

Arc Flash & Low Voltage

Over-Current Protective Devices (OCPDs)

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Abstract: The article discusses various reasons that why the Arc Flash Hazard concern is implemented in the electrical industry. The different types of over-current devices and their role in mitigating the Arc Flash Hazard or reducing the Hazard Risk Category (HRC) and a need to conduct the Arc Flash studies and how to interpret the study results are also addressed in this paper.

Arc Flash Hazard is gaining more interest because of several reasons. Some of these reasons are:

1. A continuing general awareness of safety
2. Standards enforcement - NFPA70E
3. Insurance coverage and its implications
4. Advance tools, software and intelligent power distribution equipment availability

There are several factors which play a vital role to minimize the Arc Flash Hazard, or HRC, to an acceptable value. To comprehend the role of each factor, we should have a thorough understanding of the power

distribution system that is being analyzed. The following are some of the factors which affect the Arc Flash Hazard or Hazard Risk Categories:

- a. Short circuit current available from a utility company
- b. Onsite power generating sources
- c. Short circuit current available at various buses where Arc Flash Hazard or HRC value is calculated
- d. Type of over current protective devices (OCPDs)
- e. Location of power distribution equipment (Cable lengths)

All of the above factors play a significant role in calculating the Arc Flash Hazard, or HRC. Some of these factors depend on the location of a project and may not be changeable. For example, one such factor is the utility short circuit current, which depends on utility parameter. These parameters may have been chosen by the utility's engineer long before the inception of this project and now these are unalterable.

Utility fault current contribution affect short circuit values at various buses throughout the power distribution system. If the available short circuit current is higher from a utility, the calculated short circuit values at various buses would also be higher. The Arc Flash Hazard, or HRC, depends on a calculated short circuit current value. When the calculated short circuit value is higher, HRC may be low or vice a versa, so this relationship is inversely proportional.

Onsite generation parameters may be controllable to some extent. For example, size, location, impedance, etc., but the

amount of available short circuit current from a generator is relatively small as compared to an amount from a utility company, which adversely affects Arc Flash Hazard, or HRC.

The short circuit current has a very vital role in calculating Arc Flash Hazard or HRC. The short circuit current (I_{sc}) is interrupted by an OCPD, therefore we need to understand the behavior of these devices. In this article we are considering only low voltage (600 volts below) OCPDs. In general, there are two types of OCPDs namely:

- I. Fuses and
- II. Circuit breakers

Fuse: A device that protects a circuit by fusing open its current-responsive element when an over-current passes through it. An over-current is either due to an overload or a short circuit condition.

The Underwriter Laboratories (UL) classifies fuses by letters e.g. class CC, T, K, G, J, L, R, and so forth. The class letter may designate interrupting rating, physical dimensions, and degree of current limitation.

As per NEC [1] and ANSI/IEEE standard 242 [2] - *A current limiting fuse is a fuse that will interrupt all available currents above its threshold current and below its maximum interrupting rating, limit the clearing time at rated voltage to an interval equal to or less than the first major or symmetrical loop duration, and limit peak let-through current to a value less than the peak that would be possible with the fuse replaced by a solid conductor of the same impedance.*

Threshold Current: The magnitude of symmetrical RMS available current at the threshold of the current-limiting range, where the fuse becomes current-limiting when tested to the industry standard.

Threshold ratio: A threshold ratio is a relationship of threshold current to a fuse's continuous current rating.

$$\text{Threshold Ratio} = \frac{\text{Fuse Threshold Current}}{\text{Fuse Continuous Current}}$$

Maximum threshold ratio for various types of fuses:

Fuse Class	Ratio	
RK5	65	
RK1	30	
J	30	
CC	30	
L	30	601 – 1200 amps
L	35	1201 – 2000 amps
L	40	2001 – 4000 amps

A current limiting fuse may be current limiting or may not be current limiting. The current limiting characteristic depends on the threshold ratio and available fault current.

Let's consider an example of 1500 kVA radial service feeding a fusible switchboard with

2000 amps class L fuses. As per ANSI C 57 [3] standard, a typical impedance value for this size of a transformer is 5.75%; this value is a key factor in calculating the short circuit current.

All utility's network provides a specific fault current at a specific location which depends on various factors, e.g.; cable lengths, cable size, X/R ratio and etc. If we ignore this limitation and assume that there is an unlimited fault current available from a utility, then let's calculate short circuit current from a 1500 kVA transformer at 480 volts (see figure 1). The formula to calculate short circuit current (I_{sc})

$$I_{sc} = \frac{KVA \times 10^5}{\sqrt{3} \times V \times \%Z}$$

$$I_{sc} = \frac{1500 \times 10^5}{\sqrt{3} \times 480 \times 5.75}$$

$$I_{sc} = 31378.65 \text{ A}$$

The above calculation shows 31,378.65 amperes short circuit current is available from this transformer to the down stream equipment. A class L 2000 amperes fuses are provided as a main OCPD for this unit substation (see figure 1). If this transformer is

the only power-source for this unit-substation, the maximum fault current passing through the main OCPD (Class L fuses) will be only 31,378.65 amperes. According to threshold ratio formula the threshold current (I_{th}) for class L 2000 amperes fuses is:

$$I_{th} = 70,000 \text{ A}$$

Therefore, a class L fuse requires at least 70,000 amperes current before it becomes current limiting. Consider a fault at the unit substation secondary bus, in general, this fault is either phase to ground fault or phase to phase arcing fault. An OCPD takes longer time to clear these types of faults as compared to a bolted three phase fault. Even if we consider this as a three phase bolted fault, the fault current (31,378.65A) is much less than fuse's threshold current (70,000A) therefore, the fuses are not working in their current limiting range. This does not mean that fuses will not clear the fault current but these will clear fault current in more than one cycle time period. When a fuse is not working in its current limiting range it will take much longer time period to clear a fault current.

Fault clearing time plays a significant role in Arc Flash calculations - longer the fault current clearing time, higher is the Arc Flash Hazard or HRC.

A case study is done by using computer software (SKM Power Tools). The study results are shown in figure 1, which shows Arc Flash

Hazard category “dangerous” at the switchboard bus.

c. Low Voltage Power Circuit Breaker (LVPCB)

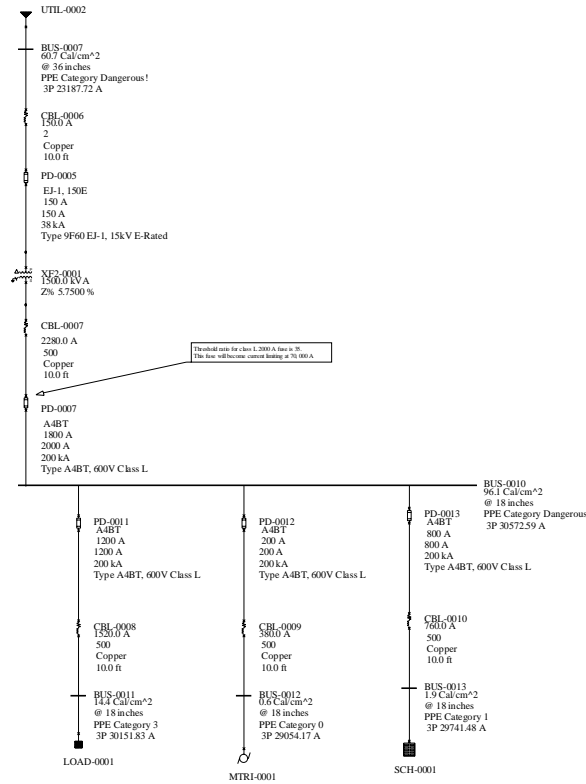


Figure 1

Circuit Breaker: As per NEC [1] a circuit breaker is a device designed to open and close a circuit by non-automatic means and to open the circuit automatically on a predetermined overcurrent without injury to itself when properly applied within its rating.

The circuit breakers are further classified by ANSI C37.100 [4] and UL 489 [5].

- a. Molded Case Circuit Breaker (MCCB)
- b. Insulated Case Circuit Breaker (ICCB)

Molded Case Circuit Breaker (MCCB): It has either a thermal magnetic trip unit or a micro process based solid state trip unit. Both of these trip units provide over load and short circuit protection. Solid state trip unit is more flexible and provide more precise protection. Its trip characteristics are more precise and adjustable.

Insulated Case Circuit Breaker (ICCB): Although this type of breaker falls under UL 489 yet these breakers are different from standard molded case circuit breakers. In general these breakers have large frame size, a typical ICCB starts with 800 ampere frame and its upper range ends at 4000 ampere or higher.

An ICCB has a stored energy mechanism and energy can be stored either manually or by an electric motor. This type of breaker has micro process based trip unit with great precision and flexibility. An ICCB provides overcurrent protection and its trip characteristics are adjustable. A standard ICCB comes with long time pick up, long time delay and instantaneous trip features. Some optional features are also available e.g. short time pickup, short time delay, ground fault pickup and ground fault delay with I²t in or out.

Molded case, as well as insulated case, circuit breakers are rated for three cycles. This means when these breakers are used in a LV power distribution system and that system endures a short circuit condition which could be either a single phase or a three phase fault; this type of breaker clears the fault current within three cycles or less.

Low Voltage Power Circuit Breaker (LVPCB):

The Low Voltage Power Circuit Breakers meet ANSI C37.100 [4] requirements. This type of breakers have large frame size, a typical LVPCB starts with 800 ampere frame and its upper frame ends at 5000 ampere or higher.

This type of breaker like ICCB has a two step stored energy mechanism but it is different in several aspects from a MCCB or an ICCB, e. g. the LVPCB does not have a molded construction. A LVPCB can be serviced in the field to replace various internal parts. The low voltage power circuit breaker has 30 cycles short time rating. In other words this type of breaker can stay closed for 30 cycles under short circuit condition and provides enough time to down stream OCPDs to clear a faulted circuit from the system. This means from this type of breaker's trip unit instantaneous trip function can be eliminated. This is not possible in the case of molded case or insulated circuit breakers as per UL 489 requirement.

The elimination of instantaneous trip function provides better selectivity with down stream circuit breakers. This feature may not be desirable if Arc Flash Hazard is a prime concern, as selectivity and Arc Flash contradict each other.

However, GE offers, "Entellisys Switchgear" with LVPCB, which achieves both of the above goals without affecting each other - *this topic is beyond the scope of this article.*

As we have briefly discussed the various types of insulated case and molded circuit breakers at low voltage, let's analyze their role in arc flash.

In the previous example we have calculated the short circuit current for a 1500 kVA unit-substation. In figure 1, if we replace all fuses

with circuit breakers of the same current ratings and then recalculate the arc flash hazard level at various buses by using computer software. Notice in figure 2, the switchboard Arc Flash Hazard or HRC has come down to 27.0 cal/cm^2 from 96.1 cal/cm^2 or Hazard Risk Category 4 from Hazard Risk Category *dangerous*.

This does not mean that fuses do not provide Arc Flash mitigation, but it proves that unless the system is completely analyzed it is difficult to predict which OCPD gives better results.

As you may have noticed in the down stream circuits from switchboard (figure 2) all of the three breakers are reducing Arc Flash Hazard to HRC 1. In figure 1, where all OCPDs are fuses the HRC at the down stream buses are 3, 0 and 1 respectively from left to right.

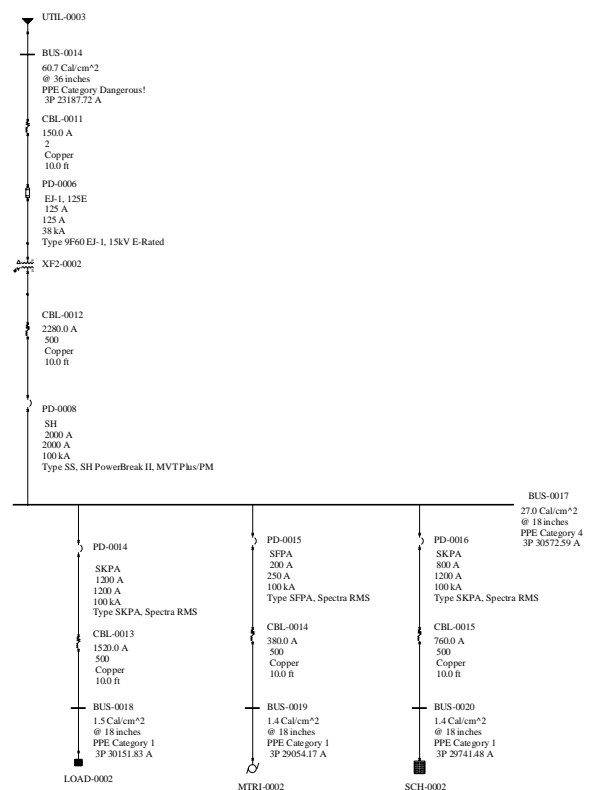


Figure 2

Therefore, before making a judgment that a fuse or a circuit breaker, or one type of fuse versus another type of fuse has a better outcome; a complete Arc Flash study should be performed. A myth that a current limiting fuse always provides better results may not hold true.

In the following example let's consider another case where we have class RK1, class J fuses and couple of molded case circuit breakers. One of the breakers is current limiting and other one is non current limiting.

All of these devices are installed in a service entrance main lug only (MLO) panel. There are four branch panels down stream from this main service entrance panel, which are being feed from fuses and circuit breakers. In general a Class J fuse is more current limiting than a class RK1 fuse.

A general perception is that a fuse is more current limiting than a molded case circuit breaker, which may be true but in figure 3, the Arc Flash study results show the following:

Fuse/CB	Bus	HRC	Cal/cm ²
Class J	0003	zero	0.2
Class RK1	0004	1	2.5
TJJ	0005	zero	0.4
SGHA	0006	zero	0.4

The above table shows that class J fuses and both molded case breakers have Hazard Risk Category zero, which mean only category zero Personal Protective Equipment (PPE) is required. While working on a branch panel which is being feed from class RK1 fuses requires Hazard Risk Category 1, clothing.

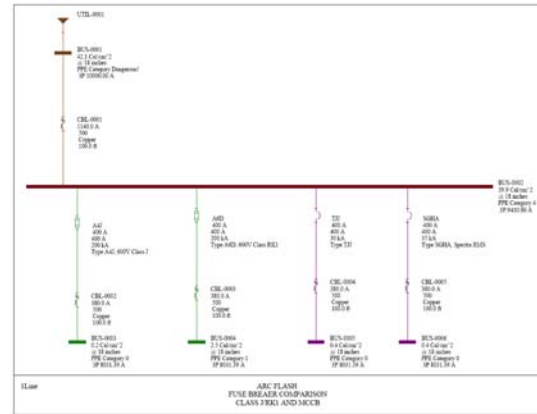


Figure 3

Conclusion:

When working on electrical equipment do not rely on general perceptions, myths and empirical formulas. Always follow OSHA, NEC and NFPA rules and the manufacturer's instructions and safety notices. Perform Short circuit, Coordination, and Arc Flash studies then follow their results. Keep up to date power distribution systems' one line and all the studies.

References:

- [1] National Electric Code 2005
- [2] ANSI/IEEE standard 242 – 1986 IEEE Recommended Practice for Protection & Coordination of Industrial & Commercial Power Systems
- [3] ANSI C 57.12.51 – 1981 Requirements for Ventilated Dry-Type Distribution Transformers
- [4] ANSI C37.100 – 1992 Standard Definitions for Power Switchgear
- [5] UL 489 Molded Case Circuit Breakers

SKM Engineering Software - Power Tools

GE Circuit Breakers Application Guide