly sized. Since Class J and CC fuses are the most current limiting fuse option for the branch fuse, designers have the greatest flexibility in selection of upstream protection of the ICP while preserving coordination and minimal arc flash energies.

To get the minimal amount of incident energy at the ICP, it is important to ensure that the fuse feeding the ICP is operating in its short circuit region for arcing faults. That is, I_{arc} must be greater than the threshold current of the fuse (see Table 3-1 for example). For example, with available fault currents between 4.5kA and 100kA, the AJT100 will limit incident energies less than 0.3 cal/cm^2 Consideration of available fault current should be part of the decision on the size of the ICP. For example, it might be beneficial to use two ICPs with 400A feeds rather one than one ICP with an 800A feed if the fault current is not sufficiently high.

It is important to note that the incident energy calculation that your customer will make for the ICP's arc flash label and used for selection of arc rated PPE is based on the highest incident energy in the ICP.

In the example on the left of figure 4-2, the maximum incident energy is at the line terminals of the ICP and determined from characteristics of the power system connection point of the panel and the OCPD upstream from the ICP. Even though the main fuse of the panel is shown to be current limiting with a low incident energy calculation at the branch circuits, the arc flash label that your customer would apply to the ICP would show a calculation of 8.6 cal/cm^2. Although interaction with the controls within the panel (e.g. troubleshooting a motor drive) would be in the area of the panel with 0.3 cal/cm², the worker would be required to wear an arc rated PPE ensemble that meets the Category 3 requirements of NFPA70E to protect against all hazards in the panel.

In the example on the right, the main fuse is moved to a separate fused disconnect switch. With the available fault current greater than the current limiting threshold (see table 3-1), the customer would then apply a label with a calculated incident energy of 0.3 cal/cm² to the ICP indicating that workers would face a much lower arc flash hazard. Of course, the fuse disconnect would have 8.6 cal/cm² on its arc flash label.

See Section 5, for SCCR labelling requirements of UL508A for when the panel relies on an external OCPD for its SCCR calculation.

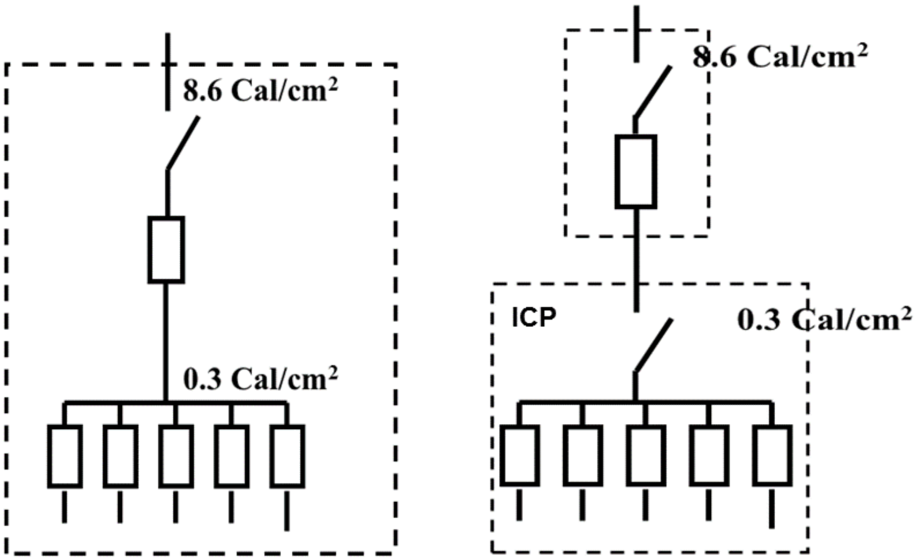


Figure 4-2. Main Fuse Options

Coordination and Continuity of Power

For optimal performance of the protection system, it is highly desirable that the Main Fuse 1 and the Feeder Fuse 2 in Figure 4-1 do not open for faults on any of the motor circuits. If it is possible for the main protective device to trip for faults downstream of a branch fuse, then all loads powered by the Main would be lost. A lack of coordination can not only result in more widespread outages but can also increase the difficulty in determining the location of the problem, increase the time to restore power and processes, and may create a situation where a worker may need to interact with an upstream device that requires higher rated PPE.

It is important to note that the OCPDs selected for the branch circuits in the ICP will limit your options with all upstream OCPD when coordination is desired. Using an upstream circuit breaker with an intentional trip delay to improve coordination with ICP branch protective devices will create higher incident energy at the ICP. These delays are not necessary with properly selected fuses.

Since current limiting fuses can be coordinated within their short circuit region without any intentional delay, it is easy to dramatically limit the energy delivered to arcing faults within the ICP without compromising continuity of service because of a short circuit event.

It is also desirable that each branch short circuit protective device coordinates with the overload devices in its circuit. If the branch fuse is sized to allow time for the overload protection to clear overloads, it will be easier to troubleshoot and faster to restore equipment to service. Opening of the branch fuse would then be a clear indication of a fault on the circuit and the need to comply with the requirements 130.6(M) of NFPA 70E.

Upstream Fuse/Branch Fuse Coordination.

Complete selective coordination between a downstream AJT Class J fuse or Class CC fuse and an upstream AJT fuse is possible for fault currents up to 200kA. That is, the feeder fuse will only open for faults on the bus between the feeder fuse and the line side of the branch fuses. To be selectively coordinated, the upstream fuse must pass the current waveform determined by the downstream fuse shown in figure 4-3 without melting its element. Lower let through currents by the downstream fuse as measured by I^2t, allow for smaller feeder fuses while maintaining coordination. The fuse coordination chart shown in Table 4-1 for fuses commonly used in ICP ensure that the let through I^2t is sufficiently low enough to prevent opening or damage to the upstream fuse element.

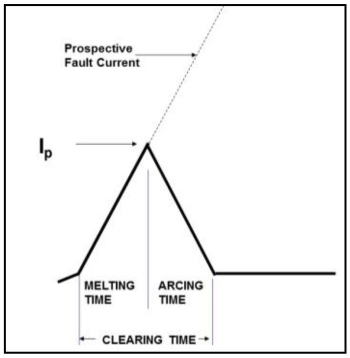


Figure 4-3. Let-through Current

Table 4-1. Coordination Chart for AJT and ATDR Fuses.

Main Fuse	Largest Downstream AJT	Largest Downstream ATDR
AJT200	AJT100	ATDR30
AJT100	AJT60	ATDR30
AJT60	AJT25	ATDR30
AJT50	AJT20	ATDR15
AJT30	---	ATDR3
ATDR30	---	ATDR3

For example, when using an AJT60 fuse as the main fuse, full coordination will be ensured if the branch fuses are no larger than an AJT25 or ATDR30 fuses. That is, the AJT25 would clear any fault well before an upstream AJT60 could melt [20].

Fuse with upstream non-current limiting circuit breaker.

Selective coordination between a downstream fuse and an upstream non-current limiting feeder breaker is limited in the short circuit region by the instantaneous pick up setting of the breaker and the degree of current limitation of the fuse. If the I_p shown in figure 4-3 is greater than that required to trip the instantaneous unit of the circuit breaker, selective coordination is lost. Fuses with lower I_p values provide coordination for larger fault currents. Designers need to evaluate the data in the let-through charts and the details of the instantaneous trip unit to ensure proper coordination. See [20] [21] for more details. AJT Class J and ATDR Class CC fuses are the best choice for the lowest I_p values.

Fuse Selection Basics

The key to obtaining all the benefits associated with current limiting fuses starts with selection of the branch circuit fuses. By optimizing the choice of AJT Class J time-delay fuses or ATDR Class CC time-delay fuses, the selection of upstream fuses can be more effective. Careful selection of fuses for motor circuits and transformers are critical for accomplishing these goals for the ICP.

Fuse Selection for Motor Circuits

Since fuses are frequently used in motor branch circuits with separate overload protection, their main purpose is to provide the short circuit protection for the circuit. Good engineering practice ensures that the following factors be considered when initially selecting a fuse for a motor circuit.

1. NEC requirements
2. Characteristics of the motor current
3. Characteristics of the fuse
4. Level of short circuit protection of circuit components
5. Coordination considerations
    a. Coordination of branch fuse with the overload relay
    b. Coordination between motor branch fuses and upstream fuses
6. Arc flash / arc fault considerations
    a. ICP maximum incident energy goal
    b. Downstream incident energy arc flash goal for each branch circuit
    c. Minimizing damage from internal arc faults

The following considerations were used to develop the AJT Class J Time Delay fuse and ATDR Class CC Time Delay sizing charts in the Annex.

1. NEC Requirements

Article 430.52 specifies the maximum fuse ampere rating allowed for time-delay and non-time delay fuses. Table 430.52 allows for sizing of AJT Class J Time-Delay fuses up to 175% of motor full load amps (FLA) when a properly sized overload protection device is used. A note to the table allows sizing to 225% under certain conditions. These limits ensure that the overload relay is not called upon to clear a low-level fault beyond its interrupting capability.

A note to the table allows sizing to 300% of FLA for the ATDR Class CC Time-Delay fuses because of the shorter time delay requirement of the Class CC standard.

2. Characteristics of the motor current

The ampere rating of the fuse should be selected so that it can be expected to have a long life under normal operations of the motor. Both the full load amps and starting current of the motor must be considered. Since the starting current will be greater than the ampere rating of the fuse, the magnitude and duration of this current must be considered so that fuse elements are not exposed to excessive heat cycles that could shorten their life. Fuse selection tables in the Annex using full load amps, locked rotor amps and start times give the recommendations that ensure reliable operation. See [19] for more details.

3. Characteristics of the fuse

Overload Operation.

Fuses should be sized to carry the normal starting current without opening. The UL 248-8 standard requirement that Class J Time-Delay fuses shall carry 5 times their ampere rating for a minimum of 10 seconds, allows these fuses to withstand starting currents throughout their lives when sized per the fuse selection charts in the Annex.

As stated in note 1 of Table 430.52 of the NEC: "The values in the Nontime-Delay Fuse column apply to time-delay Class CC fuses". The UL 248-4 standard for Class CC Time-Delay fuses requires that these fuses carry 2 times their ampere rating for a minimum of 12 seconds. Because of its reduced clearing time for currents near to the starting currents, the ATDR series of fuses will need to be sized slightly larger than the AJT. See the Annex for fuse selection charts that recommend fuse sizing for various applications.

Short Circuit Protection.
As discussed earlier, UL listed current limiting fuses must clear a fault within their short circuit region in less than 1/2 cycle while preventing the fault current from reaching the first peak of the prospective current. Whereas any UL listed Time-Delay fuse can handle the sizing basics discussed in this section, it is necessary to use the more current limiting Class J or Class CC fuses to obtain the maximum safety and protection benefits for fault currents. Since Time-Delay fuses have overload characteristics that better match motor starting current characteristics, they can be sized smaller than the non-time delay fuses. The smaller ampere ratings of the time delay fuses typically provide better short circuit protection for motor circuits and easier coordination with upstream OCPD.

An excellent choice for ICP motor branch circuits is the AJT Class J Time-Delay fuse. The superior current limitation requirements of this standard ensure that all the short circuit protection benefits mentioned herein can be obtained. The unique dimensions required of this fuse class, ensures that protection and reliability are not compromised by improper replacements in the future.

Another excellent choice for ICP motor branch circuits is the ATDR Class CC Time-Delay fuse for ampere ratings up to 30A. If the reduced time delay of this class can be adequately addressed, then the superior current limitation will provide all the short circuit protection benefits discussed within this guide. The smaller footprint of Class CC fuseholders and disconnect switches make them an excellent choice when panel space within an ICP is limited.

Note that you will need to specify Class CC fuseholders and/or disconnect switches to prevent the accidental replacement with lesser rated fuses. The rejection feature of these devices only allows Class CC fuses with their rejection tab on the end cap to be inserted. Because several UL listed supplemental 'Midget' size fuses have lower Voltage and AIR, an incorrect substitution could cause a damaging failure if called upon to interrupt a fault beyond their ratings.

4. Level of Short Circuit Protection - Starter Protection.
For faults on the motor branch circuit, starters are exposed to very rapid heating of their contacts and overload elements which can cause damage to the device in less than 1 cycle. Additionally, electromagnetic forces from high fault currents can cause significant arcing damage within the starter by separating contacts during the fault. All major starter manufacturers have certified their conventional products to the Type 2 level of ‘no damage’ protection for fault currents as high as 100,000A when protected with Class J or Class CC fuses sized according to their selection charts. Sizes recommended for Class J Time Delay fuses in the Type 2 tables typically are adequate for addressing the requirements discussed above. See [14] and [15] for more details.

5. Other Coordination Considerations

In addition to the discussion above on coordination with upstream overcurrent devices, it is suggested that attention be paid to coordinating the short circuit protection with the overload protection. Fuses are considered coordinated with the circuit’s overload relay if they are sized so that the overload relay will clear all overcurrents up to and including the locked rotor amps of the motor. This can be accomplished if the time current characteristic of the fuse intersects that of the overload relay at a current value near 25% higher than the magnitude of the locked rotor current of the motor (see figure 4-2). The UL 248 standard requirement that time-delay fuses shall carry five times their ampere rating for 10 seconds, makes coordination with overload relays easy to obtain with AJT fuses.

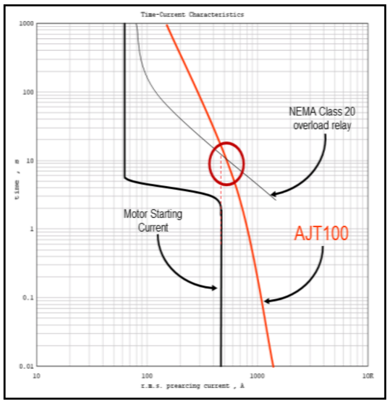


Figure 4-2. Coordination with OL relay.

NFPA70E [3] is clear that when an OCPD opens a short circuit, a qualified person must examine the circuit before it is re-energized per section 130.6 (M). When these devices are coordinated and the fuse opens, it is a good indication of a fault. On the other hand, if the circuit is cleared by the overload device, the circuit can easily be re-energized by resetting the overload with proper safety procedures.

6. Other Arc Flash Considerations

Downstream arc flash considerations. Although infrequent, serious injuries have occurred for arc faults within motor terminal boxes. The energy delivered to an arc fault within the box will rapidly raise the pressure. Although internal pressures can be relieved into the motor, the common failure mode is to launch the cover away from the box posing a potential hazard to any nearby worker [16]. Since Class J and CC fuses let through the lowest electrical energy, the worker protection is greatly improved if the calculated arc fault current is greater than the fuse's threshold current [7]. Incident energies can be less than 0.5 cal/cm^2 at motor disconnects if the calculated I_{arc} is greater than current limiting threshold of the branch fuse. For example, with an AJT60, incident energy will be less than 0.5 cal/ cm^2 if the available fault current is greater than 2kA at the disconnect.

Recommendations.
By optimizing the choice of AJT Class J time-delay fuses or ATDR Class CC time-delay fuses for the consideration of the factors mentioned above, the reliability of the short circuit protection can be greatly enhanced. Using the fuse selection tables in the Annex is a good way to start.

Fuse Selection Basics for Transformer Circuits

There are three key criteria when selecting a fuse for transformer protection: primary full load amps (FLA), NEC requirements and magnetizing inrush current. It is recommended that the fuse be sized at least at 125% of FLA to ensure a long reliable life. NEC Table 430.3(B) shows two protection methods: Primary-only and Primary and Secondary. With a secondary fuse protecting against overloads, the primary fuse can be sized up to 250% of FLA. Using the larger primary fuse minimizes the chance that the fuse is opened by inrush current.

When voltage is switched on to energize a transformer, the transformer core can saturate. This results in a large inrush current which is greatest during the first half cycle (approximately 0.01 second) and becomes progressively less severe over the next several cycles (approximately 1 second) until the transformer reaches its normal magnetizing current.

To reliably pass this inrush current, Mersen recommends that fuses should be selected to have time-current curve values of at least 12 times transformer primary rated current for 0.1 second and 25 times for 0.01 second. For AJT fuses and ATDR fuses, this requires that transformer secondary protection be used. The recommended primary and secondary fuses for popular, low voltage 3-phase transformers are shown in the Annex.

For control circuit transformers with a primary FLA less than 2A, the fuse may sized at up to 500% per 430.72(C)(4). For primary FLA greater than 2A the requirements of 450.3 still apply. For the smaller control circuit transformers, Mersen recommends that the primary fuse be able to pass 45 times the primary full load amps for 0.01 seconds. The recommended primary and secondary fuses for popular control circuit transformers are shown in the Annex.

5. Improving Control Panel SCCR with Current Limiting Fuses

Introduction

Because of clarifications in the 2017 NEC regarding the installation requirements of ICPs, more end users are requiring SCCR greater than the 5kA that has been commonly accepted in the past. This section shows how selection of components that have been type tested for high fault currents can make it simple to obtain SCCR of 100kA using the methodology of UL508A Supplement SB [8]. This standard is accepted by the NEC and is used by most panel shops as a means of deriving the ICP SCCR from component SCCR ratings. Critical to higher SCCR is the proper selection of overcurrent protection. For additional details on the application of this methodology see [22].

Overview of NEC Requirements for Control Panel SCCR

Article 409 of the NEC identifies various requirements for the safe installation of ICP. Article 670 addresses the SCCR requirement for controls of Industrial Machinery and is similar to the 409 articles.

NEC 409.110 (4) requires that the control panel be marked with its SCCR. The SCCR can be determined as a listed assembly (by test) or by an approved calculation method. In an Informational Note to Article 409.110 (4) and 670.3, Supplement SB of UL508A is identified as an approved method for establishing the short circuit current rating of the panel.

Articles 409.22 (A) and 670.5 (1) require that the SCCR of the control panel be greater than the available fault current at the panel.

- 409.22 (A) requires that panel "…*not be installed where the available short-circuit current exceeds its short-circuit current rating … "*
- 670.5 (2) requires that the machinery be *"…not be installed where the available short-circuit current exceeds its short-circuit current rating …."*

New in 2017, Articles 409.22 (B) and 670.5 (2) require that the user determine the maximum available fault current at the panel.

- 409.22 (B) requires that "…*the available short-circuit current at the industrial control panel and the date the short-circuit current calculation was performed shall be documented and made available to those authorized to inspect the installation."*
- 670.5 (2) requires that the machinery be *"…marked in the field with the maximum available short-circuit current. The field markings(s) shall include the date the short-circuit current calculation was performed…"*

Although the NEC requires that ICP have a SCCR greater than the available fault current, designs for enhanced safety must also consider the impact of OCPD selection on safety. See the discussion in the previous sections for more details.

Article 670.6 has the additional requirements for Surge Protection: "Industrial machinery with safety interlock circuits shall have surge protection installed." See [23] for more information.

Overview of UL508A Supplement SB Methodology

The methodology of Supplement SB allows the panel manufacturer to assign an SCCR to a panel without testing the assembled panel. This approach is particularly attractive for low volume panels where the cost of testing the assembled panel would be prohibitive. In this method, the panel SCCR is typically limited to the SCCR of the lowest rated component or the lowest rated branch circuit protective device in the panel. Resolving the low SCCR issues of the branches will lead to higher panel SCCR. For more information on this methodology see [22]

Although there are only three steps identified in the procedure of Supplement SB, using this method to achieve a high SCCR for a panel can be tedious when the panel contains many power circuits. This section, provides suggestions to achieve high SCCR for various branches by using type tested components, using current limiting devices per SB and using AJT and ATDR fuses.

The procedure for determining the panel SCCR is contained in section SB4.1.1 of UL508A which states [*Underlining added for emphasis.]*:

> "The short circuit current rating of the overall industrial control panel shall be determined based upon:
>
> a) First, establishing the short circuit current ratings of individual power circuit components as specified in SB4.2;
>
> b) Second, modifying the available short circuit current within a portion of a circuit in the panel due to the presence of current limiting components as specified in SB4.3, when applicable; and
>
> c) Third, determining the overall panel short circuit current rating as specified in SB4.4.

Step 1 Establishing Component SCCR

There are 3 ways to establish SCCR of components for the first step. These are identified in SB4.2.2 which states [*Underlining added for emphasis.]*:

> "The short circuit current rating of a feeder or branch circuit component shall be established by one of the following methods:
>
> a) The short circuit current rating marked on the component or on instructions provided with the component;
>
> b) The short circuit current rating determined by the voltage rating of the component and the assumed short circuit current from Table SB4.1; or
>
> c) The short circuit current rating for a component that has been investigated in accordance with the performance requirements, including short circuit test requirements for standard fault currents or high fault currents specified in the associated product standard, and described in the manufacturer's Procedure.

The high fault current rating mentioned in c) can be as high as 200kA but requires that the OCPD used in the qualification tests of the product must be used in the circuit as stated in SB4.2.3.

> "A high fault short circuit current rating for a feeder or branch circuit component, as specified in SB4.2.2 (a) or (c), shall only be used as the short circuit current rating of the component when the specified branch circuit protective device is provided."

Using the high fault current ratings of components simplifies the rules of SB4.4 for determining the panel SCCR.

Step 2 Using Feeder Fuse Let Through Current to Improve SCCR

In addition to using type-tested components, SB 4.1.1 (b) provides the option of modifying the available short circuit current downstream of a current limiting feeder OCPD per the rules of SB4.3. If the current limiting device can limit the fault current downstream to a value lower than the component with the smallest SCCR then the rating of the branch can be elevated per the rules of 4.3. The devices allowed are current limiting fuses, current limiting circuit breakers and transformers.

For current limiting feeder fuses, Table SB4.2 is used to determine the let through current used in evaluation of branch circuit SCCR improvement. A section of this table for Class J and Class CC fuses are shown in the Annex.

The SCCR of the branch can be elevated *"..when all of the individual components in the branch circuit have a short circuit current rating not less than the peak let-through current corresponding to the specific fuse class, ampacity and selected available short-circuit current employed from Table SB4.2,.."* [SB4.3.3 (a)].

For example, if the designer chose the 100kA column from Table SB4.2 for a feeder AJT60 fuse the let-through current of 10kA would be compared to the SCCR of components in the branch circuit. If the components in the branch had an SCCR of 10kA or greater, then the value of 100kA would be used in the determination of the panel SCCR. If a component had an SCCR of 5kA then a higher value could not be used in the determination of the panel SCCR.

However, the branch OCPD rating cannot be elevated by using the let through current and could be a limiting factor in the panel SCCR. If the branch OCPD has an AIR of 14kA and all of the components had their SCCR values elevated to 50kA, the value of 14kA would be used in the determination of the panel SCCR.

Step 3 Determining Panel SCCR

Section SB4.4 of Supplement SB of UL508A provides direction on how to develop a panel SCCR from the information determined in the previous steps. SB4.4.1 directs the designer to pick the lowest of the OCPD AIR and the SCCR of all components on each branch circuit. This value is then assigned to the branch.

Section 4.4.4 c) then provides guidance on how to use the feeder OCPD and the branch circuit ratings to develop the panel SCCR for panels with multiple branch circuits. The designer is directed to choose the lowest of:

1) The lowest short circuit current rating of any branch circuit in accordance with SB4.4.1 that has not been modified by SB4.3.1 – SB4.3.3;
2) The short circuit current rating of any feeder component not covered by SB4.4.4(c)(3) and any control circuit overcurrent protection connected to the feeder as in SB3.2.1; or
3) The modified short circuit current rating determined from SB4.3.1 – SB4.3.3 for each branch circuit supplied by the associated feeder component

Section SB5 provides guidance on how to label the panel.

Calculation Examples

A review of SCCR determination is provided here by using the small control panel depicted in Figure 5-1. For more information on the Supplement SB method see [22].

Using the methodology of SB4.4.4(c) the panel <u>SCCR will be the lowest of</u>:

1. The SCCR for branch circuits ② and ③
2. Feeder component④ SCCR and ⑤ AIR.
3. Control circuit OCPD ①rating.
4. Modified SCCR for ② and ③ (if possible) based on the current limitation of the feeder fuse ⑤ per the rules of SB4.3.3.

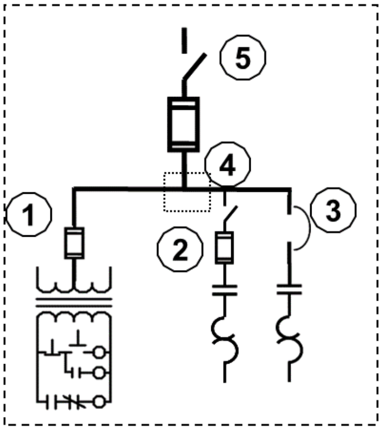


Figure 5-1. Example Circuit

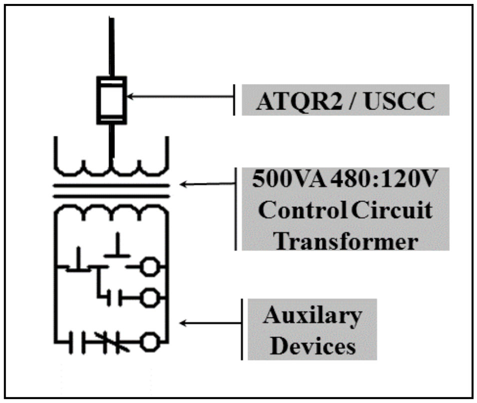
The biggest challenge to achieving panel SCCRs of 50kA or greater is in the selection of components that have been type-tested to higher SCCR. The UL508 Standard allows component manufacturers to test components at higher current levels with specific OCPDs to establish what UL refers to as "high fault short circuit current ratings." This process is referred to as type-testing. Rather than use the minimum SCCR levels given by Table SB4.1 (see Annex), research the manufacturer's literature or website to determine what higher ratings have been established for a specific component. The most common concern are components within the branch circuits.

Sometimes branch components can have their SCCR 'modified' by current limiting devices per the rules of SB4.3.1-SB4.3.3.

In the following examples, the SCCR options for each circuit connected to the feeder are determined using the rules contained within Supplement SB. For branch circuits, their SCCR is determined by selecting the smaller of the OCPD AIR and the smallest SCCR rating of components in that branch per SB4.4.1. For control circuits connected to the feeder, the SCCR is simply the AIR/SCCR of the control circuit OCPD.

SCCR Determination Examples

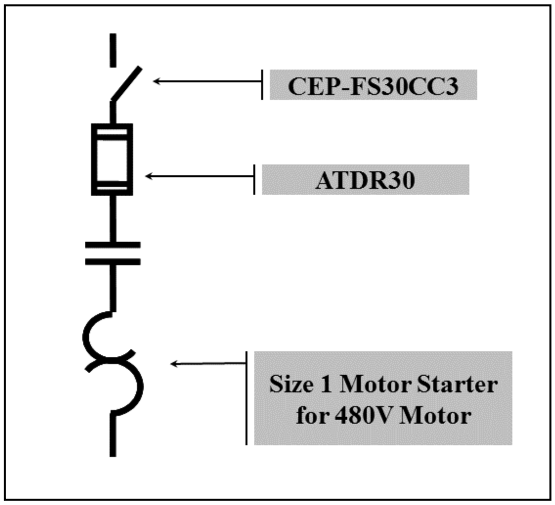
Control Circuit - ①



SB 3.2 and SB 4.4.4 (c)(2) make it clear that the AIR/SCCR of the control panel OCPD can be a limiting factor in determining the panel's SCCR. Since the SCCR assigned to the control circuit is limited by the rating of the circuit's OCPD, using an OCPD with a 10kAIR would limit the panel SCCR to no greater than 10kA. This potential weak link can be eliminated by protecting the control circuit with <u>ATQR Class CC time-delay fuses, which allow for up to a 200kA panel SCCR</u>.

RECOMMENDATION: Use ATDR fuses and an IP-20 fuse holder such as the USCC Ultrasafe series. Note that the ATQR Class CC fuse was designed to pass the higher inrush currents of small control circuit transformer (>40xFLA).

Branch Circuit - ②

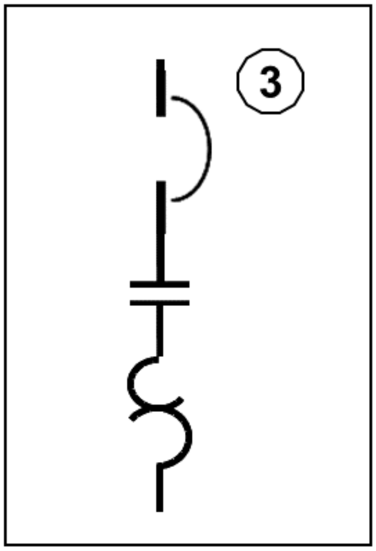


For most starters, designers will have up to three component SCCR to choose from: the value from Table SB4.1, the SCCR marked on the device or a type-tested SCCR. For the example here, the chosen starter has a marked SCCR of 5kA and a type-test rating of 100kA from the manufacturer documentation. The type-test rating requires the use of a 30A Class J fuse or smaller.

Since Exception No.1 of SB 4.2.3 allows fuses with equal or better current limitation, such as the ATDR30 Class CC fuses, this component will also qualify for the 100kA rating. By protecting this circuit with an ATDR30 (200kAIR) and using the component's type-tested SCCR this branch circuit is assigned 100kA and allows panel SCCRs of up to 100kA.

RECOMMENDATION: Use AJT fuse or ATDR fuses in motor circuits to take advantage of 100kA type-testing of starters and possibly Type 2 ratings [14][15].

Branch Circuit - ③

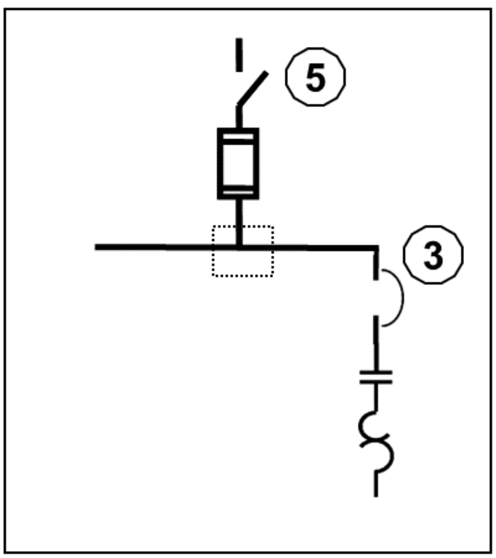


For the example here, the chosen starter has a marked SCCR of 10kA and no type-test rating information available from the manufacturer. The marked rating requires the use of a 30A OCPD or smaller as required by the NEC. The AIR of the circuit breaker in this example is 14kA.

In this case, the SCCR of this branch circuit can be rated no higher than 10kA. Thus, this component will limit panel SCCRs to no greater than 10kA unless the current limiting fuse ⑤ in figure 1 can obtain a higher rating for the starter using the rules of SB4.3.3. See the next example for details on this.

If there was no marked rating on the starter, the SCCR of this branch circuit can be rated no higher than the 5kA component rating of Table SB4.1 (See Annex).

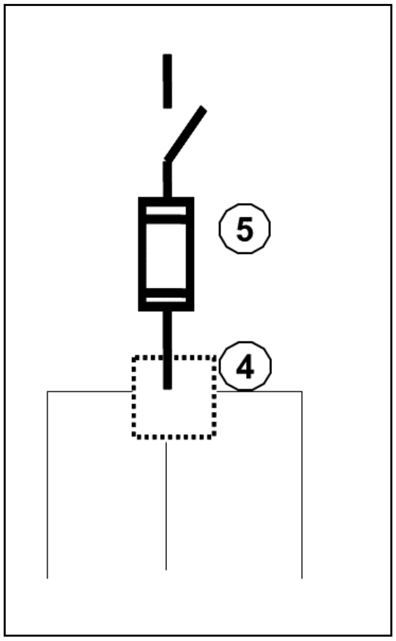
Branch Circuit ③ - Using Feeder Fuse Let Through Current to Improve SCCR



In the example above for Branch ③ the branch SCCR was determined to be 10kA because of the starters marked SCCR of 10kA. If the feeder fuse ⑤ is an AJT 60, the let-through current of 10kA shown in Table SB4.2 for an available fault current of 100kA allows this component to use an SCCR of 100kA. The 14kAIR rating of the circuit breaker in branch ③ would be the limiting factor for this branch and perhaps the panel. In this case the 14kAIR of the circuit breakers used in ③, would place an upper limit on the panel SCCR of 14kA.

RECOMMENDATION: Use AJT fuse or ATDR fuses in motor circuits to take advantage of 100kA type-testing of starters where possible. When using the let through methodology, their 200kAIR will not place any constraints on panel SCCR as described here.

Feeder Components ④ - Using Current Limiting Fuses to Improve SCCR



The feeder circuit in the example panel contains a UL Component Recognized power distribution block ④ not marked with an SCCR. Using Table SB4.1 (See Annex), the PDB is assigned an SCCR of 10kA. Although an AJT60 (Class J) fuse is in the feeder circuit ⑤ and the I_p is limited to 10kA for available currents up to 100kA, (Table SB4.2 in the Annex), the 10kA rating of the PDB cannot be raised using any rules of SB4.3.3

Since the rules of SB4.3.1 – SB4.3.3 do not provide directions to elevate the feeder component SCCR with let-through current, the following part of section SB4.4.4 (c) does not allow SCCR improvement of the ICP beyond the SCCR of the component:

2) The short circuit current rating of any feeder component not covered by SB4.4.4(c)(3) and any control circuit overcurrent protection connected to the feeder as in SB3.2.1

RECOMMENDATION: Use Mersen's FSPDB and AJT fuses for feeder protection to take advantage of 100kA type-testing of PDBs [13].

The Advantage of Using High Fault Current Ratings

If components with high fault current ratings are not used or if the high fault current ratings for components are not used, the SCCR of the control panel will likely be limited to 5kA or 10kA.

Supplement SB gives several ways to determine component SCCR and how to use let through current where applicable. Table 5-1 shows a comparison of two approaches. The first uses component values from Table SB4.2.1 or component labels. The second uses the high fault current ratings of components with Class J Fuses.

In the first calculation, the 5kA SCCR of the starter in circuit (2) limits the entire panel rating to 5kA. Although, the let through current of the AJT60 can be used to raise the SCCR of branch circuit (3) to 14kA as discussed above, the panel is still limited to 5kA.

In the second calculation, the 100kA high fault current rating of the starter in circuit (2) is used. The required maximum ampere rating of the Class J or CC is not exceeded. In this calculation the circuit (3) is replaced with that of circuit (2) and a 100kA rating is claimed. Also, the 100kA high fault current rating of the PDB (4) is used since it is protected by the proper size AJT fuse. The result is a panel SCCR of 100kA.

Table 5.1 Advantage of using High Fault Current Rating.

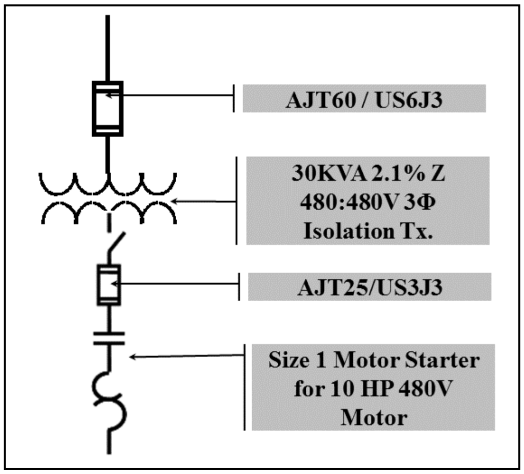
Circuit or Device	SCCR Assignment From Table SB4.1 or Component Marking		SCCR Assignment Using High Fault Current Rating	
	SCCR Assignment	Device Limiting SCCR	SCCR Assignment	Device Limiting SCCR
Control Circuit ①	200kA	ATQR2 Primary Fuse	200kA	ATQR2 Primary Fuse
Branch Circuit ②	5kA	Starter per Table SB4.1	100kA	Starter high fault current rating with Class J Fuse
Branch Circuit ③	10kA	Starter per Component Marking*	100kA	Protection **changed** to the same as circuit ②
Component ④	10kA	Distribution Block per Table SB4.1	100kA	PDB high fault current rating with Class J Fuse
Feeder OCPD ⑤	200kA	Class J Disconnect and AJT60	200kA	Class J Disconnect and AJT60
Panel SCCR	**5kA**	Branch Circuit ②	**100kA**	Branch Circuits ② & ③ and Component ④

Other Examples

Using Transformers to improve SCCR

Because of their impedance, transformers will limit the amount of fault current to components in downstream branch circuits. If the available short circuit current on the secondary is less than the short circuit ratings of all components in the branch circuit, then the AIR of the primary fuse can be assigned as the SCCR for that branch. For AJT primary fuses, this allows panel SCCRs of up to 200kA.

Branch Circuit ③ - Using a Transformer to Improve SCCR

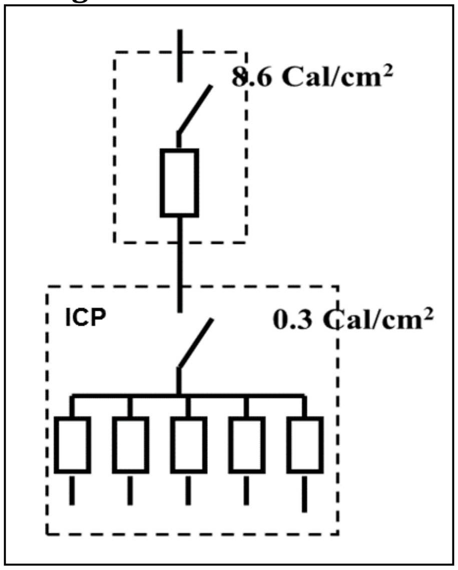


If the branch circuit ③ had a starter with a 5kA rating and was fed by a transformer as shown, it would be possible according to the rules of SB 4.3.1 to achieve a higher SCCR.

Per the equation for 3 phase transformers in SB4.3.1, the calculated secondary available fault current is only 1,720A.

Since the starter SCCR of 5kA is higher than this available fault current and the fuses' 200kAIR, the SCCR assigned to the line side of the primary fuse is 200kA -the AIR of the AJT60 fuse.

Using an external main disconnect



As noted in Section 3, it may be desirable to have the feeder fuse (panel main fuse) in an external enclosure to limit the incident energy to the panel containing the branch circuits feeding the power circuits as shown again here. This may also have the side benefit of a lower cost enclosure for the controls.

In order to label the panel with a high SCCR based on the performance of the external feeder fuse, the panel must also include on its label the required circuit protection device. See section SB5.1.3 below. For our example, the label must identify the AJT60 as required for the high SCCR rating.

SB5.1.3 An industrial control panel marked with a high fault short circuit current rating and is not provided with the required feeder circuit protective device as specified in the SB4.3.4 shall be marked with the type and size of feeder circuit protection required to be installed in the field. This marking shall be included as part of the marking in SB5.1.1.

FAQ for SCCR Calculations

With control panels, there can be a wide variety of components and circuits used that may require clarification of the rules of Supplement SB. As always, refer to the appropriate standard for clarification of your specific question and application.

Mersen engineers are available to assist you in getting answers to your questions. The answers to the Frequently Asked Questions below are based on our understanding of the standards at the time of this writing. See Disclaimer in the Preface.

The component that I am using claims a 100kA SCCR with a 30A Class J fuse. Can I use a 30A Class CC and still claim a 100kA rating?

Yes. Exception 1 of SB4.2.3 allows the use of a more current limiting fuse to claim the higher fault rating. The I_p and I^2t values shown in table SB4.2 shows the Class CC fuse to be more current limiting.

> *"Exception No. 1: When the specified branch circuit protection related to the high fault short circuit current rating is a Class CC, G, J, L, RK1, RK5, or T fuse, a fuse of a different class is able to be used at the same high fault rating where the peak let-through current and I2t of the new fuse is not greater than that of the specified fuse. See Table SB4.2 for maximum let-through currents and I^2t."*

Can an external main be used in SCCR determination?

Yes, if the panel is marked accordingly per SB5.1.3.

> *"SB5.1.3 An industrial control panel marked with a high fault short circuit current rating and is not provided with the required feeder circuit protective device as specified in the SB4.3.4 shall be marked with the type and size of feeder circuit protection required to be installed in the field. This marking shall be included as part of the marking in SB5.1.1."*

Can the let-through current of the feeder fuse be used to increase the SCCR of a feeder's Power Distribution Block (10kA per Table SB4.1)?

No. Supplement SB does not specifically identify this method to increase SCCR. See Section 5, Feeder Components - Using Current Limiting Fuses to Improve SCCR. Use Mersen's FSPDB and AJT fuses for feeder protection to take advantage of 100kA type-testing of PDBs

Does a phase monitor relay/meter need a SCCR?

Since these relays work in the same manner as a voltmeter by measuring the circuit voltage without being in the power circuit current path, they can be covered by SB4.2.1, Exception No. 1. Since short circuit current would not flow through the relay in the event of a fault in the power circuit it would not require a short circuit current rating (SCCR).

This also requires that the outputs contacts of the phase monitor are only used within control circuits.

Do terminal blocks need an SCCR established for determining panel SCCR?

If terminal blocks are applied in the power circuit, then they must be considered in the evaluation. Their assumed value from Table SB4.1 is 10kA, however there are options rated much higher with Class J fuses

Does a DC Power Supply need a SCCR or is it treated like a CC Tx?

-or-

How can I get a 100kA rating for a 24VDC power supply fed by 480V power circuit?

Refer to UL508A SB3.2.1 *"For control circuits tapped from the feeder circuit, the overcurrent protection for the common control circuit or for the primary of a control transformer or power supply shall be provided with branch circuit protective devices having a short circuit current rating not less than the overall panel short circuit current rating, see SB4.4.4."*

See also the exception for this section: "*Exception: Secondary circuits operating at 24 vdc maximum and supplied from a source with a maximum output power of 100 VA, shall be considered control circuits for the purpose of applying SB3.2.1.*

Protecting the control power supply with an ATDR Class CC fuse would allow a panel SCCR of up to 200kA.

Does a 240V fan need a SCCR on a 240V panel?

Refer to UL508A SB 4.2.1 *Exception No. 3: Enclosure air conditioners that are cord-and-attachment-plug connected are not required to have a short circuit current rating.*

How can I install a GFCI (with an SCCR of 2kA per table SB4.1) in my panel without reducing the panel SCCR?

If the GFCI receptacle is connected through 1500VA 480:120V transformer the maximum fault current would be less than 2kA at 120V. If the transformer is protected by an **ATDR7** Class CC fuse installed in an UltraSafe Class CC fuseholder, an SCCR of 200kA could be used for that branch circuit. (see next two question for more info on using transformers to reduce available fault current)

How do I handle the SCCR requirements of components connected to the load side of the transformer?

If the SCCR of the devices on the transformer secondary are greater than the fault current on the transformer secondary, then the branch is rated based on rating of the primary OCPD. *See page 38 for an example*.

How much does a transformer limit fault current?

The secondary I_{bf} for a 3Φ transformer can be calculated with the following formula.

(Transformer kVA * 1000) / ((V_{L-L} * 1.732) * (Transformer Impedance (Z))

For example, a 15KVA 3Φ transformer with a 208V secondary and 4% impedance would limit the secondary available fault current to 1,040A.

Tables SB4.3 and SB4.4 provide calculations for various voltages and low transformer impedances.

References

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[21] Marcelo Valdes, Cindy Cline, Steve Hansen and Tom Papallo, "Selectivity Analysis In Low Voltage Power Distribution Systems With Fuses And Circuit Breakers," IEEE Industrial and Commercial Power Systems Conference Record, May 2009.

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[23] Mersen TT-SPN5 - Industrial Machinery and Surge Protection Devices

Product Information

Fuses

AJT Class J Fuses
ATDR Class CC Fuses
ATQR Class CC Fuses

Fuseholders

Class J Ultrasafe Fuse Holders
Class J Fuse Holders
Class CC Ultrasafe Fuse Holders

Switches

UL 98 Non-Fusible Disconnect Switches
UL98 Fused Switch
Class CC Compact Fused Switch

Power Distribution Block

Finger Safe Power Distribution Blocks
Compact EP Power Distribution Blocks
Open-Style Power Distribution Blocks

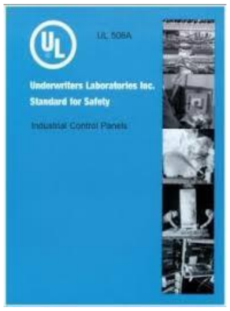
Surge Protective Devices

ST Series Modular
STP Series Pluggable
Complete Brochure

Other Information

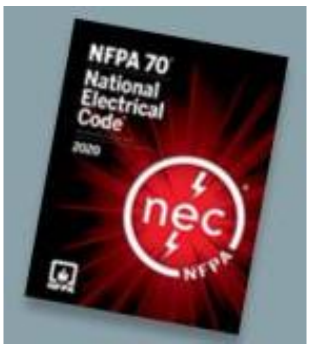
Arc Flash Info Center
Mersen SCCR Quick Select Guide
Mersen Type 2 Reference Charts Allen-Bradley
Mersen Advisor, Section P
Tech Topics (Filter Category for Tech Topics)
FUSE Control (inventory consolidation service)

References - Codes and Standards



UL508A Industrial Control Panels

Whereas UL508 is the standard for industrial control equipment, UL508A is the standard for the construction Industrial Control Panels. The requirements of UL508A cover the construction of industrial control panels intended for general industrial use for voltages of 1000 volts or less. These panels are intended for installation in accordance with the National Electrical Code, NFPA 70, where the ambient temperature does not exceed 40°C (104°F). Guidelines on a variety of issues are provided including wiring, component selection and SCCR calculation (with Supplement SB)



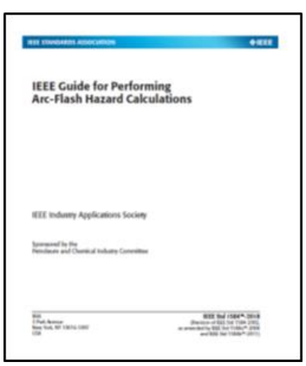
NEC

Inadequate short circuit ratings (both AIR and SCCR) are on the list of causes of arc flash events. Over the past several cycles the NEC has added and modified sections to more effectively address this issue. The first step in properly selecting adequate short circuit ratings is to know the available fault current. It is now clear in Article 409, that equipment installed under this section must have a SCCR greater than the maximum available fault current at the location of installation. It is the end user and/or installer's responsibility to properly specify the needed short circuit performance required. Table 409.3 lists other sections of the NEC that are relevant for Industrial Control Panels.

NFPA 70E

The first several editions of the standard, originally titled "Standard for Electrical Safety Requirements for Employee Workplaces," primarily focused on the prevention of electrocution. In the 1995 edition, arc flash hazards started to be addressed with addition of "arc flash hazard boundaries." Through extensive work, more details on protecting workers against arc flash hazards have been included in subsequent editions.

The last two editions have significantly improved the coverage of risk management concepts. With the inclusion of the risk control pyramid of ANSI Z10 (shown on the cover of the 2018 edition), employers are being directed to lower risks by considering options from the more effective methods at the top of the pyramid. See Mersen's Arc Flash Info Center on our website for more details.



IEEE1584-2018 Guide for Performing Arc Flash Hazard Calculations

As implied by its title, IEEE Standard 1584 provides techniques for designers and facility operators to apply in determining the arc flash-protection boundary and arc flash incident energy for PPE selection. The recently released 2018 edition contains extensive changes in the calculation model that could yield dramatic differences to incident energy calculations from previous analyses. The challenges in applying the new model includes selecting electrode configuration. For more information see the Arc Flash Info Center on Mersen's website.

Annex

Fuse Selection Tables

The following selection tables are for some of the more common applications. For additional selection table covering other fuses and voltages see Section P of Mersen's Advisor [19].

Table A1. 480 V Motors

Motor HP	Full Load Current	Recommended Ampere Rating Motor Acceleration Times Minimum	Typical	Heavy Load	Minimum	Typical	Heavy Load
460V		J-AJT			CC-ATDR		
1/2	1.1	1 1/2	1 6/10	2	3	3 1/2	6
3/4	1.6	2	2 1/4	2 8/10	3 1/2	5	6 1/4
1	2.1	2 1/2	3 2/10	4	5	6 1/4	8
1 1/2	3	3 1/2	4 1/2	5 6/10	6	9	12
2	3.4	4	5	6	8	10	15
3	4.8	6	7	9	12	15	17 1/2
5	7.6	10	12	15	17 1/2	25	30
7 1/2	11	15	17 1/2	20	25	30	-
10	14	17 1/2	20	25	30	-	-
15	21	25	30	40	-	-	-
20	27	35	40	50	-	-	-
25	34	40	50	60	-	-	-
30	40	50	60	70	-	-	-
40	52	70	80	100	-	-	-
50	65	80	100	125	-	-	-

Table A2. 208V Motors

Motor HP	Full Load Current	Recommended Ampere Rating Motor Acceleration Times Minimum	Typical	Heavy Load	Minimum	Typical	Heavy Load
208V		J-AJT			CC-ATDR		
1/2	2.4	3	3 1/2	4 1/2	5	8	10
3/4	3.5	4 1/2	5	6 1/4	8	10	15
1	4.6	6	7	9	10	15	17 1/2
1 1/2	6.6	8	10	12	15	20	25
2	7.5	9	12	15	17 1/2	25	30
3	10.6	15	15	20	25	30	-
5	16.8	20	25	30	-	-	-
7 1/2	24.2	30	35	45	-	-	-
10	30.8	40	50	60	-	-	-
15	46.2	60	70	90	-	-	-
20	60	80	90	110	-	-	-
25	75	90	110	150	-	-	-
30	88	110	150	175	-	-	-
40	114	150	175	200	-	-	-
50	143	175	225	300	-	-	-

Table A3. Control Circuit Transformers - 480V

Trans VA	FLA	ATQR
25	.052	1/10
50	.104	1/4
75	.156	3/10
100	.208	4/10
130	.27	1/2
150	.313	1/2
200	.417	6/10
250	.52	8/10
300	.62	1-1/2
350	.73	1-1/2
500	1.04	2

Table A4. Transformers

480V Primary			120V Secondary		208V Secondary		240V Secondary	
Transformer (kVA)	FLA	AJT	FLA	Fuse rating	FLA	Fuse rating	FLA	Fuse rating
3	3.6	6	14	20	8	12	7	9
5	6	12	24	30	14	17-1/2	12	15
7.5	9	15	36	45	21	30	18	25
9	11	25	43	60	25	35	22	30
15	18	35	72	100	42	60	36	45
30	36	60	145	200	83	110	72	100
45	54	100	217	300	125	175	108	150
75	90	175	361	450	208	300	181	250
100	120	225	482	600	278	350	241	350
112.5	135	300	542	700	313	400	271	350
150	180	400	723	900	417	600	361	500
225	371	500	1084	1350	625	800	542	700

Table A5. Maximum Fuse Size for Full Coordination

Main Fuse	Largest Downstream AJT	Largest Downstream ATDR
AJT200	AJT100	ATDR30
AJT100	AJT60	ATDR30
AJT60	AJT25	ATDR30
AJT50	AJT20	ATDR15
AJT30	---	ATDR3
ATDR30	---	ATDR3

Table A6. Minimum Available Fault Currents (I_{bf}) for current limitation for VCB

FUSE	Minimum I_{bf} for Current Limitation	Minimum I_{bf} for 1.2 cal/cm^2
AJT60	2.2kA	1.5kA
AJT100	4.5kA	2.2kA
AJT200	8kA	5kA
AJT400	15kA	9.6kA
AJT600	25kA	15kA

- Calculations based on IEEE1584-2018 equations at 480V.

Table A7. Select UL limits for Let through currents

See Table SB4.2 of UL508A for a complete listing

Fuse Type	Fuse Rating amperes	Between threshold and 50kA		100kA	
		$I^2t \times 10^3$	$I_p \times 10^3$	$I^2t \times 10^3$	$I_p \times 10^3$
Class CC	15	2	3	2	3
	20	2	3	3	4
	30	7	6	7	7.5
Class J	1			0.8	1
	3			1.2	1.5
	6			2	2.3
	10			3	3.3
	15			4	4
	20			5	5
	25			5.5	6
	30	7	6	7	7.5
	35			12	7.5
	40			17	8
	45			18	8.5
	50			22	9
	60	30	8	30	10
	70			50	11.5
	80			60	12.5
	90			75	13.5
	100	60	12	80	14
	110			100	14.5
	125			150	15.5
	150			175	17
	175			225	18.5
	200	200	16	300	20

Table SB4.1

Assumed maximum short circuit current rating for unmarked components

Table SB4.1 effective April 25, 2006

Component	Short circuit current rating, kA
Bus bars	10
Circuit breaker (including GFCI type)	5
Current meters	a
Current shunt	10
Fuseholder	10
Industrial control equipment:	
a. Auxiliary devices (overload relay)	5
b. Switches (other than mercury tube type)	5
c. Mercury tube switches	
Rated over 60 amperes or over 250 volts	5
Rated 250 volts or less, 60 amperes or less, and over 2 kVA	3.5
Rated 250 volts or less and 2 kVA or less	1
Motor controller, rated in horsepower (kW)	
a. 0 – 50 (0 – 37.3)	5[c]
b. 51 – 200 (38 – 149)	10[c]
c. 201 – 400 (150 – 298)	18[c]
d. 401 – 600 (299 – 447)	30[c]
e. 601 – 900 (448 – 671)	42[c]
f. 901 – 1500 (672 – 1193)	85[c]
Meter socket base	10
Miniature or miscellaneous fuse	10[b]
Receptacle (GFCI type)	2
Receptacle (other than GFCI type)	10
Supplementary protector	0.2
Switch unit	5
Terminal block or power distribution block	10

[a] A short circuit current rating is not required when connected via a current transformer or current shunt. A directly connected current meter shall have a marked short circuit current rating.

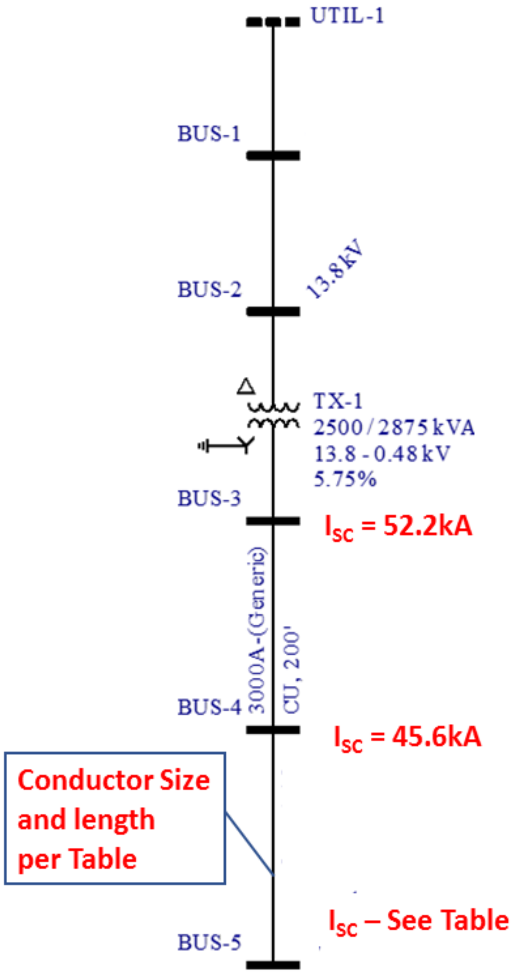
[b] The use of a miniature fuse is limited to 125-volt circuits.

[c] Standard fault current rating for motor controller rated within specified horsepower range.

UL Fuse Classes and Basic Ratings

Fuse Type	Voltage	Ampere Rating	Interrupting Rating – kA	Mersen Part #	UL
Class CC	600VAC	0-30	200	ATDR, ATQR, ATMR	248-4
	300VDC	0-30	100	ATDR, ATQR	
	600VDC	0-30	100	ATMR	
Class G	480/600VAC	0-20/21-60	100	AG	248-5
Class H (Renewable)	250/600VAC	0-600	10	RF/RFS	248-7
Class H (Non-Renew)	250/600VAC	0-600	10	NRN, CRN/NRS, CRS	248-6
Class J	600VAC	0-600	200	AJT, HSJ, A4J	248-8
	300VDC	0-30	100	A4J, HSJ(1-10)	
	500VDC	0-600	100	AJT, HSJ(15-600)	
Class K-5	250/600VAC	0-600	50	OT, OTN/OTS	248-9
Class L	600VAC	601-6000	200	A4BQ, A4BY, A4BT	248-10
	500VDC	601-3000	100	A4BQ	
Class RK1	250/600VAC	0-600	200	A2D, A2K/A6D, A6K	248-12
	600VAC	70-600	200	HSRK	
	250VDC	0-600	100	A2D	
	600VDC	0-600	100	A6D	
Class RK5	250/600VAC	0-600	200	TR/TRS	248-12
	300/600VDC	0-30/35-400	20	TRS-RDC	
Class T	300/600VAC	0-1200/0-800	200	A3T/A6T	248-15
	160/300VDC	0-1200	50/100	A3T/A6T	
Semiconductor	130-4000VAC	0-2000	Up to 300	See Section D	248-13
Glass/Electronic	32-350VAC	0-30	Up to 10	See Section C	248-14
Midget	125/250VAC	0-30	0.2-10	TRM, OTM, GFN	248-14
	500/600VAC	0-30	10,100	ATQ, ATM, SBS	

Short Circuit Calculation Example



In the example at left, the short circuit current at the secondary terminals of the transformer was calculated to be near 52kA. The calculated short circuit current at the end of the 200 feet of 3000A bus duct fed by the transformer is 45.6kA.

If a control panel was installed at bus 5, the calculated available short circuit current would depend on the impedance of the cable drop from the bus.

Calculations at bus 5 were made with a variety of cable sizes and lengths. The results of which are shown in the table.

As can be seen in the table, a range of possible faults currents is highly dependent on the length of the run from bus 4 to bus 5 and the size cable.

A customized fault study on your power system should be run by a qualified analyst to ensure that all variations of impedance and current sources (such as motor contribution) are considered when calculating available fault current for selecting proper ratings of equipment.

Conductor Size (AWG or kcmil)	Prospective Fault Current at BUS-5 (in kA)				
	Conductor Length (feet)				
	20'	40'	60'	80'	100'
500	39.9	35.4	31.8	28.9	26.4
250	38.9	33.6	29.5	26.2	23.6
4/0	38.6	33.2	28.9	25.6	22.9
1/0	35.9	28.6	23.5	19.8	17.0
2	32.7	24.0	18.6	15.1	12.7
6	21.9	13.1	9.3	7.1	5.8