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CONSTANT PPE (or INCIDENT ENERGY) LINES

Knowing where the constant PPE lines are on the TCCs can be very helpful in designing a system and in choosing the best overcurrent protection that is appropriate for the system. Here are some examples to illustrate this concept …

Doing arc flash calculations to determine incident energies and arc flash boundaries can be a little mysterious. The equations that are typically used today are given in IEEE Standard 1584-2002. However, there are some basic observations that one can make, which are noted in this document. This document presents the concept of Constant PPE Lines and applies them to a 480V system. This exercise may help to give some incite in designing a system before a detailed arc flash analysis is done.

1.0 CONSTANT PPE LINES

In IEEE Standard 1584-2002, an equation for calculating the incident energy for 480V systems is given in Section 5.3. There are a number of variables in the equation:

- Grounded or ungrounded systems,
- Equipment type – open air, switchgear, MCCs, panels, and cables, and
- Gap between conductors.

For a given set of parameters, it is possible to draw a line on a TCC (time vs. arcing current) for a given incident energy value. Below the line, the incident energy is less than the given value and above the line the incident energy is greater than the given value. In this discussion, three constant incident energy lines will be determined. They will be referred to as Constant PPE Lines as follows:

- PPE = 0 Incident Energy = 1.2 cal/cm^2
- PPE = 2 Incident Energy = 8.0 cal/cm^2
- PPE = 4 Incident Energy = 40.0 cal/cm^2

The objective of this document is to draw the lowest set of curves from the variables listed above and then to apply them to practical applications. The parameters used for this analysis are the following:

- A working distance of 18” on a 480V system,
- The typical gaps between conductors that are given in IEEE Standard 1584-2002 Table 4,
- MCCs on an ungrounded system since those conditions give the lowest PPE curves.

The resultant three Constant PPE Lines are illustrated in Figure 1.1. As noted above, below each line the incident energy for a given arcing current and clearing time is less than the given value for the line, and above the line, the incident energy is greater than the given value. The lines are drawn over the arcing current range that was documented in the test data given in IEEE Standard 1584-2002.

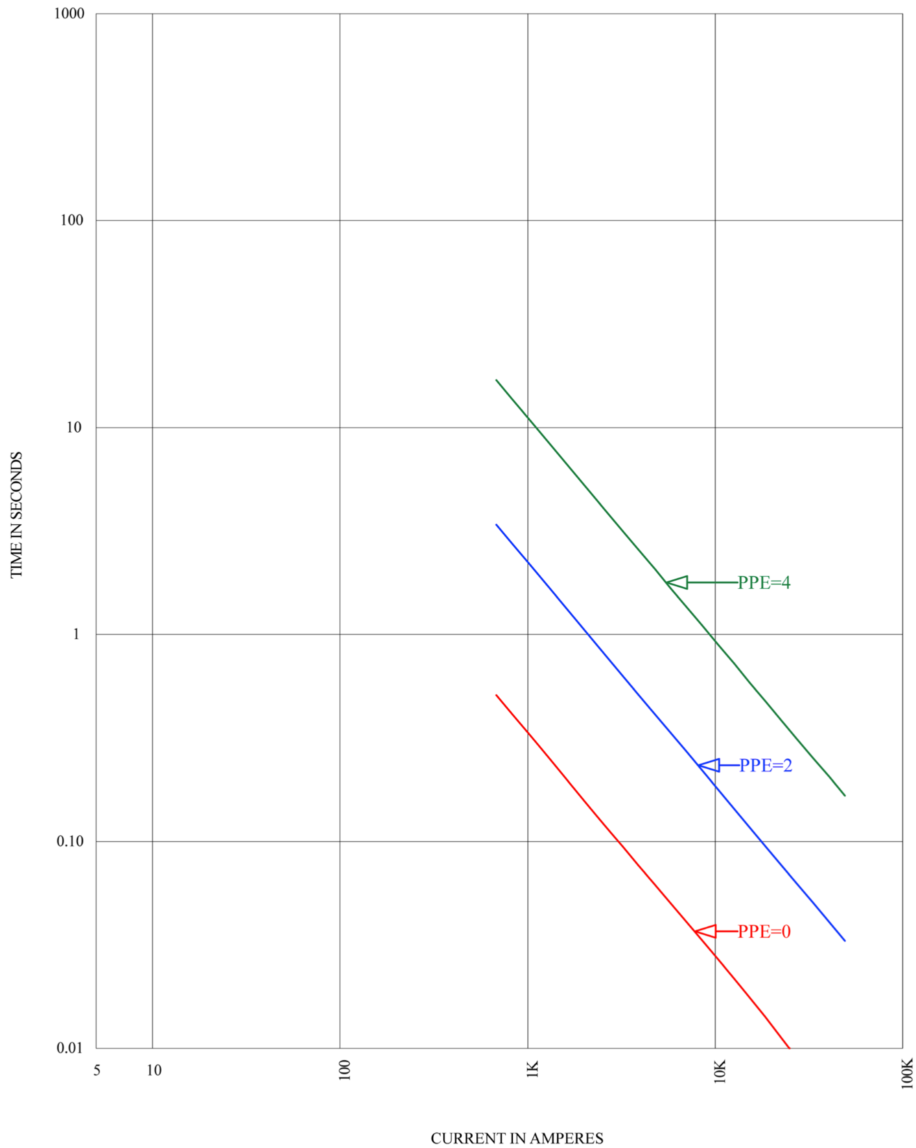

Figure 1.1 – Constant PPE Lines Based on IEEE 1584 Equations

2.0 PPE = 0 – Examples and Observations

Example 2.1

In Figure 2.1, the three PPE curves derived in Figure 1.1 are compared to three fuses whose characteristics are typical of RK5 fuses. They are rated 10A, 30A, and 60A. The RK5 fuses tend to be the slowest type in this ampere range, and they are typically used for feeding individual motors. They are slower (or delayed) so that they do not melt during motor starting. Type RK1 and J fuses tend to be faster and to the left of the fuses shown in Figure 2.1.

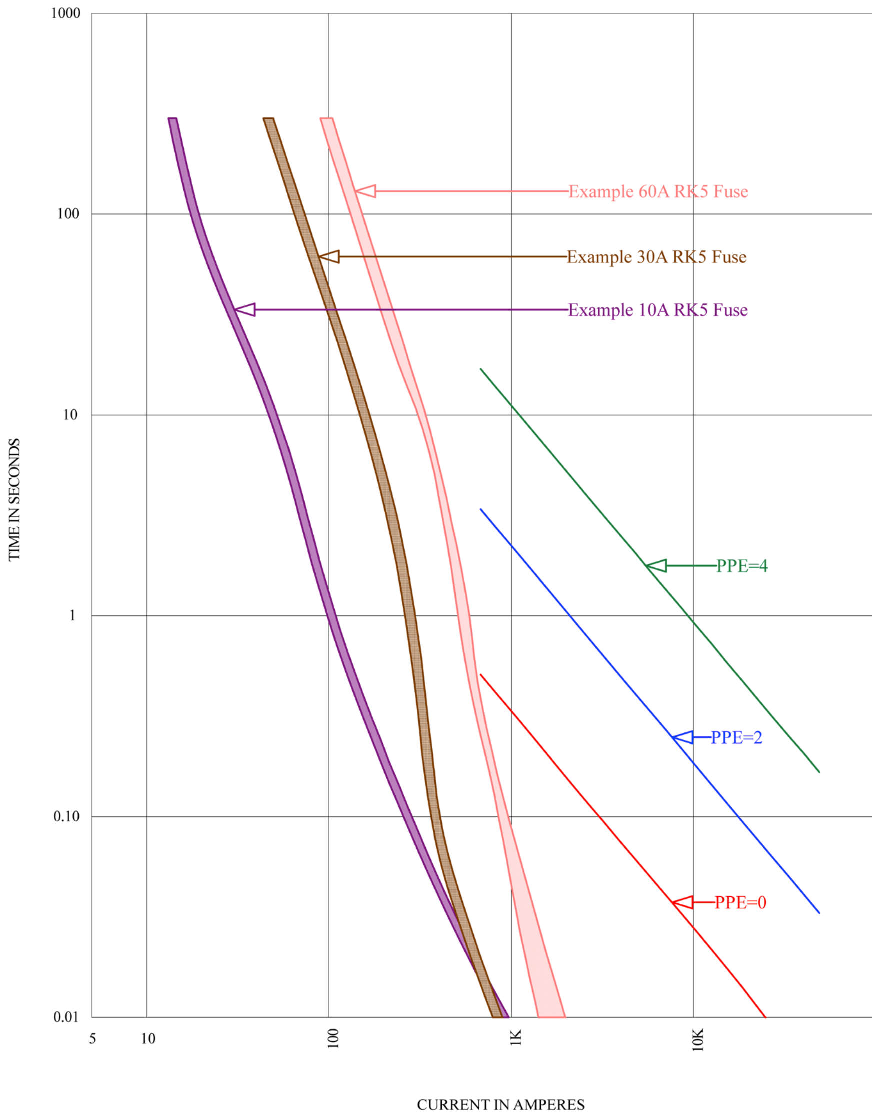

Figure 2.1 – Example RK5 Fuses

The following observations are noted with respect to Figure 2.1:

- The 60A fuse intersects the PPE = 0 curve at approximately 650A. At arcing currents above 650A, the fuse clearing characteristic is below the PPE = 0 line. Consequently, above 650A, the fuse would clear quickly enough to limit the incident energy to less than 1.2 cal/cm^2, i.e., PPE = 0.

- At the higher fault currents in the current limiting region, testing has shown that the incident energy is < 0.5 cal/cm^2 at a working distance of 18" for fuses rated < 400A.
- The 10A and 30A fuses are well below the PPE = 0 line.
- At PPE = 0, the personal protective equipment needed is minimal. Although it seems reasonable to extend the PPE = 0 curve to the left to determine where it might intersect the smaller fuses, it also seems wise to limit the amount of time that the arc would occur when wearing PPE = 0. The authors have chosen one second for the limit in this analysis. This is a somewhat subjective limit, but it seems reasonable to limit the acceptable arcing time so that the arc does not extend out, resulting in a fire or more extensive equipment damage.
- Based on a one-second limit, it is possible to estimate the maximum conductor lengths that would give a PPE = 0 when using one of these three fuses. This is estimated in Table 2.1 for various conductor sizes on a 480V system. Based on this analysis, copper conductor lengths up to approximately 450' would typically result in PPE = 0 when using 10A fuses with #14 wire or larger, 30A fuses with #10 wire or larger, or 60A fuses with #6 wire or larger.

Table 2.1

Estimate of Maximum Conductor Lengths

		Conductor Impedance From NEC, Chapter 9, Table 9 Cu in Steel Conduit (ohms/1000')			Minimum		
Fuse Amps	Conductor Size	R	X	Z	Arcing Isc for PPE = 0 (Amps)	Bolted Isc for PPE = 0 (Amps)**	Maximum Length for PPE = 0 (Feet)***
10	#14	3.10	0.073	3.101	110 *	160	501
	#12	2.00	0.068	2.001	110 *	160	777
	#10	1.20	0.063	1.202	110 *	160	1294
30	#10	1.20	0.063	1.202	310 *	452	459
	#8	0.78	0.065	0.783	310 *	452	705
	#6	0.49	0.064	0.494	310 *	452	1116
60	#8	0.78	0.065	0.783	650	948	336
	#6	0.49	0.064	0.494	650	948	532
	#4	0.31	0.060	0.316	650	948	833

* This minimum short circuit current is based on a 1 second maximum duration of the fault current.

** At these low currents the arcing current is estimated at 98% of the bolted fault current, based on extrapolating the test results. The minimum arcing current is assumed to be 70% of the 100% arcing current as defined in IEEE 1584.

*** These conductor lengths are 90% of the calculated values determined from the conductor impedances. This factor is intended to allow for some up-line impedance.

Example 2.2

An example characteristic of a 150A thermal magnetic circuit breaker is illustrated in Figure 2.2. Arcing currents above 3000A would need a PPE = 0 over a small range of fault currents and a PPE = 2 for a much wider range of fault currents. Using this 150A breaker with a 1/0 copper conductor would give a PPE = 2 for lengths up to approximately 300'. (See Table 2.2.)

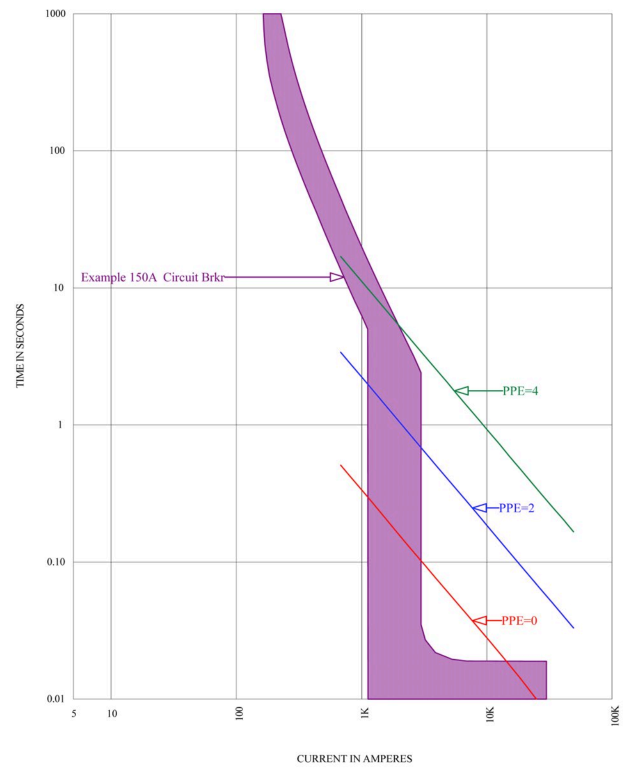

Figure 2.2 – Example 150A Thermal-Magnetic Circuit Breaker

Table 2.2
Estimate of Maximum Conductor Lengths

Circuit Breaker Amps	Conductor Size	Conductor Impedance From NEC, Chapter 9, Table 9 Cu in Steel Conduit (ohms/1000') R	X	Z	Minimum Arcing Isc for PPE = 2 (Amps)	Minimum Bolted Isc for PPE = 2 (Amps)**	Maximum Length for PPE = 2 (Feet)***
150	#1	0.160	0.057	0.170	3000	6100	241
	1/0	0.120	0.055	0.132	3000	6100	310
	2/0	0.100	0.054	0.114	3000	6100	360

** The minimum arcing current is assumed to be 70% of the 100% arcing current as defined in IEEE 1584.

*** These conductor lengths are 90% of the calculated values determined from the conductor impedances. This factor is intended to allow for some up-line impedance.

Example 2.3

An example characteristic of a 150A circuit breaker with an adjustable LSI trip unit is illustrated in Figure 2.3. With the settings illustrated, arcing currents above 510A would be below the PPE = 0 curve up to arcing currents of approximately 5000A. Using this 150A breaker with a 1/0 copper conductor would give a PPE = 0 for lengths in the range of approximately 300' to 2500'. (See Table 2.3.) Compare this to Example 2.2 for a thermal magnetic circuit breaker that does not have adjustable settings.

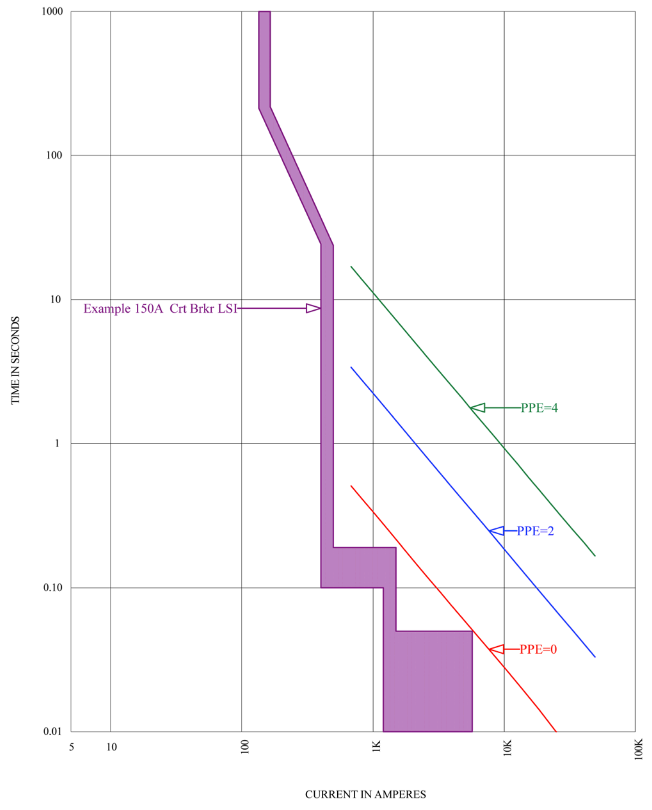

Figure 2.3 – Example 150A Circuit Breaker with LSI Trip Unit

Table 2.3
Estimate of Maximum Conductor Lengths

Circuit Breaker Amps	Conductor Size	Conductor Impedance From NEC, Chapter 9, Table 9 Cu in Steel Conduit (ohms/1000') R	X	Z	Minimum Arcing Isc for PPE = 0 (Amps)	Minimum Bolted Isc for PPE = 0 (Amps)**	Maximum Length for PPE = 0 (Feet)***	Maximum Arcing Isc for PPE = 0 (Amps)	Maximum Bolted Isc for PPE = 0 (Amps)^	Minimum Length for PPE = 0 (Feet)***
150	#1	0.160	0.057	0.170	510	743	1974	5000	7300	201
	1/0	0.120	0.055	0.132	510	743	2540	5000	7300	259
	2/0	0.100	0.054	0.114	510	743	2951	5000	7300	300

** At these low currents the arcing current is estimated at 98% of the bolted fault current, based on extrapolating the test results. The minimum arcing current is assumed to be 70% of the 100% arcing current as defined in IEEE 1584.

*** These conductor lengths are 90% of the calculated values determined from the conductor impedances. This factor is intended to allow for some up-line system impedance.

^ This maximum bolted fault current is based on 100% arcing current and the equations given in IEEE Std 1584.

Observations About PPE = 0

This section is focused on the PPE = 0 line and how to achieve incident energies that are $\leq$ 1.2 cal/cm^2. At PPE = 0, the personal protective equipment needed is minimal. Consequently, if PPE = 0 is being recommended for a given location, it is important to be confident in that recommendation. The following observations are noted:

1. In doing calculations of incident energies, the common practice is to evaluate the primary protective device based on that device operating properly. Consideration of the failure of the protective device and the fault being cleared by a backup device is not normally considered. In most locations, the failure of the primary protective device could result in a significant increase in the incident energy. The premise is that the protecting device has been maintained and is in proper working order.

2. In PPE = 0 locations, the primary protective device is often a small ampere-rated fuse or a small ampere-rated circuit breaker. What is the probability of failure of this primary protective device?
    a. Fuses operate based on the melting of the fuse element when the current becomes high enough. This is considered a highly reliable response. It is unlikely that a fuse would take longer to clear than expected; however, the fuse might clear faster due to damage to the element over time from marginally high currents in the past.
    b. Circuit breakers are mechanical devices. Due to a lack of operation and/or maintenance, a circuit breaker may take longer to operate than expected. This type of failure would result in a higher incident energy than expected.

Based on the observations above, there are several approaches that could be used with regard to PPE = 0. Some of these options include the following:

1. Label the down-line equipment based on the calculated incident energies. If the incident energy is $\leq$ 1.2 cal/cm^2, label the equipment as PPE = 0 regardless of the protection means.

2. Do not use PPE = 0. Only have PPE = 2 and PPE = 4 levels of personal protective equipment.

3. Another option is the following:
    a. Only apply PPE = 0 when the low calculated incident energy is the result of a fuse operation.
    b. When circuit breakers are used for protection, do not go below PPE = 2.
    c. A possible exception is the following: If the use of a circuit breaker calculates to a PPE = 0 for the down-line location and the backup device to the circuit breaker (either a fuse or another circuit breaker) also gives a PPE = 0, then a PPE = 0 could be used for the down-line location.

    This would be somewhat of a risk assessment in the labeling of the equipment based on the possible failure modes of the protecting devices.

3.0 PPE = 2 and PPE = 4 – Examples and Observations

Example 3.1

Referring to Example 2.3, it may not be appropriate to use the settings illustrated due to motor starting or other down-line coordination issues. An example characteristic of the same 150A circuit breaker with delayed settings is illustrated in Figure 3.2. Arcing currents above 1180A would be below the PPE = 2 curve. Using this 150A breaker with a 1/0 copper conductor would give a PPE = 2 for lengths up to approximately 800’. (See Table 3.1.)

Figure 3.1 – Example 150A Circuit Breaker with LSI Trip Unit

Table 3.1
Estimate of Maximum Conductor Lengths

Circuit Breaker Amps	Conductor Size	Conductor Impedance From NEC, Chapter 9, Table 9 Cu in Steel Conduit (ohms/1000') R	X	Z	Minimum Arcing Isc for PPE = 2 (Amps)	Minimum Bolted Isc for PPE = 2 (Amps)**	Maximum Length for PPE = 2 (Feet)***	Maximum Arcing Isc for PPE = 2 (Amps)	Maximum Bolted Isc for PPE = 2 (Amps)^	Minimum Length for PPE = 2 (Feet)***
150	#1	0.160	0.057	0.170	1180	2100	699	33000	66000	22
	1/0	0.120	0.055	0.132	1180	2100	899	33000	66000	29
	2/0	0.100	0.054	0.114	1180	2100	1045	33000	66000	33

** This minimum bolted fault current is based on 70% arcing current and the equations given in IEEE Std 1584.

*** These conductor lengths are 90% of the calculated values determined from the conductor impedances. This factor is intended to allow for some up-line system impedance.

^ This maximum bolted fault current is based on 100% arcing current and the equations given in IEEE Std 1584.

Example 3.2

An example of a 2500A main circuit breaker at the secondary of a transformer with an 800A feeder breaker is illustrated in Figure 3.2. The following observations are noted:

- The settings on the 800A feeder breaker are chosen to give a PPE = 2 for the down-line equipment, such as a motor control center, a power distribution panel, a disconnect switch, etc.
  - This can generally be accomplished by setting the short time delay in the range of 0.1 to 0.2 seconds with the instantaneous setting at 10 kA or less.
  - The 10 kA instantaneous setting may not always coordinate with other down-line protective devices. In that case, one must decide between coordination and PPE Level.
  - This particular 800A circuit breaker has an instantaneous override at higher fault currents, which results in an even faster time than the instantaneous function.
- The settings on the 2500A main breaker are chosen to give a PPE = 4 for the down-line feeder breakers.
  - The short-time pickup is set as low as possible to coordinate with the feeder breakers, such as the 800A breaker, which is shown on the TCC, and to coordinate with the starting of any large down-line motors on the feeders while carrying significant load current.
  - The short delay is generally set in the range of 0.2 to 0.3 seconds.
- Other details of coordination are given in this document: http://www.qualtecheng.com/docs/overcurrent-protection/QT-608.pdf

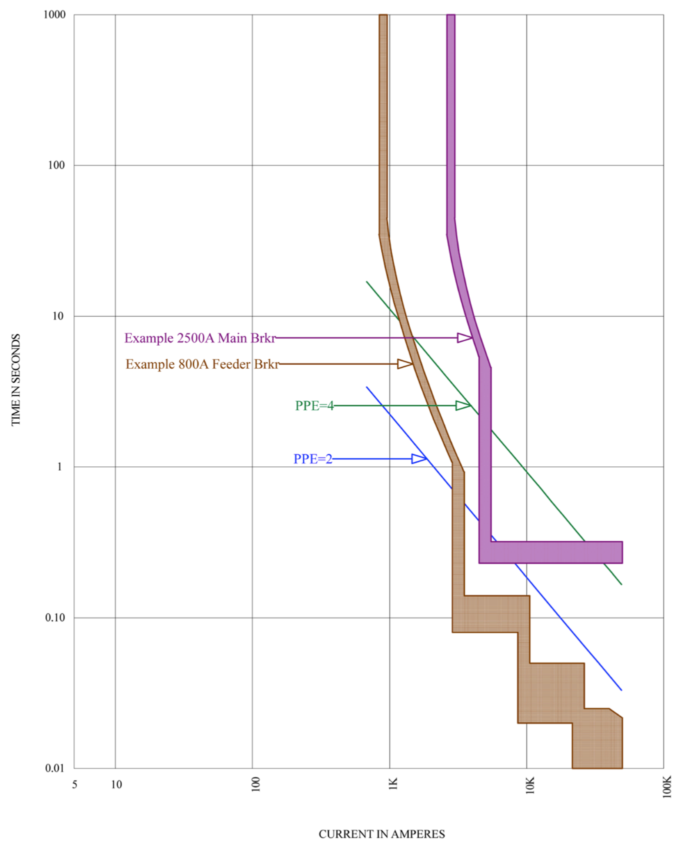

Figure 3.2 – Example 2500A Main and 800A Feeder Circuit Breakers

4.0 Example System PPE Levels

Based on the examples in Sections 2.0 and 3.0, Figure 4.1 illustrates typical PPE Levels on a 480V system. Key observations and characteristics are noted as follows:

- A fuse on the primary of the transformer typically does not limit the PPE to $\leq$ 4 on the low voltage secondary for transformers of $\geq$ 1500 kVA. Consequently, the main 480V circuit breaker would have a PPE level >4, unless some other steps are taken to reduce the incident energy at this location. The following document provides more details on this issue: http://www.qualtecheng.com/docs/arc-flash-hazard/QT-616.pdf
- The feeder breakers are typically PPE = 4. (See Example 3.2.)
- The downline motor control centers and power distribution centers can generally be protected by PPE = 2. (See Example 3.2.)
- The equipment fed by motor control centers and power distribution centers can typically be protected to be PPE = 2 or PPE = 0. (See Sections 2.0 and 3.0.)

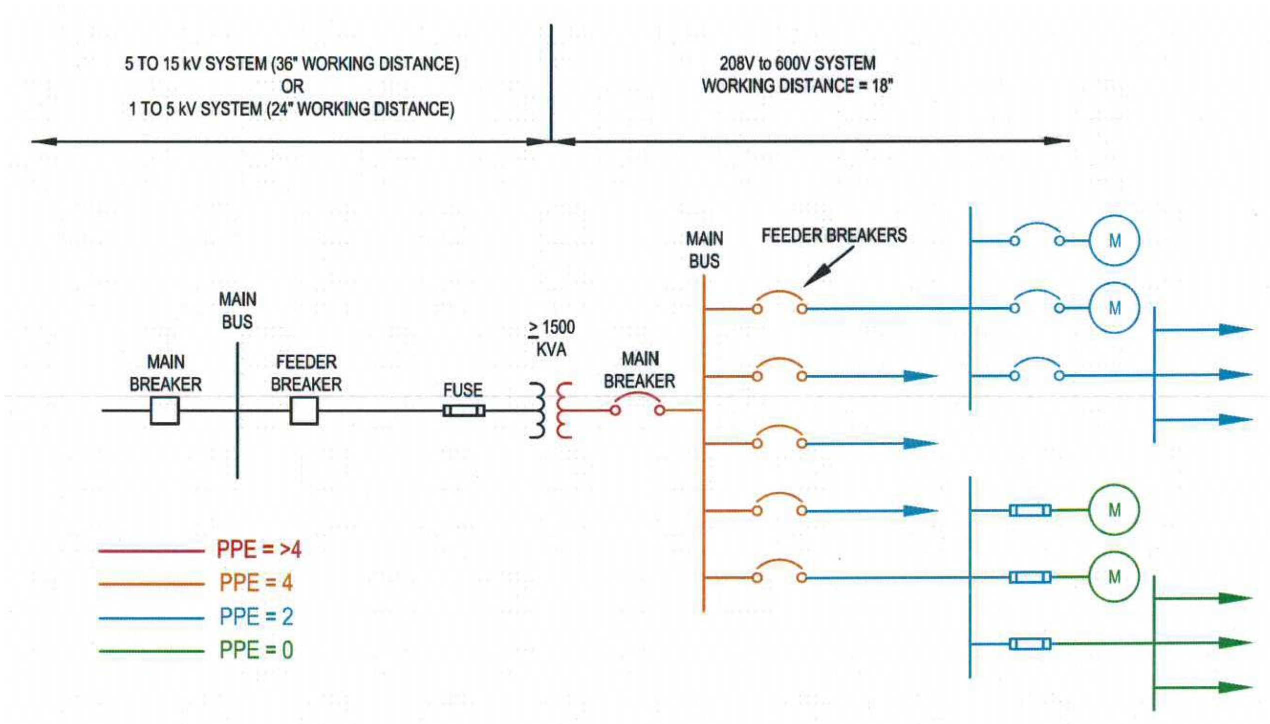

Figure 4.1 – Example System PPE Levels

Note: ***The analysis in this document was done based on the arc flash methodology given in IEEE Standard 1584-2002. Recently, this standard was updated in 1584-2018. Although the results in this document are based on 1584-2002, they are comparable to those calculated based on 1584-2018 at low voltage for the VCB electrode configuration and at medium voltage based on the VCBB electrode configuration.***