Practical Solution Guide to Arc Flash Hazards

THIRD EDITION

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Written and compiled by
Bentley Systems,
developers of **EasyPower**
software

EasyPower®

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Bentley Systems

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Published by EasyPower - Part of Bentley Systems, Inc.
First edition was published and copyrighted in 2002
Second edition was published and copyrighted in 2015
Third edition was published and copyrighted in 2022

ISBN 978-0-9971026-1-1

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FORWARD

EasyPower, LLC is pleased to bring you the Third Edition of the "Practical Solution Guide to Arc-flash Hazards." This edition has been fully updated to reflect the most recent changes in standards and best-case practices. We believe this will be a valuable tool for electrical engineers, safety managers, or anyone responsible for implementing and maintaining an arc-flash hazard safety program.

The guide was designed to walk you through the necessary steps of implementing an arc-flash assessment as part of your overall safety program requirements. It will help you and your team make important decisions concerning the safety of your employees, contractors and help manage the complex tasks of OSHA and NFPA 70E® compliance for arc-flash hazards.

Arc-flash risk assessment techniques and the development of comprehensive safety programs to protect against arc-flash hazards has progressed significantly over the last few years. Research into the arcing phenomena is ongoing as the industry tries to better understand and model arcing faults. Standards and recommended practices are changing constantly to reflect these new understandings and to better protect workers. Personal protective equipment (PPE) is also changing at a rapid pace as new and better technology is developed. EasyPower, LLC has many arc-flash related resources on their website at www.easypower.com/arcflash to keep you up-to-date as new information becomes available and industry advancements are made. We are very pleased and excited to bring you the third version of this guide as we continue to enhance and add new technology to the arc-flash risk assessment process.

EasyPower, LLC is committed to providing the industry with the most advanced state-of the-art technology in our EasyPower® software product line. We believe the EasyPower software provides the self-documenting solution capabilities to keep your safety program current and in compliance with OSHA and NFPA 70E standards. EasyPower, LLC can also provide detailed engineering studies and arc-flash assessment programs to help your company get started.

We know that the "Practical Solution Guide to Arc-flash Hazards" will become a valued resource in your library.

DISCLAIMER

Warning - Disclaimer: The calculation methods listed in the book are based on theoretical equations derived from measured test results. The test results are a function of specific humidity, barometric pressure, temperature, arc distance, and many other variables. These parameters may not be the same in your facility or application. The results calculated from these equations may not produce conservative results when applied to your facility. PPE recommended by any calculation method will NOT provide complete protection for all arc hazards. Injury is possible even when wearing recommended PPE. The results should be applied only by engineers experienced in the application of arc-flash hazards. The authors make no warranty concerning the accuracy of these results as applied to real world scenarios.

Arc-flash as considered in NFPA 70E® and IEEE Std 1584™-2018 is concerned with personal injury when a worker is near or working on energized equipment. Working on energized conductors should only be done when it is infeasible to comprehensively de-energize the equipment. This book does not condone working on energized equipment at any time.

Using the methods in NFPA 70E or IEEE Std 1584 does not ensure that a worker will not be injured by hazards from an arc-flash. Following the NFPA 70E and IEEE 1584 procedures and wearing the proper protective equipment appropriate in the circumstances will greatly reduce the possibility of arc-flash injuries.

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Introduction

CHAPTER 01

Working on or around energized electrical power equipment has always been recognized as potentially dangerous. For most of the electric power era, the main risk associated with electricity was electrocution. However, in addition to the shock injuries that result from direct contact of live conductors with the body, another hazard has always been present – the risk of burns due to electric arcs. These arc-flash injuries can occur without any direct contact with energized parts. While this hazard has existed from the beginnings of the electric power industry, the risk of arc-flash burn injuries has only recently been addressed as a specific hazard in industry safety programs and the relevant safety codes.

An electric arc or arcing fault is the flow of electric current through the air from one conductor to another conductor (or to ground). Arcs are generally initiated by a flashover caused by some type of conductor that subsequently vaporizes or falls away, leaving the arc. Arcing faults create many hazards, but the greatest risk to personnel is **burn injury** due to exposure to the radiant and convective heat generated by the arc. This heat can cause serious, even fatal burns, as well as ignite clothing and other nearby material and objects. In addition, electric arcs can produce **molten metal droplets, ultra-violet radiation, superheated metal vapor**, shrapnel and air pressure waves that can cause hearing damage and even internal injuries.

Back in 2003, when we were approached by plant engineers, technicians, consultants, electrical contractors, and safety managers, we attempted to provide a brief description of the various aspects of arc-flash hazards, resulting in the original version of this book. It was written to describe the nature of arc-flash hazards, how to calculate potential arc-flash energy as well as ways to address the hazard through reduction in arc-flash risk and use of appropriate PPE.

Any discussion of arc-flash safety must begin by recognizing the pioneer who brought our attention to this safety hazard. Ralph H. Lee published the first paper on arc-flash, The Other Electrical Hazard: Electric Arc Blast Burns, in the journal "IEEE Transactions on Industry Applications," (Volume: IA-1 Issue: 3) in May 1982. This paper not only pointed out that arc-flash was a potentially deadly phenomenon, but also provided a method to calculate the heat energy exposure to workers.

In the first two decades after publication of Ralph Lee's seminal paper, recognition of arc-flash hazards and implementation of arc-flash safety programs proceeded fairly slowly within the electrical power industry. Significant highlights during this period were papers by Richard Doughty, Thomas Neal, et al. that gave empirical equations for incident energy calculations, as well as recognition of arc-flash hazards in the 2000 edition of the NFPA 70E® standard. Then in 2002, IEEE 1584-2002 was published. This standard provided detailed empirical methodology for calculating arc-flash hazards based on a large amount of test data. Since then, arc-flash safety has become almost universally recognized as a significant workplace hazard. Every subsequent update of NFPA 70E has refined and expanded arc-flash hazard safety requirements. Most companies have made some effort at compliance with the NFPA 70E requirements including arc-flash studies, warning labels, training, and use of Personal Protective Equipment (PPE) best practices. The long-awaited revision of IEEE 1584 issued in late 2018 further refines how arc-flash hazards are calculated. At this point, it is fair to conclude that arc-flash is a "recognized hazard" in the workplace and that everyone involved with electrical power systems needs to be aware of arc-flash hazards. Arc-flash safety must be a part of any electrical safety program.

The third revision of this book incorporates all major updates in the various standards relating to arc-flash including IEEE 1584 and NFPA 70E. The updated OSHA requirements for arc-flash safety for electric utilities are also discussed. Several examples are provided to illustrate arc-flash calculations.

Concepts and Definitions For Arc Flash Risk Assessment

CHAPTER **02**:

This chapter describes the nature of electric arcs, how they occur, the risks associated with arcing faults, as well as the nature of arc-flash injuries. In addition, it also discusses the relevant standards that address arc-flash hazards and some of the important terminology. When addressing any hazard, it is first necessary to understand the nature of the hazard.

What is an Arc?

As mentioned in Chapter 1, an arc is essentially the flow of electrical current through the air, generally hot ionized air or plasma. The various mechanisms by which arcs are created are discussed below. In electrical power systems, this arc must be part of a complete electrical circuit of which the arc is one element. In other words, there must be a complete current path in order to have a sustained arc. The main physical property of arcs that we are concerned with related to arc-flash hazards is the incredible amount of heat that can be generated by the arc.

Causes of Electric Arcs

Arcs can be initiated in a variety of ways. Some of the most common are listed below:

- Glow to arc discharge:
  - Dust and impurities: Dust and impurities on insulating surfaces can provide a path for current to potentially track, allowing it to flashover and create arc discharge across the surface. This can develop into greater arcs. The fumes or vapor of chemicals can reduce the breakdown voltage of air and cause an arc-flash.
  - Corrosion: Corrosion of equipment parts can provide impurities on insulating surfaces. Corrosion also weakens the contact between conductor terminals, increasing the contact resistance through oxidation or other corrosive contamination. Heat can be generated on the contacts and sparks may be produced. This can lead to arcing faults with nearby exposed conductors of a different phase or ground.
- Condensation of vapor and dripping water can also cause tracking on the surface of insulating materials. This can create a flashover to ground and potential escalation to phase-to-phase arcing.
- Shorting of energized parts:
  - Accidental touching: Accidental contact with live exposed parts can initiate arc faults.
  - Dropping conductive tools: Tools dropped accidentally can cause a momentary short circuit, producing shorts and initiating arcs.
  - Animals contacting energized parts often initiate arcs, especially for outdoor equipment.
- Overvoltages across narrow air gaps: When the air gap between conductors of different phases is very narrow (due to poor workmanship or damage of the insulating materials), arcs may strike across during overvoltage events.
- Failure of the insulating materials.

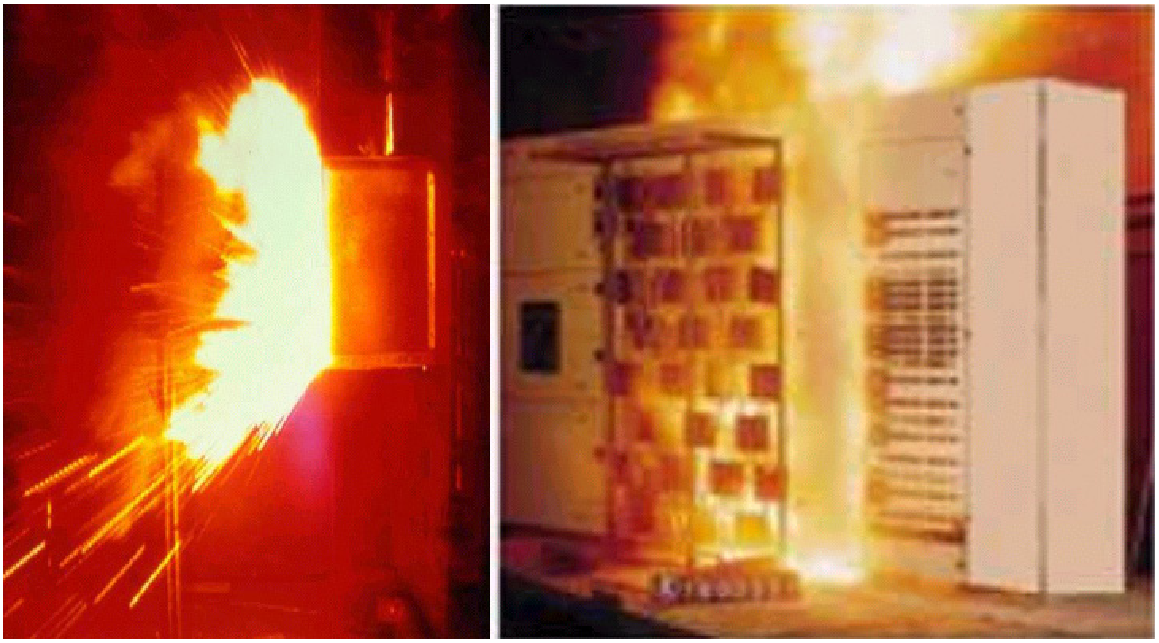


Figure 2.1: (a) Arc Blast in Box; (b) Arcing Fault in an Electrical Panelboard

The Nature of Electrical Arcs

- Electric arcs produce some of the highest temperatures known to occur on earth— up to 35,000 degrees Fahrenheit[1] at the arc terminals. This is four times the surface temperature of the sun.
- The intense heat from an arc causes the sudden expansion of air. This can result in a blast with very strong air pressure (lightning is a natural arc).
- All known materials are vaporized at this temperature. When materials vaporize they expand in volume (copper— 67,000 times, water to steam—1,670 times[2]). The air blast can spread molten metal to great distances with force.
- For a low voltage system (600/480), a 3 to 4-inch arc can become "stabilized" and persist for an extended period of time under certain conditions.
- The heat energy released is a function of system voltage, fault current magnitude, and fault duration.
- Arcs in enclosures, such as in a motor control center (MCC) or switchgear, can magnify the blast and energy transmitted as the blast is forced to the open side of the enclosure and towards the worker.

Hazards of Arcing Faults

The primary hazard created by an arcing fault is the risk of serious burn injuries due to the intense heat created by the arc. Fatal burns can occur when the victim is several feet from the arc. Serious burns are common at a distance of 10 feet.[3] Staged tests have shown temperatures greater than 437°F on the neck area and hands for a person standing close to an arc-flash.[4] Ordinary clothing can be ignited several feet away. Clothed areas on the body can be burned more severely than exposed skin depending on the garment's fabric.

Additional hazards that can occur include:

- Damage to Eyes: Infrared and ultraviolet radiation can damage unprotected eyes.
- Molten Metal: Arcs can spray droplets of molten metal at high-speed to unprotected parts of the body.
- Shrapnel: Metal shrapnel created by an arcing fault can injure the body.
- Metal Vapor: Vaporized metal can be created causing serious injury if inhaled.
- Air Pressure: Extreme arc-flash events can create air pressure waves similar to chemical explosions. These have thrown workers across rooms and knocked them off ladders.
- Hearing damage: The sound magnitude has been shown to be more than 140 dB within 2 to 3 meters of an arc.[5]

Probability of Survival

Injuries due to arc flash can often be severe. According to statistics from the American Burn Association, the probability of survival decreases with the increasing age of the burn victim.

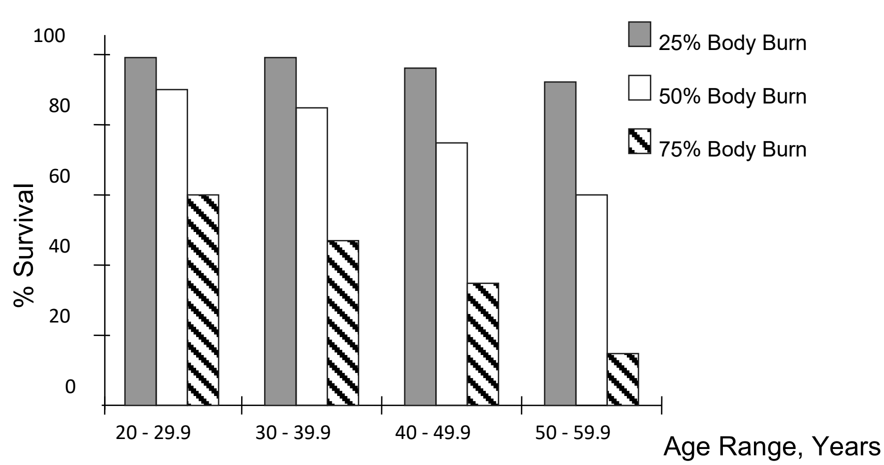


Figure 2.3: Burn Injury Statistics – Probability of Survival (Source: American Burn Association, 1991-1993 Study; Revised March 2002)

Impacts of Arc Flash Injuries

Treatment of arc-flash burns can require years of grueling rehabilitation. The victim may never return to work or retain the same quality of life.

In addition to the human costs and injuries, arc-flash injuries can create significant financial liabilities:

- Medical costs for serious burn injuries can exceed $1,000,000/case
- Litigation fees
- Production loss
- Increased workers' compensation payments
- Increase in standard business insurance costs
- OSHA fines

Potential Exposure to Arc Flash

Although it may appear that shock and arc-flash incidents are uncommon, statistics show that the damage they cause is considerable. Bureau of Labor Statistics injury and fatality data for exposure to electricity in 2020 shows 2,220 cases of nonfatal occupational injuries and illnesses involving days away from work, and 126 fatal occupational injuries.

A 2019 report published in Industrial Safety and Hygiene News estimated that, on average, there are 30,000 arc flash incidents every year. The report went on to estimate that those incidents resulted in an average annual total of 7,000 burn injuries, 2,000 hospitalizations, and 400 fatalities per year. Some arc-flash accidents and injuries occur that do not require a stay or are not properly documented for national tracking purposes. The number of arc-flash accidents is greater than many engineers realize since many arc-flash accidents do not make the daily news.

The IEEE Industry Application Society (IAS) Safety Workshop is a good resource for those wanting to get additional statistical data regarding arc-flash incidents.

The likelihood of an arc-flash event occurring is influenced by numerous factors such as:

- Complexity of the task performed, the need to use force, the available space and safety margins, reach, etc.
- Frequency that energized work is performed
- Safety training and arc-flash awareness

- Use of a safety observer
- Qualifications of workers
- Use of proper tools
- Age and condition of equipment

Developments in Addressing Arc Flash Hazards

Historically, the National Electric Code (NEC®) and other safety codes were primarily concerned with protection from fire, electrocution, and shock hazard; arc-flash hazards were not well understood or addressed. This changed in 2002, when NEC included requirements for shock and arc-flash warning labels. Some additional requirements related to services have subsequently been added. The National Fire Protection Association (NFPA®) is responsible for the NEC (NFPA 70). Since the NEC (NFPA 70) was concerned mainly with electrical design, construction, and inspection, it could not be adopted by employers and employees with regard to implementing standards for workplace electrical safety. To bridge this gap, a new standard, NFPA 70E®, Standard for Electrical Safety Requirements for Employee Workplaces[6], was developed. NFPA 70E is intended for use by employers, employees, and the Occupational Safety and Health Administration (OSHA). As of 2000, the NFPA 70E includes the arc-flash hazard as a potential danger to workers on and near exposed energized electrical parts. NFPA 70E and IEEE Std 1584 provide guidance on implementing appropriate electrical safety procedures and also provide methods for performing arc-flash calculations.

NEC Article 110.16 requires "field marking" of potential shock and arc-flash hazards for panels likely to be serviced or examined in an energized condition. This article also contains a fine print note (FPN) regarding proper signage and an FPN referencing NFPA 70E. These FPNs are not technically part of the NEC but are recommended practices. In addition, the current version of the NEC requires arc-flash data be provided for all services 1200 A or larger.

OSHA regulations, in general, have not provided detailed requirements for arc-flash safety related to general industry. In 2015, the OSHA regulations covering electric utilities were updated with much more specific arc-flash safety requirements. However, OSHA regulations contain what is referred to as the "General Duty" clause that requires employers to provide protection against **any known hazard** in the workplace and OSHA has routinely used the General Duty clause to cite and fine employers for failure to provide PPE for arc-flash hazards. OSHA generally considers NFPA 70E to be the recognized consensus standard for electrical safety and uses it to train its compliance officers.

1. Source: Thomas E. Neal, Presentation "Insight Into The Arc Hazard", IEEE-PCIC Electrical Safety Workshop, February, 2003; © DuPont Company.
2. Source: Danny P. Ligget, Presentation "Electrical Hazards – Taking Basics to the Future", IEEE-PCIC Electrical Safety Workshop, February 2003.
3. Neal, Presentation "Insight into the Arc Hazard"
4. Ray A. Jones, et al, "Staged Tests Increase Awareness of Arc-Flash Hazards in Electrical Equipment", IEEE Transactions on Industry Applications, Vol. 36, No. 2, March/April 2000, page 659-667.
5. Wei-Jen Lee, Tammy Gammon, et al, Presentation "IEEE/NFPA Arc Flash Phenomena Collaborative Research Project", January 2011
6. NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplaces, 2000 Edition, National Fire Protection Association.

Arc Flash Calculation and NFPA Methods

CHAPTER 03

This chapter provides an overview of arc flash hazard calculations recommended by IEEE and NFPA. All equations, data, and calculation methods listed in this chapter are the property of the IEEE and NFPA. You are encouraged to read the standards for details.

IEEE Std 1584-2018

IEEE 1584-2018 is titled "IEEE Guide for Performing Arc-Flash Hazard Calculations" and provides a methodology for calculating prospective arc-flash hazards. The 2018 version is an update to the original standard that was first issued in 2002. Based on test data, the IEEE 1584 committee developed empirical equations to calculate arc-flash incident energy for three-phase AC systems. While both the 2002 and 2018 methods are empirical, the equations in the 2018 version are vastly more complex. The IEEE 1584-2018 calculations will be discussed only in general terms in this book. For more detail, please refer the standard. This complexity is due, in part, to the huge increase in test results used. For the original 2002 version, data from approximately 300 tests were used. For the current 2018 version, over 1,800 tests were considered.

Validity of IEEE 1584 Model - Range of Test Data

It is important to understand that the IEEE 1584 equations are valid only within the ranges for which test data were evaluated. Some changes were made to the applicable limits were made in the 2018 version. Table 3.1 summarizes the limits for the 2018 and 2002 versions.

Table 3.1: IEEE 1584 Model Valid Range

Parameter	2002 Version	2018 Version
System voltage	0.208 to 15 kV	0.208 to 15 kV
Frequencies	50 or 60 Hz	50 OR 60 Hz
Bolted fault current	700 A to 106 kA	500 A – 106 kA (208 V – 600 V) 200 A – 65 kA (601 V – 15 kV)
Gap between electrodes	13 to 152 mm	6.35 mm – 76.2 mm (208 V – 600 V) 19.05 mm – 254 mm (601 V – 15 kV)
Equipment enclosure type	Open air, box, MCC, panel, switchgear, cables	Open air, box, MCC, panel, switchgear, cables
Grounding type	Ungrounded, grounded, high resistance grounded	Ungrounded, grounded, high resistance grounded
Types of faults	3-phase faults ONLY	3-phase faults ONLY
Minimum Working Distance	—	12 inches
Maximum Enclosure Size	Max Height & Width – 49 in Max opening area: 2401 in^2 Min Width = 4 x Gap	Max Height & Width – 49 in Max opening area: 2401 in^2 Min Width = 4 x Gap
Electrode Configurations	Open Air In-box - Vertical, No Barrier (VCB)	Horizontal Open Air (HOA) Vertical Open Air (VOA) Vertical No Barrier (VCB) Vertical Into Insulating Barrier (VCBB) Horizontal (HCB)

Applications Outside of IEEE 1584-2018 Test Range

Attempting to use the IEEE 1584-2018 equations for conditions outside of the stated test ranges in Table 3.1 is generally NOT RECOMMENDED. Because of the empirical nature of the equations, applying them outside the intended range can yield non-conservative or even nonsensical results.

Voltages Above 15 kV

The 2002 version recommended use of the theoretical Ralph Lee equations for equipment operating over 15 kV. The Ralph Lee equations are described later in this chapter. Use of the Lee equations is believed to yield generally conservative results. The IEEE 1584-2018 version no longer provides a recommendation for arc-flash calculations over 15 kV. In EasyPower, the default is to use the Lee equations above 15 kV, however this option can be turned off. If it is turned off, no results are provided for enclosed equipment over 15 kV. EasyPower can optionally apply open air high voltage methods to systems 1 kV to 800 kV. Open air calculations are covered in detail at the end of this chapter.

Fault Currents Above Maximum Value

For bolted fault current exceeding 106 kA (up to 600 V) or 65 kA (601 V to 15 kV), application of the IEEE 1584-2018 equations can yield non-conservative results and it is recommended that the IEEE 1584-2018 equations not be used. This is not a common situation. EasyPower does allow the IEEE 1584-2018 equations to be used when fault current exceeds the maximum current values in the standard; however, this is not recommended. A warning will be displayed if this option is selected.

The options regarding calculations outside of the IEEE 1584-2018 test range are shown in EasyPower in the Advanced Arc Flash Options. This can be accessed from the main arc-flash option page under Short Circuit Options. The Advanced Arc Flash Options are shown in Figure 3.1 below.

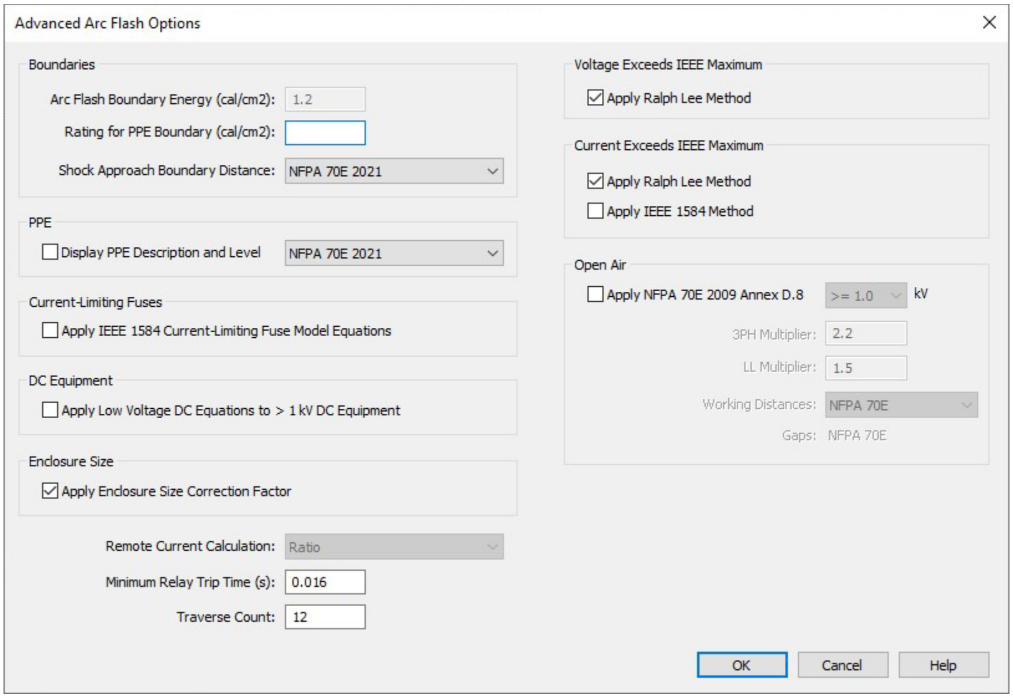


Figure 3.1 Advanced Arc Flash Options – Calculations Outside of Range

Arc-Flash Hazard Below 250 V

It is generally accepted that arcs are more difficult to sustain at voltages below 250 V. In the 2002 version of IEEE-1584, there is a statement that below 240 V, arc flash did not need to be considered if the source transformer size was less than 125 kVA. However only limited testing was done at these lower voltages for the 2002 edition. As more testing was done it was determined that under certain conditions, arcs could be sustained at voltages below 250 V. Based on this new test data, IEEE 1584-2018 adopted a new criteria in Section 4.3 that states "Sustainable arcs are possible but less likely in three-phase systems operating at 240 V nominal or less with an available short-circuit current less than 2000 A." This means that arc-flash hazards for nearly all 208 V and 240 V systems should be calculated using the IEEE 1584-2018 equations. Only systems served by very small transformers will have fault currents below 2000 A.

IEEE 1584-2018 Calculation Methodology Outline

The IEEE 1584-2018 calculation approach is described below in general terms to aid in understanding how changes to the various parameters impact the arc-flash results. For more detail on the calculation method and the equations used, please refer to the IEEE 1584-2018 standard itself.

The calculations are, in general, a two-step process, requiring first an "intermediate" value be calculated, then these intermediate values are interpolated to determine final results. Separate equations and methods are used for voltages from 208 V to 600 V and for voltages from 601 V to 15,000 V.

A: Calculation of Predicted Arcing Current

Due to the resistance of the arc, arcing current will be less than a zero-impedance (bolted) fault at the same location. The lower the system voltage, the greater impact the arc resistance has on the calculated arcing current as a function of the bolted fault current. Using the calculated bolted fault current as a starting point, equations are provided that predict the arcing current as a function of the following parameters:

- Electrode configuration (new in 2018 – discussed in detail later)
- Bolted fault current
- Voltage
- Electrode gap

Note that the magnitude of the arcing current is dependent on the electrode configuration selected.

Based on these parameters, an "intermediate average arcing current" is calculated. If the system voltage is 600 V or less, only one intermediate arcing current is calculated. Above 600 V, intermediate arcing current values are calculated at three standard voltages: 600 V, 2,700 V and 14,300 V. The final arcing current is interpolated based on the intermediate values and the actual system voltage, using equations given in IEEE 1584-2018.

Reduced Current Calculation

To account for arc variability, and the impact of lower current on protective device operating time, a second reduced arcing current is calculated at all voltage levels. In the 2002 standard, a reduced arcing current of 85% of the calculated arcing current was evaluated for systems operating at less than 1000 V. In the 2018 version, this concept has been extended to cover all voltage levels from 208 V to 15,000 V, but the amount of current reduction is not a fixed 85%. Instead it must be calculated based on the voltage level and other parameters. The greatest impact will be for systems 208 V to 600 V. As the voltage increases, the amount of current reduction diminishes. Figure 3.2 below shows the relative impact of the IEEE 1584-2018 versus the original 2002 version:

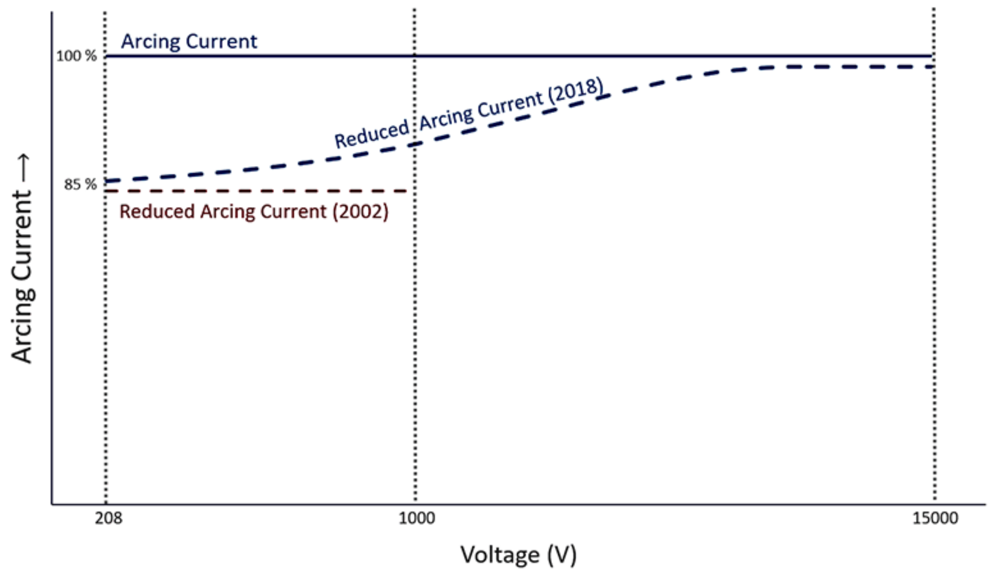


Figure 3.2: Reduced Arcing Current

The parameters used in the equations to determine the reduced arcing current are dependent on the electrode configuration and voltage. Based on these equations, a reduced arcing current is calculated based on the predicted final arcing current to establish a lower bound on the expected current.

B: Determine Arc Time

Using the "final arcing current" and the reduced arcing current as described, the respective arcing times are determined using primarily the time-current curves of the upstream protective devices. When there are multiple sources of fault current, the impact of arcing current that varies during the fault, and different clearing times for the different sources should also be considered. Any factors that could increase arc time also need to be accounted for. This includes breaker opening time, auxiliary tripping relays, and situations where fault current may continue after breaker opening, such as near generators. For special situations where the manufacturer's time-current curves cannot be used directly, or do not exist, EasyPower provides several options for specifying the arc time. These are described later in this book.

Maximum Arc Time

IEEE 1584-2018 suggests that an arc time of 2 seconds can be considered a reasonable maximum duration, provided a worker is able to move away from the arc source. This is similar to the recommendations previously given in IEEE 1584-2002. EasyPower allows for setting of maximum arc times for three separate voltage ranges in the main Arc Flash Options. The maximum time settings, within the Short Circuit Options, are shown in Figure 3.3 below.

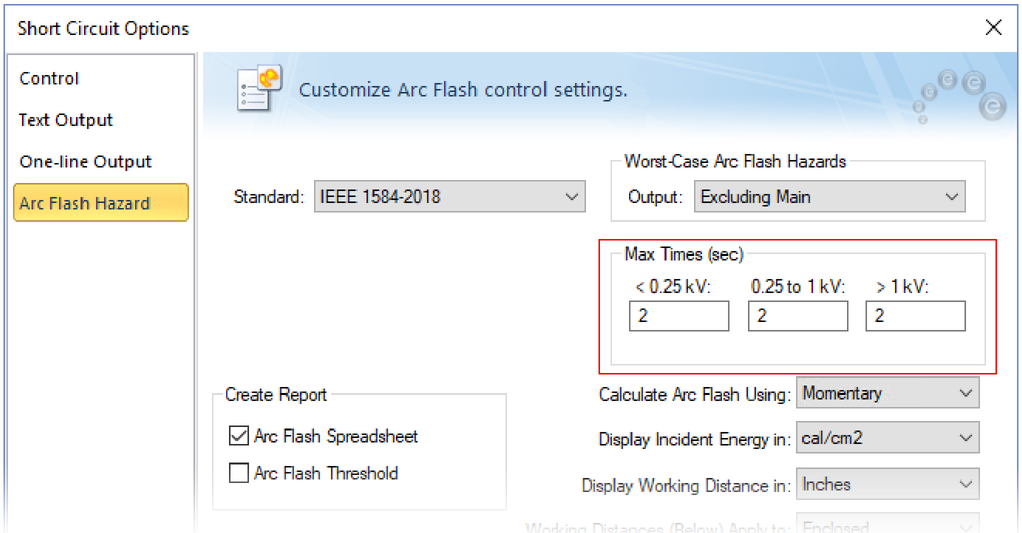


Fig 3.3: Maximum Arcing Time Settings

C: Calculation of Incident Energy

Before the incident energy can be calculated, the enclosure size correction factor must be calculated. In the 2018 version of IEEE 1584, a correction factor is calculated if the enclosure size varies from the default sizes used during testing. There are two factors related to the enclosure size: the overall size of the enclosure opening, and the depth. Enclosures are categorized as "Typical" or "Shallow." The impact of enclosure size on the IEEE 1584-2018 calculations is discussed in more detail later in this chapter. It should be noted that the enclosure size correction factor is dependent on the electrode configuration as well as the enclosure dimensions.

After the enclosure size correction factor is determined the incident energy is calculated. The methodology depends on the system voltage.

Voltage from 208 V to 600 V

The final and reduced arcing currents and the arc times are used to directly calculate an incident energy using the appropriate equation and parameters in the standard. Calculations are done for both the final arcing current and the reduced arcing current and the higher incident energy is used.

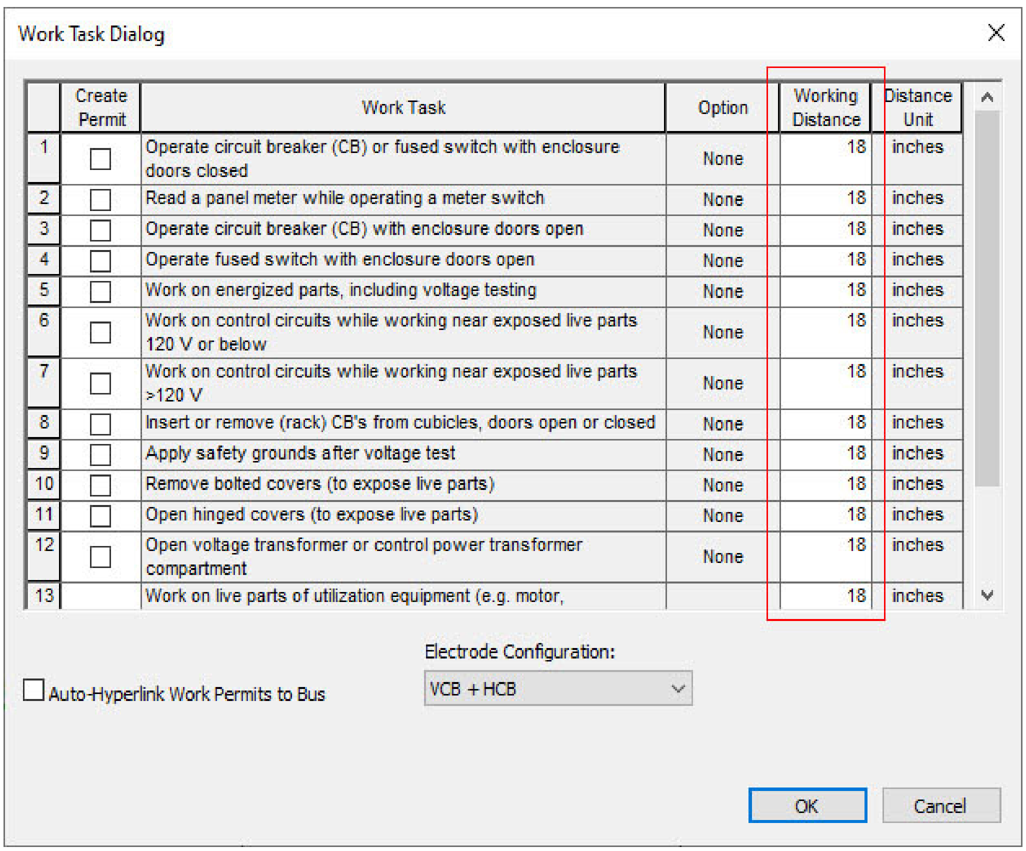
Voltage from 601 V to 15 kV

Intermediate values of incident energy are calculated at 600 V, 2,700 V, and 14,300 V using the final arcing current. From these intermediate values, a final value is interpolated based on the actual system voltage in accordance with the equations and parameters in the standard.

This procedure is repeated using the calculated value of reduced arcing current and the corresponding arc time and the greater value of incident energy is used.

Working Distance

The calculation of the incident energy is also dependent on the assumed working distance. The working distance is defined as the distance from the likely source of the arc and the worker's face or torso. It is recognized that some parts of the body may be closer than this distance. Because the incident energy is heavily dependent on the distance from the arc, the choice of working distance is a major determining factor in the incident energy calculation. Table 10 in IEEE 1584-2018 gives "typical" working distance for different classes of equipment at different voltages. Generally, 18-inches is used for all low-voltage equipment EXCEPT low-voltage switchgear where 24-inches is used. For all medium-voltage equipment, 36-inches is given as typical. EasyPower has default working distances based on the voltage level, but a specific working distance can be entered in the bus data for any piece of equipment. EasyPower also allows the working distance to be modified when Energized Work Permits are prepared, as shown in Figure 3.4 below.



	Create Permit	Work Task	Option	Working Distance	Distance Unit
1	☐	Operate circuit breaker (CB) or fused switch with enclosure doors closed	None	18	inches
2	☐	Read a panel meter while operating a meter switch	None	18	inches
3	☐	Operate circuit breaker (CB) with enclosure doors open	None	18	inches
4	☐	Operate fused switch with enclosure doors open	None	18	inches
5	☐	Work on energized parts, including voltage testing	None	18	inches
6	☐	Work on control circuits while working near exposed live parts 120 V or below	None	18	inches
7	☐	Work on control circuits while working near exposed live parts >120 V	None	18	inches
8	☐	Insert or remove (rack) CB's from cubicles, doors open or closed	None	18	inches
9	☐	Apply safety grounds after voltage test	None	18	inches
10	☐	Remove bolted covers (to expose live parts)	None	18	inches
11	☐	Open hinged covers (to expose live parts)	None	18	inches
12	☐	Open voltage transformer or control power transformer compartment	None	18	inches
13		Work on live parts of utilization equipment (e.g. motor,		18	inches

Figure 3.4 – Working Distance, Within the Energized Work Permit dialogue box

D: Calculation of Arc-flash Boundary

The arc-flash boundary is defined as the distance from the arc source at which the incident energy is 1.2 cal/cm^2. This value is considered the threshold of the amount of heat needed to cause 2nd-degree burns on bare skin. Per NFPA 70E, anyone closer than this boundary distance must wear PPE while the energized work is being done. In order to calculate the arc-flash boundary, the enclosure size correction factor must first be calculated, along with the incident energy. The arc-flash boundary calculation method depends on the system voltage, in a similar manner to the incident energy calculation. The arc-flash boundary is a function of the current, the voltage, the arc gap, the arc duration, the enclosure size correction factor, and the electrode orientation. It is possible, although not common, that the worst-case electrode orientations for incident energy and the arc-flash boundary will not be the same.

Voltage from 208 V to 600 V

Up to 600 V, the arc-flash boundary is calculated directly using an equation in the standard. As with the incident energy, this calculation is done at the final arcing fault current as well as at the reduced arcing fault current. The greater of the two results is used.

Voltage from 601 V to 15 kV

Above 600 V, three intermediate values of the arc-flash boundary are calculated at 600 V, 2,700 V, and 14,300 V using the final arcing current. Equations provided in the standard are used to then calculate the arc-flash boundary at the actual system voltage using these intermediate results. This procedure is repeated for the reduced arcing current already calculated and the greater of the two calculated boundary distances is used.

E: Electrode Configuration

One of the major changes in the 2018 version of IEEE 1584 is the addition of the electrode configuration as a factor in the arc-flash calculations. The original 2002 version recognized the difference between arcs occurring in open air, where the heat can radiate equally in all directions, and arcs occurring "in box" where the radiant heat is reflected off the enclosure walls increasing the heat the worker is exposed to at the opening. The "in box" tests conducted during the development of the original IEEE 1584-2002 standard were all done using vertical conductors that were open at the bottom. See Figure 3.5.

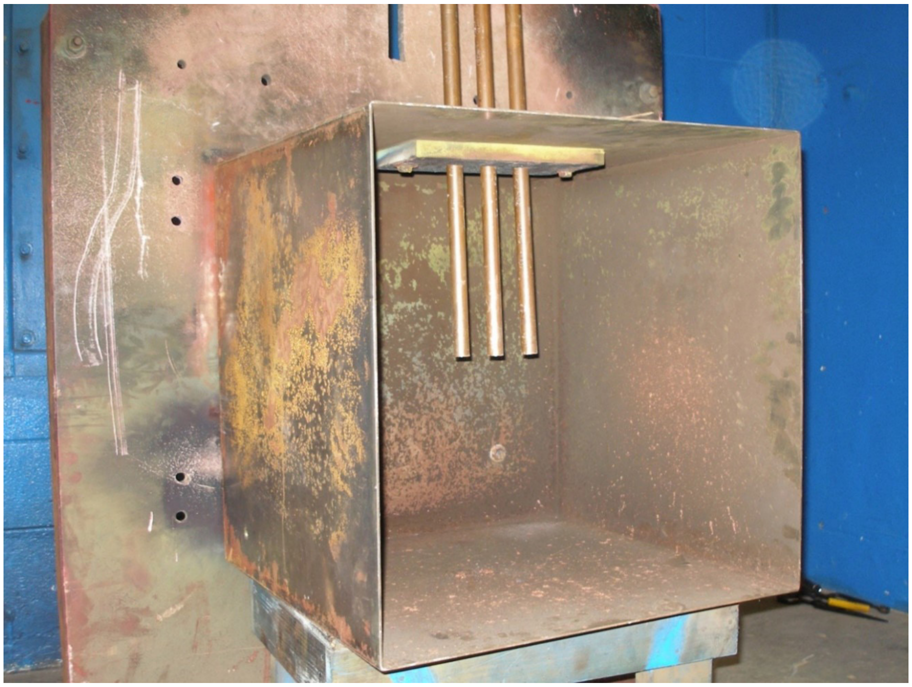


Figure 3.5 – IEEE 1584-2002 Test Setup

Subsequent to the publication of IEEE 1584-2002, much additional testing was done, and it was noted that the orientation of the bus (electrodes) had a significant impact on the heat exposure of a worker standing in front of the enclosure. This is due to the nature of arc movement during the fault and also the flow of the plasma (hot ionized gas) created by the arc. Based on the greatly expanded collection of test results and a better understanding on arc behavior, IEEE 1584-2018 added the electrode orientation as one of the primary factors in the calculation of arc-flash hazards. Five electrode orientations are defined and are described below.

Horizontal Open Air (HOA)

Based on a fault occurring in open air where the worker is exposed end-on to a horizontal bus or electrode. Plasma created by the arc tends to be pushed towards the worker, increasing the heat exposure. This is depicted in Figure 3.6 to the right:

Figure 3.6 – Horizontal Open Air (HOA)

Vertical Open Air (VOA)

Vertical open air is used for situations where the worker is exposed to vertical buses in open air. In this situation, the arc tends to travel down to the lower end of the electrodes. This is shown in Figure 3.7 to the right:

Figure 3.7 – Vertical Open Air (VOA)

Vertical in Box – No Barrier (VCB)

This category of electrode configuration is consistent with the test setup and conductor used during development of the original IEEE 1584-2002. Arcs tend to migrate downward and plasma is pushed downward from the end of the electrodes. Figure 3.8 depicts this configuration:

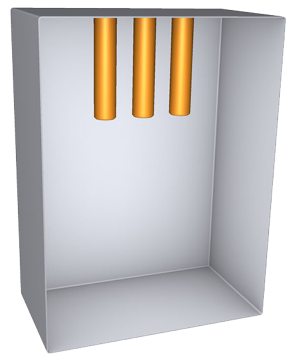


Figure 3.8 – Vertical in Box – No Barrier (VCB)

Vertical in Box with Insulating Barrier (VCBB)

If the electrodes terminate at an insulating barrier (such as a molded case circuit breaker), the plasma created by the arc tends to be pushed out towards the worker, increasing heat exposure. Arcs under these conditions can result in significantly higher incident energy than situations where no barrier is present. An example of the VCBB configuration is shown in Figure 3.9:

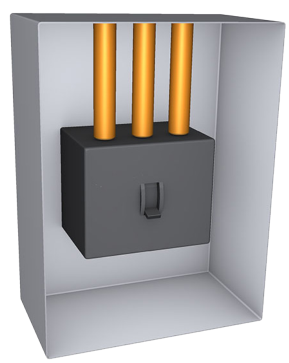


Figure 3.9 – Vertical in Box with Insulating Barrier (VCBB)

Horizontal in Box (HCB)

This configuration is intended to represent situations where the worker is exposed to the open end of a horizontal bus—looking at the electrodes "end-on." The arc tends to travel to the end of the bus and plasma is propelled out toward the worker. This configuration generally results in the highest incident energy of the five electrode orientations, other conditions being similar. The HCB configuration is illustrated in Figure 3.10:

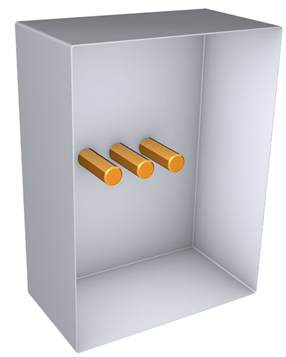


Figure 3.10 – Horizontal in Box (HCB)

Selection of Electrode Orientation

IEEE 1584-2018 provides limited guidance on how to select the electrode orientation to be used at any particular location. In fact, the standard notes that some equipment, such as motor control centers could be considered to have any of the three "in-box" configurations (VCB, VCBB, or HCB) depending on the location of the arcing fault. The worst-case energy would almost always be the HCB orientation. However, using HCB can yield results 2 or 3 times that of VCB. So, simply always using HCB to provide a "worst-case" may be overly conservative, especially since this end-on exposure to horizontal electrodes probably does not occur as frequently as VCBB or VCB in actual equipment.

In EasyPower, a default electrode configuration is set for each equipment type in the EasyPower library. However, this can be modified in the arc-flash section of the Bus Data for any equipment. Multiple configurations can also be selected and EasyPower will calculate all configurations specified and report back the orientation with the highest incident energy. For compatibility with older EasyPower models and arc-flash evaluations, at present the default electrode configuration in the EasyPower library is set to VCB for all "in-box" equipment types, since this is the configuration used for all previous IEEE 1584 calculations prior to the release of the 2018 update. It should be understood that this default electrode configuration will not yield the worst-case incident energy or arc-flash boundary.

Also, it may be necessary to modify the electrode orientation used as a function of the specific task to be performed. This can be accomplished in the Energized Work Permit. EasyPower allows consideration of specific configurations for specific tasks in the Work Permit definition process, as shown in Figure 3.11 below. This is covered in more detail in Chapter 4.

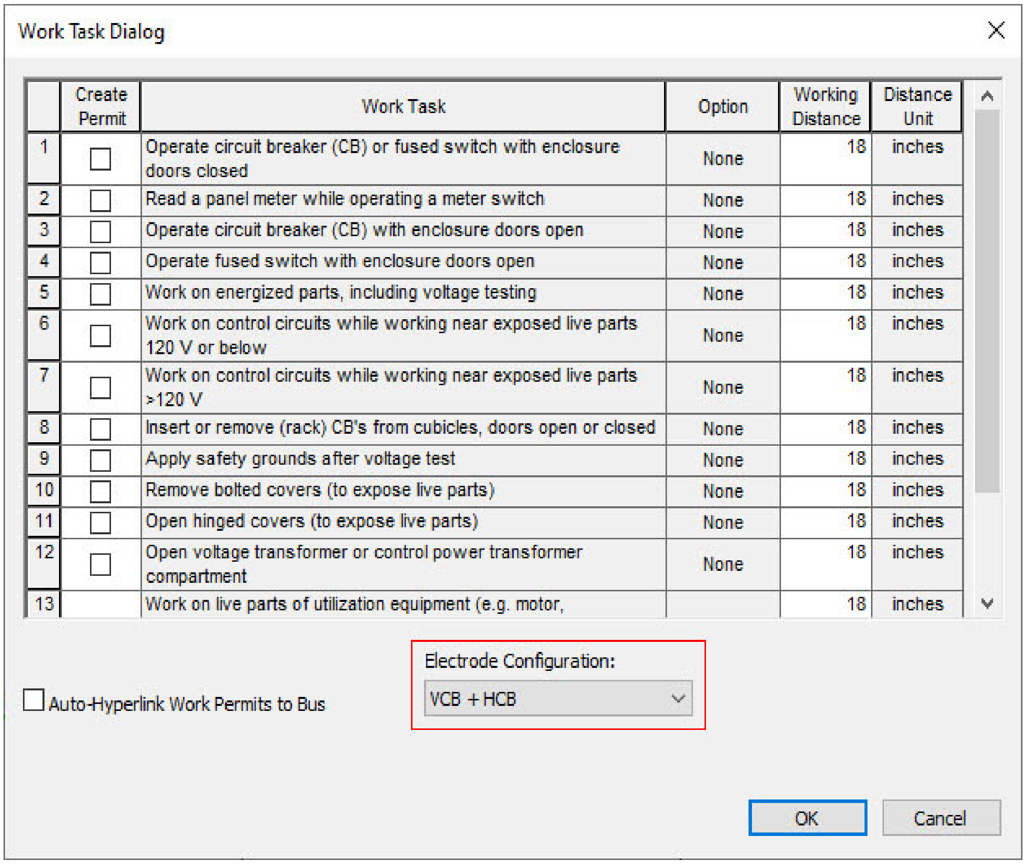


Figure 3.11 – Selection of Electrode Orientation, Within the Energized Work Permit Dialogue Box

F: Enclosure Size Correction Factor

The size of the enclosure can have an impact on the incident energy for workers exposed to an arcing fault occurring inside the enclosure. In the original IEEE 1584-2002, the enclosure size was accounted for via a "distance factor" used as the exponent when calculating the impact of the increased distance from the arc source. For open air and cable faults, the exponent is 2, following the ideal inverse square relationship. For "in-box" faults, an exponent of less than 2 is used, with the value determined by the type of equipment and voltage level.

In the updated standard, IEEE 1584-2018, the enclosure size is accounted for using what is called the "enclosure size correction factor" that must be defined for each location and each fault calculation. The three "in-box" configurations (VCB, VCBB, and HCB) use calculations normalized to a standard 20" x 20" by 20" box. For larger and smaller enclosures, the enclosure size correction factor is used to adjust the results. First an equivalent height and width are established, and these values are used to compute the enclosure size correction factor. The standard defines typical dimensions for standard types of equipment, and these are used as defaults in EasyPower. If the enclosure dimensions vary from the default values, the actual dimensions are defined in the bus data.

Table 3.2 below shows the typical enclosure dimensions for the equipment types defined in IEEE 1584-2018.

Table 3.2 – IEEE 1584-2018 Typical Equipment Dimensions

Equipment Type	H	x	W	x	D	
15 kV Switchgear	45	x	30	x	30	in.
15 kV MCC	36	x	36	x	36	in.
5 kV Switchgear	36	x	36	x	36	in.
5 kV Switchgear	45	x	30	x	30	in.
5 kV MCC	26	x	26	x	26	in.
Low Voltage Switchgear	20	x	20	x	20	in.
Low Voltage MCCs & Panelboards (Typical)	14	x	12	x	>8	in.
Low Voltage MCCs & Panelboards (Shallow)	14	x	12	x	≤2	in.
Cable Junction Box	14	x	12	x	8	in.

The effect of the enclosure size decreases as the box size gets larger. Per the standard, for openings larger than 49” by 49”, the incident energy stays constant and does not continue to decrease.

In addition to the enclosure dimensions, IEEE 1584-2018 has a separate factor for the effect of very shallow enclosure on the incident energy. This applies to low voltage panelboards and MCCs. If the enclosure depth is 8 inches or less, it is defined as “Shallow.” Deeper enclosures are defined as “Typical.”

Figure 3.12 shows, in relative terms, the impact of the enclosure size on the calculated incident energy.

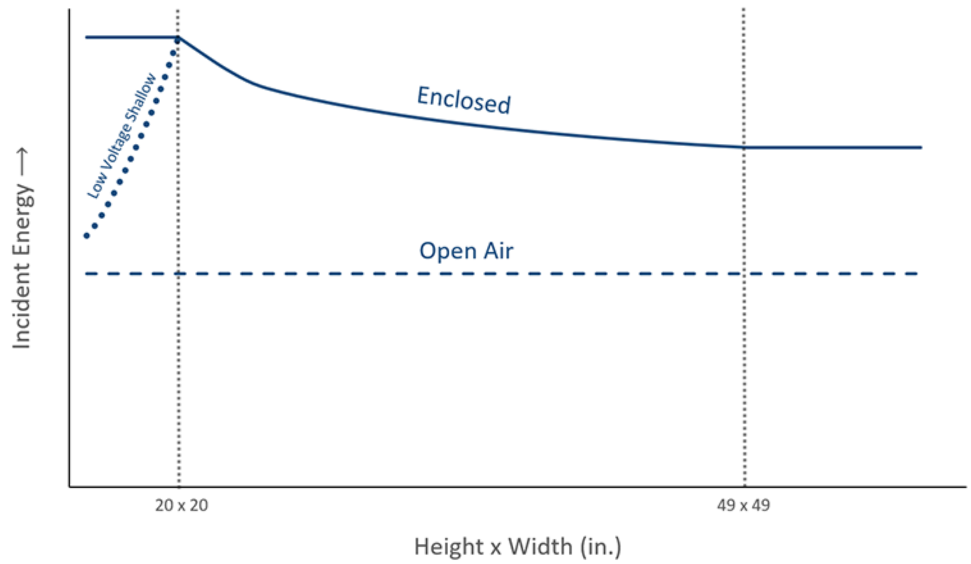


Figure 3.12 – Enclosure Size Correction Factor Influence

Because it is possible for electrical equipment to have compartments of varying sizes, it may be necessary to perform multiple arc-flash calculations for the same equipment depending on where the work is to be done. The standard does not provide specific guidance on how to address this issue.

It is also important to note that the enclosure size correction factor is sensitive to the relative values of length versus width, even for the same cross-section of opening.

Current-Limiting Fuses

The original IEEE 1584-2002 provides an alternative method for calculating arc-flash energies for arcing fault cleared by current-limiting fuses. These alternative equations were based on limited testing done for Class L and Class RK1 fuses up to 2000 A from a single fuse manufacturer. These equations are unchanged in the 2018 version but have been moved to Annex H. These current limiting fuse equations are significantly different than the normal calculation, with the determination of incident energy at an 18" working distance based solely on the available bolted fault current at the fuse and do not include factors for determination of arcing fault current, arc time, or arc gap. All testing was done within one specific enclosure size and based on vertical electrodes without a barrier (VCB). In addition, these equations are only applicable for available fault currents equal to or greater than the minimum values given for each size range and type of fuse:

Class L 1601-200 A	22.6 kA minimum
Class L 601-1600 A	5.7 kA minimum
Class RK1 401-600 A	8.5 kA minimum

Class RK1 201-400 A	3.16 kA minimum
Class RK1 101-200 A	1.16 kA minimum
Class RK1 1-100 A	0.65 kA minimum

In Annex H of IEEE 1584-2018, it states that these equations should only be used for a working distance of 18 inches and a VCB type electrode configuration. For other conditions and for other fuse types and sizes, the standard calculation method should be used, with the fuse time-current curve used to determine the arc time.

EasyPower does provide an option to use the current-limiting fuse equations described in Annex H of IEEE-1584-2018. However, this option is not selected by default. By default, the standard calculation method is used along with the fuse time-current curve. For fuses operating in their current-limiting range, fault clearing time will be ½ cycle or less, resulting in low incident energy. For fuses at fault currents less than their current-limiting range, the current-limiting effect does not play a major role in the fault clearing process.

If it is desired to use the current-limiting fuse equations, the option is accessed in **Short Circuit Options>Arc Flash Hazard>Advanced**. The setting is shown in Figure 3.13 below, and is only applicable to the VCB bus configuration and when using the momentary fault current for arc-flash calculations.

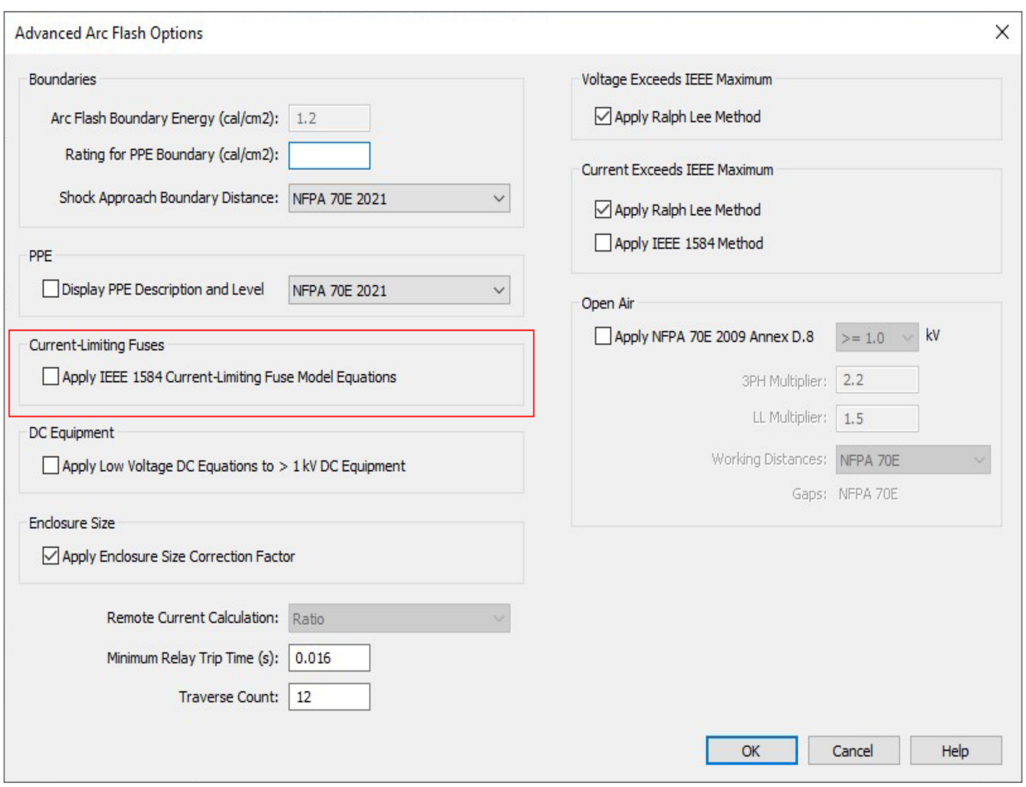


Figure 3.13 – Current Limiting Fuses

IEEE 1584-2002

Although IEEE 1584-2018 is the current version of the Guide, superseding IEEE 1584-2002, the original version that was first released in 2002 has been used for many years as the industry-standard arc-flash hazard calculation method. The calculation method in the 2002 version is still supported in EasyPower and can be selected as an option, although the new default method is IEEE 1584-2018.

As with IEEE 1584-2018, the original 2002 version is based on arc-flash test data from which empirical equations were developed to calculate the expected incident energy and arc-flash boundary. The 2002 methodology is much simpler but based on much less data. A vertical electrode configuration, with no barrier, was used for all the testing carried out when IEEE 1584-2002 was developed. This is essentially the VCB configuration in IEEE 1584-2018. A brief summary of the 2002 version methodology is given below. For more details, please refer to the standard.

Overview of IEEE 1584-2002 Calculation Method

Empirical equations are provided to estimate arcing current, incident energy, and arc-flash boundary based on bolted fault current, arc location (in air or in box), arc gap, voltage, working distance, and enclosure distance factor. In addition, the system grounding also has an impact on the calculated incident energy, resulting in higher incident energy for ungrounded systems when compared to grounded systems, holding all other variables equal. This distinction between grounded and ungrounded systems is NOT made in the new standard, IEEE 1584-2018. As noted above, all calculations were derived from test setups that had vertical electrodes with no barrier.

Estimate of Arcing Current

The IEEE 1584-2002 calculation method has empirical equations for conversion of calculated bolted (zero impedance) faults to estimated arcing fault currents. Due to the resistance of the arc, arcing current will be less than a zero-impedance fault at the same location. The lower the system voltage, the greater impact the arc resistance has on the calculated arcing current. A reduced arcing current of 85% of the calculated arcing current is used to do a second incident energy calculation for systems below 1000 V. This is done to account for the increased variability in arcing current at lower voltages. The reduced current can cause higher incident energy due to the possible increase in arc time. Note that this concept of a reduced current calculation was extended in the 2018 revision to cover all voltages up to 15 kV and with a varying amount of current reduction depending on multiple factors.

Estimate of Normalized Incident Energy

Using equations provided in the 2002 version, a normalized incident energy is calculated. This normalized value is based on a standard 0.2 second arc duration and 610 mm distance from the arc.

Estimate of Incident Energy

Using a separate equation, the calculated normalized incident energy is used to obtain the estimated actual incident energy at a normal surface at a specific distance and arcing time. The typical working distances given in IEEE 1584-2002 are the same as found in the current IEEE 1584-2018.

Flash-Protection Boundary

The flash-protection boundary is the distance at which a person without personal protective equipment (PPE) is exposed to 1.2 cal/cm^2. This is identical to the definition in the newer IEEE 1584-2018, although the calculation is not the same.

NFPA 70E® Annex D

Introduction

Although NFPA 70E is not yet specific about how incident energy and the arc-flash boundary must be calculated, Annex D of NFPA 70E describes some recognized calculation methods, including IEEE 1584-2018. However, it must be remembered that the Annexes are not a part of the actual NFPA 70E requirements but are provided for information only.

EasyPower allows for selection of various calculation methods including IEEE-1584-2018 (default), IEEE 1584-2002, and "NFPA 70E D2, D3."

Ralph Lee Calculation Method (Annex D.2)

The "Ralph Lee" calculation method is based on the original paper published by Ralph Lee regarding arc-flash hazards, "The Other Electrical Hazard: Electrical Arc-flash Burns." In this paper, calculation methods were developed based on first principles and theoretical equations. Refer to the referenced paper for greater detail. In NFPA 70E®-2021, Annex D, the Lee method is offered as a method to calculate the arc-flash boundary and also to calculate incident energy levels for systems rated above 600 V. For systems rated 600 V or less, Annex D uses the "Doughty Neal Paper" method. The combination of the Ralph Lee Method and the Doughty Neal Paper method described in Annex D are referred to as "NFPA 70E D2, D3+" in the calculation Standard option under Arc Flash Options in EasyPower.

The basis of the Lee method is a determination of the maximum possible arc energy for a given bolted fault current. Based on classic circuit theory, the maximum power can be stated:

P = Max bolted fault MVA x 0.707^2

Based on this assumption, the arc flash boundary distance is calculated based on the following formula:

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

where:

D_c = distance in FEET of the person from arc source (based on 80 deg C skin temperature)

MVA_{bf} = Bolted fault MVA at location

t = time of exposure in seconds

Doughty Neal Paper (Annex D.3)

NFPA 70E, Annex D references the paper "Predicting Incident Energy to Better Manage the Electrical Arc Hazard on 600 V Power Distribution Systems" by Doughty, et al., and refers to this as the "Doughty Neal Paper." The equations in this paper can be used to calculate the incident energy for systems at 600 V and below. Annex D.3 cautions that "The results of these equations might not represent the worst case in all situations. It is essential that the equations be used only with the limitations indicated in the definitions of variables shown under the equations. The equations must only be used under qualified engineering supervision." Please refer to the original paper and Annex D section D.3 for more information.

The equations used in this method distinguish between arcs in open air and arcs in a box, as does IEEE 1584. The prospective length of the arc gap is also factored into the equations. Fault currents are limited to the range of 16 kA to 50 kA.

For arc in open air:

$$E_{MA} = 5271 \times D_A^{-1.9593} \times t_A \begin{bmatrix} 0.0016F^2 \\ -0.0076F \\ 0.8938 \end{bmatrix}$$

Where

E_{MA} = maximum open arc incident energy, cal/cm^2

D_A = distance from arc electrodes (for distances greater than 18 inches)

t_A = arc duration, sec.

F = short circuit current, kA (valid from 16 kA to 50 kA)

For arc in box:

$$E_{MB} = 5271 \times D_B^{-1.9593} \times t_B \begin{bmatrix} 0.0093F^2 \\ -0.3453F \\ 5.9675 \end{bmatrix}$$

Where

E_{MB} = maximum 20 in. cubic box incident energy, cal/cm^2

D_B = distance from arc electrodes (for distances greater than 18 inches)

t_A = arc duration, sec.

F = short circuit current, kA (valid from 16 kA to 50 kA voltage)

DC Arc-Flash Calculations (Annex D.5)

Section D.5 in Annex D of NFPA 70E® contains information regarding calculation of arc-flash incident energy for DC systems. In D.5.1, equations are shown for calculating DC arc-flash energy based on the theoretical maximum power transfer approach. These equations are based on a paper by Dan Doan, "Arc-flash Calculations for Exposure to DC Systems" that was published in the IEEE Transactions on Industry Applications, Vol 46, No. 6. This method is applicable for DC systems up to 1000 V.

$$I_{arc} = 0.5 \times I_{bf}$$

$$IE_m = 0.01 \times V_{sys} \times I_{arc} \times \frac{T_{arc}}{D^2}$$

Where:

I_{arc} = arcing fault amperes

I_{bf} = bolted fault amperes

IE_m = estimated DC arc-flash incident energy at maximum power point, cal/cm^2

V_{sys} = system voltage, volts

T_{arc} = arcing time, sec

D = working distance, cm

For batteries, D.5.3 suggests that the battery bolted fault current be assumed to be 10 times the 1-minute battery rating (to 1.75 V per cell at 25 deg C) if more specific data is not available from the battery manufacturer.

For the DC portions of EasyPower models, arc-flash calculations are done using the NFPA 70E Annex D.5 equation. By default, no calculation is done if the nominal DC voltage exceeds 1000 V, based on the limitations stated in NFPA 70E. As an option, EasyPower allows this equation to be applied at voltages greater than 1000 V DC, although this is not explicitly recognized as valid in NFPA 70E. This option is selected in the Advanced Arc Flash Options section of the main Arc Flash Options as shown in Figure 3.14 below.

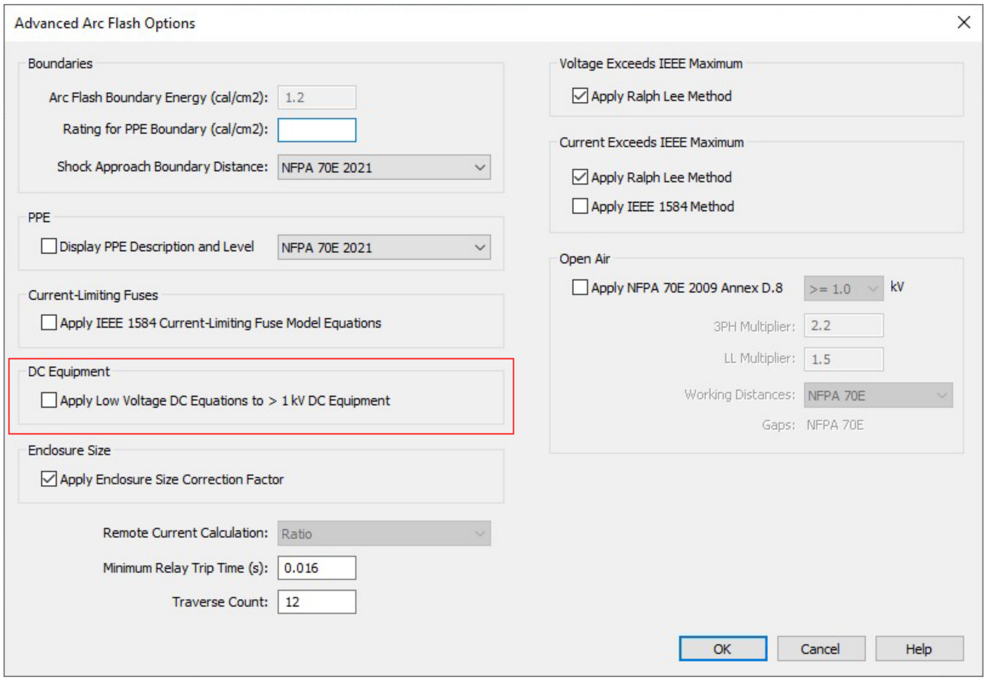


Figure 3.14 – DC Arc Flash Settings

Arc Blast Pressure

Another item associated with an electric arc is the blast energy or pressure. This hazard is not presently covered in NFPA 70E® or IEEE Std 1584. This force can be significant and can blow workers away from the arc causing falls and injuries that may be more severe than burns. In Ralph Lee's second IEEE paper,[1] *Pressures Developed by Arcs* in 1987, he cites several case histories. In one case, with approximately 100 kA fault level and arc current of 42 kA, on a 480-V system, an electrician was thrown 25 feet away from the arc. Being forced away from the arc can reduce the electrician's exposure to the heat radiation and molten copper but can subject the worker to falls or impact injuries. The approximate initial impulse force at 24 inches was calculated to be approximately 260 lb/ft^2 as determined from the equation below.

$$Pressure = \frac{11.58 \; * I_{arc}}{D^{0.9}}$$

where,

Pressure is in pounds per square foot.

D = distance from arc in feet

I_{arc} = arc current in kA

Arc-rated PPE is not tested for protection from any type of blast pressure and at this time, there are no accepted calculation methods for determining the hazard of blast pressure for any particular situation.

Calculating Incident Energy for Overhead Open-Air Systems

In the U.S., electric utilities generally adhere to ANSI C2, the National Electrical Safety Code (NESC), for issues related to electrical safety. Utility systems are outside the scope of the NEC. Beginning in the 2007 Edition of the NESC - ANSI C2, new requirements were added that specifically address a worker's exposure to arc-flash hazards. These arc flash related requirements are covered in Rule No. 410.A.3. Where working on or near energized electrical equipment, the NESC rule states: "the employer shall ensure that an assessment is performed to determine potential exposure to an electric arc for employees who work on or near energized parts or equipment. If the assessment determines a potential employee exposure greater than 2 cal/cm^2 exists, the employer shall require employees to wear clothing or a clothing system that has an effective arc rating not less than the anticipated level of arc energy. When exposed to an electric arc or flame, clothing made from the following materials shall not be worn: acetate, nylon, polyester, or polypropylene. The effective arc rating of clothing or a clothing system to be worn at voltages 1000 V and above shall be determined using Tables 410-1 and 410-2 or performing an arc-hazard analysis. When an arc hazard analysis is performed, it shall include a calculation of the estimated arc energy based on the available fault current, the duration of the arc (cycles), and the distance from the arc to the employee."

Tables 410-1 and 410-2 in the NESC 2007 Edition are now Tables 410-2 and 410-3 in the current NESC. The NFPA 70E-2009 Annex D.8 Tables listed the heat flux rate derived from the ANSI/IEEE C2 (NESC) 410 Tables. Section D.8 in Annex D was subsequently removed from NFPA 70E in later editions, but the NESC methodology is unchanged.

The NESC 2017 Table 410-3 were calculated based on following conditions:

- Arc gap—calculated by using the phase-to-ground voltage of the circuit and dividing by 10. The dielectric strength of air is taken at 10 kV per inch. See IEEE Std 4-1995.
- Distance from arc—calculated by using the minimum approach distance from NESC Table 441-2 and subtracting two times the assumed arc gap length, and using the following T values: 72.6 kV to 362 kV = 3.0, 362.1 kV to 550 kV = 2.4, 550.1 kV to 800 kV = 2.0.

EasyPower is equipped with an option to estimate the incident energy exposures for energized work on overhead open-air systems 1 kV to 800 kV based on the NFPA 70E-2009 Annex D.8 Tables, which are the same as Tables 410-2 and 410-3 in the NESC

2017 Edition. If this option is selected, this calculation method will be automatically applied to buses defined as Open Air and with nominal voltages within the specified range. This option can be selected in the Arc Flash Options in the Advanced Arc Flash Options.

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1. Ralph Lee, "Pressures Developed by Arcs," IEEE Transactions on Industry Applications, Vol. IA-23, No. 4. July/August 1987, page 760-764.

Practical Steps for Arc-Flash Calculations

CHAPTER 04

Arc-flash risk assessment procedures are needed for locations where workers are exposed to arc-flash hazards. Therefore, it may not be necessary to perform the assessment for each and every piece of equipment in the power system.

Introduction

The methodology for calculation of arc-flash hazards was described in Chapter 3. In this chapter, we look at the practical steps required for the calculation of arc-flash hazards using EasyPower on actual systems.

Conducting a detailed calculated arc-flash hazard analysis requires the following steps.

1. Identify locations and equipment for which an arc-flash risk assessment is needed.
2. Collect required system data. Calculation of arc-flash hazards requires data needed for short circuit calculations, time-current curve data for overcurrent devices, and equipment characteristics related to arc-flash behavior and heat release.
    a. Typical data needed for short circuit analysis includes system voltage; utility available fault current; transformer size, impedance, and X/R ratio; conductor size and length, as well as other data that would have an impact on calculated short circuit current.
    b. To allow EasyPower to automatically determine the arc time, protective device data is needed for overcurrent protection. The necessary data includes: type of device, device settings or size, breakers, time-current curves, and breaker opening times.
    c. Equipment data needed specifically for an arc-flash study includes type of equipment, type and size of enclosure, electrode configuration, gap between conductors, number of phases, and approximate working distance for the equipment tasks.
    d. In addition, it is necessary to determine the expected operating conditions for the system, especially system configuration changes that impact the short circuit current or the arc time.
3. Develop an accurate one-line diagram of the electrical system and enter all necessary data into EasyPower.
4. Perform a short circuit study:
    a. Calculate bolted (available) 3-phase fault current for each piece of equipment.
    b. Calculate current for every contributing branch and load.
5. Determine expected arc current (the resistance in the arc results in the arcing current being less than the bolted fault current):
    a. Calculate arc current.
    b. Calculate branch currents contributing to the arc current from every branch.
    c. Calculate the reduced arcing current value (if using IEEE 1584-2018).

6. Estimate arcing times from the protective device characteristics and the contributing arc current passing through this device for every branch that significantly contributes to the arc fault.
7. Estimate the incident energy for the equipment at the given working distances. The incident energy is calculated for full and reduced values of arcing current and the higher incident energy is used.
8. Determine the arc-flash boundary for the equipment. The arc-flash boundary is calculated at full and reduced values of arcing current and the greater distance is used.
9. Document the assessment in reports, one-line diagrams, and with appropriate labels on the equipment.

The use of EasyPower software allows for easy calculation of arc-flash incident energies and arc-flash boundaries and documentation of the analysis with reports, one-line diagrams, and arc-flash labels, all based on the one-line diagram.

Step 1 – Identify All Locations and Equipment for Arc-flash Risk Assessment

Arc-flash risk assessment procedures are needed for those locations where workers may be exposed to a risk of arc-flash injury. Per NFPA 70E, an arc-flash risk assessment is required for all equipment and locations likely to be serviced or examined while energized. All equipment with circuit breakers or fuses should generally be included in the assessment if there is potential for arc-flash injury based on the workers' tasks. Incidents may occur when operating the breakers or fused disconnects, even with the door closed. You can consult the existing one-line diagrams for determining the equipment that requires assessment. If such a diagram does not exist, it should be developed as discussed in steps 2 and 3.

Step 2 – Collect Data

Refer to Chapter 7 – Data Collection for more specific recommendations regarding the data collection process.

Data for Short Circuit Analysis

Although some equipment may not require arc-flash risk assessment, data about this equipment may be required in a short circuit analysis or protective device coordination study. Typical data required for the study is shown in Table 4.1. Short circuit analysis requires data on the utility, generators, transformers, cables, transmission lines, motors, etc. The nameplate of the equipment can provide most of the necessary data. In the absence of particular data, it may be possible to obtain the information from the manufacturers or their representatives. Also, typical data can be assumed by referring to books and product literature. Power system software such as EasyPower have an extensive library of manufacturer's data covering most electrical equipment in use today. This book is not meant to be a guide for short circuit studies. Refer to standard literature[1,2,3] for short circuit studies.

Table 4.1: Typical Data Needed for Short Circuit Analysis

Category	Data Needed
Utility Sources	Available 3-phase fault current and X/R ratio
Local Generators	Size (kVA or MVA), Subtransient reactance (X″d), transient reactance (X′d), X/R ratio.
Cables	Conductor material, conductor size, insulation, circuit construction, raceway type and material, feeder length (resistance and reactance is determined automatically by EasyPower).
Busway	Conductor material, length, ampere rating (resistance and reactance is determined automatically by EasyPower).
Transformers	Size (kVA or MVA), nameplate impedance (%Z), X/R ratio.
Motors	Motor size (hp) and X/R ratio. EasyPower can compute typical X/R values. Also, the model must distinguish between constant-speed motors and motors running on adjustable frequency drives.
Equipment Short Circuit Ratings	Short circuit withstand and interrupting ratings should be included in the model to allow determination of devices that may be underrated for the available short circuit current. EasyPower generally provides this information in the library data for circuit breakers and fuses, but it should be verified. These ratings do not directly impact the arc-flash calculations, but rather determine if the protective device can be depended on to clear the arcing fault.

Required Data for Protective Devices

The time-current curves and settings for all overcurrent protective devices must be obtained and entered into the model. In most cases, EasyPower has the necessary time-current curve data in the library for each device. The time-current curves and the settings are required to determine the predicted arc time at each location. Table 4.2 lists the typical setting and device information required. This data may be obtained from existing drawings, relay calibration data, coordination studies, and from field inspection. Obtain the time-current characteristics (TCC) for these devices from the manufacturers if necessary. If EasyPower cannot create a time-current curve for a protective device, it will not be considered in the arc-flash determination. In addition, both NFPA 70E and IEEE 1584 discuss the need to determine the condition of maintenance for the protective devices. If a protective device does not operate in accordance with the manufacturer's published time-current curves during an arcing fault, the predicted arc time and resulting incident energy calculation may not be correct. Equipment that shows signs of lack of maintenance or appears damaged can be excluded from determination of the arc time.

Table 4.2: Protective Device Data to Gather

Protective Device	Data Needed
Relays	Type, CT ratio, pickup (tap) setting, delay type (curve) and setting (time dial).
Fuses	Type, amp rating, voltage, peak let-through current.
Circuit Breakers	Type, fault clearing time, trip unit type, sensor ratings, plug ratings, pickup setting, delay curve, delay setting.

Data for Arc-flash Hazard Calculation

Depending on the method of calculation selected, the following equipment data is required for an arc-flash risk assessment study.

- Type of equipment
- Enclosed versus open air location
- Enclosure size
- Arc gap
- Electrode configuration
- Working distance

IEEE 1584-2018 includes suggested arc gaps, enclosure sizes, and working distances for different types of equipment. In the IEEE 1584-2018 equations, the arc gap, the electrode configuration, and the enclosure size all can impact not only the final arc-flash energy determination but also the predicted arcing current. This is discussed in greater depth in Chapter 3.

As discussed in Chapter 3, the selected electrode configuration can have a major impact on the calculated incident energy. The enclosure size also has an impact, although not as dramatic as the electrode configuration. When considering typical electrical equipment such as switchgear, switchboards, and motor control centers, it is possible that different electrode configurations could apply to different areas of the equipment or even for different tasks. Because of this, it may be necessary to calculate the incident energy for more than one electrode configuration. EasyPower provides the option to calculate for any applicable combination of electrode configurations at each location. The arc-flash report will show the highest incident energy and greatest AFB for the selected electrode configurations.

For equipment with compartments of varying sizes, such as switchgear and MCCs, this will also have an effect on the resulting arc-flash calculations. In EasyPower, various enclosure sizes can be evaluated by creating multiple scenarios with different enclosure sizes in different scenarios. It is also possible to set an option to NOT apply the Enclosure Size Correction Factor, and always compute a maximum arc-flash energy relative to enclosure size at each location. See Chapter 3 for more information regarding enclosure size.

Determine Operating Conditions to Be Analyzed

Complex electrical systems can have multiple operating configurations. Changes to the system that cause changes to the available short circuit current or the protective device settings can change the arc-flash hazard. Common situations include local generation being on or off, a double-ended substation configuration, and changes to the utility available fault current. As an example, Figure 4.1 shows the available fault currents for two scenarios: (a) a generator and utility operating in parallel with both motors running; and (b) the generator not running, and one of the motors turned off for maintenance. The difference in fault currents can clearly be seen. This change in fault current will likely result in different incident energies for the two scenarios. However, it cannot be assumed that the scenario with the higher fault current will also always result in the higher incident energy. This is due to the important effect that the arc time plays in the arc-flash energy calculations. Table 4.4 is an example worksheet for this case that considers multiple connections. For complex systems, it may be necessary to evaluate many different scenarios. EasyPower can evaluate arc-flash hazards for multiple operating conditions and report back the maximum incident energy at each location automatically using Scenario Manager.

Table 4.3: Example Worksheet for Connection Scenarios

Equipment Connected	Normal Operation	Co-generation	Maintenance Schedule A	Maintenance Schedule B
Utility	ON	ON	OFF	ON
Generator	OFF	ON	ON	OFF
Motor	ON	ON	ON	OFF
M-2	ON	ON	ON	ON

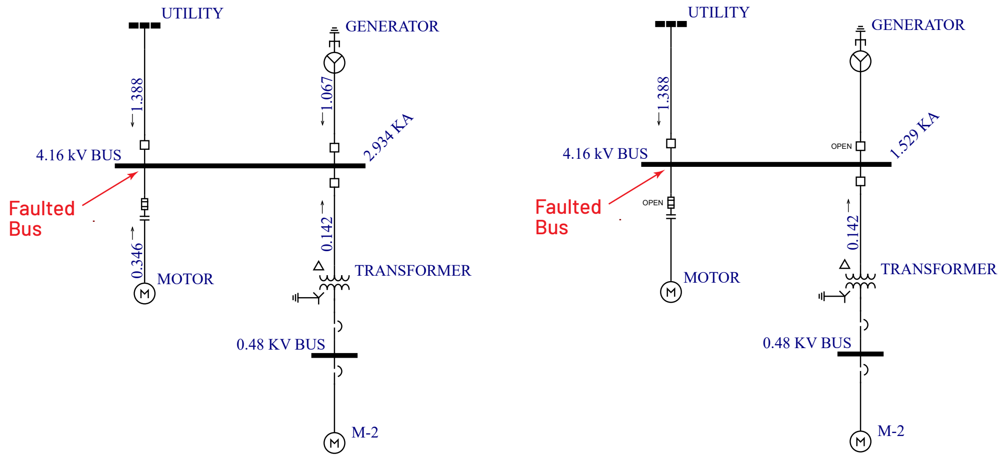


Figure 4.1: EasyPower Example of Connected Equipment for Two Possible Cases

Step 3 – Prepare a One-line Diagram of the System

One-line (single-line) diagrams are powerful tools for documenting and communicating information about power systems. They are easy to read, show the connections and status of equipment, and contain much of the data required for analysis. The results of analysis such as short circuit studies and arc-flash risk assessment can easily be placed on the diagrams. Most existing plants should already have accurate one-line diagrams. The accuracy of these should be verified before commencing the assessment. If a new diagram is required, it can be prepared using the data collected.

Arc-flash analysis using EasyPower begins with creating a one-line model of the electrical system. Data for each element in the model is entered by the user and the software uses this information to create a digital model of the system. From this model, EasyPower can provide a fully integrated analysis of short circuit, arc flash, coordination, power flow, and more. EasyPower provides an easy way to create, update and maintain your power system one-line as required by NFPA 70E. Using EasyPower's Scenario Manager, the various operating modes that require arc-flash analysis can be created and stored along with the base one-line diagram.

Step 4 – Perform a Short Circuit Study

Once the EasyPower model is created and the necessary data entered, the software can perform a wide variety of short circuit calculations. The EasyPower short circuit module automatically calculates the bolted fault and arcing fault currents that are applied in the arc-flash energy equations. Steps 4 and 5 in this chapter describe the different currents calculated by the program. While these calculations are done by EasyPower, it is important to understand the different short circuit currents used in the arc-flash calculations and why they are necessary. This will enable you to check the results for reasonableness and to understand the basis of the arc-flash results.

For arc-flash calculations performed using IEEE 1584, only 3-phase faults are considered. There are several reasons for this. One is that 3-phase faults generally give the highest arc energy and represent a worst-case. Another important reason is that experience has shown that arcing faults in equipment or air that begin as line-to-ground faults can escalate rapidly into 3-phase faults as the air ionizes across phases. This progression from single-phase to 3-phase happens rapidly, generally within a few cycles. Because of this, most testing done on arc-flash energy has been based on 3-phase faults. For single-phase systems, IEEE 1584 recommends that calculations be done for an equivalent 3-phase system and states that this will yield conservative results. Based on the data collected for various system operating modes, arc-flash calculations should be performed for each possible case. Traditionally, when performing short circuit calculations to determine maximum short circuit current, extremely conservative estimates and assumptions are often used. This makes sense if the goal is to determine maximum breaker or equipment short circuit duties. However, for arc-flash risk assessment, using overly conservative short circuit data can yield non-conservative (low) arc-flash results since a higher fault current may produce a shorter arc duration (and therefore arc energy) due to the operation of inverse-time or instantaneous trip elements. The highest fault current does not necessarily produce the highest possible arc-flash hazard because the energy released during an arcing fault is a function of not just the arc current, but also the arc time. For arc-flash hazard determinations, short circuit calculations may be conservative, but should be as realistic as possible.

Calculate Bolted Fault Current

Calculate the 3-phase bolted fault current in symmetrical RMS amperes for all buses or equipment, and for the various operating modes identified. This bolted fault current becomes the starting point for calculation of the predicted arcing fault current. For any arc-flash calculation, EasyPower automatically calculates the bolted fault current as part of the arc-flash calculation process.

Short Circuit Ratings of Protective Devices

Once the one-line diagram and system model have been completed, it is recommended that an Equipment Duty calculation be done for all protective devices to determine that all devices have an adequate short circuit rating for calculated fault current. While this is not directly related to arc-flash calculations, any device that is underrated could potentially fail to interrupt an arcing fault as expected. In addition, underrated devices constitute potential safety and fire hazards. EasyPower's Smart Duty feature can quickly evaluate all protective devices and provide a report listing all underrated devices.

Step 5 – Determine Expected Arc Current

Calculate Arc Current

Bolted faults are based on a fault impedance of zero ohms. Because arcs have resistance that is not accounted for in the bolted fault calculation, the arcing current will generally be less than the bolted fault current. The selected calculation method includes equations that calculate the predicted arc current for all locations using one of the empirical formulas described in Chapter 3. The arc current is a function of the bolted fault current, the open circuit voltage, the type of enclosure, and the assumed arc gap between conductors and the electrode configuration, but the exact determination depends on the calculation method selected.

Consider Variability of Arcs and Arcing Current

Using the available data and equations, arcs are not fully deterministic events, meaning that the same test repeated multiple times will yield a range of results. The major impact of this is the effect on arc time, since the clearing time of the protective devices is generally inversely proportional to the current. For low voltage circuit breakers, as an example, a small decrease in the current can cause a large increase in clearing time if the current level moves from the instantaneous trip range of the device to the much slower long-time or thermal trip region. The lower the system voltage, the greater the variability in the arcing current that will occur.

To account for this variability, the IEEE 1584-2018 procedure requires two separate calculations: one at the arcing current predicted by the equations, and a second "reduced current" calculation. The case with the highest incident energy is used to determine the arc-flash hazard at that location. This is covered in greater detail in Chapter 3. This reduced current calculation is performed automatically by EasyPower if IEEE 1584-2018 equations are selected.

Total Arcing Current Versus Branch Arcing Current

The basic three-phase bolted fault calculation determines the total bus fault current at the bus or location being evaluated. The arcing current derived from this bus fault current is used to calculate the arc energy that is released during the fault. This arc energy also depends on one other key value: the arc time. This arc time is determined by the speed of operation of the upstream protective device. However, in many cases the fault current seen by this upstream protective device is not the same as the total bus fault current. Where multiple sources are present, each protective device may see a different current. Also, if motor contributions are present, these currents are not seen by the upstream protection.

To determine the arcing fault current through the various branches that are contributing fault current, EasyPower first determines the ratio of the total bus arcing fault current to the total bus bolted fault current. This ratio is then applied to the bolted branch fault current to calculate the individual branch arcing fault currents. To calculate the contributing branch arcing currents to the arc fault, use equation.

$$I_{x,arc} = I_{x,BF} * I_{arc} / I_{BF}$$

Where,

$I_{x,arc}$ = Current through branch x for arc fault

$I_{x,BF}$ = Current through branch x for bolted fault

I_{BF} = Bolted fault current

Arc currents have been observed to be non-sinusoidal due to the non-linear nature of the arc resistance. The harmonic contribution of different branches may vary, but the fundamental component can be approximated using the method describe above. It has been observed that although the voltage waveform is highly distorted, the arc current has low harmonic content. Therefore, the linear relation (4.1) is a reasonable approximation.

Step 6 – Determine the Arc Time

Along with the arcing current, the arc time is the second critical value that determines the energy released during an arcing fault. The incident energy is directly proportional to the arc time. It is also the factor that we have the most control over when considering various techniques for reducing arc-flash energy.

In most cases, the arc time is determined by using the time-current curve (TCC) of the upstream protective device that would clear the fault most quickly. For any specific value of arcing current, the arc time can be read directly from the TCCs of the upstream devices. EasyPower can determine the arc time automatically for overcurrent devices with TCCs defined in the EasyPower library. For these devices the manufacturer's TCC has been digitized and stored as part the device's library data. For protective devices that do not have some type of inverse time characteristic and no time-current curve, it is often possible to directly define the operating time. This is caller a User-Defined Time in EasyPower. Examples of devices where a user-defined time might be used include optical arc-flash detection relays and current differential relays. A user-defined time could also be used for protective devices that are not in the EasyPower library, but a time-current curve is available for determination of the arc time.

EasyPower's Protection & Coordination™ module automatically determines the arcing time for each protective device, operating condition, and arcing current level. Seamless integration with the arc-flash calculation module enables the immediate recalculation of arc-flash results when settings are changed.

Typically, time-current response curves for protective devices have tolerance bands or minimum and maximum operating times. In addition, for low voltage devices, the TCCs generally include the time required to fully clear the fault and reach zero current. Many low voltage breakers and fuses specify the upper and lower limits of the trip time for different current values. For such cases, the time-current curve looks like a thick band instead of a single line. Protective relays used at medium and high-voltage typically show only a single line for the TCC curve and specify an accuracy or tolerance in their product literature. Also the relay manufacturer has no control over the quality and accuracy of the current transformers that the relays are connected to. Another important consideration is that the protective relay curves do not include the opening and clearing time for the circuit breaker being tripped to clear the fault. To determine the arc time, the breaker opening time must be added to the relay operating time. EasyPower does this automatically. Some fuse curves provide only the average melting time or the minimum melting time. Follow the guidelines provided below for determining the trip time. In general, a worst-case or maximum clearing time must be used for the arc time.

- TCC with tolerance band: The arc time is based on the total clearing time (upper bound of the band) corresponding to the branch current seen by the device. For all TCCs with a tolerance band, the top or left-most (slowest) time must be used for the arc time to be conservative. This can have significant consequences if the calculated arcing current is within the instantaneous pickup band of a molded-case circuit breaker. In this situation, it must be assumed that the breaker will not trip (reliably) on instantaneous trip and the much slower thermal band clearing time must be used.

- Relays with a single line curve: Breaker opening time must be added to the time indicated by the relay TCC. EasyPower does this automatically for medium-voltage and high-voltage circuit breakers.

- Fuse TCC with total clearing time: No adjustment is required. This maximum clearing time is used directly as the arc time.

- Fuse TCC with average melting time: For cases where the fuse manufacturer provide only an "average melt time" curve, additional time must be added to this line to establish a conservative arc time. IEEE 1584 recommends adding 10% additional time plus 0.004 sec when only an average melt curve is available. This is done automatically by EasyPower.

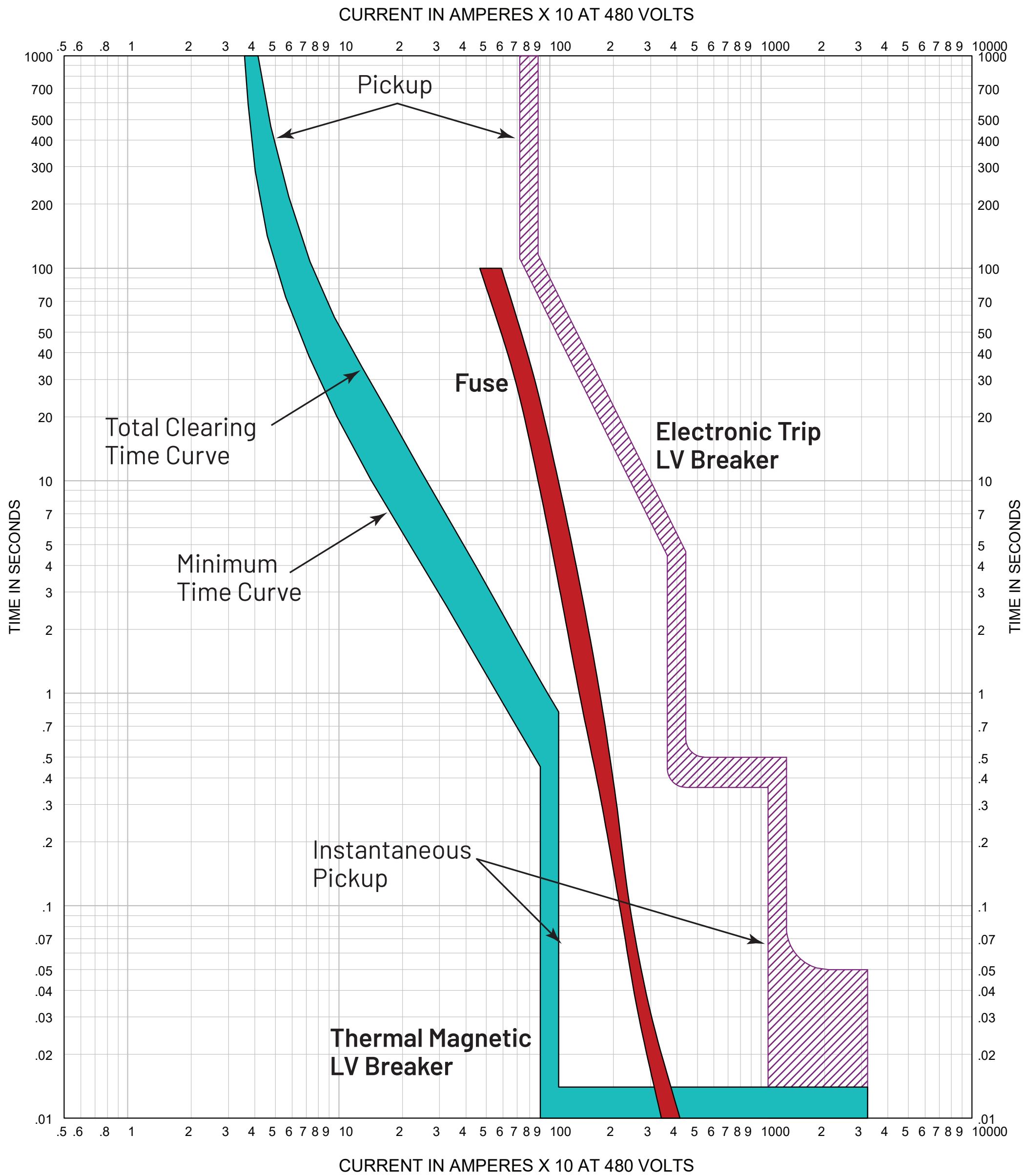


Figure 4.2: Example of TCC Plot with Tolerance Band

Evaluate Protective Device Performance

The arc time is determined by the time-current curve of the fastest upstream device. Since coordination in industrial and commercial power systems is generally time-based, then in a perfectly coordinated system, the fastest upstream device should be the protective device closest to the faulted equipment. However, fully selective systems are not always achievable for a variety of reasons. So, the fastest upstream device used to determine the arc time is not always the closest device. EasyPower evaluates the protective device upstream of the fault and always uses the fastest device to determine the arc time even if it not the closest device.

The determination of arc time described above is based on the assumption that all of the protective devices in the system, regardless of age, will operate in accordance with the manufacturer's published time-current curves. There is no allowance for the possibility of a device to fail to operate, although that can certainly happen in practice.

Both NFPA 70E and IEEE 1584 state that the person responsible for the arc-flash study must take into account the condition of maintenance of the protective device. If it appears that the device is damaged, non-functional, or shows any evidence of impending failure, then the time-current curve for this device should not be considered when calculating arc-flash energy levels downstream.

It is also important to realize that any changes to the protective device settings or sizes can have a major influence on the arc energy for downstream equipment. If device or setting changes are made, the arc-flash calculations should be re-checked, and appropriate changes made if necessary.

Equipment with Main Devices

Equipment with an integral main device (circuit breaker or fused switch) requires additional evaluation when determining the arc time. Unless the equipment is specifically arc-rated, it is possible that an arcing fault inside of the equipment could propagate to the line side of the main device. At this point, arcing would occur on the line side of the main device and the fault would have to be cleared by the next upstream device. For any equipment with an integral main breaker such as the panelboard shown in Figure 4.3, it is always conservative to base the arc-flash hazard calculation on a fault that occurs on the line side of the main device. In other words, the protective function of the main device is EXCLUDED from the arc time determination. In this situation, the fault will have to be cleared by a protective device upstream of the panelboard. In some cases however, the resulting line side calculation will be significantly higher than if the main breaker's time-current curve was used to determine the arc time.

The decision to include or exclude the main device from the arc time determination requires engineering judgment by the person responsible for the study. If the main device is included in the calculation (load side value), then there will be second calculation required to determine the arc time for faults on the line side of the main device if energized work is done on the main breaker section. In EasyPower, there are global settings regarding the inclusion or exclusion of the main device from the arc time determination. In addition, these global settings can be overridden for any individual piece of equipment.

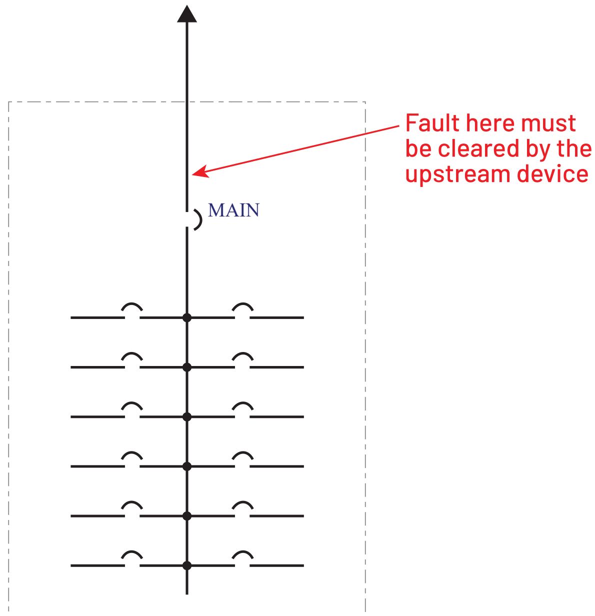
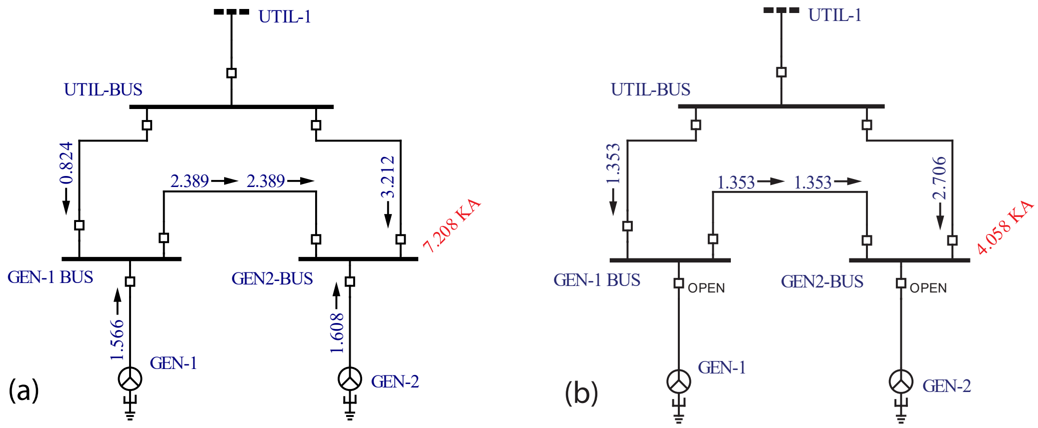


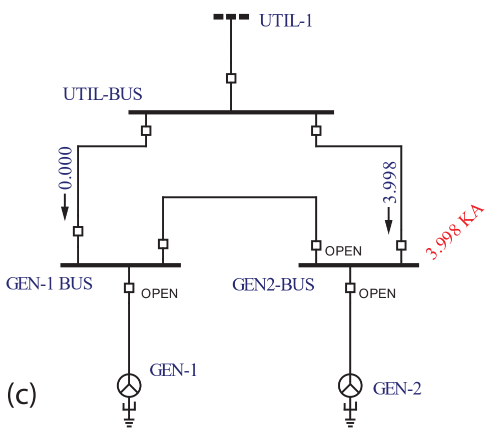
Figure 4.3: Faults on the Line Side of a Main Device

Trip Time for Multiple Sources

When a bus is fed from multiple sources, as shown in Figure 4.4, a fault at the bus may require more than one protective device to operate in order to fully clear the fault. The arcing current will decrease as the protective devices for the various sources operate, since the sources of power will be sequentially removed from the faulted bus. Since the current seen by the relays will change during the fault, further calculations are required to determine the actual trip time for each breaker. We cannot simply obtain the trip time corresponding to a single branch current by looking at the TCC data. Protective devices with time-overcurrent functions typically operate like an integrating device. This means, the overcurrent or its function is integrated or "added" over time until the sum reaches a predetermined trip value. This is when the relay trips. For details on how a relay or fuse integrates the function of current, refer to literature on the operation of protective devices. IEEE 1584-2018 states that for situations where the fault current changes during the fault multiple calculations may be required.

In EasyPower, this Integrated method is the default when doing calculations per IEEE 1584-2018. It automatically performs multiple calculations and 'integrates" the released energy during the fault based on the actual fault currents seen by each of the protective devices that respond to the fault. The older Momentary Current method is still available and will provide conservative results. The Integrated method will be more accurate but is still conservative in determining how the fault current varies during the fault.





Connection Status	Bolted Fault Current (kA) at 5 cycles
(a) All connected	7.208
(b) Generators disconnected	4.058
(c) Only one feed	3.998

Figure 4.4: Example Showing a Multiple Source Fed Bus Fault and the Series of Operations with the Fault Current Changing with the Breaker Operation

Step 7 – Calculate Predicted Incident Energy

At this point in the process, we are now able to calculate the incident energy. Chapter 3 covers the calculation methodology of IEEE 1584-2018 as well as other methods. Using the equations in IEEE 1584-2018, the incident energy is a function of the arcing current, arc time, the enclosure type, electrode configuration, electrode gap, and the distance from the arc (working distance). The new equations in IEEE 1584-2018 are quite complex, making hand calculations impractical. EasyPower automatically applies the appropriate equations and calculates the incident energy based on the calculation method selected. If using IEEE 1584-2018, two incident energy calculations must be performed to account for arcing current variability. As previously discussed, in addition to the incident energy at the predicted arcing current, a second reduced current calculation is performed, and the higher resulting incident energy is used for that equipment.

As noted earlier, it is normally necessary to consider various operating scenarios in order to find the maximum incident energy. Using these scenarios, the arc-flash incident energy calculation process described above is done for each scenario at every location and the maximum incident energy at each location is used. In EasyPower, this process is easily managed using Scenario Manager and the Scenario Comparison Report. A working distance must be assumed in order to calculate the incident energy. Therefore, any incident energy is only valid at one specific working distance. In the US, incident energy is generally expressed in calories per square centimeter (cal/cm^2). A more consistent set of units is Joules/cm^2 as used in IEEE 1584. In NFPA 70E, both values are given.

Step 8 – Determine the Arc-Flash Boundary

The arc-flash boundary (AFB) is the second value required by NFPA 70E as part of the Incident Energy Analysis Method. The arc-flash boundary is an approach limit from an arc source at which the incident energy equals 1.2 cal/cm^2 (5 J/cm^2). 1.2 cal/cm^2 (5 J/cm^2) is generally accepted as the level of heat energy that can cause the onset of a second degree burn on bare skin. The arc-flash boundary is a function of the energy released during the arcing fault and must be calculated for each location. The higher the arc-flash energy, the farther away the boundary will be. Per NFPA 70E, anyone closer to the likely source of an arc than the AFB must wear appropriate PPE when an arc-flash hazard exists.

When IEEE 1584-2018 is used, the determination of the arc-flash boundary is a function of multiple factors, including electrode configuration. The equations for calculation of the arc-flash boundary are independent of the incident energy calculation, so it is possible that if different electrode configurations are considered, the electrode configuration giving the maximum incident energy may not be the configuration that gives that greatest arc-flash boundary. EasyPower will always report back the maximum incident energy and the maximum AFB when multiple electrode configurations are considered.

Step 9 – Document the Arc-Flash Risk Assessment

NFPA 70E requires that the arc-flash risk assessment must be conducted and documented prior to any energized work. In most facilities this is ultimately done by means of an arc-flash hazard warning label that is applied to each piece of equipment. In addition, it is helpful to have a detailed text report showing the relevant data associated with the arc-flash calculation at each location, including the available short circuit current, arcing fault current, upstream trip device, arc time, and other information. This text report is invaluable in reviewing and troubleshooting arc-flash results as well as working on arc-flash mitigation. It may also be helpful to display the key arc-flash results directly on the one-line diagram.

EasyPower provides a detailed text report that documents the results of the arc-flash calculations as well as the key parameters that determine the arc-flash results. When it is necessary to evaluate multiple scenarios, EasyPower's Scenario Comparison Report will provide detailed results for each scenario evaluated. In addition, arc-flash labels as well as Energized Work Permits can be created directly from EasyPower.

In addition to simply documenting the results of the calculations and preparing the labels, an arc-flash study should include a report that provides background information, methodology, protective device data, and the source of the data used in the calculations.

Documenting the Arc-Flash Study

The following should generally be part of the documentation in the arc-flash study report:

- Qualified Person who conducted the study
- The date of assessment
- Scope of the study including any equipment not included in the evaluation.
- All data collected and used in the assessment, including protective device data and settings. Also include the dates when the data was collected.
- Any protective devices found to show evidence of impending failure or deemed to be non-functional
- Any required assumptions
- Calculation method
- Software, including the version that was used to perform the calculations.
- Utility fault data and the source of the data
- Operating scenarios that were evaluated
- Three-phase bolted fault current report
- Equipment Duty Report with discussion and recommendations for any equipment found to be underrated.
- Table of Arc-Flash Results, Incident Energy with Working Distance, and Arc-Flash Boundary for each piece of equipment in the scope of the study.
- If protective device changes are recommended, these need to be documented using tables and time-current curves.
- Any recommended changes to reduce or mitigate arc-flash hazards.
- In addition to the arc-flash text report, consider including a one-line diagram that displays arc-flash results.

Arc-Flash Labeling

Arc-flash labels are placed on equipment to provide warning of the potential arc-flash hazards present during energized or potentially energized work and to document the required PPE. Arc-flash labels should be located in a place that is easily visible and readable from some distance. Consistency in the format of the label and its location on the equipment helps in compliance with arc-flash PPE requirements. An example arc-flash label is shown in Figure 4.5. NFPA 70E-2021[3] Article 130.5 (H) covers the minimum requirements for arc-flash labeling. The following information is required on the label:

- Nominal system voltage.
- Arc-flash boundary.
- At least one of the following:
  - Available incident energy and the corresponding working distance, or arc-flash PPE category in Table 130.7(C)(15)(a) or Table 130.7(C)(15)(b) for the equipment, but not both.
  - Minimum arc rating of clothing.

Refer to Chapter 9, Arc Flash Labels: Printing & Labeling, for more detailed information on arc flash labeling.

Site-specific level of PPE.

NFPA 70E is not specific about details such as the size of the label, location and quantity of labels, or the use of "Warning" versus "Danger." Also, although it is common to include the shock risk assessment information on the label, as in Figure 4.5, this is not required on the label per NFPA 70E-2021. EasyPower provides many label templates to choose from and also allows full customization of the label information.

An exception in 130.5(H) also allows other forms of documentation to be used in lieu of labels in supervised industrial installations.

For equipment where a maintenance mode setting is being employed to reduce the incident energy and resulting PPE requirements, the labeling must clearly indicate this, or the label should give the worst-case arc-flash energy with the maintenance mode reduction covered in the Energized Work Permit.

One key final step in the arc-flash study is to ensure that the correct label is applied to each piece of equipment. To minimize errors, the naming of equipment on the one-line diagram should match the actual names shown on the equipment.

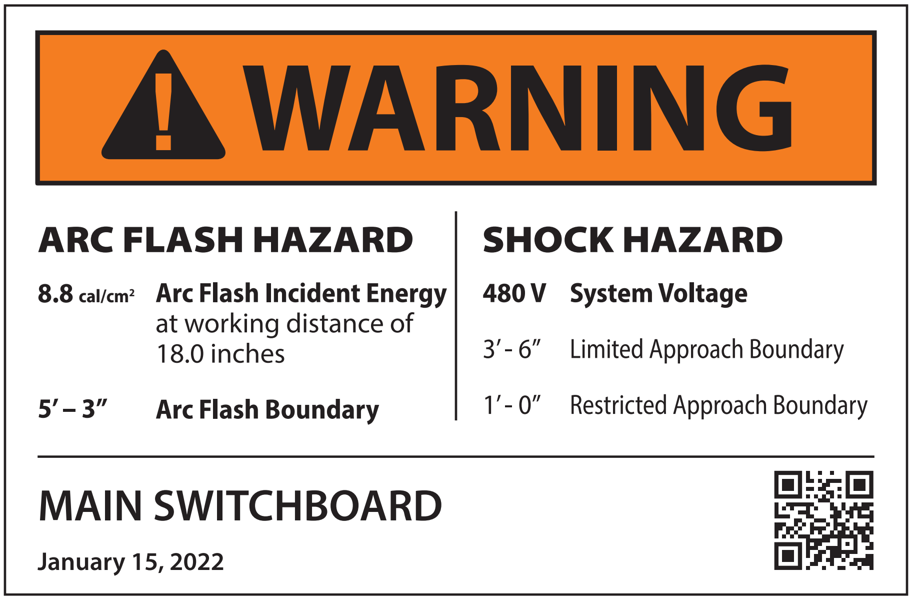


Figure 4.5: Example of an Arc –Flash Warning Label Created by EasyPower

Updating the Arc-Flash Study

NFPA 70E recognizes the need to periodically review the results of the arc-flash study for accuracy whenever system changes are made and at least once every 5 years but also states that labels do not have to be updated just because the label requirements in the standard change unless the actual system has changed. The one-line diagram should be kept up to date as changes are made and arc-flash results recalculated whenever equipment is changed out or upgraded.

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1. Conrad St. Pierre, A Practical Guide to Short-Circuit Calculations, Electrical Power Consultants, LLC, 2001.
2. William D. Stevenson, Jr., Elements of Power System Analysis, McGraw-Hill.
3. NFPA 70E, "Standard for Electrical Safety in the Workplace," 2021 Edition.

Reducing Arc Flash Risks

CHAPTER 05

The occurrence of arc-flash incidents can be reduced through adequate training, proper procedures, use of appropriate tools, and good preventive maintenance. In NFPA 70E®, Article 110.5 discusses the requirements for a comprehensive Electrical Safety Program for each facility. This comprehensive coordination of work, as well as skill development and practical experience, are critical to safer electrical work. In addition to PPE and other requirements, the mental and physical conditions of the workers is also an important consideration. Informative Annex Q – Human Performance and Workplace Electrical Safety discusses the human factors that contribute to electrical accidents and how to reduce the associated risks. Taking care of the causes of arc flash is the principal strategy for avoiding exposure

Avoiding Arc-Flash Incidents

Arc-flash incidents can be avoided by understanding their causes and taking steps to reduce the risk of initiating an arcing fault. The various causes of arc flash discussed in Chapter 1 are summarized below and the mitigation measures are described in this chapter. This book is not intended to provide complete safety information and training requirements related to your electrical safety program.

An arc-flash risk assessment procedure requires that hazards are identified, risks are assessed, and risk control is implemented based on the hierarchy of risk control methods described in Informative Annex F of NFPA-70E.

An example of the hierarchy of methods in order of effectiveness is shown in Figure 5.1:

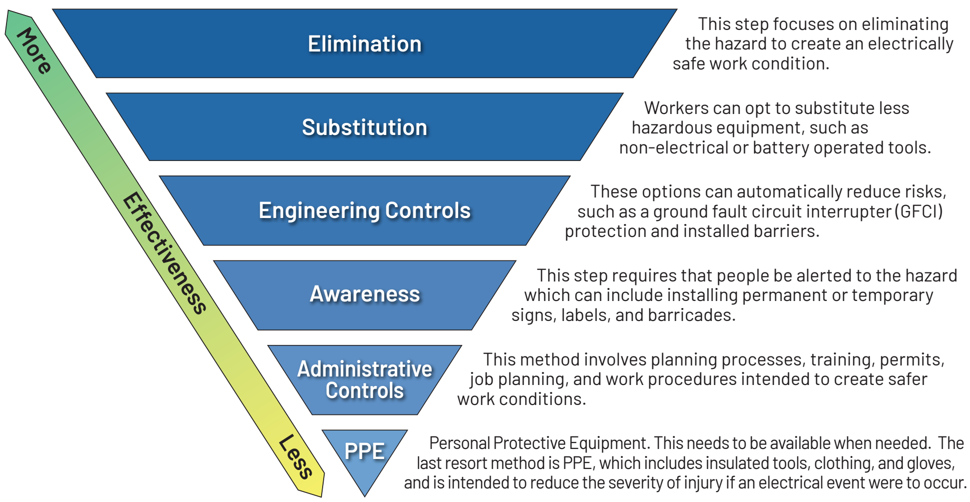


Figure 5.1: A Hierarchy of Effectiveness in Risk Control Methods

Preventive Electrical Maintenance

Preventive electrical maintenance practices are employed in most companies that require high reliability and safety on their electrical power supply and for process continuity. Preventive maintenance also provides for a safer workplace. Consider improving maintenance procedures for inspections, performing preventive maintenance, or performing breakdown maintenance, by including procedures that address the arc-flash hazards. This can reduce the overall cost of implementing an arc-flash program and your electrical safety program. Also see NFPA 70B Recommended Practice for Electrical Equipment Maintenance for reference.

The following list summarizes some of the common causes of arc-flash incidents and suggests mitigation measures that could be used.

- Dust, impurities, and corrosion at contact surfaces that produce heat, loosen contacts, and create sparks.

- Sparks produced during the racking of breakers, replacement of fuses, or when breakers or fuses close into faulted lines.
- Failure of insulating materials.
- Snapping of leads at connections due to force—human, rodents, or birds.
- Accidental touching and dropping of tools, nuts or bolts, or metal parts.
- Rodents and birds entering panels and switchgear are common initiators of arcing faults. These can lead to short circuits that often result in arc flash. This risk can be reduced by closing all open areas of equipment with wire net or sealant so that rodents and birds cannot enter.
- Corrosion can lead to the snapping of small wires, which in turn may create sparks and fumes when the tip of the wire hits the metal enclosure or another phase conductor. Check for corroded terminals and parts regularly if the electrical equipment is located in harsh environments. Use corrosion-resistant terminals.
- Heating of cable insulation can damage the insulation—another cause of flashover. Check for loose connections and overheated terminals. Infra-red thermography and ultrasonic inspections can provide valuable data on poor connections and overheated electrical conductors or terminations.
- Insulate exposed energized parts to the extent feasible. Insulation prevents arcing. For example, if a worker drops an uninsulated wrench that touches the bare bus bars of two phases, a short circuit will occur. However, this does not happen if the wrench or the bus bar is insulated.
- Perform acceptance and maintenance testing of relays and breakers to verify proper operation. Arc-flash incident energy calculations are based on the proper operation of the upstream protective device. If this upstream device should fail to operate properly, the arc energy released during an arcing fault could be many times the calculated value. The frequency of testing varies depending on the type of equipment, service conditions, and equipment age. Consult the NETA recommendations and the manufacturers' recommendations to develop a testing schedule. Also review NFPA-70B – Recommended Practice for Electrical Equipment Maintenance. Verify that all protective devices are being operated within their short circuit ratings. If a circuit breaker or fuse is subject to more fault current than it is rated to interrupt, it cannot be relied upon to safely clear a downstream fault. In addition, the device itself could fail and create an arcing fault when attempting to clear a high magnitude fault.
- Pitting of contacts can occur when breakers and fuses are operated. For devices with visible contacts, replace contacts when pitting is noticed.

- When a protective device trips or a fuse melts, make sure that the cause of the fault has been found and cleared before re-energizing the circuit. While it is common practice to try to immediately re-energize a circuit after a fault since many trips are "nuisance" trips, this is a potentially dangerous practice that should be discouraged. Closing back into a fault can produce an arc flash and equipment damage.
- Check for water, excessive moisture, or ice on insulating surfaces of equipment. This may cause flashover, especially on high-voltage equipment.

Working on Energized Equipment

It is ALWAYS preferable to work on de-energized equipment and this is the basic requirement of NFPA 70E®. When work on energized equipment is infeasible because of equipment design or operational limitations then justification and written authorization is required in the form of an Energized Electrical Work Permit as per the requirements of NFPA-70E.

Use approved insulated tools. A dropped tool can cause momentary faults, sparks, and arcs. Insulated tools help reduce the risk of this type of incident.

Even when equipment is de-energized for maintenance, it is important to follow the correct procedures as outlined in NFPA-70E to establish an electrically safe work condition. This requires that a voltage test be performed to verify the absence of voltage and, when required, installation of suitably rated temporary grounding. These activities require appropriate arc-rated PPE. Refer to NFPA-70E for more details on voltage testing and establishing an electrically safe work condition.

Do not use paint, cleaning chemicals, spray, etc., on energized exposed metal parts. The fumes or spray may be conductive, and it may reduce the insulating property of air and allow an arc to strike through. Spraying directly onto an energized conductor can also provide a conducting path that results in electric shock or arc flash.

Reducing Incident Energy

The incident energy exposure can be reduced by system design or operating procedures. Possible methods to reduce the incident energy on an existing system include:

- Reducing the fault current magnitude
- Reducing the arc time
- Remote operation of circuit breakers
- Remote racking of circuit breakers

Reducing the Fault Current Magnitude

Reducing the available fault current decreases the arcing current, assuming that the arc time does not increase. In existing systems, reducing the fault current magnitude is generally difficult, since it is a function of the system itself—mainly the size of the transformers. Some options for reducing the magnitude of arcing current could include:

- Modifying the system configuration to reduce available fault current such as through the use of smaller kVA transformers and eliminating parallel operation of transformers on double-ended substations.
- Application of current-limiting fuses and breakers
- Use of current-limiting reactors or resistors

See NFPA-70E Informative Annex O – Safety-Related Design Requirements for more information.

System Configuration

For any location in an industrial system, the fault current magnitude is most greatly influenced by the capacity and impedance of the upstream transformer. Reducing the kVA rating of a transformer directly reduces the maximum possible downstream fault current. This reduction of fault current can lead to a reduced arc-flash level provided the fault clearing time does not increase significantly. A point may be reached where further reduction in transformer size will actually cause an increase in incident energy downstream due to increased fault clearing times.

Double-ended substations (Main-Tie-Main configurations) with a normally closed tie (Figure 5.2) are a prime example where the fault level can be reduced by either opening the tie or one incoming breaker. The fault current will be reduced by approximately 50% and the incident fault energy will also be reduced, although not necessarily in the same proportion. If the bus has two sources, or a source and a normally closed tie as shown in Figure 5.3, opening one of the sources (or tie) will reduce the fault level while maintenance is done on the equipment. *For both situations, the loading and relay setting should be checked to make sure that the opening of a breaker does not overload the other source.*

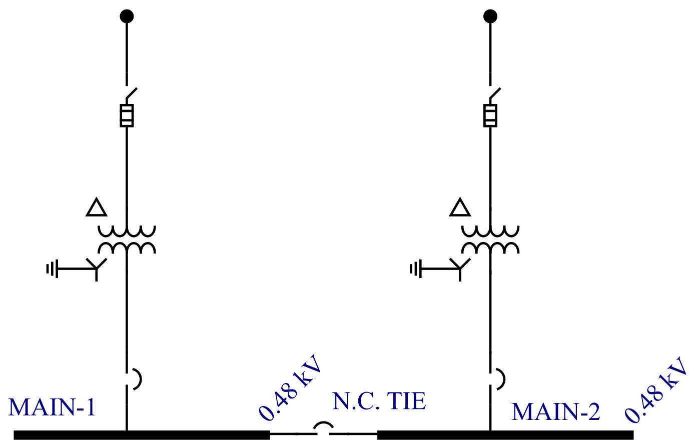


Figure 5.2: Double-End Load Center Configuration

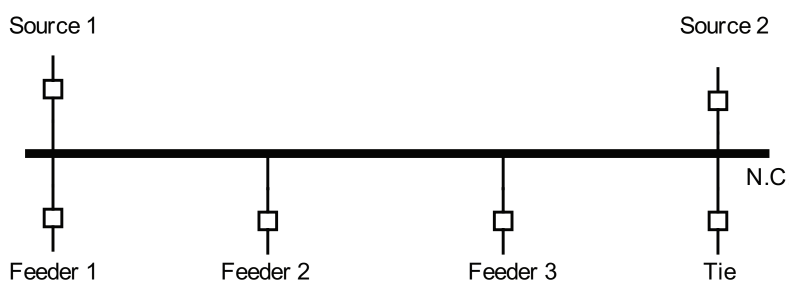


Figure 5.3: Dual Sources

Current-Limiting Fuses and Breakers

Current-limiting fuses and breakers can reduce the maximum "let-through" current for fault current that is in the current-limiting range of the fuse. A fuse is considered to be current-limiting if it reduces the magnitude of the first current peak and clears the fault within ½ cycle. In addition to limiting the maximum fault current in this case, the fuses clear the fault extremely rapidly resulting in low arc-flash incident energy downstream of the fuse. However, if the available fault current is such that the fuse is below the current-limiting range of the fuse, then the fuse does not provide any reduction in arc-flash incident energy when compared to a molded case circuit breaker that clears the fault in a similar amount of time. Special current-limiting circuit breakers are also available and function in a similar manner to current-limiting fuses. The short circuit and protective device coordination studies and analysis as provided by EasyPower can greatly assist with these safety and cost-saving mitigation strategies.

Current-Limiting Reactors

Current-limiting reactors introduce additional impedance in the system and are used to limit the fault current. This not only reduces damages caused by faults but also allows the use of circuit breakers with lower interrupting ratings. Limiting the fault current can also increase the fault clearing time if the fault current happens to lie in the inverse time delay characteristics of the protective relays. Therefore, protective device coordination analysis is also required when selecting current-limiting reactors. Because current-limiting reactors are always in the circuit there is a limit to the amount of impedance that is practical. In general, current-limiting reactors are used primarily to reduce the available fault current to a level that the downstream circuit breaker can interrupt and are not specifically for arc-flash reduction.

Reducing Arcing Time

For existing systems, reducing the duration of an arc is the most practical method of reducing the incident energy. The arc time is a function of the time-current characteristics of the upstream device that must clear the fault. Arc time can be reduced in several ways. Some changes in the system settings may be required for this purpose. There also may be compromises required with the system coordination to achieve the reduced arc time. The following techniques are discussed in this chapter.

- Perform or update a protective device coordination study to reduce protective device operating times.
- Implement maintenance mode settings for low voltage breakers and protective relays.
- Implement Zone Selective Interlocking for low voltage switchgear.
- Implement “Fast Bus Tripping” schemes for medium voltage switchgear.
- Use of fast acting bus and transformer differential protection to combine selectivity with instantaneous operation.
- Retrofit time-overcurrent relays with a delayed instantaneous trip (definite-time) element if needed.
- Use of optical sensors to rapidly clear faults in the event of arc flash within an equipment enclosure.
- Installation of remote feeder breakers to reduce arc-flash levels for group-mounted low voltage switchboards and panelboards.

Perform a Protective Device Coordination Study

Many industrial and commercial power systems have never had a comprehensive protective device coordination study and even where studies have been done, arc-flash levels may not have been a concern at the time the coordination study was performed. Incident energy is primarily a function of the arc current magnitude and the arc duration. When coordinating inverse time type devices such as overcurrent relays, circuit breakers and fuses, selectivity is achieved by making each upstream device slower than all of the downstream devices that it must coordinate with. While this slower operation may provide adequate equipment protection, it results in longer arc times and higher arc energy. Coordination of overcurrent devices is generally a compromise between protection (fast operation) and selectivity (slower operation), and these two goals are normally directly in conflict. In the past, coordination settings were based on equipment protection boundaries and arc-flash levels were not a consideration. Often, significant reduction in incident energy is possible without sacrificing coordination by simply lowering the device settings. To maintain selectivity between two overcurrent relays in series, it is necessary to allow a safety margin between the two time-current curves to account for the breaker opening time, CT error, and other sources of error. This safety factor is referred to as the Coordination Time Interval or CTI. Traditionally, when coordinating between two electromechanical overcurrent relays, a CTI of 0.3 to 0.4 sec was used. This was based on the accuracy and operating characteristics of electro-mechanical induction disk overcurrent relays. With modern digital relays, this CTI can be reduced to the range of 0.2 to 0.25 seconds. This reduction can significantly reduce the incident energy levels. Replacement of electromechanical overcurrent relays with modern digital relays offers many advantages including the possibility of lowering the related incident energy levels.

Maintenance Mode Settings

As discussed in the previous section, to achieve selectivity, inverse time overcurrent devices must be coordinated so that upstream devices are slower than downstream devices. For main buses in switchgear, this means that the overcurrent device that is protecting the main bus should be slower than all of the downstream devices that it is expected to coordinate with. This can result in very long clearing times for a fault on the main bus, and this in turn results in high incident energy, exceeding 40 cal/cm^2 in many cases. One approach to reducing these high arc-flash energy levels is to speed up the upstream device only when work is being done on the equipment. This is typically referred to as a “maintenance mode” switch setting and is manually initiated prior to any maintenance or inspection activity near the equipment. In maintenance mode, a low-pickup instantaneous trip function is used to provide for sensitive high-speed fault clearing for any fault that may occur. This can reduce the incident energy level significantly. The trade-off is that while the device is set to the maintenance mode, it will no longer coordinate with downstream protective devices and any fault downstream can result in a wider outage than is necessary. While use of a properly installed and tested maintenance mode setting can provide significant arc-flash reduction, it suffers from three major weaknesses:

- Lack of coordination while in maintenance mode.
- Requires the correct manual initiation of maintenance mode.
- Require manual switching off of maintenance mode after the work is completed.

The main advantage of the maintenance mode approach is that it is usually the least costly technique to implement in most cases, especially for existing systems.

For low voltage power circuit breakers and larger molded case circuit breakers with digital trips, a maintenance mode option will be available. When set to maintenance mode, a low-pickup instantaneous trip function is added to the normal device functions. Per the National Electrical Code, any new protective device that does not have an instantaneous trip function in normal service must be provided with a maintenance mode setting option. For older trip units lacking this feature, new trip units from a variety of manufacturers can be retrofit to the existing circuit breakers.

For medium voltage equipment, most modern digital relays can be programmed and configured to provide for a maintenance mode setting that is manually set using a front panel pushbutton or a separate selector switch using a discrete input. As with the low voltage devices, the maintenance mode setting enables a sensitive instantaneous trip element (ANSI Device Function Code 50) that provides for rapid clearing of a downstream fault while in maintenance mode. Unlike the low voltage breaker trip units, this maintenance mode function generally must be specially programmed and configured in the relay.

For any type of maintenance mode setting, it is important that the worker is provided positive feedback that the trip unit or relay is definitely in maintenance mode. This can be done using an LED on the device or a custom LCD message.

The final consideration regarding use of the maintenance mode is how the protected equipment should be labeled for arc-flash hazard. Normally, the incident energy level on an arc-flash label is based on the worst-case situation that can be reasonably expected. Since the maintenance mode must be manually initiated, it is probably reasonable to assume that a worker might not remember to place the device in maintenance mode, especially if contractors are working on site. In this case, the label should reflect the incident energy based on the normal system conditions with the maintenance mode switched OFF. The Energized Electrical Work Permit (EEWP) could be used to specify the use of the maintenance mode setting and then reflect the lower incident energy level on this specific Work Permit. **If a decision is made to base the arc-flash label data on the maintenance mode being switched ON, it is imperative that this be clearly indicated on the arc-flash label.**

For low voltage trip units and relays defined in the EasyPower library as having maintenance mode options, EasyPower provides a convenient method for switching any device into maintenance mode to assess the impact on the downstream arc-flash energy.

The time-current curves below show the impact of implementing a maintenance mode setting for a transformer primary protection relay:

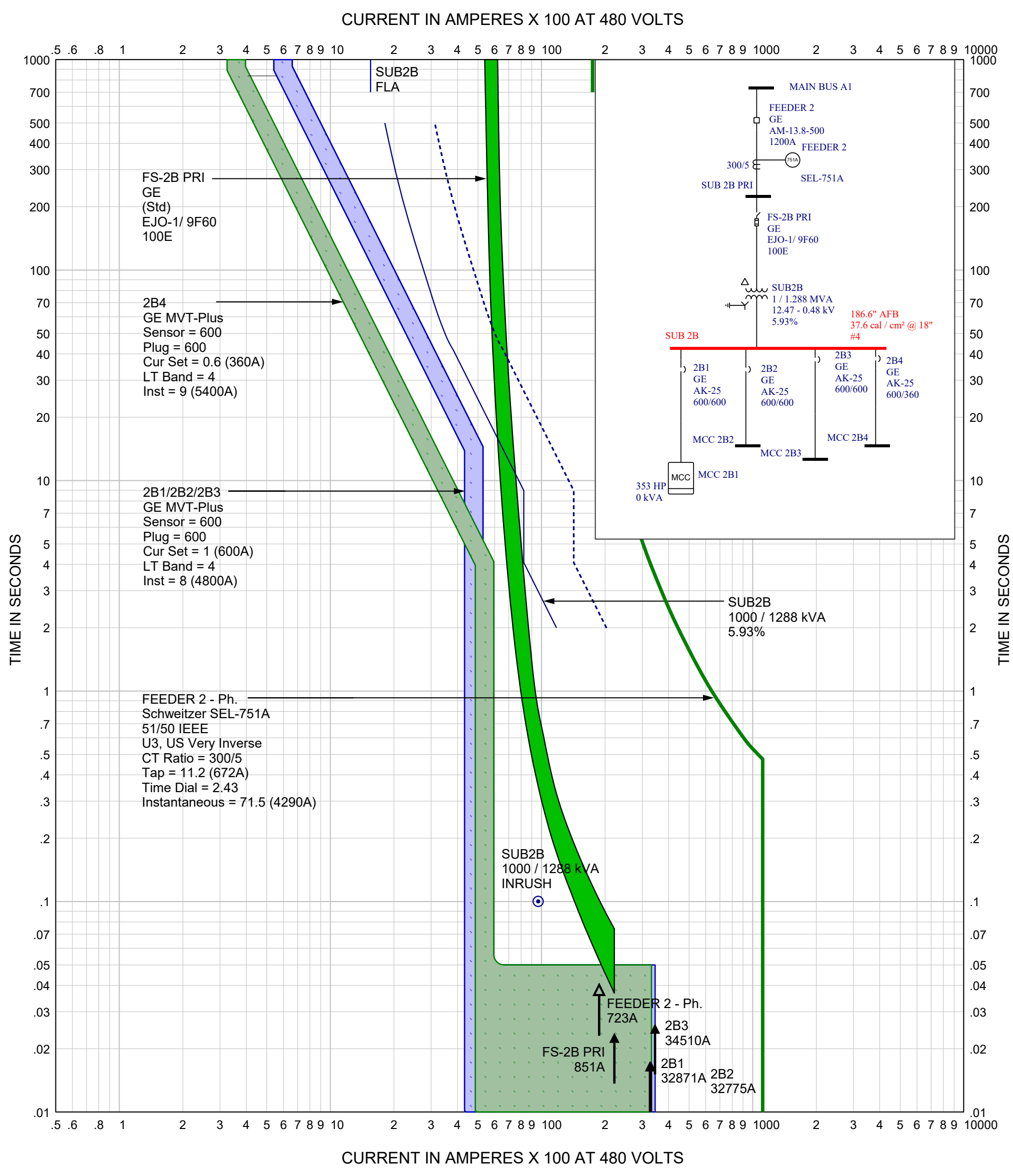


Figure 5.4: Feeder 2 Relay Normal Settings – Arc-Flash at Sub 2B Bus – 37.4 cal/cm²

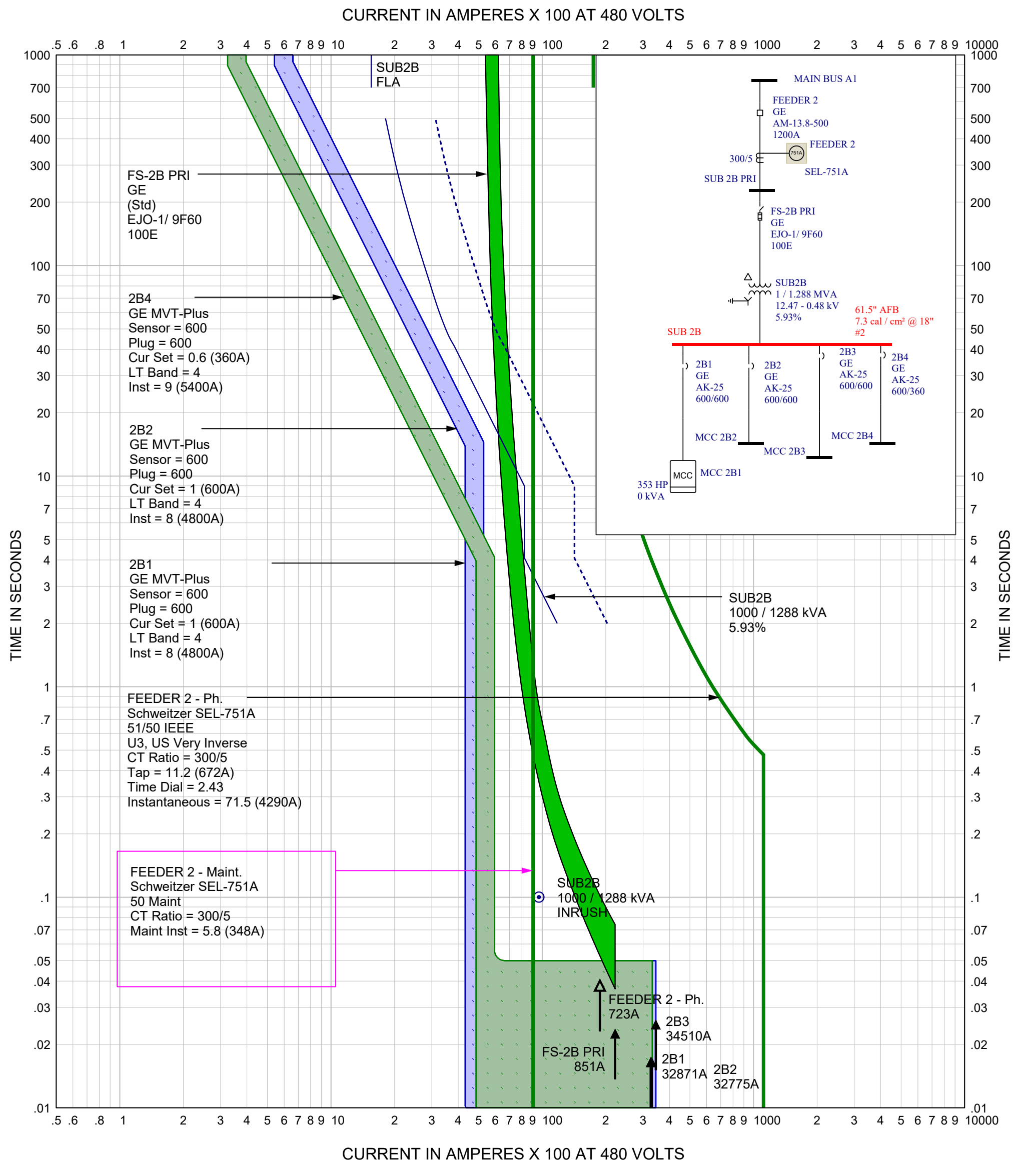


Figure 5.5: Feeder 2 Relay in Maintenance Mode – Arc-Flash at Sub 2B – 7.3 cal/cm²

Zone Selective Interlocking (ZSI)

For low voltage power circuit breakers, it has long been an option to provide a signaling system between downstream and upstream trip units to decrease fault clearing time for bus faults that must be cleared by the main breaker. This system is called "Zone Selective Interlocking" or ZSI. To be selective with the downstream feeder breakers, the main and tie breakers must be set slower than the slowest feeder breaker for normal operation. This can result in relatively long clearing times and this translates to high incident energy levels for bus faults. A ZSI system provides a communications path between the feeder breakers and the main (and tie) breakers so that the upstream trip unit receives a "restraining signal" indicating that a downstream trip device has also detected the fault. When the upstream device receives this restraining signal, it operates on its normal (slow) time-current curve that coordinates with the downstream devices. However, if the fault is on the main bus, none of the feeder breaker trip units will detect this fault and no restraining signal will be received by the main breaker trip unit. If no restraining signal is received, the main trip unit will operate on a very fast Short-Time trip function with the minimal time delay required to allow the signal processing to occur (generally 1 to 2 cycles). This faster tripping time results in significantly lower arc-flash levels for faults occurring on the main bus. Arc-flash levels will be comparable to what can be achieved through the use of a maintenance mode switch, but with a ZSI system, the system is always in service, so no operator action is required to switch it on or off. In addition, the ZSI system provides full selectivity, unlike the maintenance mode.

ZSI is limited to low voltage power circuit breakers trip units and cannot be applied to molded case circuit breakers. For medium-voltage systems, an approach similar to ZSI can be used. It is referred to as Fast Bus Tripping and is described in the next section.

EasyPower provides built-in support for ZSI systems provided the trip unit is properly defined in the EasyPower library. When the ZSI system is properly defined and enabled in EasyPower, the program correctly calculates the downstream arc-flash based on the operation of the restraining signal.

In the example system shown below, the main breaker and the two feeder breakers are equipped with Zone Selective Interlocking (ZSI). For a fault on the Main Switchboard bus, the main breaker does not receive a restraining signal from either of the feeder breakers and therefore operates on its "fast" unrestrained time current curve. This results in much faster fault clearing and greatly reduced arc incident energy. Unlike the maintenance mode approach, ZSI is fully automatic and provides complete selectivity at all times between the main breaker and the feeder breakers.

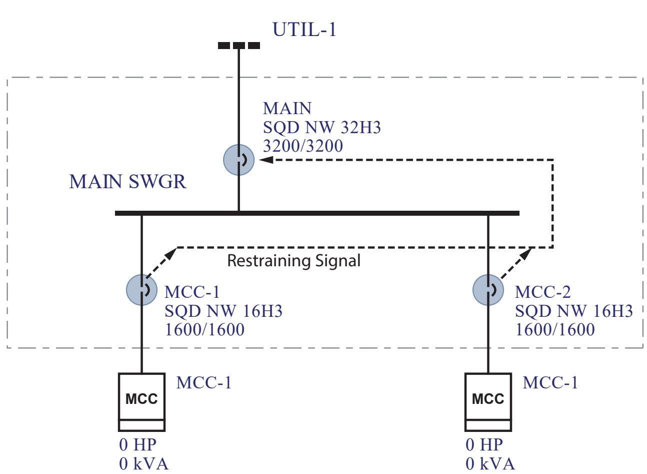


Figure 5.6: Zone Selective Interlocking

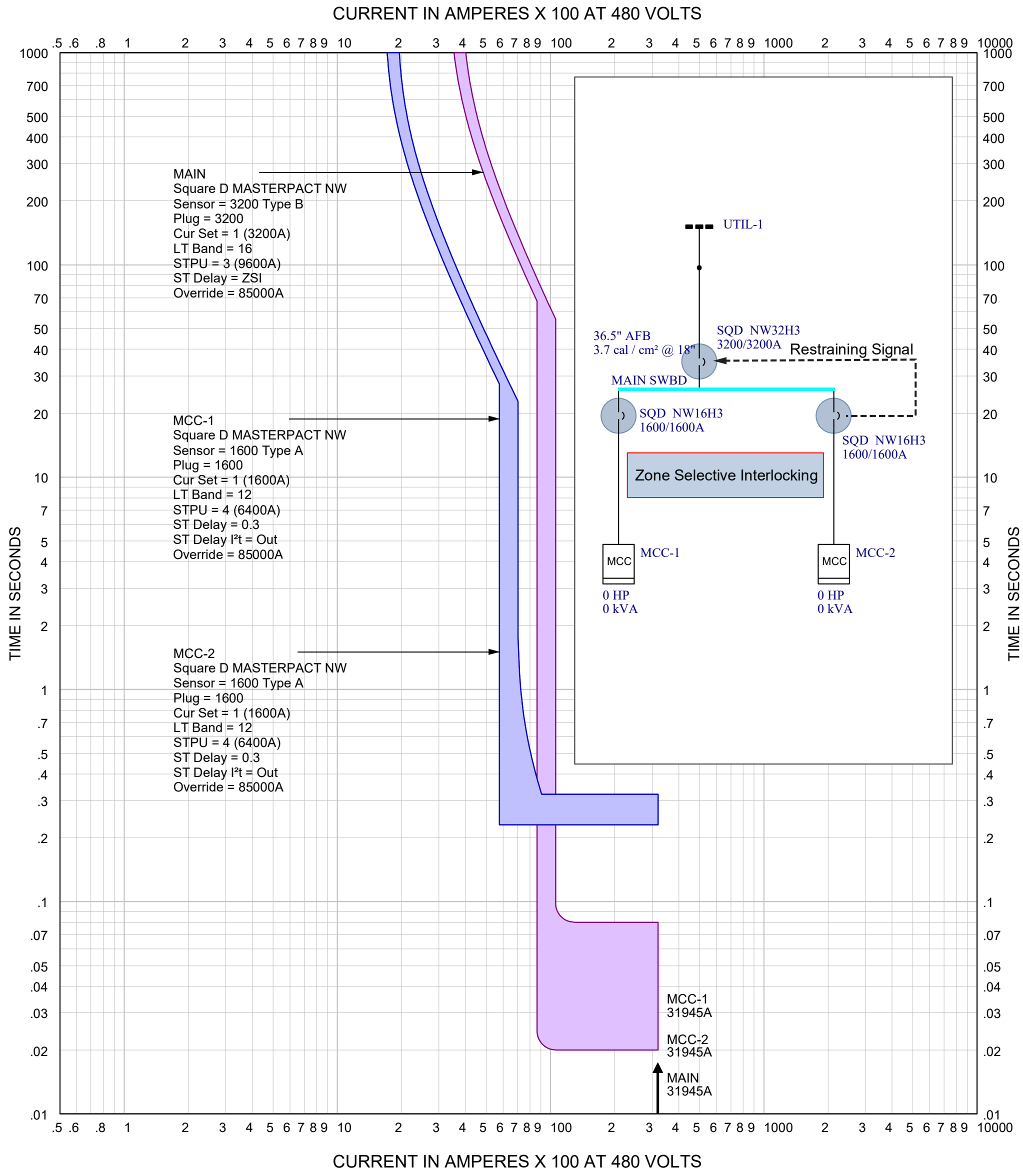


Figure 5.7: ZSI Time Current Curves

Fast Bus Tripping

The same concept described above for low voltage power circuit breakers can also be applied to overcurrent relays used for the protection of medium and high voltage systems. This is generally referred to as "Fast Bus Tripping." It is relatively easy to implement if digital relays are used. For this method to be effective, it must be applied to all sources and feeders on the bus. Using digital relays, normally open output contacts from every feeder relay are connected to a discrete input on the main breaker relay. The output contacts are configured (as part of the relay programming) to close whenever any overcurrent element picks up. As with the ZSI system, this acts as a restraining signal to the upstream relay and causes it to operate on its normal "slow" response curve to allow the downstream relay time to clear the fault. If none of the downstream relays detect the fault, then a low-set instantaneous trip function with a very short time delay (approximately 1 cycle) in the main breaker relay quickly clears the fault.

Fast bus tripping can be fairly easily retrofit into existing switchgear and provide nearly as much arc-flash reduction as the bus differential relaying described below.

Differential Relaying

Differential relaying works on a fundamentally different concept than standard overcurrent relaying. As shown in Figure 5.8 below, a differential relay monitors the sum of all current entering and leaving a bus in each phase. Under normal operating conditions, the sum of all of the currents entering a bus should be zero. If the sum of these currents is not zero, or very close to it, it indicates current is going somewhere it should not be—a fault condition. Note that if the differential relay detects a fault condition, the fault must be within the zone defined by the location of the current transformers. This is known as the differential zone. For a bus differential fault, there is no need to wait on some other downstream device to operate, as is the case with overcurrent relaying. The relay can operate extremely quickly, typically within a cycle, to issue a trip signal to the lockout relay which in turn trips all the breakers within the differential zone.

Differential relaying can also be applied to other critical equipment and systems such as transformers, generators and large motors. The original impetus for differential relaying was improved equipment protection and reduced damage, but it also provides for significantly reduced arc-flash energy levels due to the high-speed fault clearing it achieves. Also, it can be designed to incorporate the source (main) breakers in the differential zone of protection. This solves one of the thornier issues in arc-flash reduction since the main breaker cubicle in a metal-clad switchgear lineup often has very high incident energy levels. However, this does require that there is a circuit breaker upstream of the main breaker that can be tripped by the bus differential lockout.

The major downside to bus differential relaying is that it is difficult to retrofit into existing switchgear. The traditional high-impedance bus differential relay requires dedicated and matched current transformers for each breaker position. However, for new installations, bus differential protection is highly recommended. Unlike some other newer approaches to arc-flash energy reduction, differential relaying is a proven concept that has been successfully used for many decades.

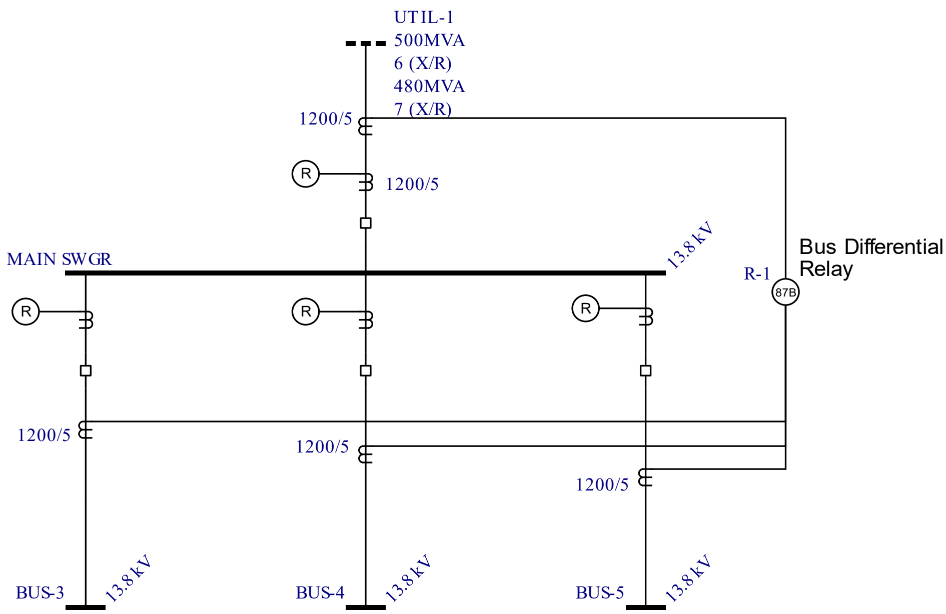


Figure 5.8: Typical Bus Differential Relaying System

Upgrade Relays and Settings for Unit Substation Transformer Primary Protection

For larger industrial facilities that take service at medium voltage, unit substations provided power transformation to a lower voltage (480 or 600 V) and distribution switchgear. For the low voltage main breaker (or for the entire low voltage bus if no main breaker is present), arc-flash energy is generally higher than desired since a fault in this portion of the system must be cleared by the transformer primary protection. Assuming there is an upstream medium voltage breaker that can be tripped, arc-flash levels on the low side can often be made safer by upgrading the overcurrent relaying on the primary side and implementing a protection scheme more focused on reducing arc-flash through faster clearing times.

Figure 5.9 below shows a typical relay curve for transformer primary protection. This extremely inverse curve provides reasonable transformer protection and coordinates with the downstream 480 V main breaker. However, for faults in the 480 V main breaker section, the clearing time will be quite long.

By adding a "definite time" function in addition to the inverse time function, the relay curve can be made to much more closely match the 480 V main breaker trip unit TCC and provide much faster tripping for a 480 V fault. Figure 5.10 shows the revised TCC. Arc-flash incident energy at the main breaker has been reduced from 98 cal/cm^2 to 22 cal/ cm^2 by the addition of the definite time overcurrent function to the primary relay.

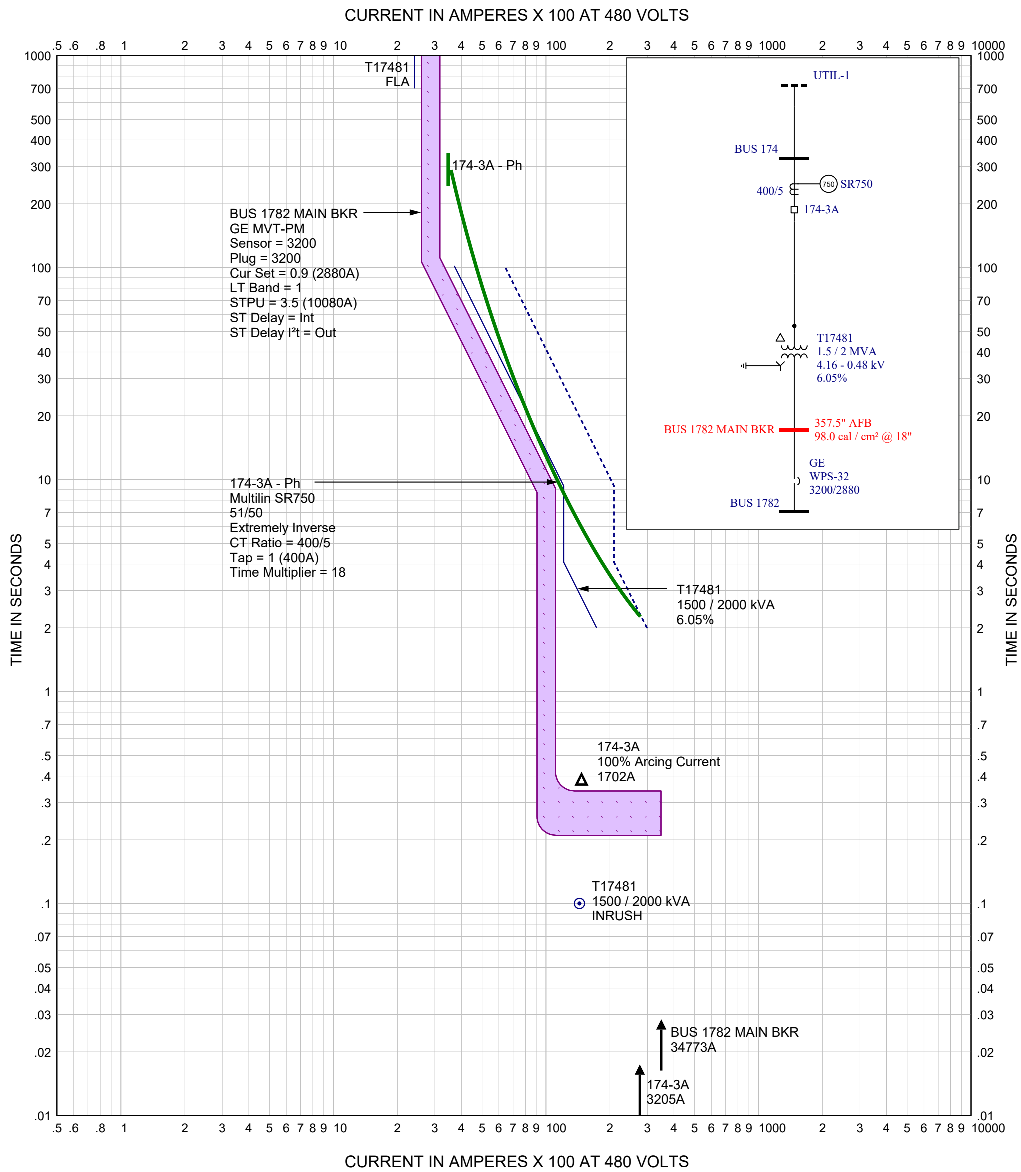


Figure 5.9: Typical Time Overcurrent Curve for a Transformer Primary Relay

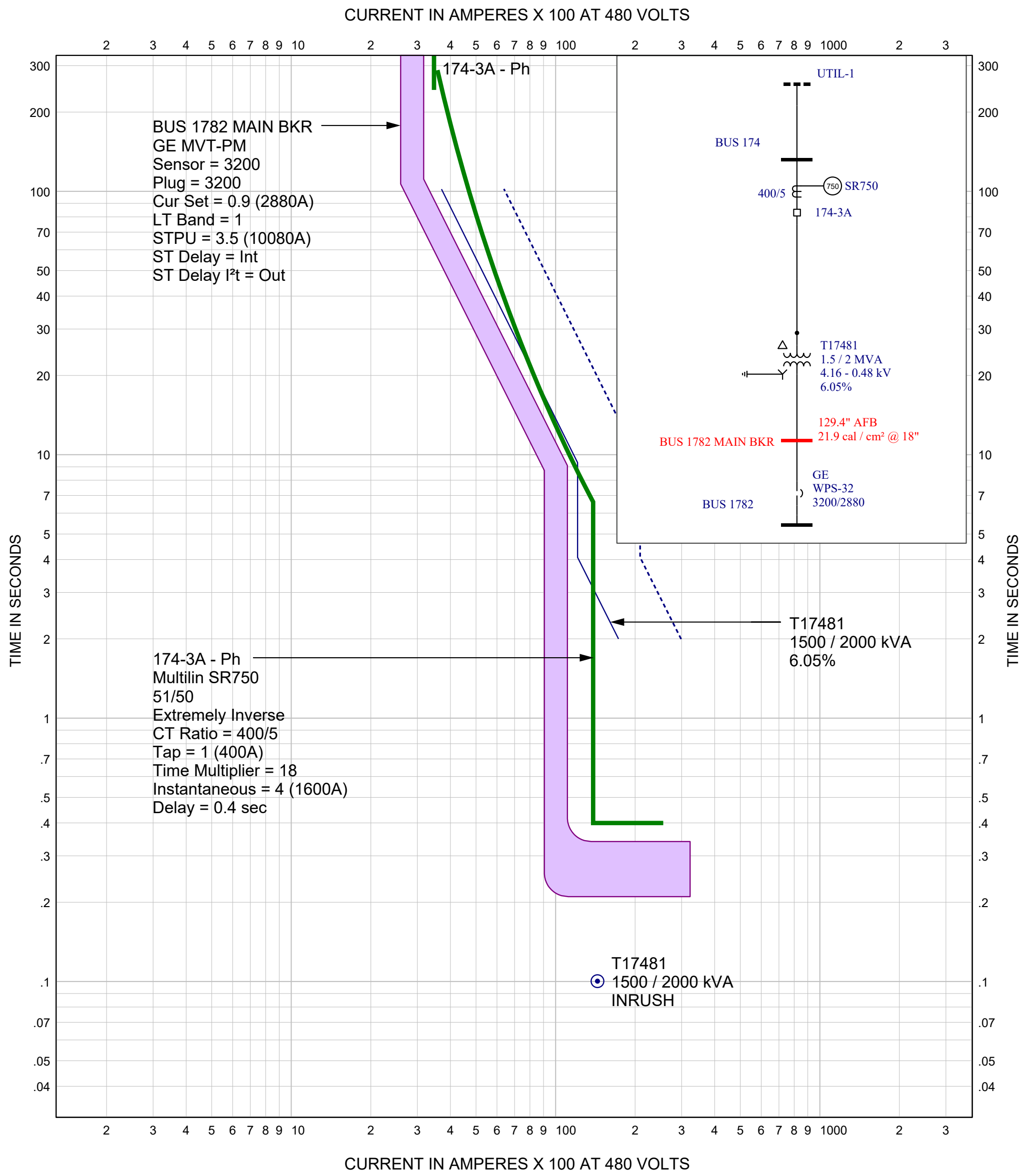


Figure 5.10: Typical Time Overcurrent Curve for a Transformer Primary Relay (Revised)

Install Optical Arc Detection Relays

ABB, SEL, and others offer an arc-flash detection system using light sensing fiber optic cable or individual optical sensors installed inside of the equipment to be protected. The sensor detects the flash of light when an arc occurs and the arc detection relay output contact trips the upstream circuit breakers. Per the manufacturer's data, the response time for these systems is in the range of ¼ to ½ cycle. This puts this system on par with differential relays for the speed of operation. For new equipment, the sensors should be laid out and installed by the equipment manufacturer to ensure reliable operation. In addition to the light sensors, current transformer inputs are required to supervise the optical sensing. This is to avoid nuisance tripping due to stray light entering the equipment enclosure.

Install Remote Circuit Breakers or Fuses to Improve Main Breaker and Bus Arc-flash Levels

In many cases, arc-flash levels at main switchgear, service entrance panels and their associated main breakers will be quite high because fault clearing depends on the operation of a primary fuse or relay. Often, the incident energy at the main switchboard may exceed 40 cal/cm². In these situations, owners may determine it is not safe to allow any operation of circuit breakers or switches in the main equipment while it is energized. To mitigate this situation, a separate circuit breaker or fused switch can be installed upstream of the main switchboard. This device protects anyone working on the main equipment but is remote so that it can be included in the arc time determination since there is minimal risk of arc propagation in this situation. Of course, the incident energy at this new remote device will also be very high, but this approach would provide a lower energy level at the main switchboard and allow operation of the breakers and switches in the main board. Operation of this remote breaker would not commonly be required for normal maintenance activities.

Remote Breaker Operation and Breaker Racking

Placing distance between energized parts and the worker can significantly reduce the arc incident energy. New high voltage equipment can be ordered with the breaker "Open" and "Close" switches remote from the breaker unit. These could be placed on a non-breaker unit, in a separate control panel, or in a remote room. Older switchgear can be retrofitted with remote control switches.

New microprocessor relays can be programmed to manually supervise the closing of a breaker using a "punch and run" timer, which allows the operator 3 to 10 seconds after initiating a "close" to evacuate the vicinity before the breaker is actually closed.

While fully electrically operated low voltage breakers are available, they are not the norm. Low voltage breakers that are fully electrically operated would allow the breaker to be closed without an operator being in front of the breaker.

Racking a circuit breaker in or out of an energized switchgear cubicle exposes the workers to an arc-flash hazard. While the breaker's mechanical indicator may note that the breaker is fully open, there have been cases where it was not open due to contact or indicator failure. The automatic breaker trip mechanism has also been known to fail in similar cases. Placing a breaker in a cubicle when it is not in the fully open condition can result in an arc flash.

Using a longer cranking tool to rack in the breaker can provide additional distance. Remotely controlled electric breaker racking devices are available for most circuit breakers as part of the new equipment or as retrofits. These remote racking systems provide a motor to rack the breaker in or out with a remote-control unit so that the operator can be a safe distance from the breaker as it is racked. These motors typically are calibrated for the specific manufacturer's breaker for design torque and number of turns. Use of remote racking devices should be a standard operating procedure whenever possible.

Personal Protective Equipment (PPE)

CHAPTER 06

Arc-rated personal protective equipment (PPE) can reduce the risk of injury from arc-flash burns. It is important that workers understand the use, care, and limitations of PPE and related equipment. Employers have a responsibility to provide training so that the workers have adequate understanding and training on the use of PPE. PPE is considered to be the least effective of the NFPA 70E®-2021 Hierarchy of Needs for Arc-Flash Risk Assessment procedures and should always be considered a last line of defense.

Personal protective equipment (PPE) is required by various standards such as NFPA and OSHA to protect workers from hazards in the workplace. The type of PPE required depends upon the magnitude of the hazard that has been identified, as well as the relative risk of the planned activity. This determination should be documented in an Electrical Safety Program as described on NFPA 70E. For arc-flash hazards, the main purpose of PPE is to reduce burn injuries to a worker to a level of curable burn (less than a third-degree burn).

Even when PPE is selected and used in accordance with the arc-flash risk analysis, the worker should not assume that there will be no risk of injury. Employers must provide training on the proper use and care of the arc-rated PPE and workers must not treat PPE as though it eliminates the need for safe work practices and common sense.

The most common and industry-accepted PPE that protects the body from arc-flash are arc-rated clothing ensembles. Arc-rated clothing is tested for performance under exposure to electric arcs. This is different from flame-resistant clothing. Arc-rated (AR) clothing ensembles are flame-resistant (FR) but not all FR clothing ensembles are AR.

NFPA 70E®

NFPA 70E-2021 provides arc-flash PPE requirements in section 130.7. Shock risks are covered in section 130.4. Workers must use PPE appropriately suitable for the work to be performed. Various standards pertaining to care, testing, and use of PPE are outlined in this section. Refer to the standards for complete details. Some of the main requirements are as follows:

- Anyone within the arc-flash boundary is required to wear arc-flash PPE while an arc-flash hazard exists.
- When arc-rated clothing is worn for protection, it must cover all ignitable clothing while still allowing for visibility and movement.
- Non-conductive protective head protection is required. The face, neck and chin must be protected. Any hairnets or beard nets must be arc-rated.
- Eye protection from infrared and ultraviolet radiation is required.
- Hearing protection is required as part of all arc-flash PPE due to the high sound pressures that may occur.
- Body protection is required using arc-rated clothing when the calculated incident energy at the body exceeds 1.2 cal/cm^2.
- Voltage-rated gloves complete with approved leathers are required to protect the hands, or arc-rated gloves if no shock hazard exists.

- Non-melting, flammable clothing may be worn UNDER adequately rated arc-rated PPE.
- Any outerwear such as jackets, rain gear and high visibility gear must be arc-rated. Where outerwear is worn over arc-rated clothing of adequate rating, the arc-rating of the outerwear does NOT have to equal to the calculated incident energy.
- An arc-rated hood or an arc-rated balaclava with a face shield is required when the back of the head is within the arc-flash boundary.
- Leather or dielectric footwear is required unless alternative footwear has been tested to demonstrate no ignition, melting, or dripping at the expected incident energy.
- Hard hat liners used within an arc-flash boundary must be arc-rated.

Selection of Arc-Flash PPE

NFPA 70E® provides two different methods of selecting PPE for arc flash. Section 130.5(F) states that either one of these methods may be used but never both methods at once on the same piece of equipment. These two distinct methods are:

- Incident Energy Analysis method (130.5(G))
- Arc-Flash PPE Category method (130.7(C)(15))

Incident Energy Analysis Method

As per section 130.5(G), arc-rated clothing and other PPE shall be selected based on the calculated incident energy in cal/cm^2 at the working distance specific to the task to be performed. Incident energy analysis calculation details are described in Chapter 3. The working distance can vary with the tasks being performed.

Although the incident energy exposure decreases as the working distance increases, workers will not have the knowledge to properly assess the hazard as a function of working distance. The more conservative and practical approach is to consider the closest working distance amongst the expected tasks and use that distance for the incident energy calculation and labeling. This way the label will display the highest expected level incident energy, and the PPE selected based on this energy level should be adequate for any expected task.

Because the Energized Electrical Work Permit (EEWP) is task-specific, it is permissible to modify the working distance used to calculate the incident energy for that specific task as part of the arc-flash risk analysis required in the EEWP. EasyPower can use this task-specific working distance when calculating the working distance for any EEWP.

Using the calculated incident energy, the general PPE requirements can be determined by using NFPA 70E® Table 130.5(G) – Selection of Arc-Rated Clothing and Other PPE When the Incident Energy Analysis Method Is Used. This Table has 2 levels of protective clothing and PPE requirements based on the incident energy exposure:

- 1.2 cal/cm^2 up to 12 cal/cm^2
- Greater than 12 cal/cm^2

The basic requirement is that the PPE clothing worn must have an arc rating equal to or greater than the expected incident energy. For details on this table refer to the NFPA 70E-2021 standard. For example, if the incident energy for a particular task on an equipment is 4 cal/cm^2, you can use 4 cal/cm^2 rated clothing if available and it is not necessary to use 12 cal/cm^2 rated clothing.

Arc-Flash PPE Category Method

NFPA 70E allows an alternative method of determining the required PPE instead of performing a calculated hazard assessment. This is called the PPE Categories Method and is detailed in NFPA 70E-2021 Article 130.7(C)(15). Two tables are provided – one for AC systems and one for DC systems. The tables list different types of equipment and voltage levels, indicating the Arc-Flash PPE Category (1 through 4) for each. The PPE requirements for each of the four PPE categories are listed in Table 130.7(C)(15)(c).

Per NFPA 70E this Category Method can be used in lieu of doing the detailed modeling and calculations required by the Incident Energy Analysis Method so this would seem to be a simpler approach. However, the arc-flash PPE categories given for the various equipment types are only valid up to specific maximum fault current and maximum clearing times. So, to properly apply the Category Method, the level of fault current and the fault clearing should be known and this may require engineering effort that is similar to the Incident Energy Analysis method. Table 6.1 below shows a sample of the AC systems PPE Categories Table in NFPA 70E.

Table 6.1: AC Systems PPE Categories Table in NFPA 70E®

Equipment	Max SC (kA)	Max Clear (sec)	Work Dist. (in)	PPE	AFB
Panelboards <250 V	25 kA	0.03	18	1	19″
Panelboards <600V	25 kA	0.03	18	2	36″
600 V MCC	65 kA	0.03	18	2	60″
600 V MCC	42 kA	0.33	18	4	14′
600 V Switchgear	35 kA	0.5	18	4	20′

One other concern is that these tables do not provide any guidance on required PPE when the available fault current or maximum clearing time exceeds the limits stated in the Tables. The Incident Energy Analysis Method has the advantage of providing more accurate assessments at each location and also finding those areas where the expected incident energy is higher than might be anticipated.

CHAPTER 07

Data Collection for an Arc Flash Hazard Study

Arc-flash calculations are only as accurate as the model used as the basis of the calculations. Creating an accurate model requires collection of system data, either from existing documentation, field data collection, or more commonly, a combination of the two. Data collection and system modeling can require a considerable amount of time and effort—often more than actually performing the study. Any existing documentation or previous studies should be used to reduce the amount of time required for field data collection.

Introduction

Like any other project, data collection requires prior planning and should take into consideration the following concerns.

- What existing documents are available and how accurate are these documents?
- What is the scope of the study and how much of the system is included?
- Where are the interfaces between the system to be evaluated and the local utility or other entities?
- How much field data collection will be required and how will it be done?
- What are the responsibilities of the facility team versus the study team?
- How will the safety of the data collection team be addressed?

Based on the answers to these questions, the arc-flash risk assessment may need to be broken up into different phases. It might be better to collect data and build the one-line model from the medium and high voltage distribution downstream to the individual low voltage substations, collecting data for each feeder serving a switchboard, MCC and panelboard. Typically, arc-flash incident energies are higher at these locations than in other low voltage equipment further downstream in the system. After the intermediate study has been completed, then additional data may be collected and added to the EasyPower model to perform the arc-flash risk assessment. The scope of the study and the best approach to sequencing the work should be discussed with the facility staff and well-documented.

The scheduling and sequencing of data collection will depend on who will be doing the on-site work: a member of plant staff, a contracted individual who is normally on-site, or a consultant or contracted individual who has traveled to the site. If site personnel will be responsible for data collection, it will be important to communicate clearly regarding what data is required.

Obviously, the amount of time required for data collection depends on many factors, including:

- Size and complexity of the electrical system.
- Physical access constraints.
- Quality of data available from existing documentation.
- Number of people available to do the data collection.

The following steps can serve as rough mileposts for the data collection process, recognizing that every facility and situation will have unique aspects.

1. Review available documentation, especially one-line diagrams and physical layout drawings, including site plans. In many cases, these may be available electronically, but for older facilities, hard copy documents and drawings may be the only option. It is also important to capture notes and red-lines on existing drawings that indicate changes to the system subsequent to the original document. Even if the documentation is not totally current or needs field verification, review of this information can save hours of on-site field work. For arc-flash studies, the following documents can be helpful:
   - Existing one-line diagrams.
   - Previous electrical system studies, including short circuit, coordination, and any previous arc-flash studies.
2. Discuss with site staff any known issues with the documentation and system changes that they are aware of. Also, make note of any previous system studies that may be available along with shop drawings, bills of materials, and test reports.
3. If possible, based on the available documentation, develop a preliminary one-line diagram to get an overall understanding of the system, making note of additional data that will be required. This preliminary one-line diagram is helpful for identifying missing data and developing the necessary data collection forms where field data collection is necessary.
4. For larger systems, it may be helpful to create a rough physical map or layout of the key components including transformers, sources, switchgear/switchboards, and distribution points (MCCs, panels, etc.). A simple hand drawing will do for a start. Plant engineers and electricians typically have knowledge of the layout of the system. Consultants can obtain information from plant personnel or existing drawings to create this rough map.
5. Based on the preliminary one-line diagram and the physical layout sketch, develop a list of data needed and plan for on-site data collection. Data collection forms or templates can be helpful for keeping track of details, organizing information, and saving time. A few example templates are included later in this chapter in the Data Collection Template section.
6. Coordinate with the plant personnel for the site visit. If data collection is to be done by persons not familiar with the facility, it is necessary to have a site electrician assist with the location of all equipment. In some cases, it may not be possible to obtain the required data if it becomes necessary to open some equipment covers, as that may require de-energization and interfere with the plant operation. The information may be obtained later during scheduled maintenance or reasonable assumptions may be made. Any assumptions made should be noted in the study report.
7. Use a digital camera if possible. The pictures often reveal more information than what you record in your notes. If you have difficulty understanding any of

the equipment data, you can obtain help from experienced people using the picture.

8. Most equipment has nameplates that show the equipment ratings. Note the details from the nameplates and take a photo if possible.
9. For equipment with adjustable settings, note the range of available settings and the current setting. The status of switching devices should also be noted (open or closed).
10. Create a one-line diagram showing all the equipment such as utility connections, transformers, cables, switches, circuit breakers, fuses, loads, switchgear, etc. Make sure that their interconnection is correctly represented in the drawing. Mark each equipment item with the ID names and enter the relevant data. Commercial power system software like EasyPower can create one-line diagrams, store all the necessary equipment data, and perform arc-flash risk assessment. ID names are also important for placing arc-flash labels in the appropriate locations after the equipment incident energy has been determined.
11. The more knowledge the electrician (plant personnel) has of the facility, the better the final model will be. You may need to consult with several plant individuals before you understand or gather data you need.
12. If you have information from previous studies with recommended settings or drawings, be sure to verify the data. The facility may not have been updated after the previous study, fuses may have been changed, or the instantaneous trip functions may have been adjusted due to nuisance tripping.
13. Before beginning data collection, understand the purpose and scope of the data collection. What kind of study are you performing and what areas of the facility must be modeled?
14. Strive to collect all necessary data while in a particular area to minimize the need for additional site visits or data requests. Take photographs of equipment whenever possible.
15. The electrical safety of the data collection team is the first priority and needs to be included in a comprehensive Job Safety Plan document for the data collection project.

This book is focused on performing arc-flash hazard assessment studies, but if other studies could be performed in the future using the one-line model developed for the arc-flash study, you may want to consider collecting additional information while performing this study. The data to be collected as described in this chapter will allow for short circuit analysis, protective device coordination, and arc-flash studies

Items Useful for Data Collection

The following material and items may be required or useful while collecting power system data:

- A signed energized electrical work permit if required.
- Clipboard, pencils, highlighter, graph paper, or notebook.
- Existing one-line diagrams.
- Facility drawings.
- Templates for protective device settings.
- Tables of protective device settings (such as relay setting sheets).
- A non-conductive flashlight.
- A non-conductive mirror and handle, so that you can view difficult locations and avoid blind reaching.
- A digital camera or cell phone camera.
- A laptop or tablet for entering information directly into EasyPower.

Safety Tips for Data Collection

Although not comprehensive, keep the following tips in mind:

- Whenever possible, perform data collection on de-energized equipment unless it is not feasible.
- Avoid opening equipment doors on energized equipment unless truly necessary. Electrician opening the door should be wearing appropriate PPE. Everyone else should be behind the arc-flash boundary and the Restricted Approach Boundary while the door is opened.
- Remain behind the Restricted Approach Boundary at all times while collecting data.
- Some data may not be safely obtainable through field inspection. If the equipment is energized and all the necessary information cannot be obtained, perform data collection during a scheduled shutdown, or obtain data from shop drawings, test reports, or other documentation. In some cases, reasonable assumptions must be made. Any assumptions should be noted in the report. Do not take unnecessary risks when collecting data.
- Electrical hazards such as shock and arc flash are not the only hazards that

exist during data collection. Follow all site safety policies regarding the use of ladders and lifts for work above the floor and use fall protection as required. If necessary, shutdown and lockout conveyors or other moving equipment.

- Watch for loose screws, bolts, or other metallic parts.
- Do not touch any equipment unless necessary and avoid leaning or sitting on equipment.
- Keep track of all tools, cameras, phones, and backpacks, and avoid leaving things behind. All equipment should be left in the same condition as found.
- Do not open any enclosure doors or covers without permission or without proper PPE. It is preferable for the plant maintenance staff to open and close all equipment doors.

Estimations and Assumptions

During data collection, there may be some estimations or assumptions that must be made when information is not available or cannot be safely obtained.

Be sure to document all assumptions in the report in case any questions or issues should arise in the future.

Common Items that may need to be assumed or estimated:

- Missing or unreadable nameplates. Review existing drawings or data sheets to obtain available information. If drawings or data sheets are unavailable, base your assumptions on similar equipment installed close by or at the same time as the equipment you are documenting.
- Conductor length. It can be difficult to determine cable, busway, and transmission line length due to walls, high ceilings, or difficulty tracking conduit or cable tray. Length estimates within 10% of the actual length are generally acceptable. Do not forget the vertical portions of the cable and conduit runs. The importance of cable length on short circuit calculations increases as the voltage level decreases. For example, ignoring a 50-foot conductor at 13.8 kV may not affect calculations, while ignoring a 50-foot conductor at 480 V or 208 V may affect calculations more significantly. 208 V arc-flash calculations are highly sensitive to cable length data.
- For molded case circuit breakers (MCCBs) with an unknown instantaneous setting, assume it is at the maximum available setting. This will always be conservative for arc-flash calculations.
- For MCCs and panelboards, it may not be necessary to collect data and model every feeder completely. If no arc-flash label is needed at the downstream

equipment, it may be sufficient to record the type of load present. If labeling is not required at individual motors, the motor loads fed from each MCC may be grouped based on size. For a typical MCC, the minimum data required is listed below.

- Main breaker/fuse.
- Largest feeder breaker/fuse and load/motor information.
- Protective device and conductor information for any equipment that needs to be modeled for arc-flash analysis, such as a sub-panel or sub-MCC.
- Group total <50hp motor horsepower.
- Group total >50hp motor horsepower.

This grouping of motor load is only applicable for constant-speed motors. Motors fed from adjustable frequency drives do not generally contribute fault current so must be modeled separately. Also, any downstream equipment that requires an arc-flash calculation and label must be included in the model explicitly.

A template showing the minimum recommended MCC information is shown in the Data Collection Template section.

- For long runs of bus duct with numerous taps, it may be time consuming to collect data for all the equipment served from the bus taps. If time or access to the bus plugs are an issue, consider collecting feeder data for an assortment of bus plug sizes along the length of the bus duct. For example, if a bus plug is 200 feet in length, you might consider collecting data at the beginning (0 feet), middle (100 feet) and end (200 feet), for different bus plug sizes (30 A, 100 A, 200 A). Then in the EasyPower software, model a bus at each of the three bus duct locations and add the generic feeder data for each of the bus plug sizes at each bus. An example is shown in the following figure. As long as the conductor length is similar, using the generic arc-flash incident energy should be sufficient. If the length is much longer, then these cases should be modeled individually. Also, it is recommended that any bus plugs 400A or larger should be modeled individually. Since an EasyPower bus is required to show taps from the bus duct, it is reasonable to group the taps at buses instead of creating a bus for each tap. It is important to get an approximation of the total length of the bus duct and model the bus duct system such that the modeled length is roughly equal to the actual length.

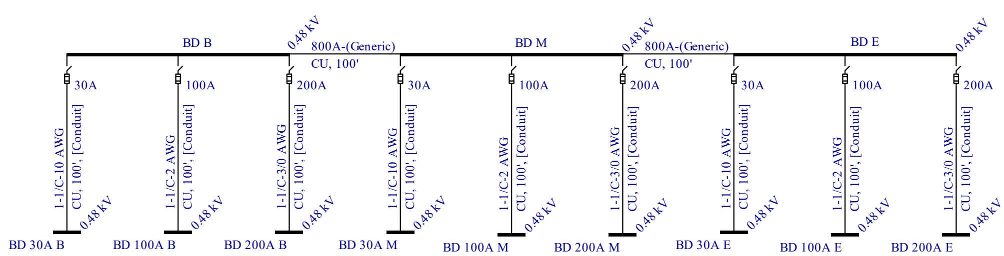


Figure 7.1: Generic Bus Duct Example

- There are books and papers from manufacturers available that provide typical data for equipment. A book that has quality data that can be used as estimations is A Practical Guide to Short-Circuit Calculations by Conrad St. Pierre. The book can be purchased by contacting EasyPower.

Time Current Curves and Arc Duration

In certain situations, the published manufacturer's time-current curves do not provide sufficient information to determine a precise arc time. EasyPower determines the duration of the arcs based on the following IEEE 1584-2018 recommendations:

- Where the current-limiting fuse equations are not applicable or not used, the manufacturer's time-current curve information is used. If the manufacturer's curve includes both minimum melt and total clearing time curves, the total clearing time is used as the arc time. If the manufacturer's curve has only the average melt time, an additional 10% of the average melt time plus 0.004 seconds is added to that time to determine the arc time. If the total clearing time at the arcing fault current is less than 10 milliseconds, use 0.01 seconds for the time.
- For relays operating in their instantaneous region, a minimum time of 16 milliseconds (on 60 Hz systems) is used for the relay trip time. The breaker clearing time is always added to this relay time for medium and high-voltage circuit breakers. This default minimum time of 16 ms can be adjusted by the user in the Advanced section of the Arc Flash Options.

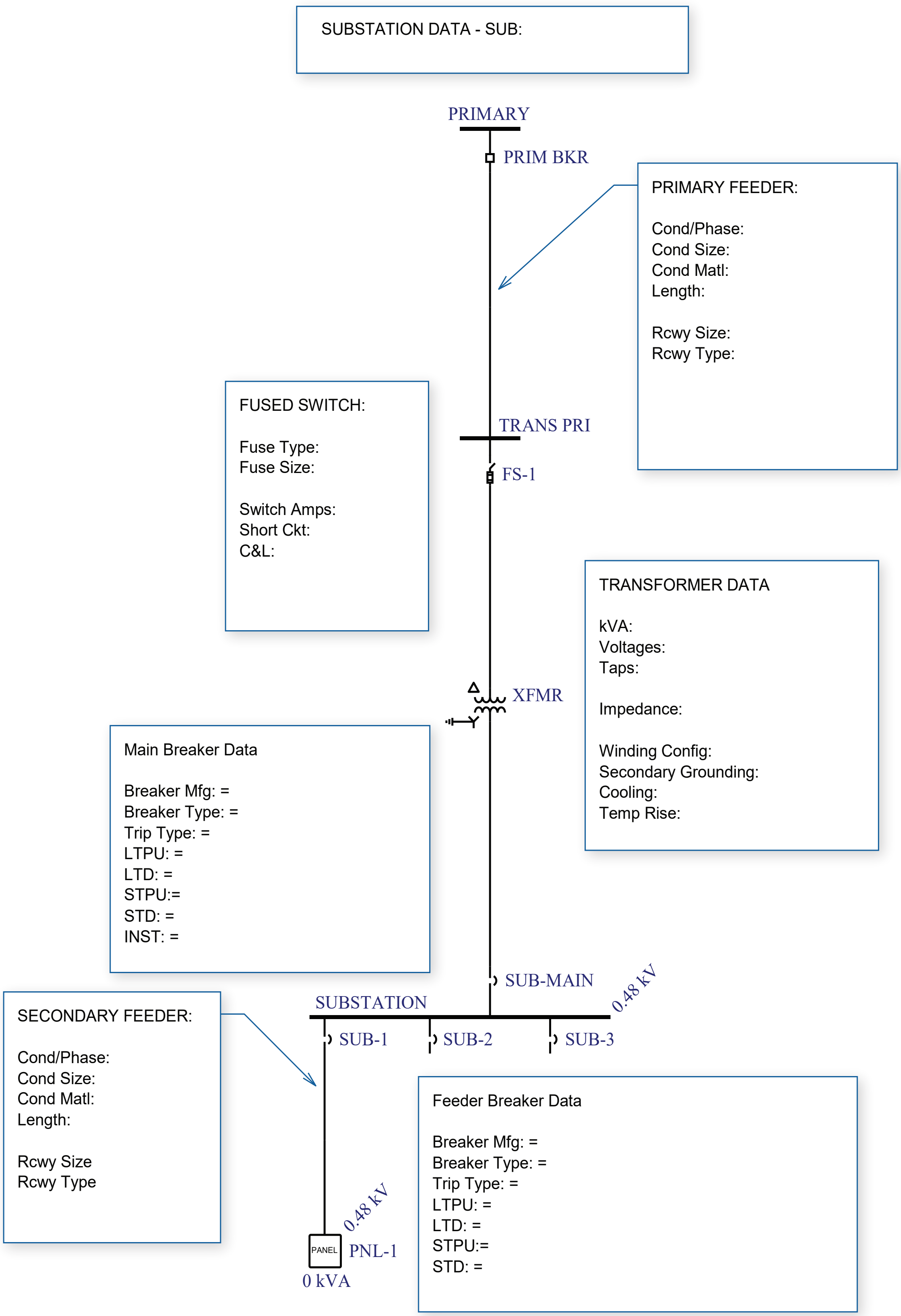
For situations where the arc time cannot be determined based on time-current curves, EasyPower provides for use of a "User-Defined" arc time that can be set in the arc-flash options for any bus. An example of the use of a User-Defined time is to provide an arc time for equipment protected by differential relays or arc-flash detection relays.

Data Collection Templates

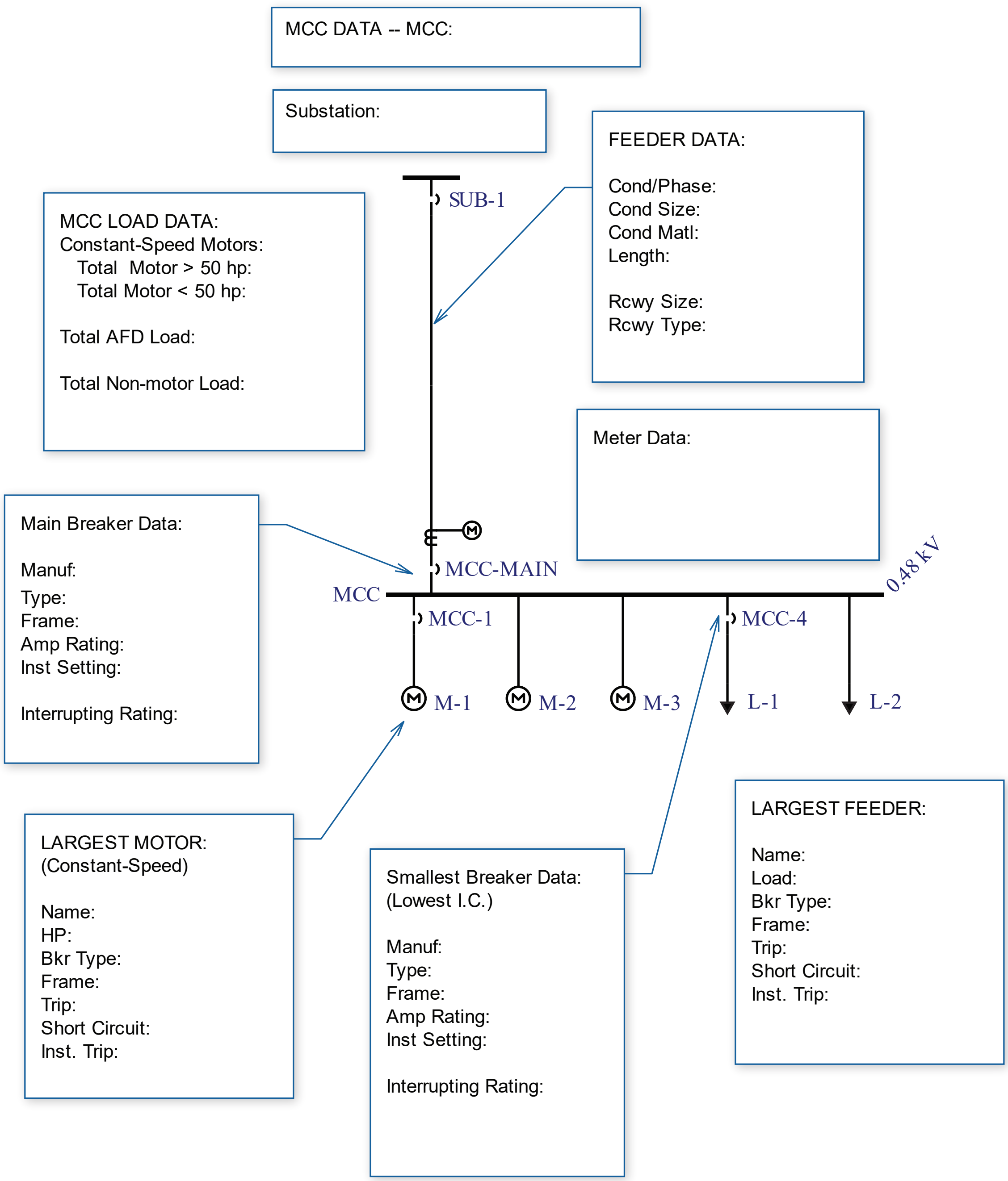
In this section, sample templates are provided for a low-voltage substation and an MCC that show the type of data collection that is generally required. These templates may be used directly or as a guide for creating your own templates. It also may be more convenient for you to create spreadsheets instead of using one-lines.

The third template is for data collection of low voltage power circuit breakers with associated trip units. The template includes all the different device types and settings that are required to properly model the breaker and trip units in the EasyPower software. For other types of protective devices, data collection templates may be created based on the software requirements.

Substation Data Collection Template



MCC Data Collection Template



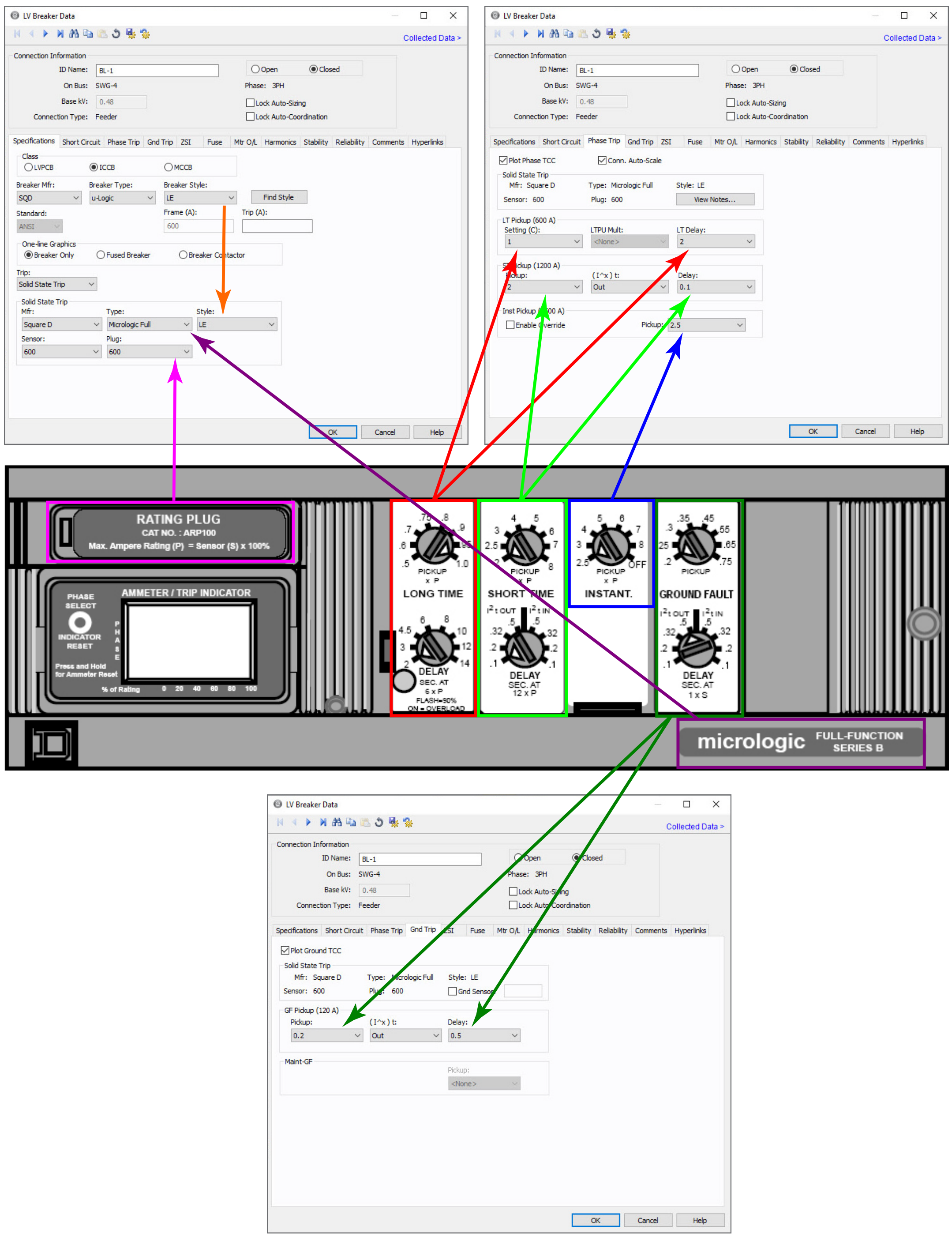
Form for Low Voltage Breaker with Trip Units

Breaker ID	Breaker Mfr/Type	Frame Size / Sensor	Trip Unit Mfr/Type	Plug Rating	Long Pickup	Long Time Delay	Short Pickup	Short Time Delay	I^2T	Inst. Pickup	Ground Pickup	Ground Time Delay	Interupting Rating	Comments

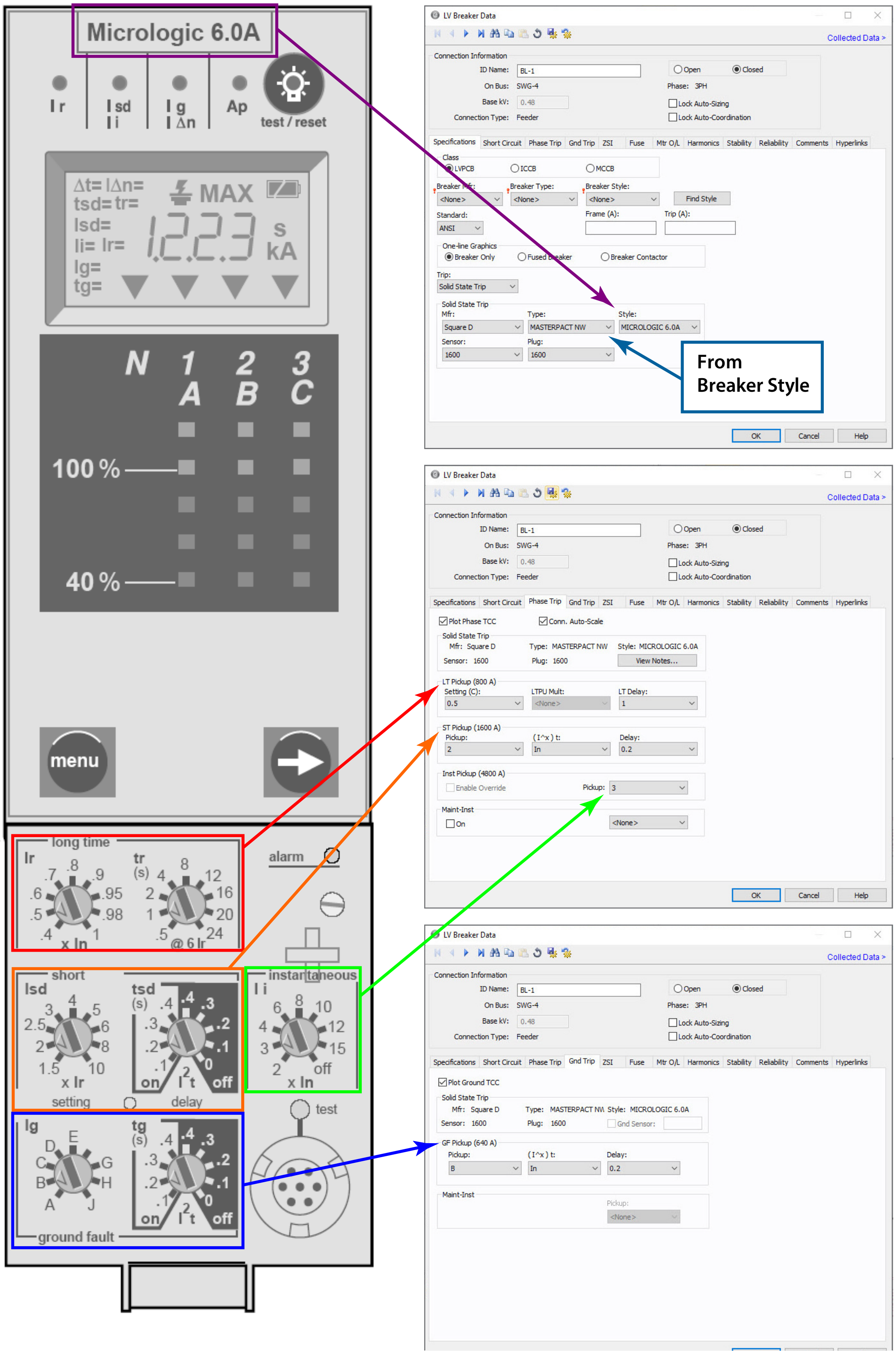
Equipment Name Plates and EasyPower Data

In this section, you will see how to use name plates to collect data as well as where it will be placed in EasyPower power system software, for later arc flash analysis.

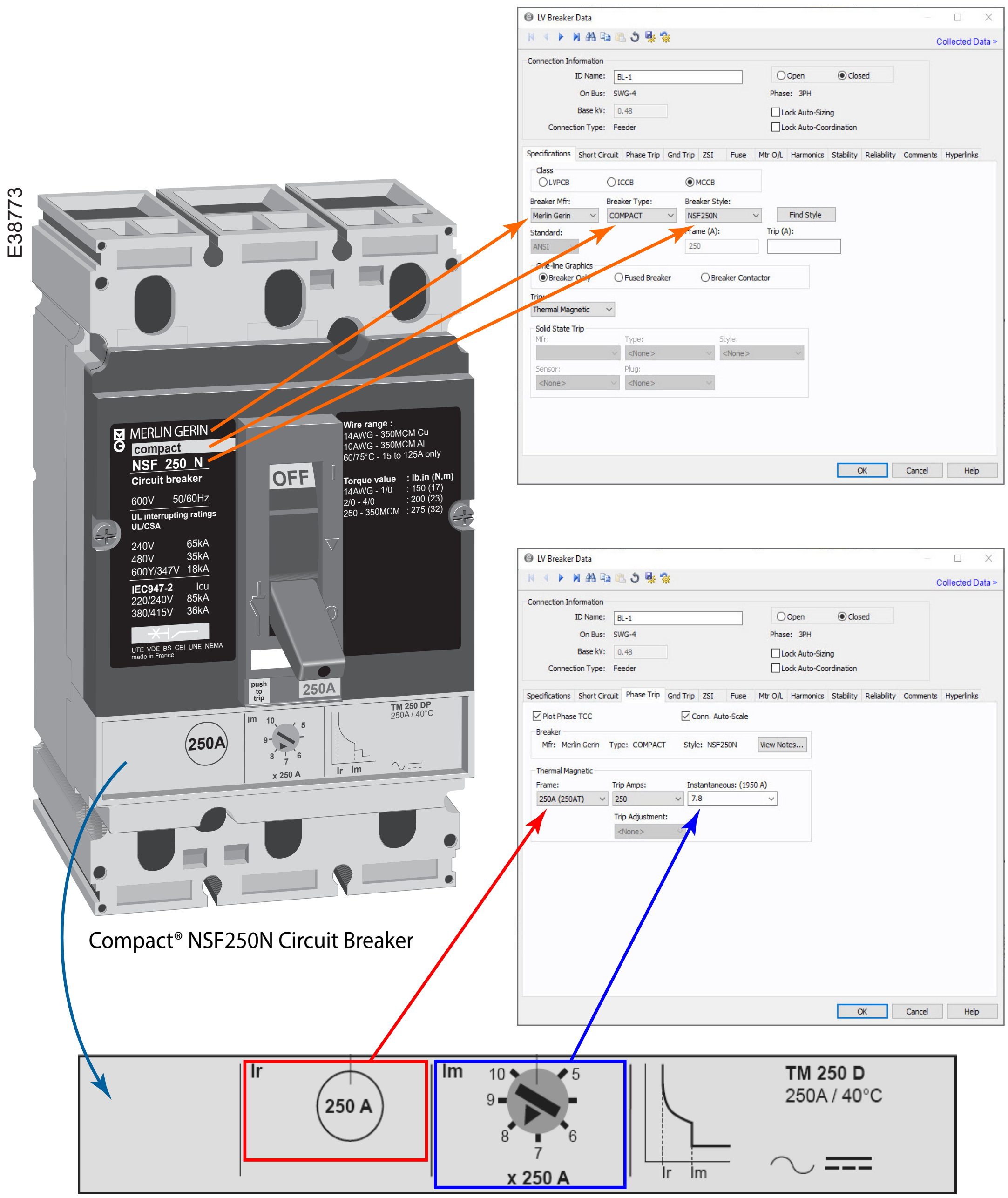
Solid State Trip (Example A)



Solid State Trip (Example B)

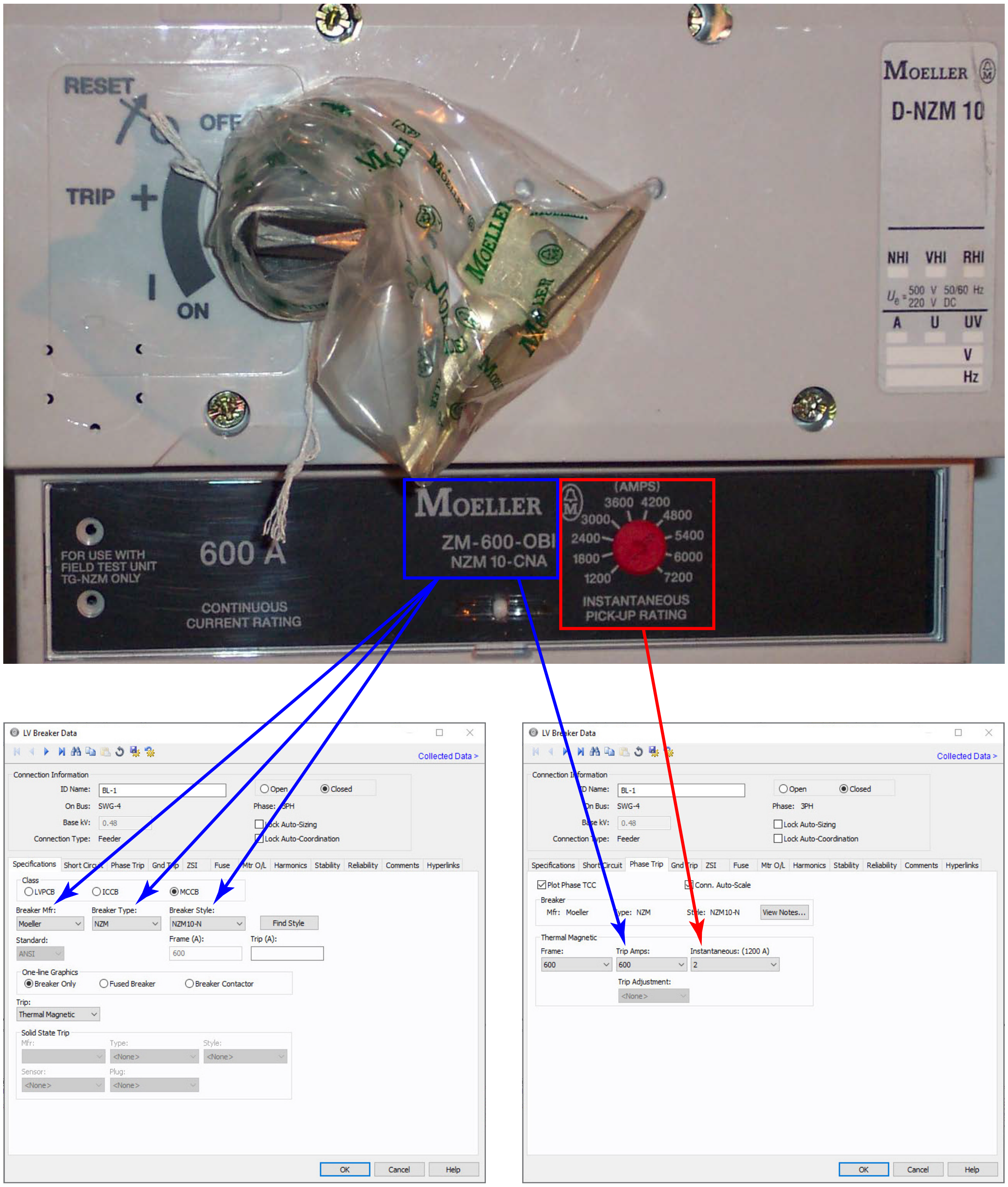


Thermal Magnetic Breaker (Example A)

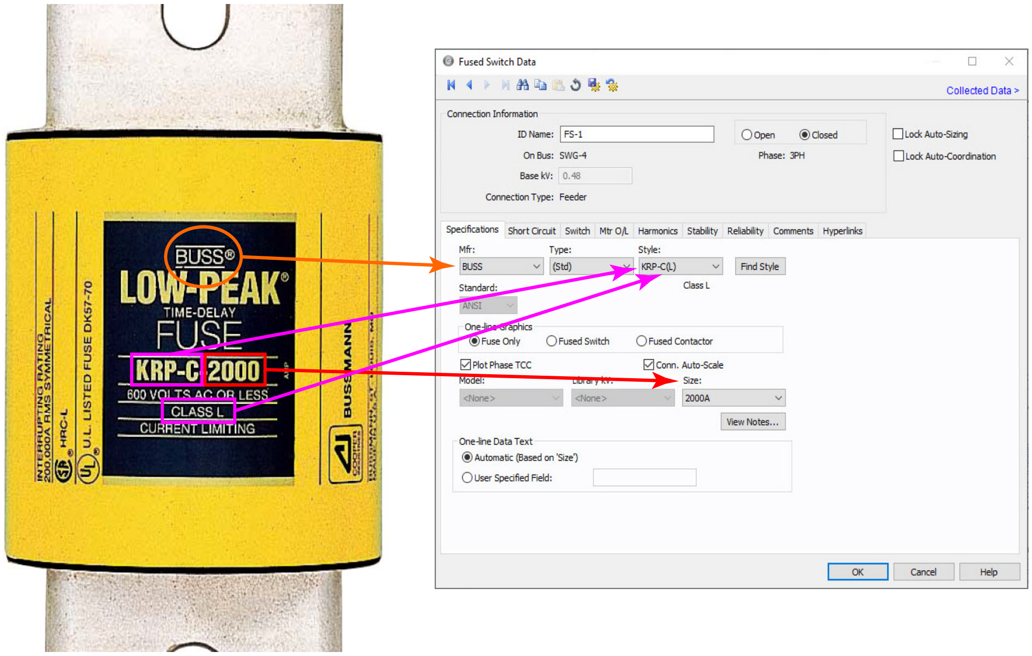


Compact® NSF250N Circuit Breaker

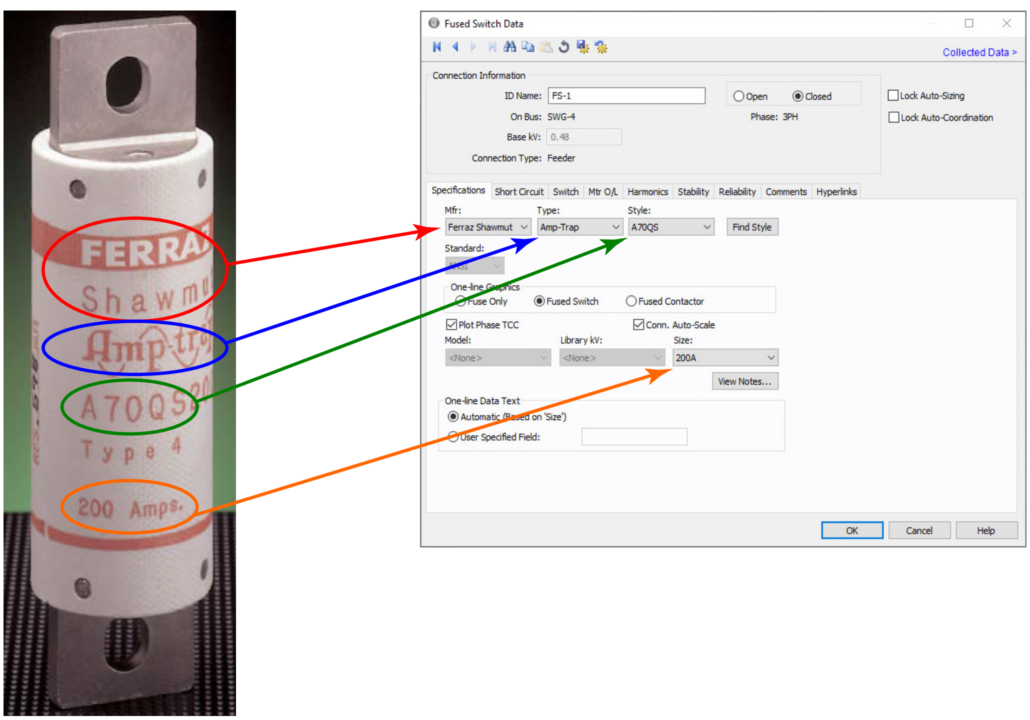
Thermal Magnetic Breaker (Example B)



Low Voltage Fuse (Example A)

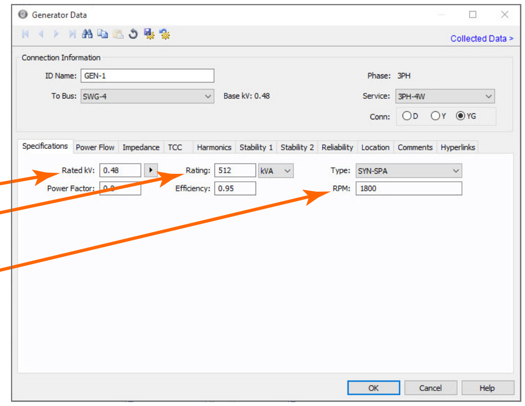


Low Voltage Fuse (Example B)



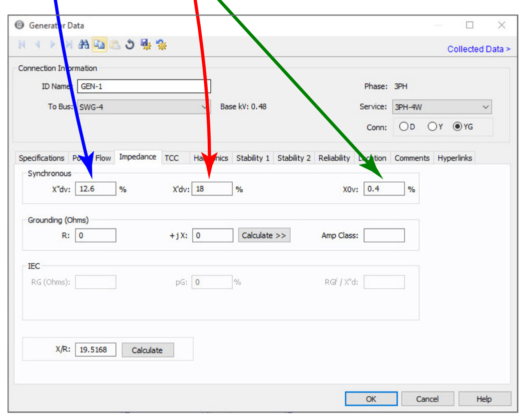
Generator (Example A)

Model	S4
Power Factor	0.8
kVA	512
kW	410
RPM	1800

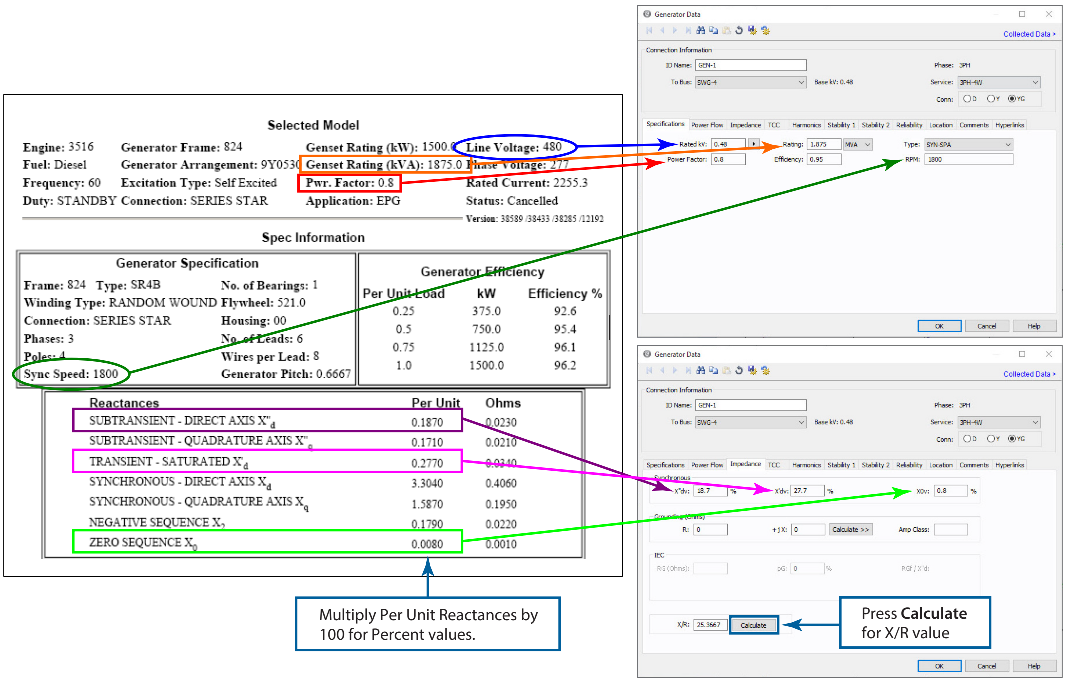


Reactances Class H / 480 V - Time constants (ms)

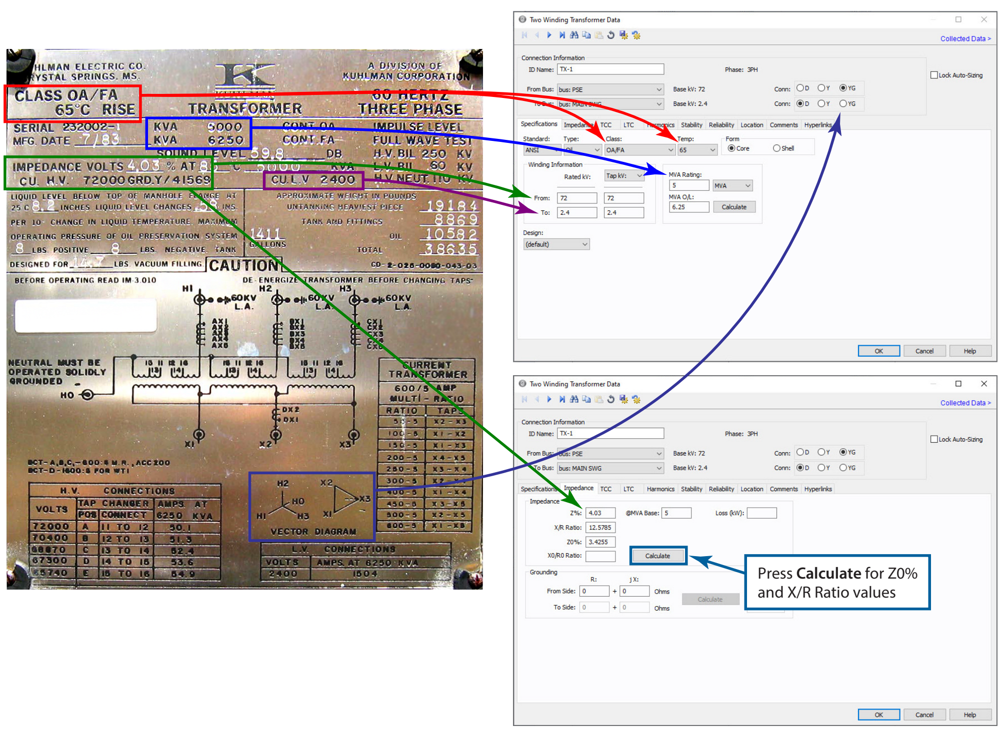
		VS2	S4	S5	M7	M8	L9	L9 (6w.)
Kcc	Short-circuit ratio	0,36	0,36	0,32	0,40	0,31	0,35	0,36
Xd	Direct axis synchro. reactance unsaturated	349	335	373	319	376	344	338
Xq	Quadra axis synchro. reactance unsaturated	209	201	223	191	225	206	203
T'do	Open circuit time constant	1738	1855	1855	1930	1958	1997	1997
X'd	Direct axis transient reactance saturated	20,1	18	20,1	16,5	19,2	17,2	16,9
T'd	Short circuit transient time constant	100	100	100	100	100	100	100
X"d	Direct axis subtransient reactance saturated	14,1	12,6	14	11,6	13,4	11,8	12,1
T"d	Subtransient time constant	10	10	10	10	10	10	10
X"q	Quadra. axis subtransient reactance saturated	19,1	16,9	18,8	15,3	17,8	15,6	15,8
Xo	Zero sequence reactance unsaturated	0,1	0,4	0,1	0,1	0,9	0,9	0,4
X2	Negative sequence reactance saturated	16,6	14,8	16,5	13,5	15,6	13,7	14
Ta	Armature time constant	15	15	15	15	15	15	15



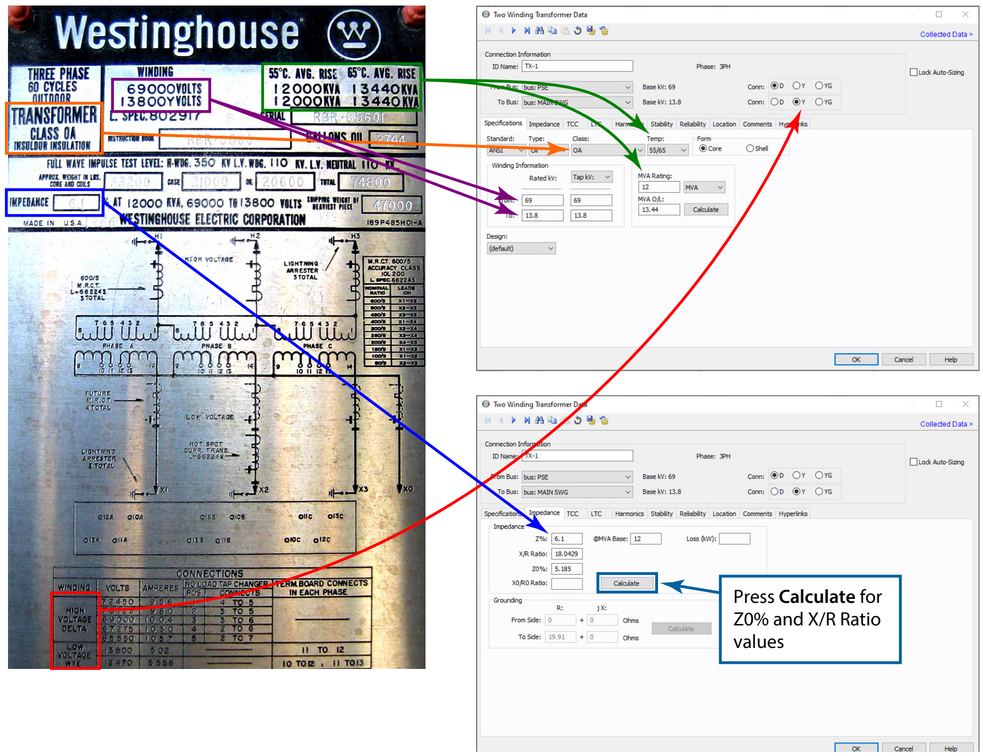
Generator (Example B)



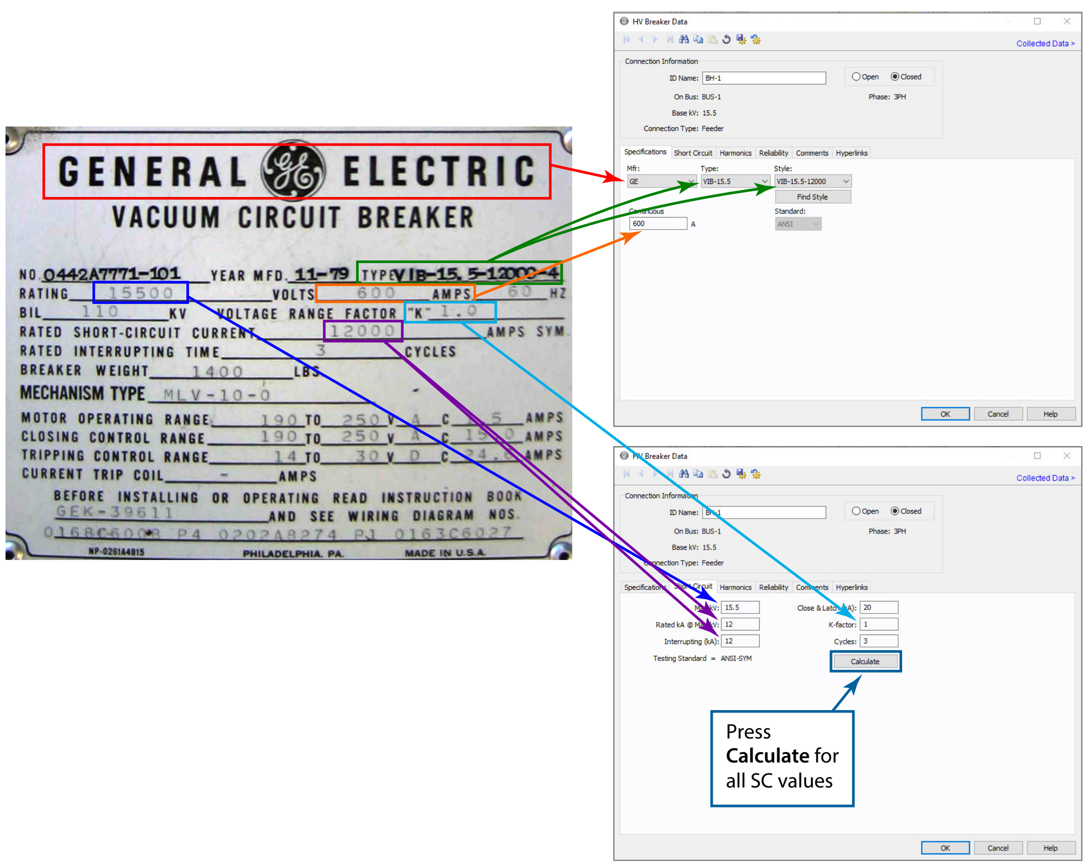
Transformer (Example A)



Transformer (Example B)



Medium Voltage/High Voltage Breaker



Modeling and Arc Flash Analysis in EasyPower®

CHAPTER

08

An up-to-date and accurate one-line diagram is the essential basis for all system studies. The one-line describes the electrical power system equipment, layout, and connections. Creating a one-line diagram in EasyPower from the data collected in the field is fast and easy and facilitates accurate analysis. It also fully supports and facilitates safer work for Lock Out/Tag Out tasks.

EasyPower is a powerful software program you can use to quickly model and analyze industrial, utility, and commercial electric power systems. It supports both AC and DC modeling. You can create one-lines and perform analyses such as short circuit, arc flash, and coordination. The program includes a comprehensive equipment library for all major manufacturers.

Here, we will describe briefly how you can use EasyPower to create a one-line and perform an arc flash hazard analysis.

The Start Screen

The Start Screen makes it easy to open files and learn more about the EasyPower program. This page opens automatically the first time you open EasyPower. The button options at the top enable you to start a **New** one-line or **Open** an existing one-line by clicking the appropriate button. The Start Screen contains links to many helpful EasyPower resources, as seen in Figure 8.1 below.

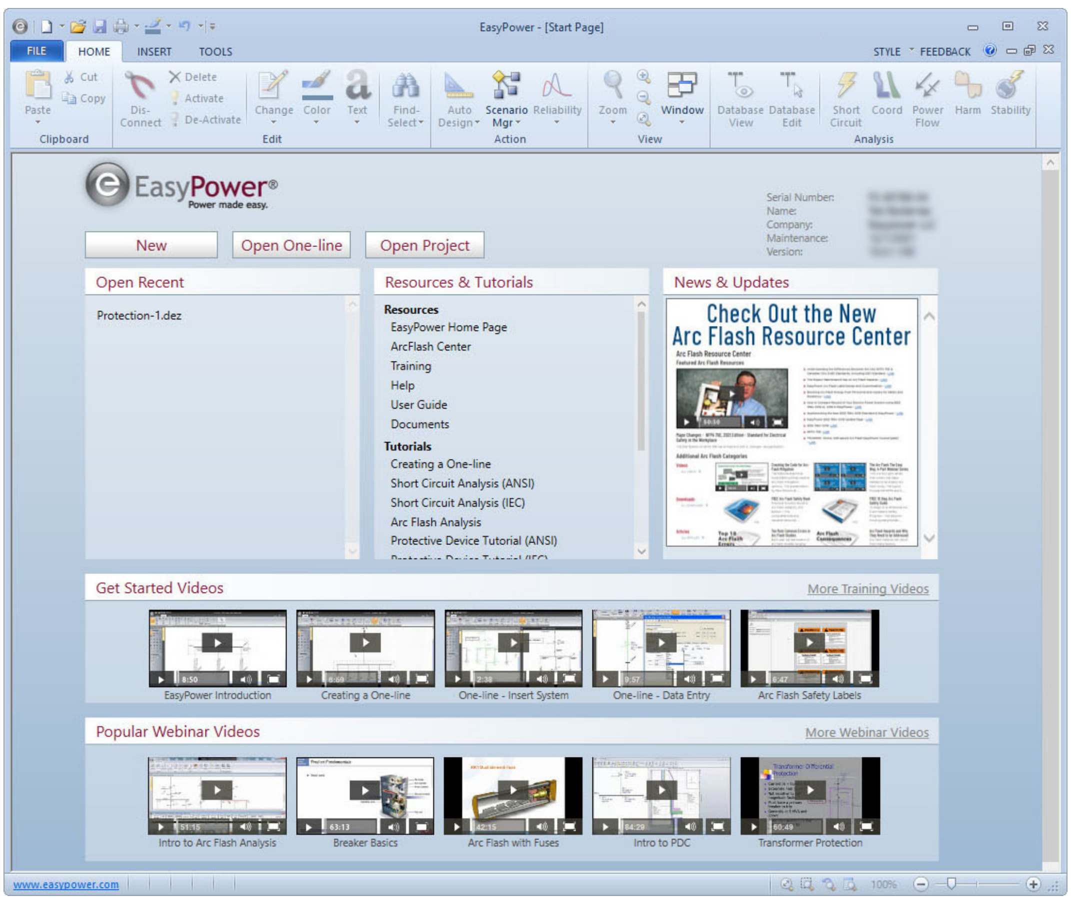


Figure 8.1: The EasyPower Start Page

Creating a New One-line

Click **New** on the **Start Screen** to open a new one-Line design. (If you are not viewing the **Start Screen**, you can also click **File > New > New One-line** to start a new one-line.)

Toward the top left corner of the window, the **Quick Access Tool** bar contains icons for **New**, **Save**, **Print** and **Undo**.

Just below the **Quick Access Tool** bar is the area called the ribbon which contains several tabs, including **File**, **Home**, **Insert**, and **Tools**. The Home tab has numerous icons you use to manipulate the one-line diagram and perform analysis. A new file always opens in the **Database Edit** focus as indicated by the highlighted **Database Edit** icon.

Database Edit permits the construction or modification of a one-line diagram in the white desktop area of the display by using the icons for the equipment items from the **Equipment Palette**. Located along the left vertical sidebar, the **Equipment Palette** contains AC and DC equipment along with icons to add notations to the one-line diagram. EasyPower does not permit changing focus to any of the analytical modules (such as **Short Circuit** or **Coordination**) until the one-line schematic contains a minimum number of details entered for the equipment in the one-line.

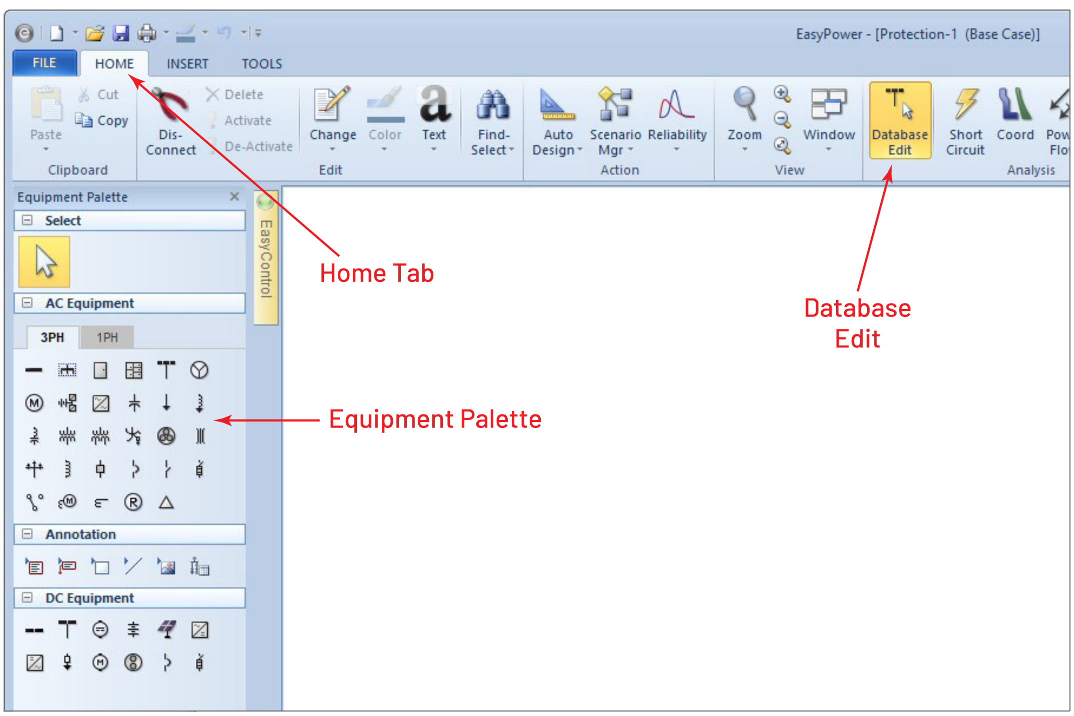


Figure 8.2: The EasyPower New Session Window – Home Tab Selected

Select and Place Equipment Icons

The mouse action to select and place equipment from the Equipment Palette requires the following procedure and is repeated many times during this example.

1. If you hover the mouse pointer over any icon in the Equipment Palette, the equipment item's name is displayed.
2. To select that equipment item, click the left mouse button once.
3. Position the pointer in the white desktop area where you want anchor the equipment item.
4. Click the left mouse button a second time to place the equipment item.

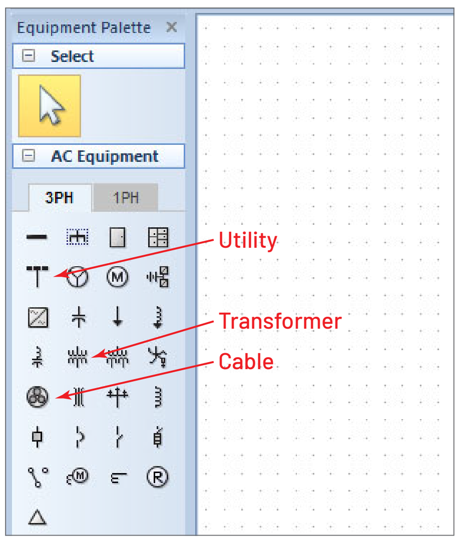


Figure 8.3: Icons for a Utility, Transformer, and Cable on the Equipment Palette

Notes to remember while drawing your first one-line diagram:

- As equipment is connected in the one-line, EasyPower carries several data values through the connections. If you make a mistake as you draw your first few one-line diagrams, you may find it easier to close and re-start the construction to avoid any mistakes.
- Do not draw a large one-line diagram until you have a better understanding of how EasyPower works. Start with a very simple one-line (like our example below). Ensure that you can produce the arc flash results as expected. Observe the connection between the data collected from the electrical system and the results produced during calculations.

Simple One-line Starter Example

The following example is a good place to start. Assume that we have collected all the necessary data on the system. The goal is to include examples of several types of loads and protective devices. This example is for illustration only and is not meant as a design reference.

The system includes the following equipment:

- Utility source
- Primary fuse
- Utility transformer
- Switchgear bus
- Feeder cables
- Multiple protective devices (fuses and breakers)
- Loads, including a motor, panel, and motor control center (MCC)

Add the Utility

The first equipment we need to place on the drawing area is the utility. Its icon looks like a capital "T." Every new one-line requires at least one source of energy.

1. Open a new one-line as shown and described earlier.
2. Hover over the utility icon in the **Equipment Palette** and then click to select the icon.
3. Position the mouse pointer near the middle of the white drawing area where we are going to build our one-line and click once to place the utility. It appears red since it is not connected yet.

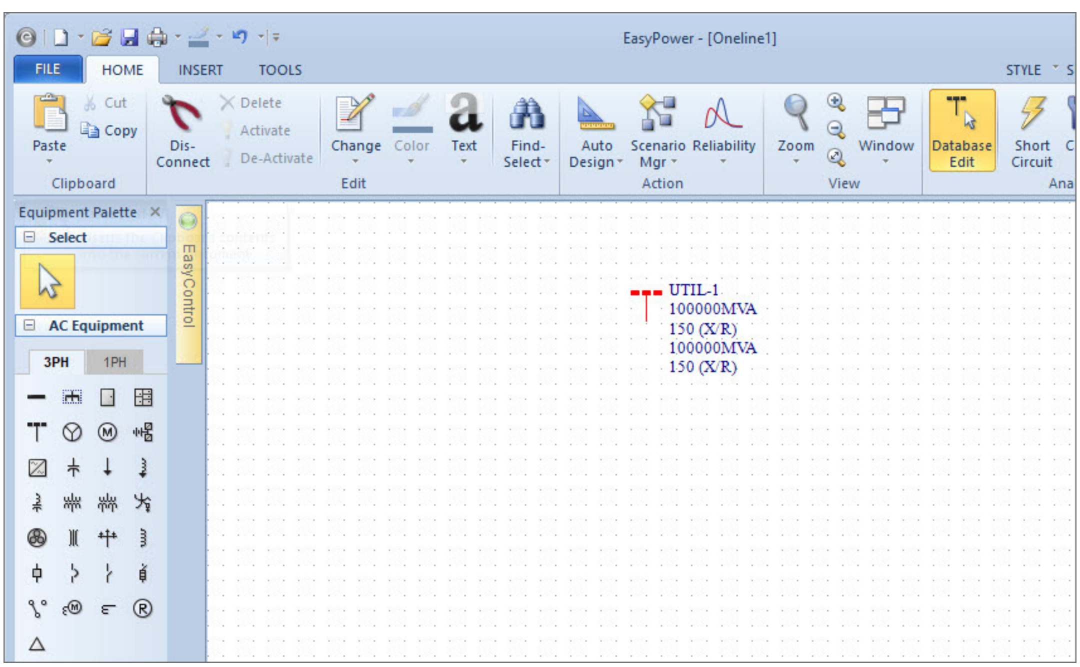


Figure 8.4: Utility Placed on the One-line Drawing

Tip: You can use the mouse roller wheel while hovering over the white drawing area zoom-in and enlarge the utility icon. There are also zoom controls in the menu and at the bottom right of the window.

Add the Transformer

Next, we want to connect the two-winding transformer icon to the utility icon.

1. On the **Equipment Palette**, select the two-winding transformer icon.
2. On the one-line, position the transformer icon so that it overlaps the bottom of the utility icon.
3. Click again to place the transformer and connect it to the utility.
4. A dialog box opens to **Set Bus Base kV**. Type 13.8 and click **OK**. (Our incoming utility voltage is 13.8 kV.)

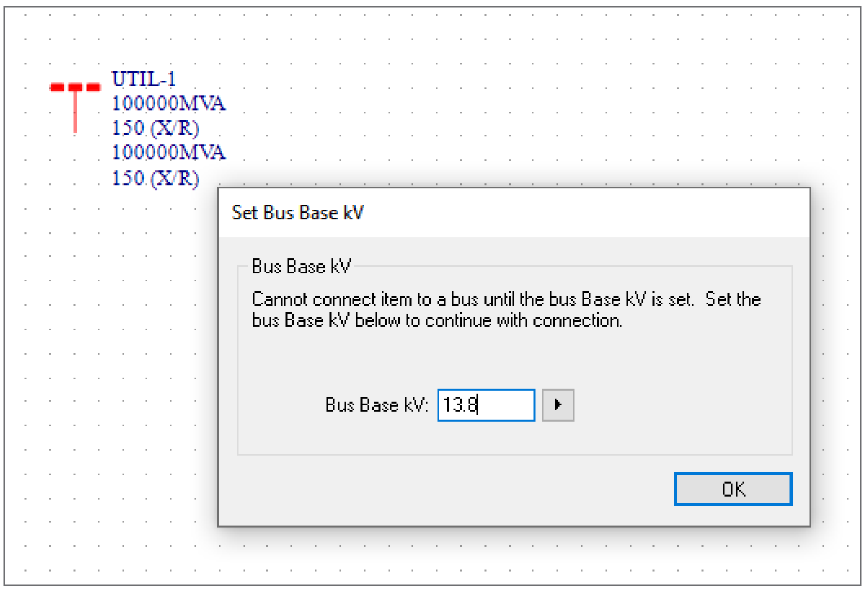


Figure 8.5: Set the Bus Base kV

5. EasyPower automatically creates a bus (a connection point) between the utility and the primary side of the transformer. The secondary connection of the transformer remains red since it is not connected.

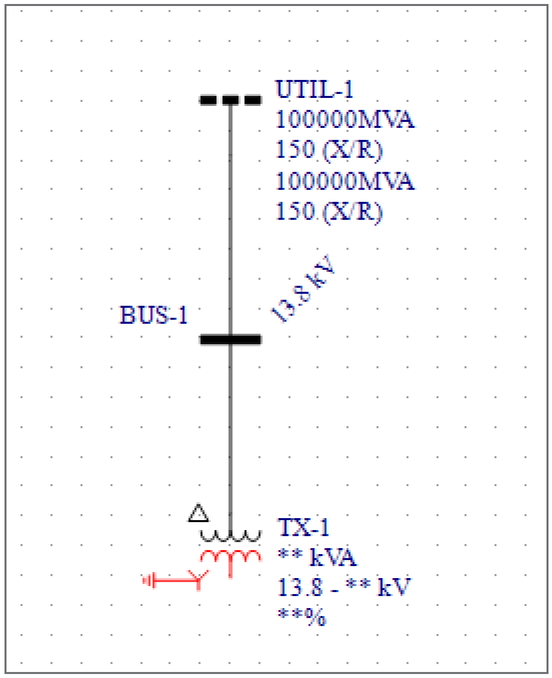


Figure 8.6: Two-Winding Transformer is Connected to the Utility

Add a Cable

Now we want to connect a cable to the secondary of the transformer.

6. Select the cable icon on the **Equipment Palette**. The cable icon is a circle with three smaller circles inside.
7. On the white drawing area, position the mouse pointer (which now is a cross-hair icon) so it touches the red end of the transformer. Click once to attach the cable.
8. A dialog box opens to **Set Bus base kV**. Type 0.48 and then click **OK**. Our system is 480 volts. Once again, EasyPower automatically creates a bus, which this time connects the transformer secondary to the cable.

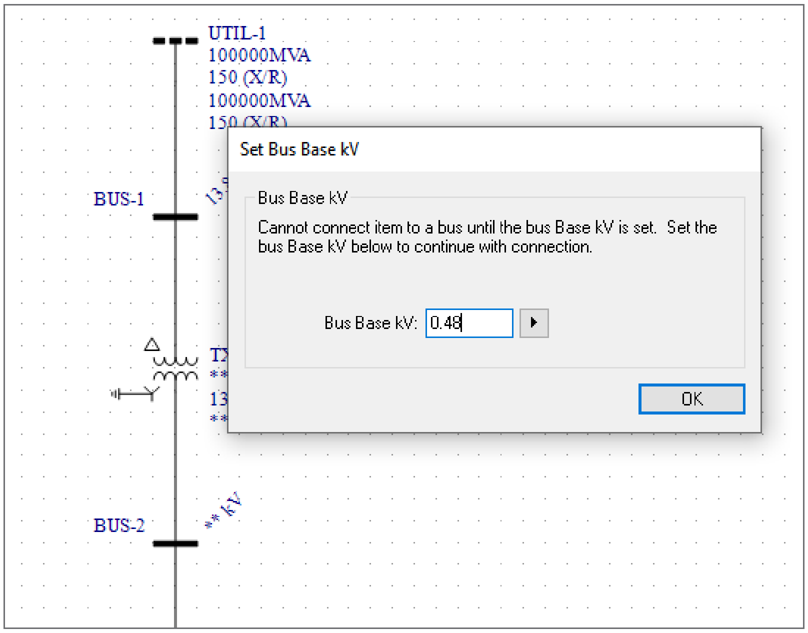


Figure 8.7: Set Bus Base kV on the Secondary Connection

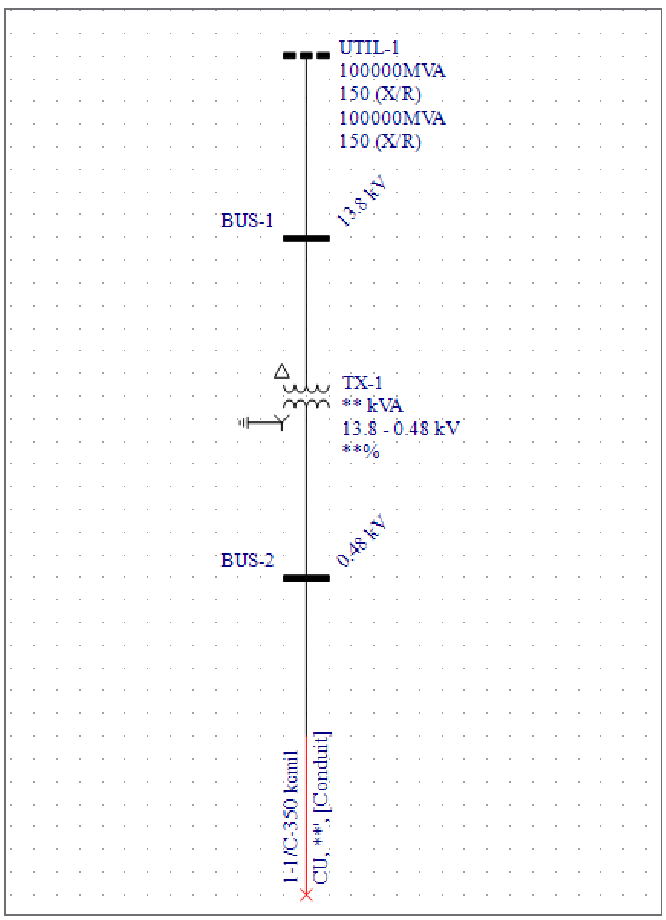


Figure 8.8: Cable Connected to the Transformer

Add a Bus

Now we want to add a bus to connect to the red end of the cable.

1. In the Equipment Palette, select the bus icon (the black bar in the top left corner of the palette).
2. Move the pointer into the white drawing area and position the bus icon so that it touches the red X at the bottom end of the cable. Click again to place the bus at the end of the cable. Your one-line diagram should look like Figure 8.9. There should be no red equipment showing.

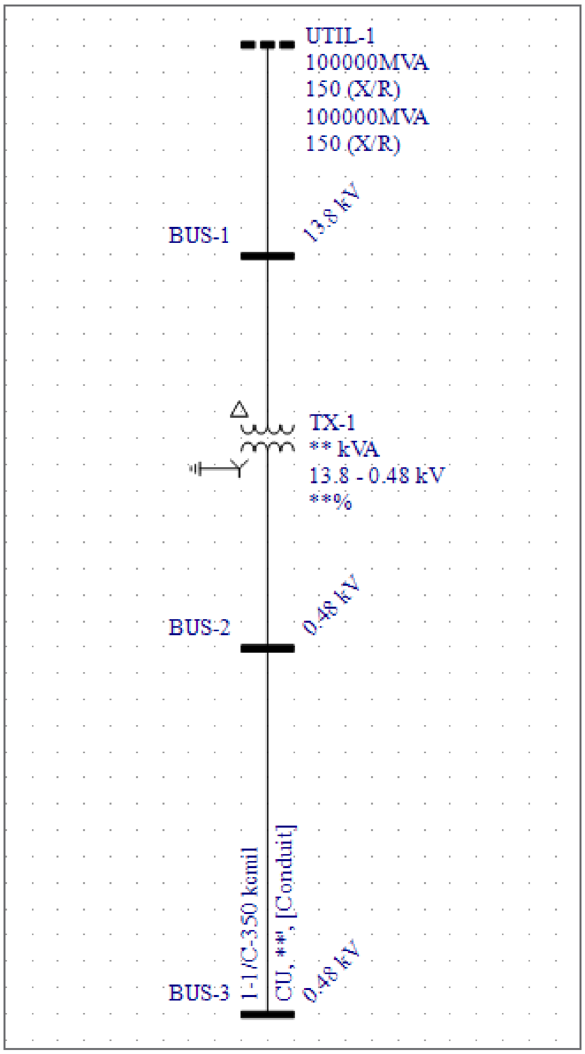


Figure 8.9: Initial One-line Diagram

Note: Names and values for newly placed equipment are set by the default equipment settings in EasyPower. Do not be concerned if you have different names or values from what is indicated for now.

Additional Functions When the Mouse Pointer is Positioned in the White Drawing Area

- If you position the pointer over the midsection of the bus (BUS-1) connecting the utility and the transformer, the pointer icon becomes a quad-arrow shape. When the quad-arrow pointer is displayed you can click and drag that equipment item anywhere on the screen.
- If you position the pointer over the end of a bus, it will become a double-ended arrow. When the pointer is a double-ended arrow, you can click and drag to extend or contract the bus length horizontally.
- If you position the pointer in an open area of the white drawing area:
  - Use the mouse roller wheel to zoom in and out to size the entire one-line drawing.
  - Press the roller wheel and drag the white hand pointer to pan (move the entire drawing).

Resize BUS-3 and use the zoom and pan features as described above to show only the bottom portion of your one-line, so the display looks like Figure 8.10.

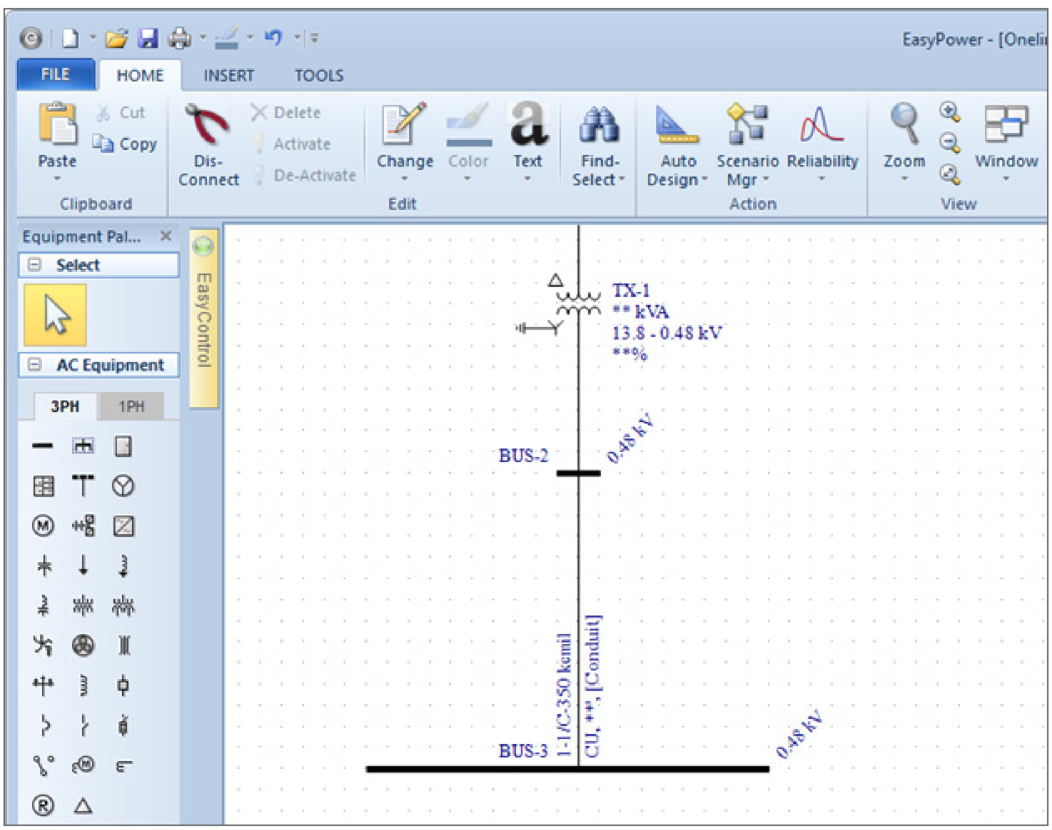


Figure 8.10: Resizing a Bus and Zooming and Panning the One-line Drawing

Add Feeder Cables to the Bus

We want to add three feeder cables to BUS-3.

1. Position the mouse pointer over the cable icon in the **Equipment Palette** and then click to select the cable icon.
2. Now, press and hold the CTRL key on your keyboard. This enables you to place the cable multiple times.
3. Position the mouse pointer to touch BUS-3 and place three cables as follows:
   a. On the left side of BUS-3, click and release.
   b. In the middle of BUS-3, click and release.
   c. On the right side of BUS-3, click and release.
   d. Now release the CTRL key.

Your one-line display should look like Figure 8.11.

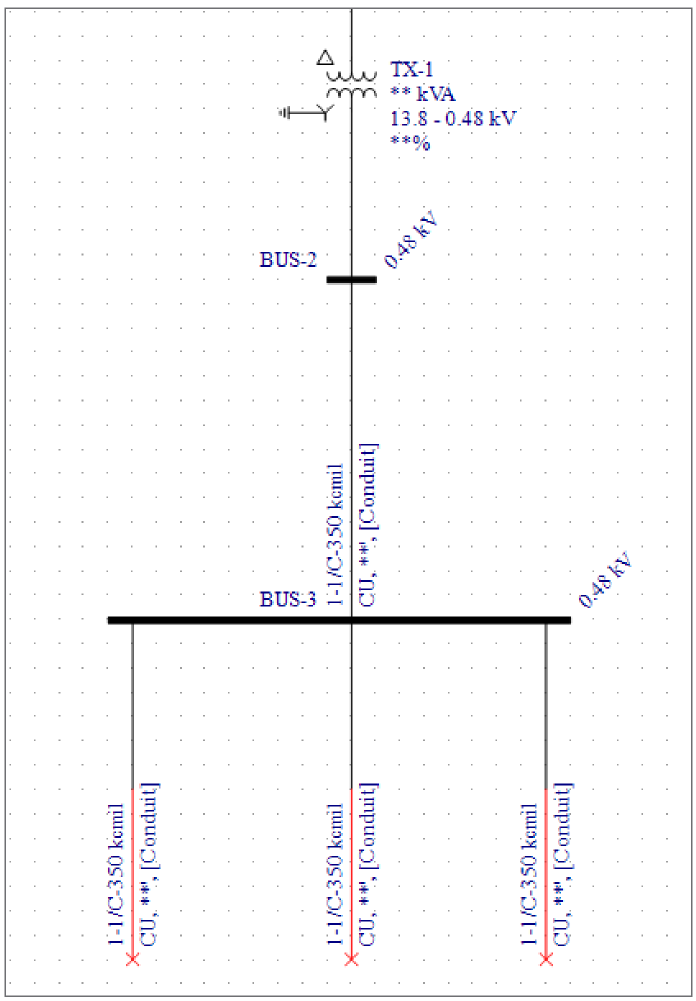


Figure 8.11: Three Cables Connected

Correct Drawing Errors with Undo

The Undo arrow in the Quick Access Tool bar can be used to remove the most recent actions in the one-line. (CTRL+Z also works). If you had a problem adding the three cables, use Undo and try again.

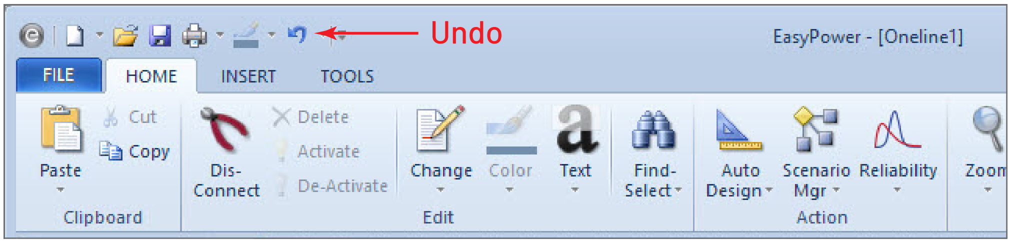


Figure 8.12: Undo

Add Loads to Each Feeder Cable

Next, we will add a motor, panel, and MCC to the bus.

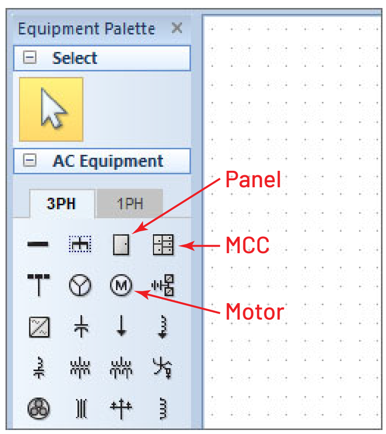


Figure 8.13: Panel, MCC, and Motor Icons on the Equipment Palette

To add the motor:

1. Select the motor icon from the **Equipment Palette**.
2. Position the mouse pointer (which now displays the motor icon) in the drawing area so that the line on the icon touches the red X on the cable (C-2) farthest to the left under BUS-3.
3. Click again to place the motor on the end of the cable. The dark color indicates the motor is connected to the cable.

If the motor icon is red, it is not touching the cable. Drag the icon until it touches the red X of the cable and then release the mouse button. If done correctly, the motor icon will no longer be red.

To add the panel:

1. Select the panel schedule icon from the **Equipment Palette**.
2. Position the mouse pointer in the drawing area so that it touches the red X of the middle cable (C-3).
3. Click again to place the panel schedule. If the icon is connected, the cable will no longer be red.

To add the MCC:

1. Select the MCC icon from the **Equipment Palette**.
2. Position the mouse pointer in the drawing area so that it touches the red X of the far-right cable (C-4).
3. Click again to place the MCC. If the icon is connected, the cable will no longer be red.

If properly completed, the lower part of the one-line diagram should look like Figure 8.14.

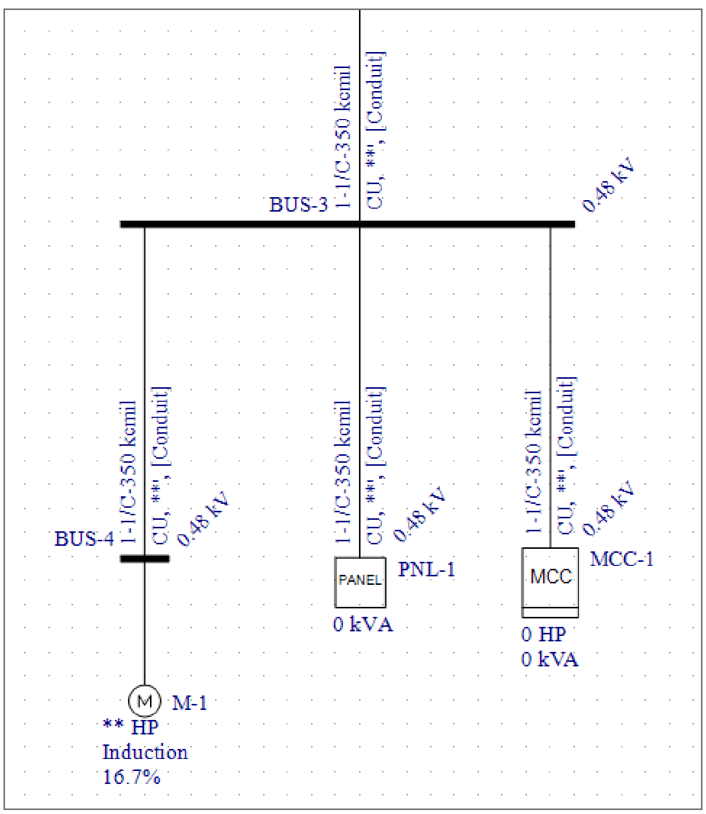


Figure 8.14: Motor, Panel, and MCC are Connected

Save Your File

It is a good idea to save your one-line periodically as you build it. Click the **Save** icon in the **Quick Access Toolbar** to save your file. You can specify a different file name and location, if desired.

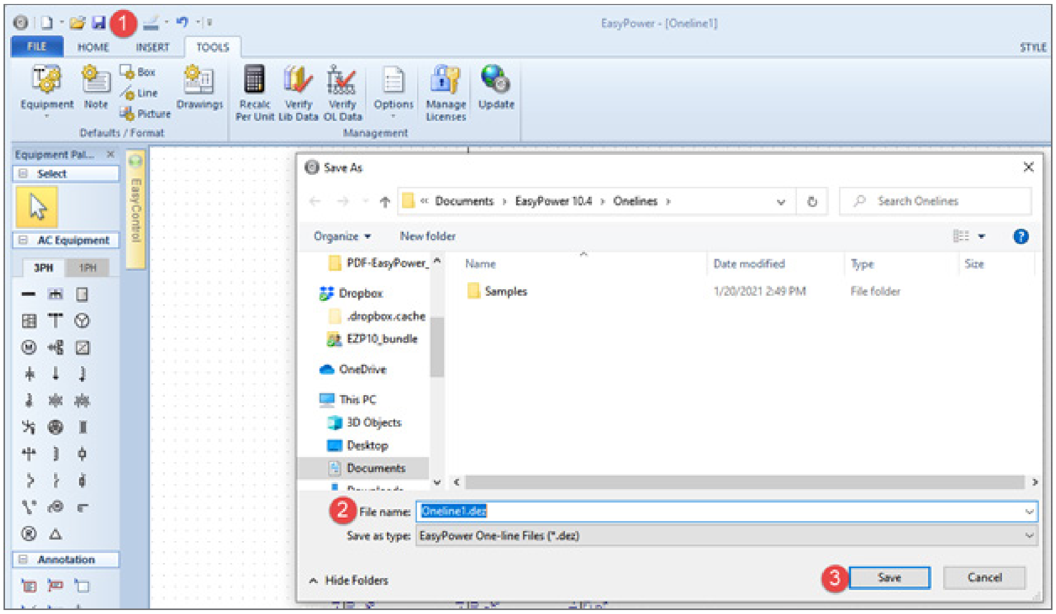


Figure 8.15: Saving Your One-line

Enter Collected Data to Model the System

Every equipment in the system has a **Data** dialog box. For now, we will only focus on required data for each equipment.

Enter the Motor Data

Let us start with the motor.

1. Double-click on the motor icon in the one-line diagram to open the **Motor Data** dialog box.
2. A unique **ID Name** is required for each equipment. At the top left of the **Motor Data** dialog box, type in SUMP PUMP to identify this load.
3. Note that there are several tabs across the center of the dialog box that are labeled **Specifications**, **Short Circuit**, **TCC**, and so on. Under the **Specifications** tab, look for the box labeled **HP** that has a red exclamation mark beside it. The red mark indicates this data is required. This motor is 50 horsepower, so type the number 50 in that box.

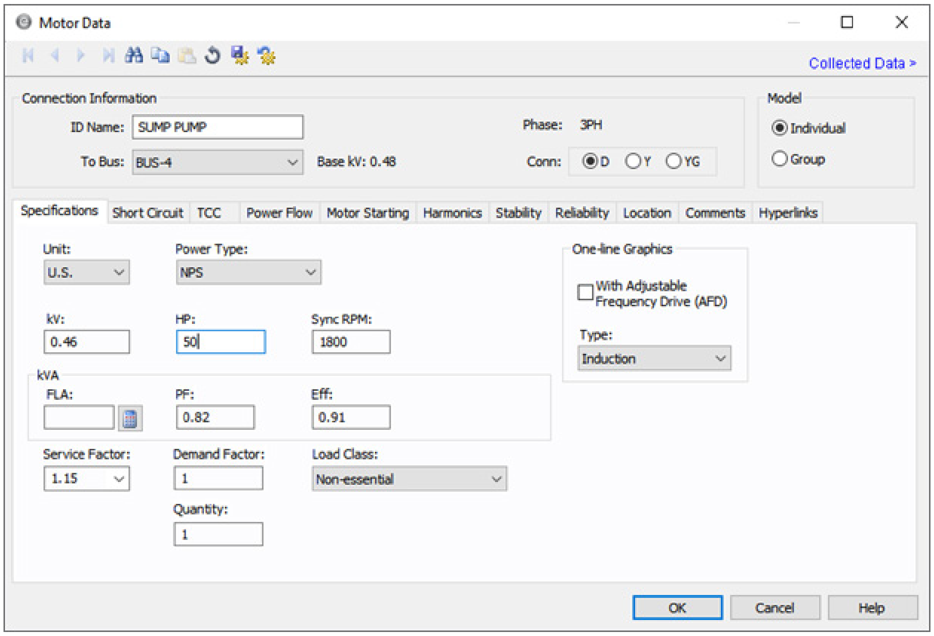


Figure 8.16: Data Entered in the Motor Specification Tab

4. Now click the **Short Circuit** tab.
5. Note that the box labeled **X/R** that has a red exclamation mark beside it. We do not know the X/R value of the motor, but EasyPower can calculate it based upon the typical values shown. Click the **Calculate** button and note the change in X/R.

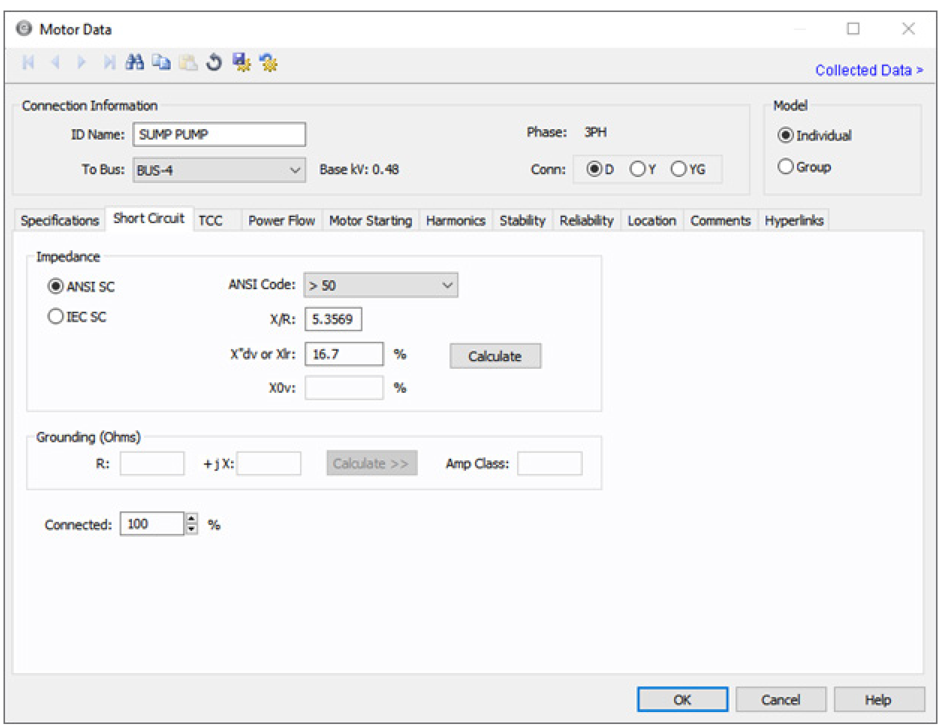


Figure 8.17: X/R Calculated in the Motor Short Circuit Tab

6. For now, this completes the minimum data required to calculate short circuit current with this motor. Click **OK** at the bottom on the dialog box and the one-line diagram is updated.

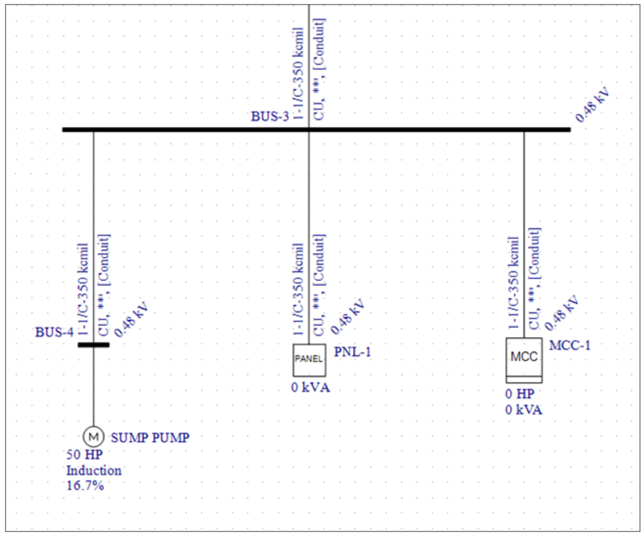


Figure 8.18: Data Displayed on Motor

Label Options for Equipment on the One-line

Notice in the figure below, the name for the motor is missing and the name and data for the cables are oriented differently than we saw in Figure 8.18. This is due to modifications to the global settings for **Text Visibility** which we will discuss next.

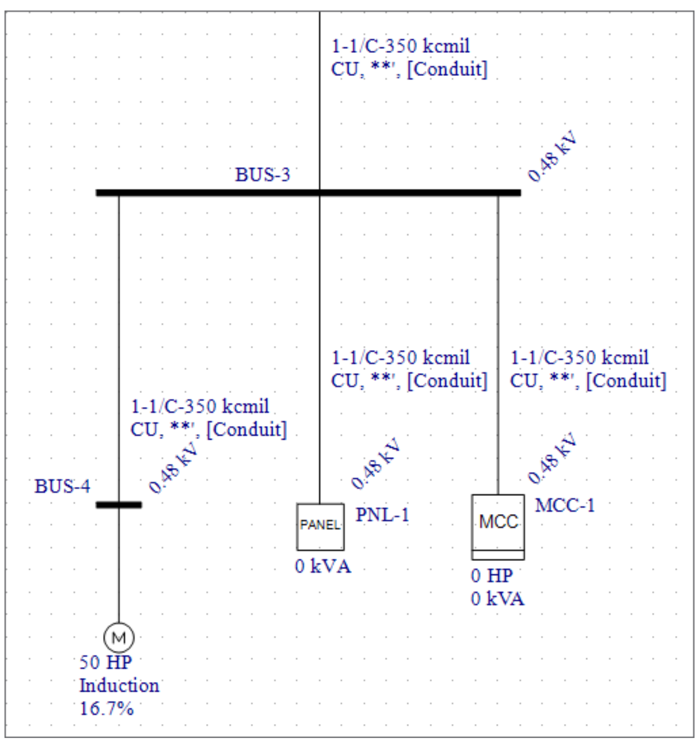


Figure 8.19: One-line that Reflects Text Visibility Settings

Change the Options for Text Visibility

You can specify which items display their names and data globally on the one-line.

1. Position the pointer in an open white space of the drawing with nothing selected, and then right-click to display a context menu.
2. Click **Options**.
3. Click **Text Visibility**. Refer to Figure 8.20 below.
   - To display the name of an item on the one-line diagram, in the **Show name for** column, select the check box for that equipment type.
   - To display data for an item on the one-line diagram, in the **Show data for** column, select the check box for that equipment type.
4. To display cable data horizontally, under **Line Data Text Location**, select the **With ID Name** option.
5. In the **Show name** for column, clear the **Motor** check box.
6. Click **OK** to close the dialog box. Note that your one-line display now matches Figure 8.19.

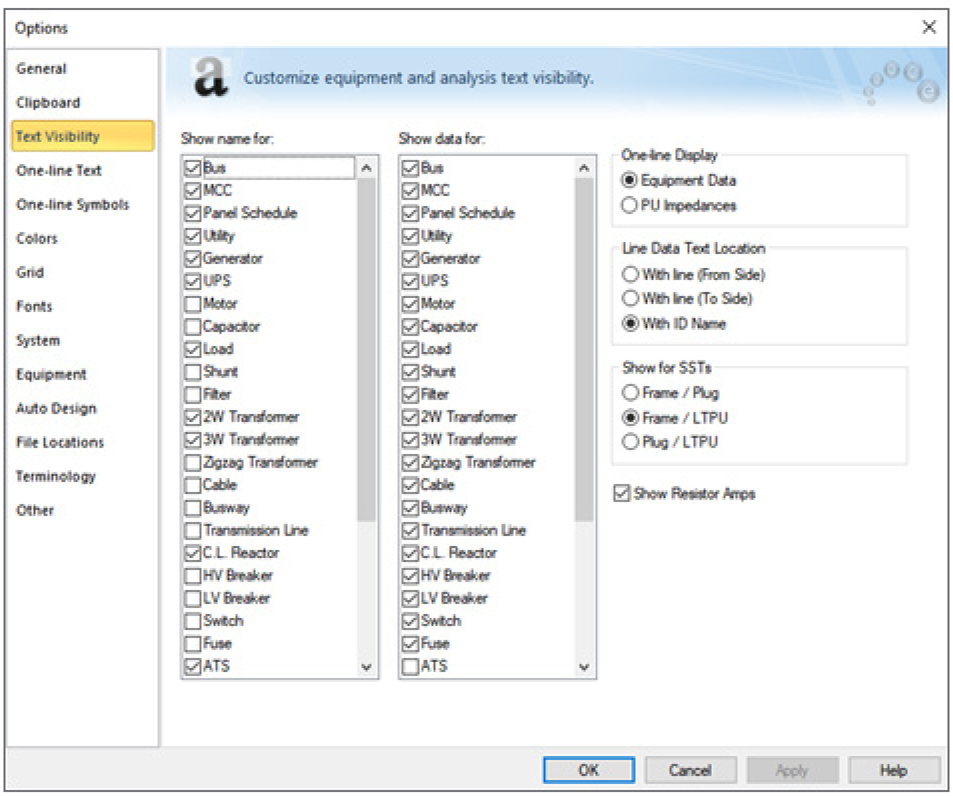


Figure 8.20: Options – Text Visibility Tab

To help identify the different equipment on the one-line for the remainder of this exercise, reopen the **Options** dialog box, click the **Text Visibility** tab, and select the

Show Name for check boxes to show the names for the following items:

- **Motor**
- **Cable**
- **LV Breaker**

Click **OK** to save your changes.

Add Breakers

We can add breakers to the one-line by selecting the **LV Breaker** symbol on the **Equipment Palette**, and then clicking on the places where we want to add the breakers.

Place the main breaker for BUS-3 and the three feeder breakers as shown below in Figure 8.21. Zoom in and ensure the breaker icon is aligned with its respective cable.

If the breaker is properly inserted, it will move with the cable when you position the mouse pointer on the cable and move cable a small distance left or right.

The breaker data displayed in your one-line may be slightly different from what is shown because of different default settings.

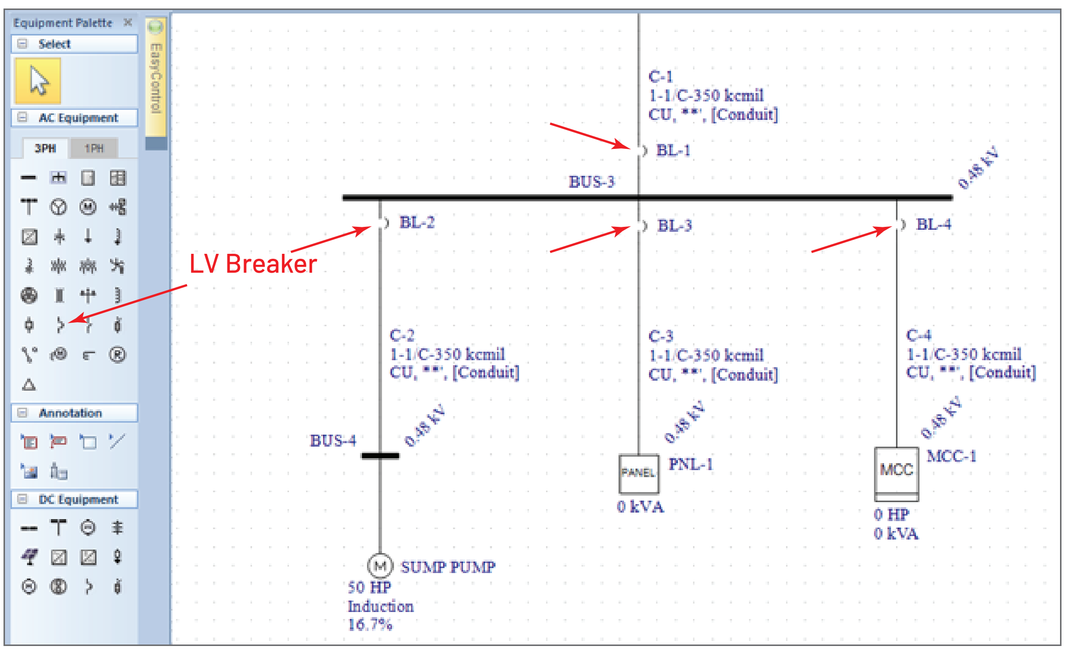


Figure 8.21: Adding Breakers

Enter the Cable Data

For this exercise we will enter data for Cable C-2 and then copy and paste the data into the other 3 cables. Actual systems usually have different values for each feeder, but this copy and paste feature can become useful as you build larger one-line projects.

1. Double-click on cable C-2 to open the **Cable Data** dialog box.
2. Enter the following data:
    - **No/Ph**: 1
    - **Type**: 1/C
    - **Insulation**: THHN
    - **Size**: 2
    - **Length**: 50 (Note that this is a required field)
    - **Conduit Material**: Copper
    - **Raceway**: Conduit
    - **Material**: Steel

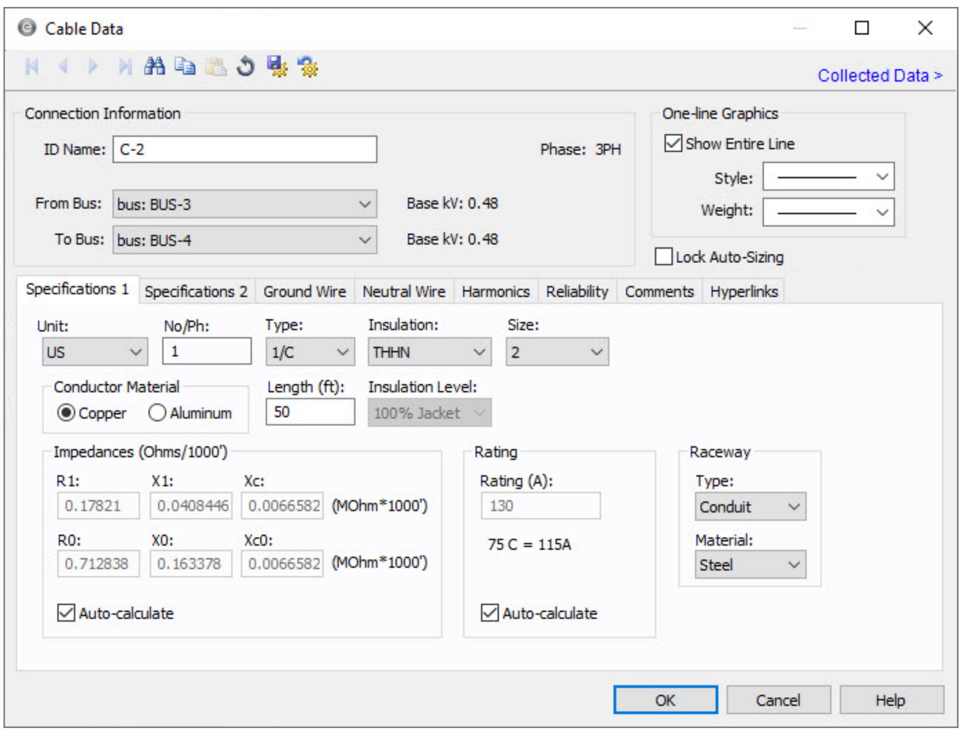


Figure 8.22: Cable Data

3. With the **Auto-calculate** boxes checked, the **Impedances** and **Rating (A)** data boxes are filled with required data.
4. Click **OK** to close the dialog box and save the data. Note that the data displayed for cable C-2 on the one-line has been updated.

Copy and Paste the Cable Data

To copy and paste the data:

1. Right-click on cable C-2 and select **Copy**.

2. Right-click on cable C-3 and select **Paste**.
3. Repeat Step 2 for cables C1 and C4.

Tip: You can also copy the data from one item and then select multiple items in which to paste the data. Data for equipment items that are of a different type than the equipment from which the data was copied are ignored. The type of equipment from which you are copying data is displayed in the **Status** bar.

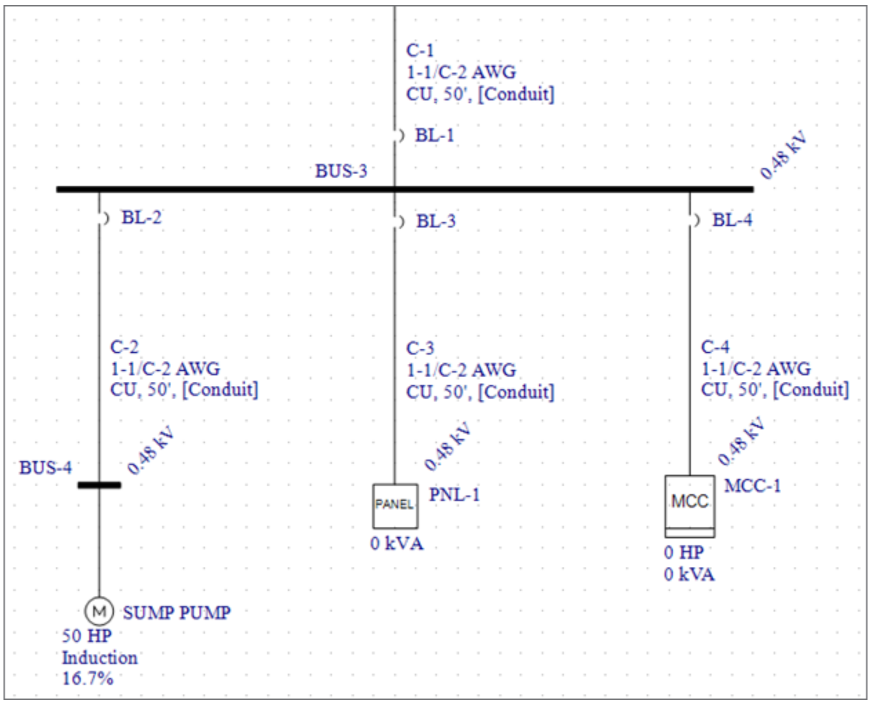


Figure 8.23: One-line Display After Copying and Pasting the Cable Information

Enter the Panel Data

For this exercise we will only enter one load for the panel. More detailed information on data entry for panels can be found in the EasyPower User Manual.

To enter the panel data:

1. Double-click on the panel icon and enter the data below:

   a. On the **Specifications** tab, enter:

   - **Mfr** (manufacturer): SQD
   - **Main Bus Rating**: 200
   - **Panel SC Rating** (short circuit rating): 22

   b. Click the **Incoming** tab, and enter the following data:

   - **Incoming Device Type**: Main Lug Only
   - **Incoming Branch**: Cbl:C-3

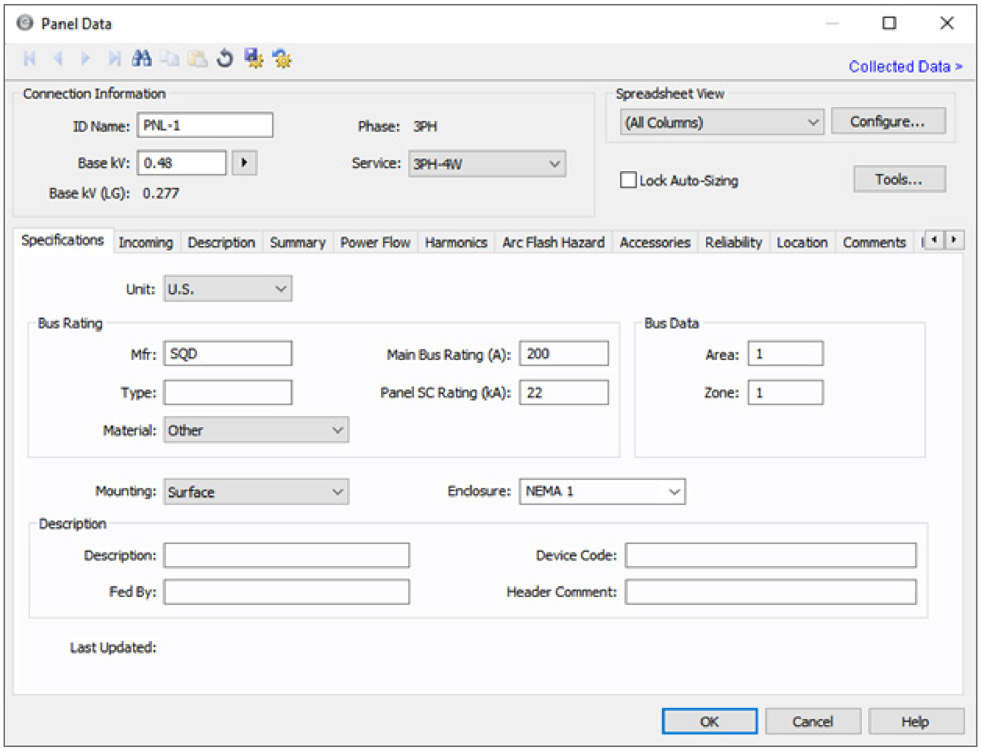


Figure 8.24: Panel Specifications Tab

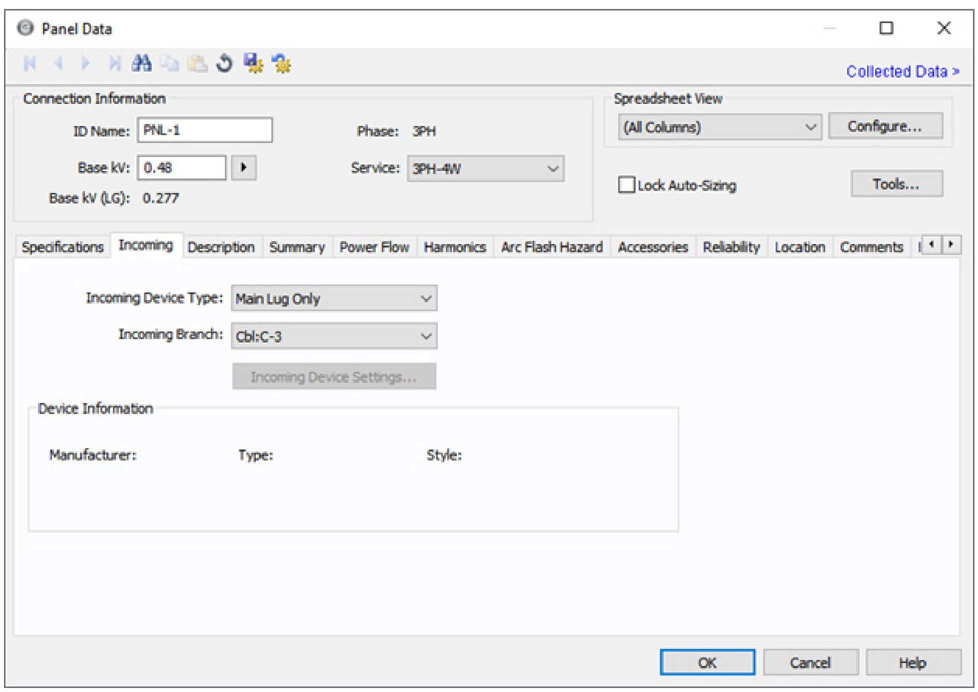


Figure 8.25: Panel Incoming Tab

2. Click the **Description** tab. The **Panel Schedule Spreadsheet Creation Wizard** is automatically displayed.
3. For the number of rows to create, enter 3 and then click **OK**.

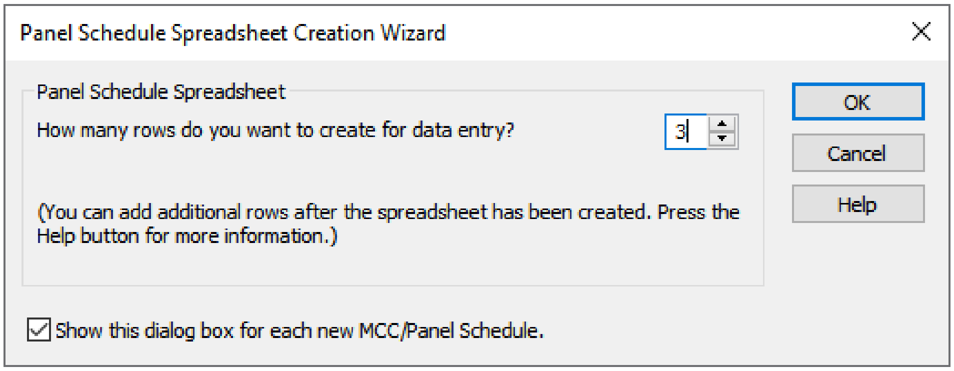


Figure 8.26: Panel Schedule Spreadsheet Creation Wizard

4. The spreadsheet is displayed with 3 rows created. This example is using one three-phase load for the panel. For the **View**, select **Detailed – Right Side**.
5. Use the scrollbar at the bottom of the spreadsheet to scroll right so that the **CB/Fuse Poles** column is displayed.
6. In the **CB/Fuse Poles** column, enter a 3 in the top row, then press TAB to move out of the cell. This indicates a 3-phase load.
7. In each **VA** column, below **Connected Load**, enter 1100. Use the scroll bar at the bottom of the dialog box to locate the correct columns.

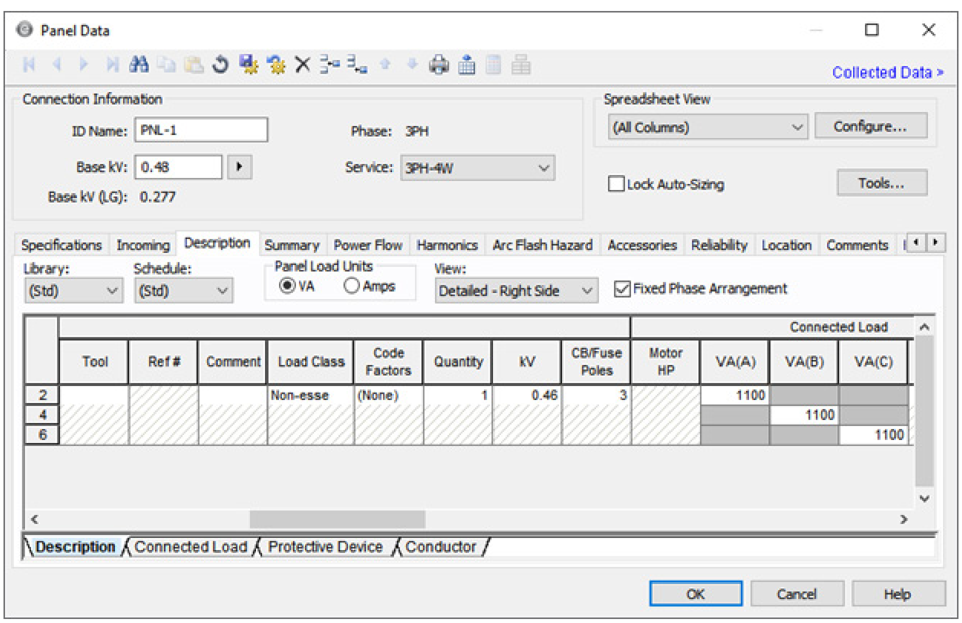


Figure 8.27: Connected Load on the Description Tab

8. Click the **Summary** tab, and then click **Calculate Downstream Load**.

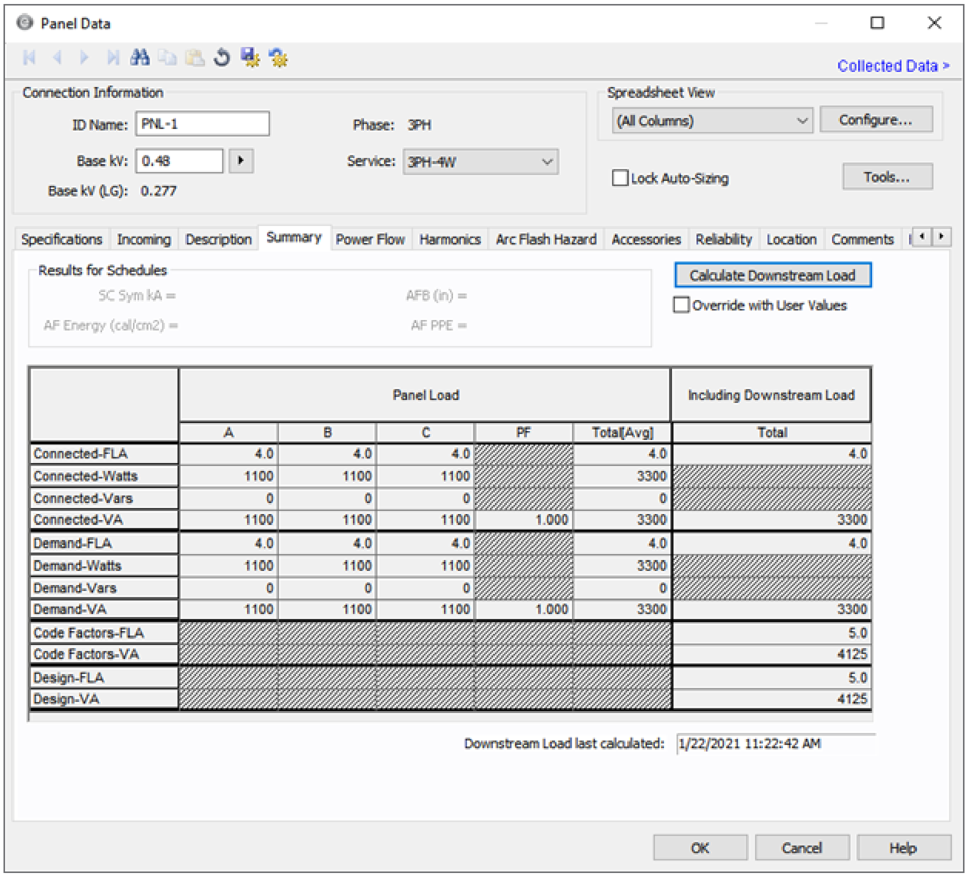


Figure 8.28: Calculate Downstream Load

9. Click **OK** when asked if you want to update the code design kVAs.

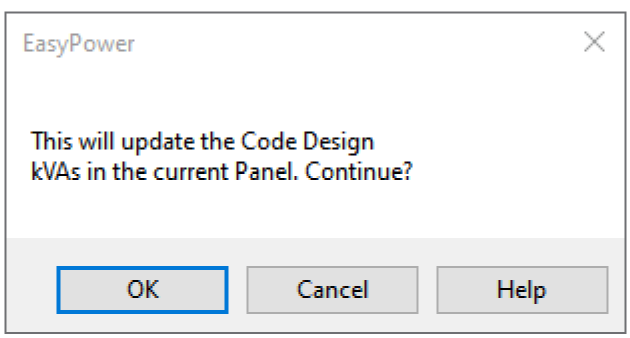


Figure 8.29: Update the Code Design kVAs Message Box

10. Click **OK** to close the **Panel Data** box.

Enter the Data for the MCC

For this exercise we will only enter one load for the MCC. More detailed information on data entry for MCCs can be found in the EasyPower User Manual.

1. Double-click on the MCC to open **MCC Data** dialog box.
2. On the **Specifications** tab, enter the following:
   - **Bus SC Rating (kA)**: 42
   - **Horz Bus Rating (A)**: 400
   - **Vert Bus Rating (A)**: 400

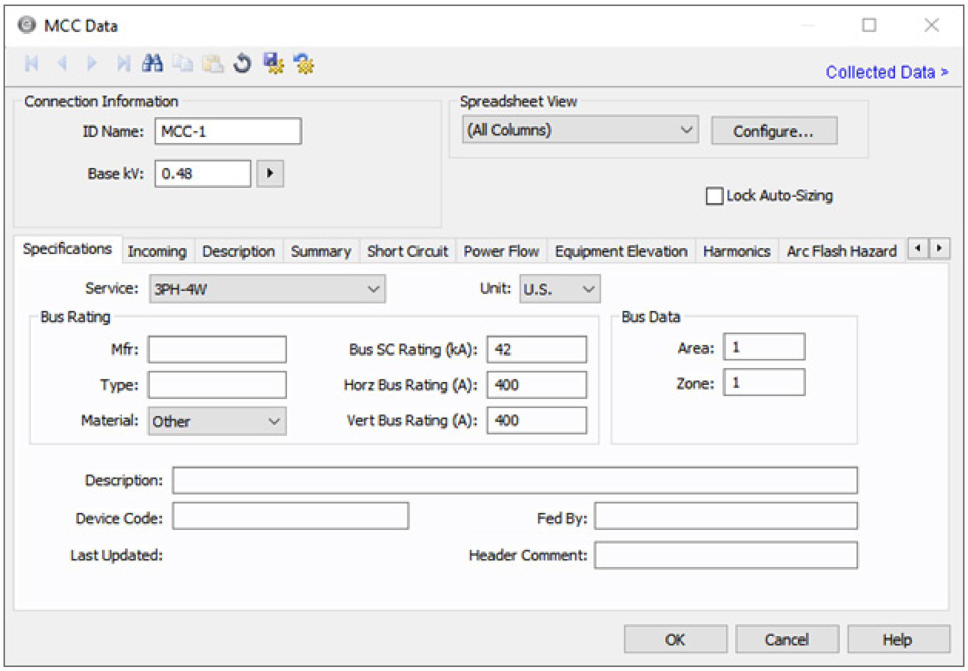


Figure 8.30: MCC Specifications Tab

3. Click the **Incoming** tab and enter the following:
   - **Incoming Device Type**: Main Lug Only
   - **Incoming Branch**: Cbl: C-4

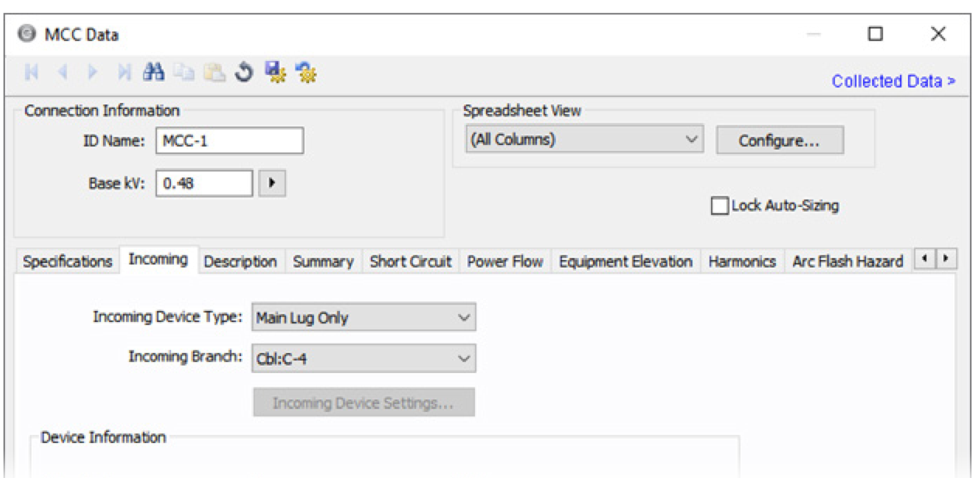


Figure 8.31: MCC Incoming Tab

4. Click the **Description** tab. This opens the **MCC Spreadsheet Creation Wizard**. We are using the main lug only and are only entering one motor to simplify the example.
5. Leave the row selection as 1 and click **OK** to display the spreadsheet.

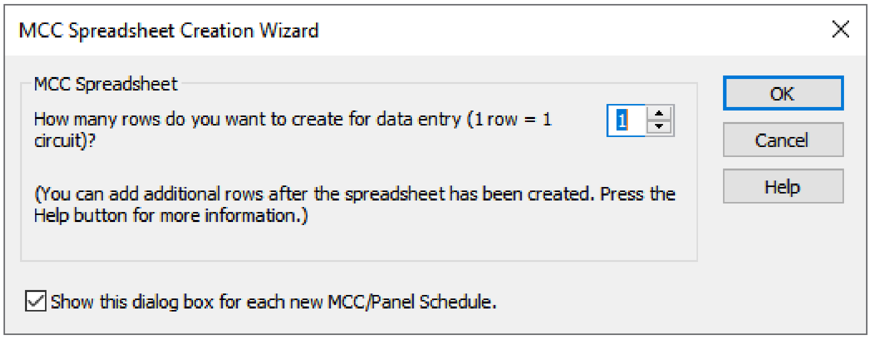


Figure 8.32: MCC Spreadsheet Creation Wizard

6. Scroll to the **Motor Specifications** section of the spreadsheet.
7. Under **Motor HP**, enter 50. The red background indicates that this is a required field.
8. Tab on keyboard to reach the **Motor X/R** column, which is highlighted in red, also indicating the value is required. The bold font in the column title indicates the value can be calculated by clicking the **Calculator** icon at the top of the **MCC Data** dialog box. Click the **Calculator** icon.

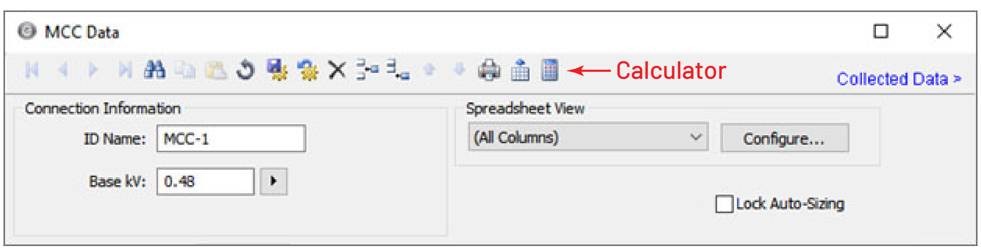


Figure 8.33: MCC Description Tab, Motor Specification Section

9. Using the bottom tabs near the lower scroll bar, click the **Protective Device** tab.
    - **Device Mfr**: (Generic)
    - **Device Type**: Std
    - **Device Style**: 150 AF
    - **Trip (A)**: 100
    - **Int kA**: (Press **Calculate** then tab off the cell.)

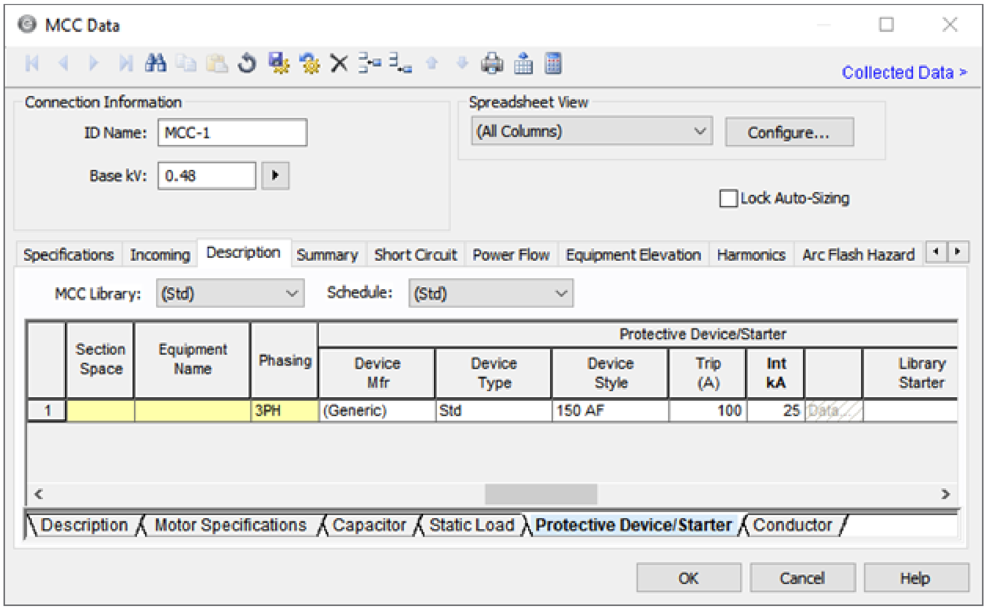


Figure 8.34: MCC Description Tab, Breaker Specification

10. Click the **Summary** tab and click then click **Calculate Downstream Load**. When asked if you want to update the Code Design kVAs in the current MCC, click **OK**.

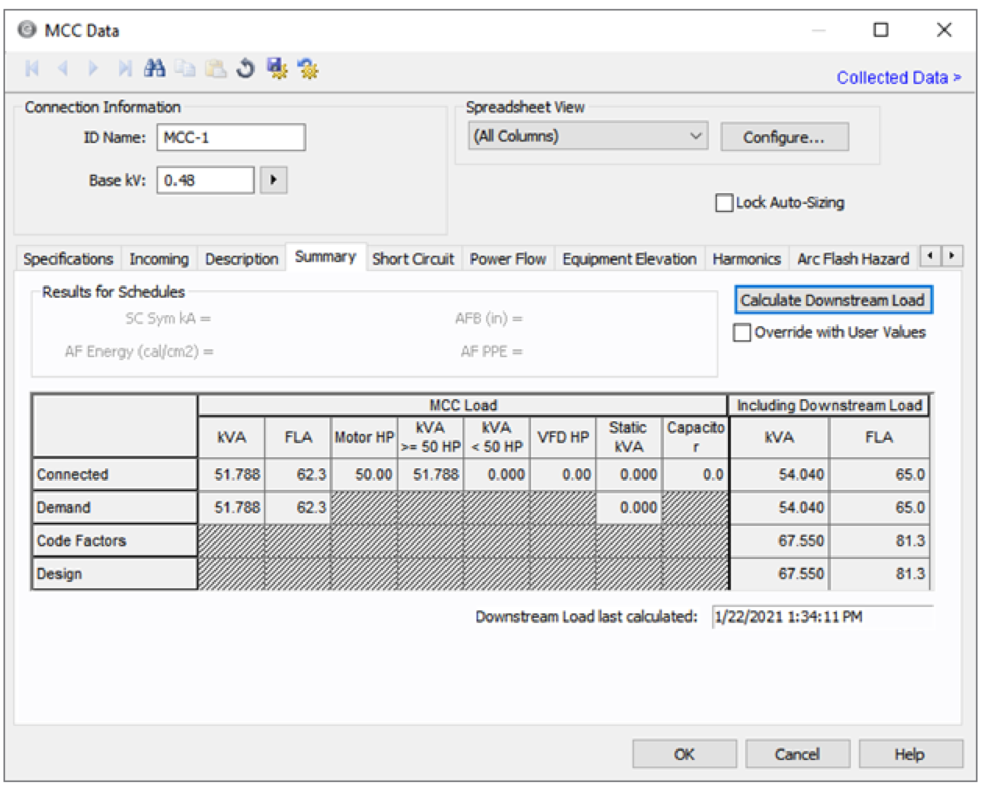


Figure 8.35: MCC Summary Tab

11. Click the **Short Circuit** tab and then click the **Calculate** button to generate the required estimate of the **X/R Avg** for the total MCC.

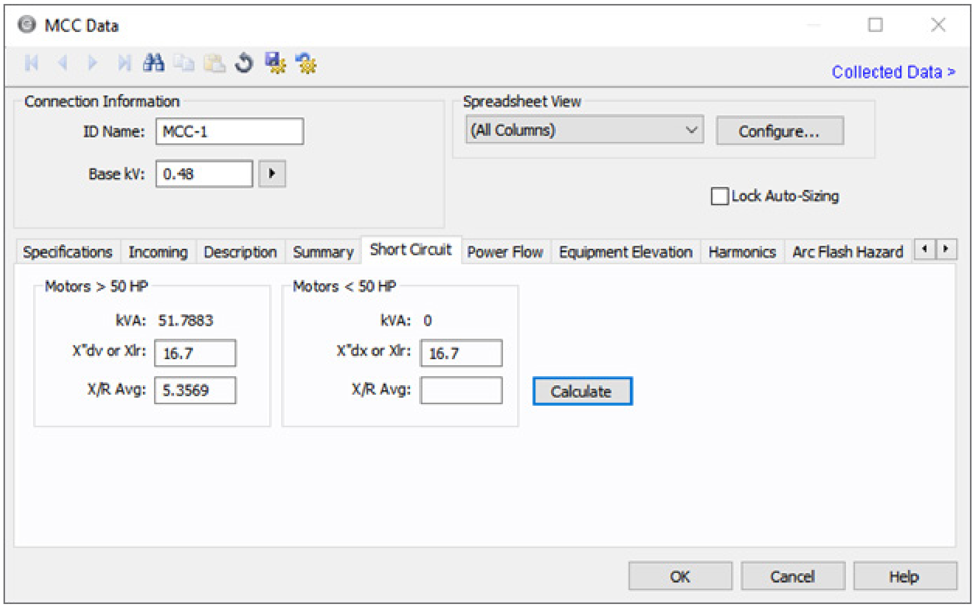


Figure 8.36: MCC Short Circuit Tab, Calculate X/R Average

12. Click **OK** to close the **MCC Data** dialog box.

Enter the Main Breaker Data

1. Double-click on the main breaker above BUS-3.
2. On the **Specifications** tab, enter data below:
   - **ID Name**: MAIN
   - **Class**: MCCB
   - **Breaker Mfr**: SQD
   - **Breaker Type**: (Std)
   - **Breaker Style**: MAL

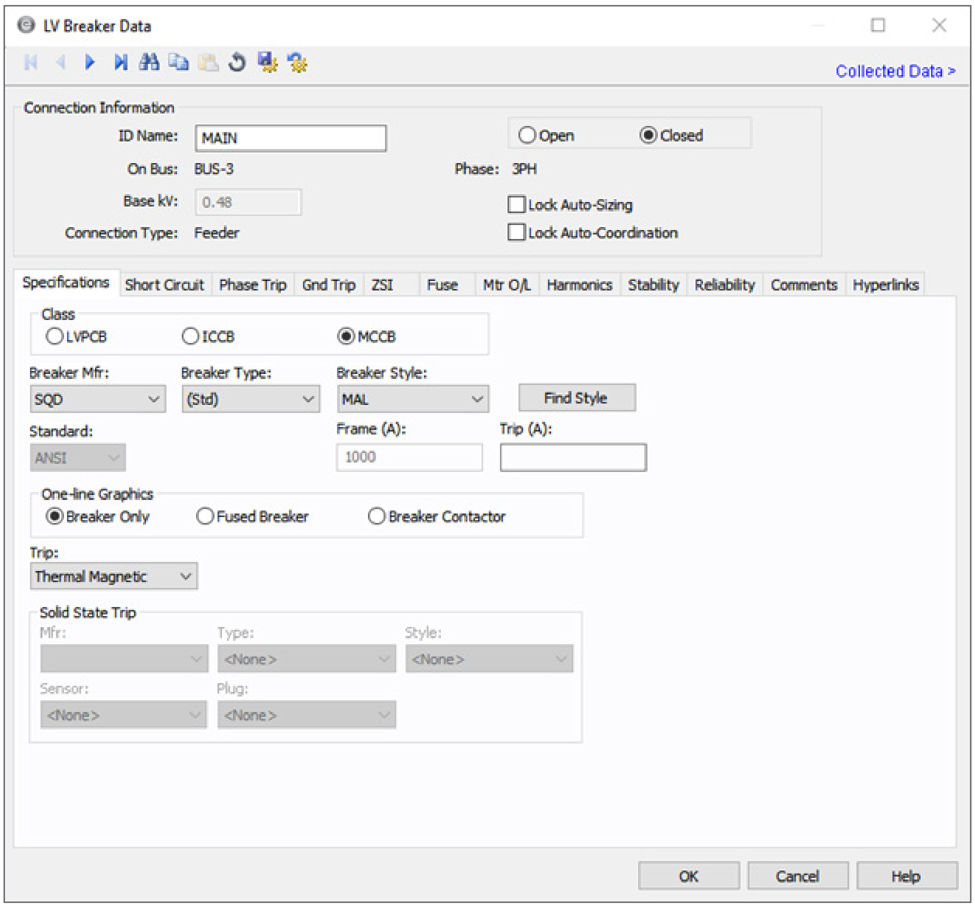


Figure 8.37: Main Breaker, Specifications Tab

3. Click the **Short Circuit** tab.
4. Click the **Calculate** button on the **Short Circuit** tab and notice that the **Interrupting** (kA) value changes. This indicates that the data sheet for the part number that was entered on the **Specifications** tab was found in the device library. These datasheet values will be used during any EasyPower analysis.

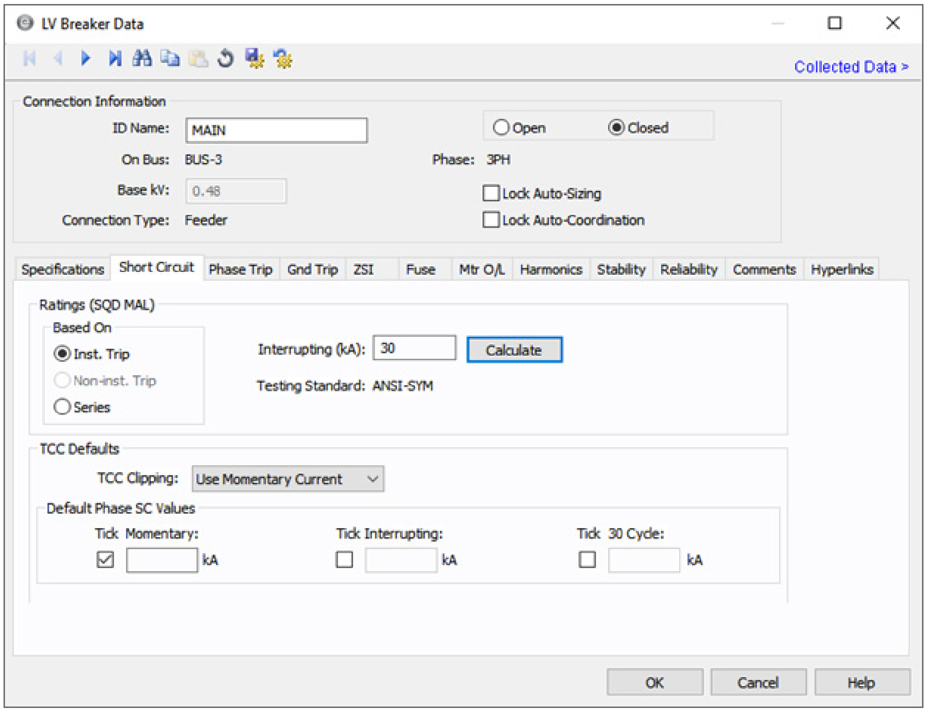


Figure 8.38: Main Breaker, Short Circuit Tab

5. Click the **Phase Trip** tab and enter the following data:
    - **Frame**: 1000A (500AT)
    - **Trip Amps**: 500
    - **Instantaneous**: 4750

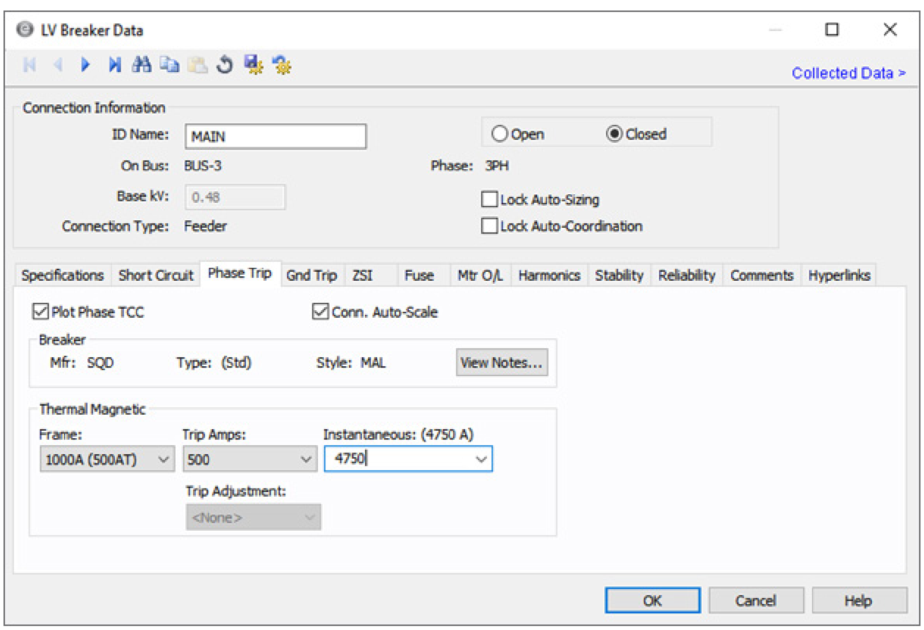


Figure 8.39: Main Breaker – Phase Trip Tab

6. Click **OK** to close the **Breaker Data** dialog box.

Enter the Feeder Breaker Data

1. On the one-line diagram, double-click on BL-2 (the left feeder breaker) to open the **Breaker Data** dialog box.
2. On the **Specifications** tab, enter the following data:
   - **Class**: MCCB
   - **Breaker Mfr**: SQD
   - **Breaker Type**: (Std)
   - **Breaker Style**: EDB

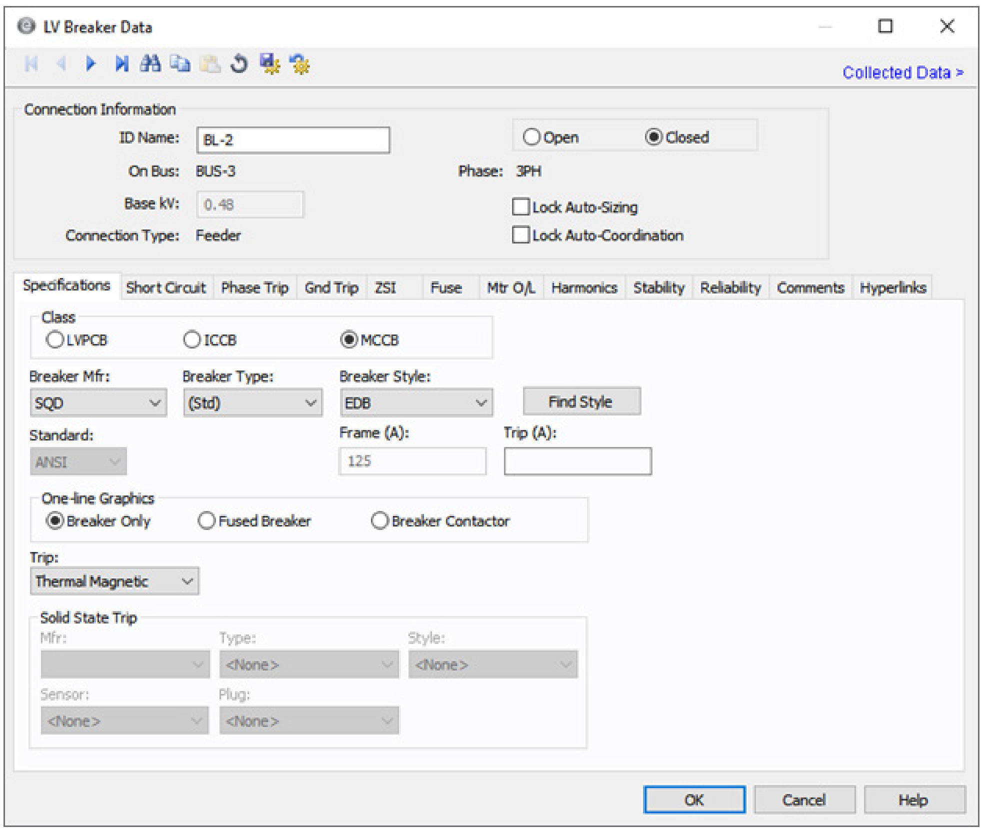


Figure 8.40: Feeder Breaker – Specifications Tab

3. Click the **Short Circuit** tab and then click on **Calculate** to import the **Interrupting (kA)** value from the device library.

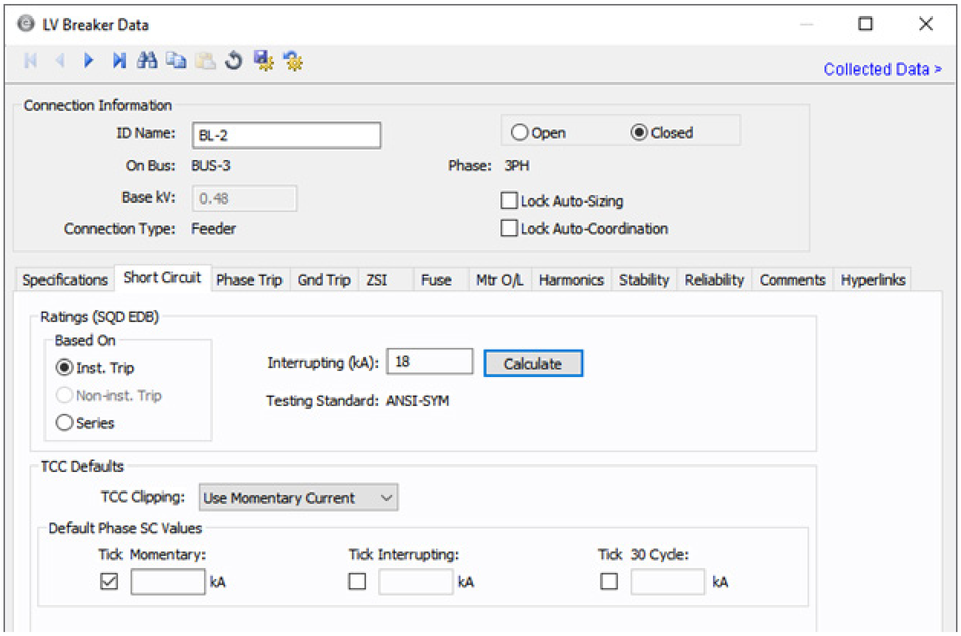


Figure 8.41: Feeder Breaker – Short Circuit Tab

4. Click on the **Phase Trip** tab to enter the following data:
   - **Frame**: 125A(110AT)
   - **Trip Amps**: 110

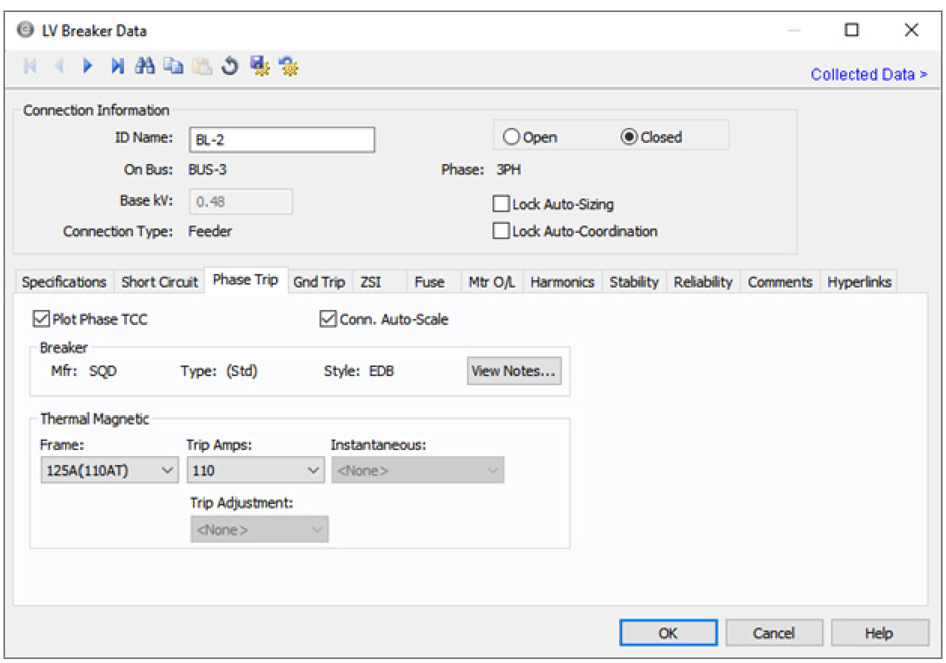


Figure 8.42: Feeder Breaker – Phase Trip Tab

5. Click **OK** to close the **Breaker Data** dialog box.

Copy and Paste Feeder Breaker Data

1. Right-click on the left feeder breaker (BL-2) and select **Copy**.
2. Right-click on the middle feeder breaker (BL-3) and select **Paste**.
3. Repeat Step 2 to paste the data to the right feeder breaker (BL-4). The one-line should look like the figure below.

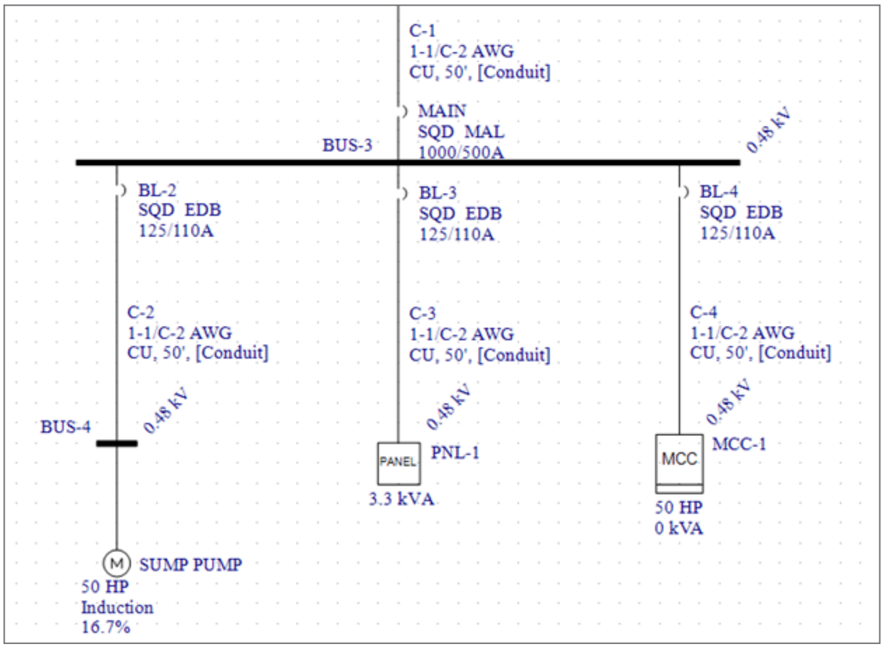


Figure 8.43: Data Entered for Loads, Cables and Breakers

Enter the Transformer Data

1. Use zoom and pan mouse controls to center the transformer on your screen.
2. Double-click on the transformer to open **Transformer Data** dialog box.
3. On **Specifications** tab, enter the following data:
    - **Standard**: ANSI
    - **Type**: Oil
    - **Class**: OA
    - **Temp**: 65
    - **kVA Rating**: 1000

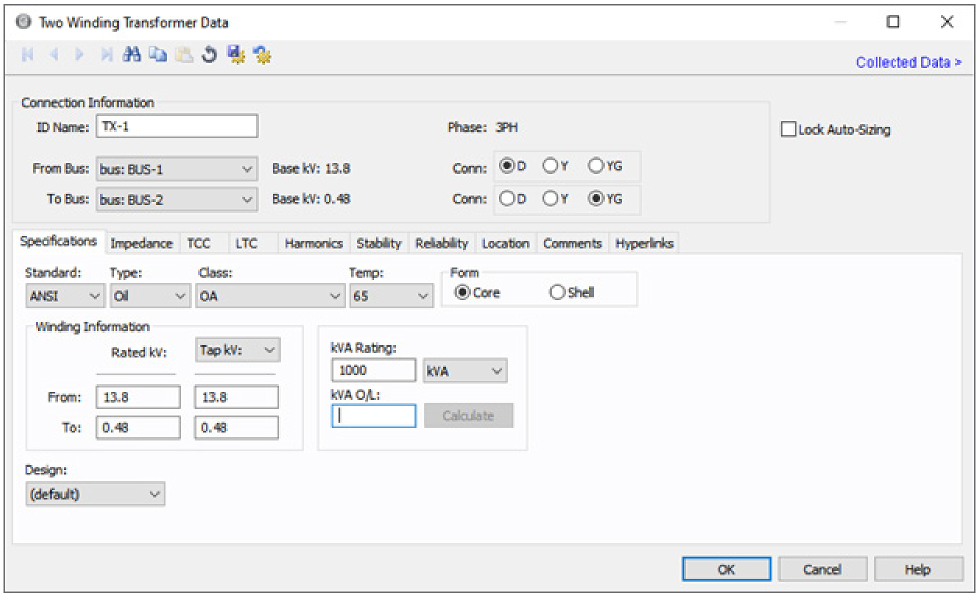


Figure 8.44: Transformer Data – Specifications Tab

4. Click the **Impedance** tab.
5. Enter 6 for **Z%** and then click **Calculate**.

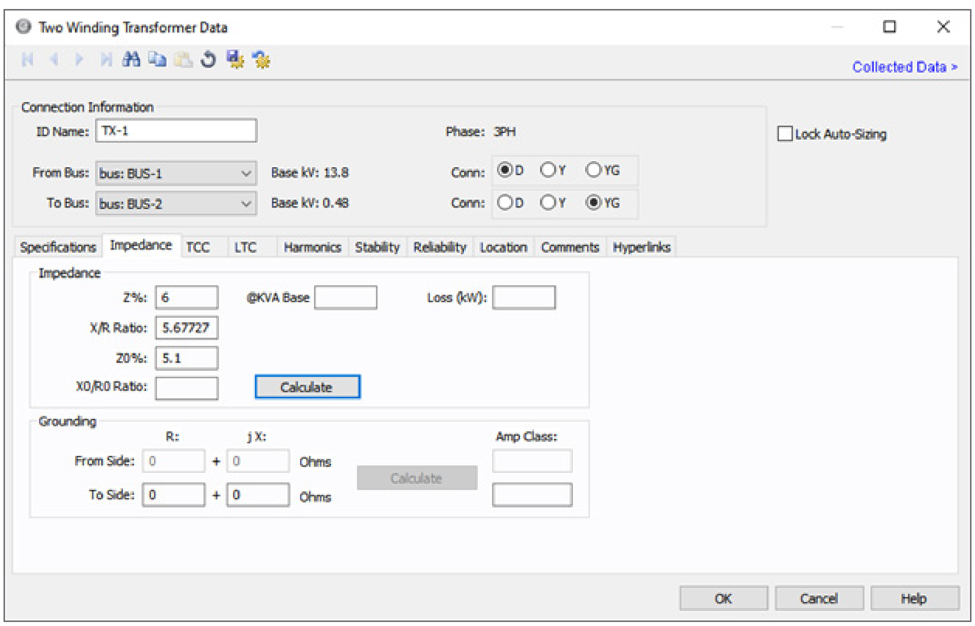


Figure 8.45: Transformer Data – Impedance Tab

6. Click **OK** to close **Transformer Data** dialog box.

Insert the Primary Fuse and Enter Data

We want to add a fused switch to our one-line on the primary side of the transformer.

1. Select the fused switch icon from the **Equipment Palette**.
2. Position the mouse pointer (which now displays the fused switch icon) below BUS-1 in line with the primary lead of the transformer and then click to place the fused switch on the line. If it remains red, it is not in the circuit and you will need to reposition it. If the fused switch is properly connected, it will not move horizontally unless transformer lead moves also.

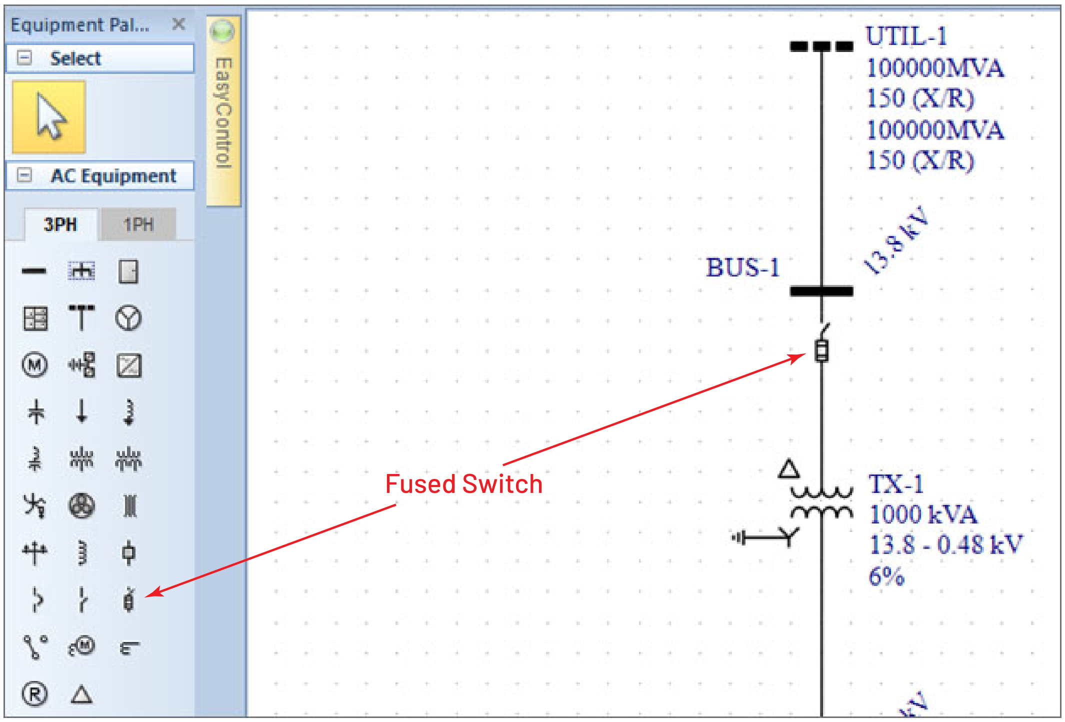


Figure 8.46: Correctly Place Fused Switch (FS-1)

3. Double-click on the fused switch to open the **Fused Switch Data** dialog box.
4. On the **Specifications** tab, enter the data shown below:
   - **Mfr**: A.B. Chance
   - **Type**: Fuse Links
   - **Style**: Fuse Link
   - **Model**: T
   - **Size**: 10

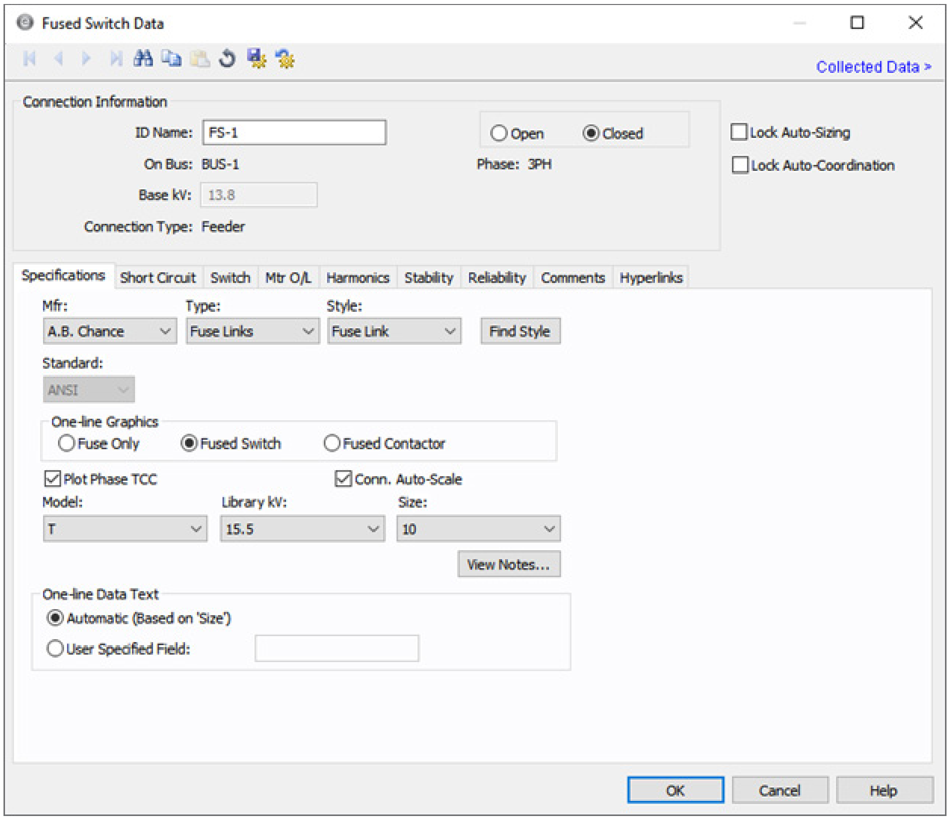


Figure 8.47: Fused Switch Data – Specifications Tab

5. Click **OK** to close the dialog box.

Enter the Utility Data

Notice that the utility icon had several data values already included when it was first placed on the one-line. These numbers are representative of an Infinite Source. This is helpful in making an initial estimate of the system's ability to withstand a fault in the system.

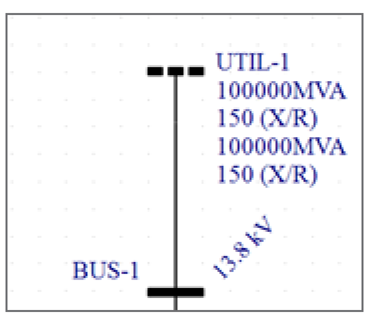


Figure 8.48: Utility Data, Infinite Source

The actual utility short circuit current may be quite different, so it is important to contact the utility company to receive actual system information before you finalize your arc flash analysis. A lower arcing current can actually yield higher arc flash incident energy in some cases since the lower current can cause protective devices to take longer to trip. For now, we will input some realistic values for utility short circuit current.

1. Double-click on the utility in your one-line diagram to open the **Utility Data** dialog box.
2. Enter the data below:
   - **Fault Duty Unit**: kA
   - **3-Phase Short Circuit kA**: 24.7
   - **3-Phase Short Circuit X/R**: 6.3
   - **SLG Short Circuit kA**: 19.2
   - **SLG Short Circuit X0/R0**: 5.5

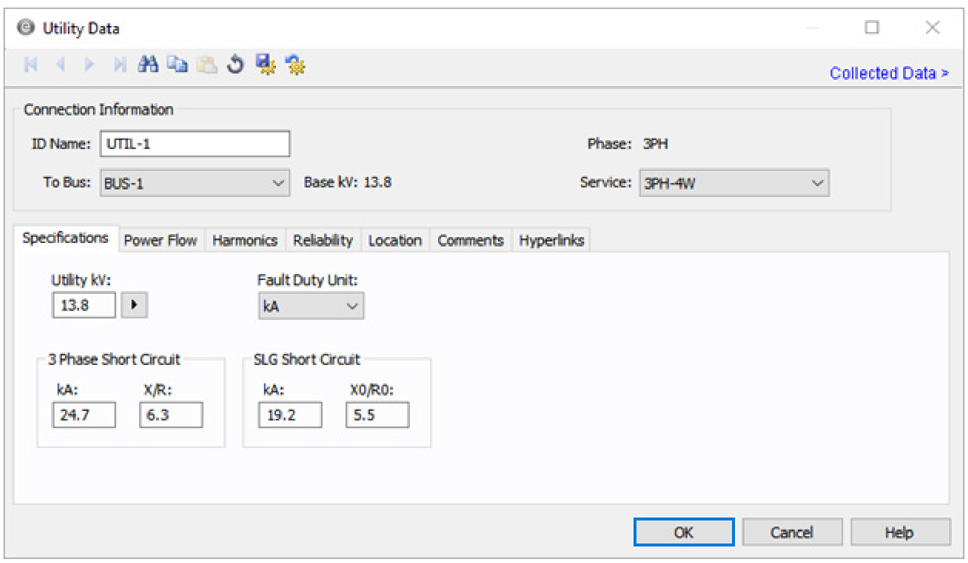


Figure 8.49: Utility Data, Actual Data

3. Click **OK** to close the **Utility Data** dialog box.

Open Short Circuit to Test for Errors

In the **Home** tab of the ribbon, click **Short Circuit**.

- If all the data for the one-line has been entered completely, then changing the focus to **Short Circuit** opens a one-line diagram with no errors.
- If any data is missing, a dialog box is displayed that asks if you want to see an error report. Click **View Report** to see an error report that indicates which equipment needs attention.

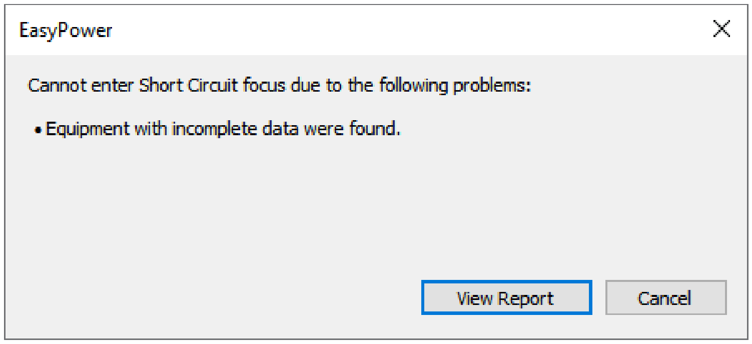


Figure 8.50: Dialog Box Indicating Errors Due to Missing Data

You can double-click the items in the error report to open the data dialog boxes and correct the data. Then re-enter **Short Circuit** to ensure all errors have been fixed.

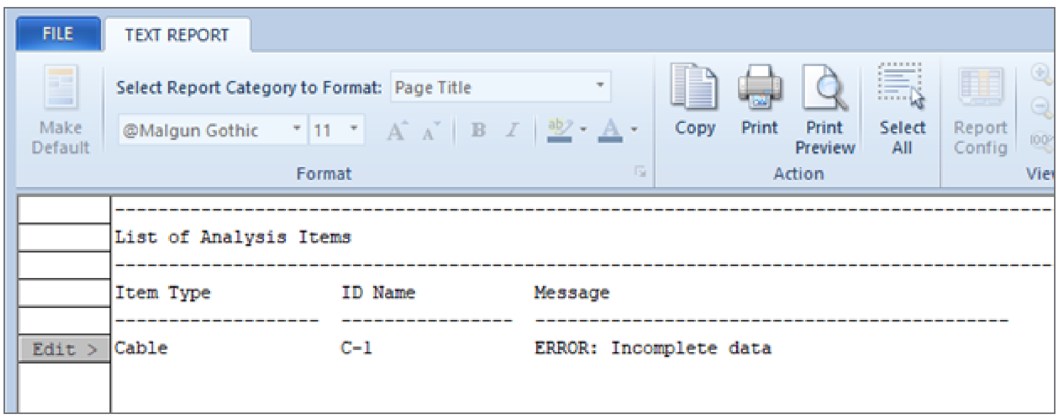


Figure 8.51: Error Report

Click **Save** to save your file before continuing.

Performing an Arc Flash Risk Assessment

In this section, we demonstrate how to perform an arc flash risk assessment in EasyPower using the model you just completed.

Tip: Use the zoom controls to see the entire one-line diagram.

Perform the Analysis

To perform an arc flash analysis, we must be in the **Short Circuit** focus.

On the **Home** tab, click **Short Circuit** to open the **Short Circuit** focus. The options for short circuit analysis are displayed.

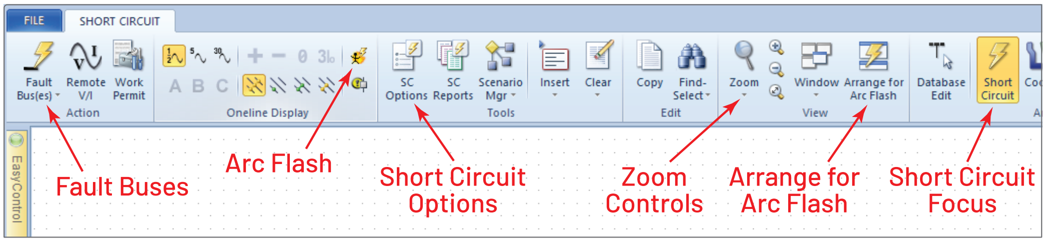


Figure 8.52: Short Circuit Tab Options

Ensure the **Arc Flash** button is selected and then click **Fault Bus(es)** to display the arc flash boundaries (AFB) and incident energies.

You can move the name and data labels around by clicking and dragging them into the position where you want them.

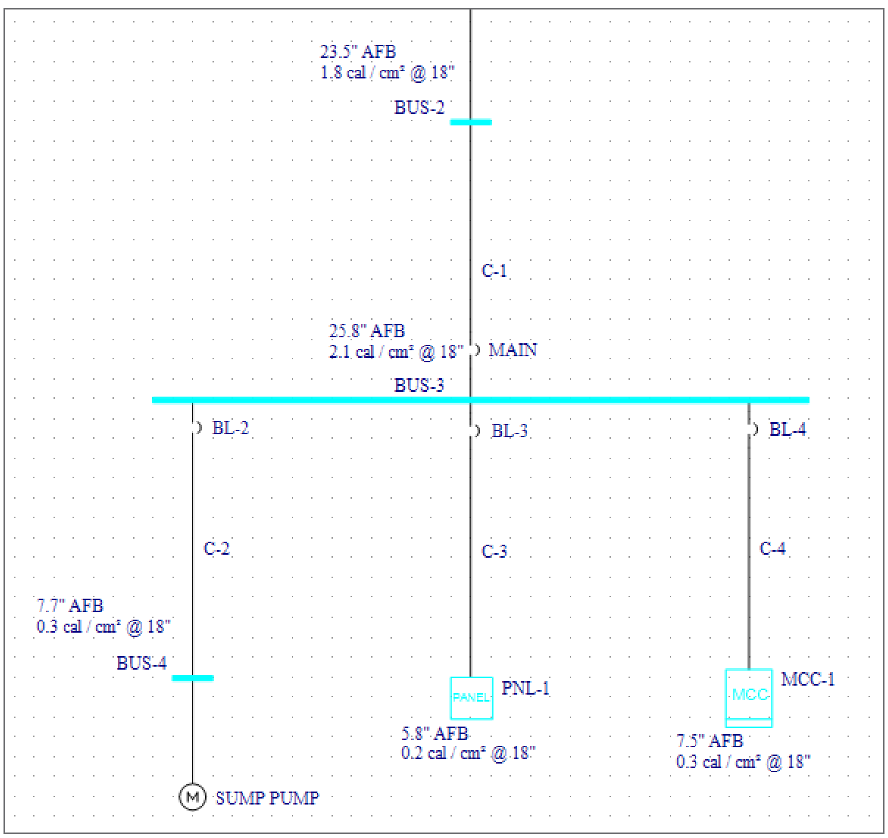


Figure 8.53: Arc Flash Results on the One-line

You can use the **Short Circuit Options** to change the information displayed on the one-line.

1. To open the options, click **SC Options** and then click the **Arc Flash Hazard** tab.
2. Make the following changes to the options:
   - **Worst-Case Arc Flash Hazards Output**: Both (Incl & Excl Main)
   - **Max Times (sec)** (for all 3 voltage ranges): 2

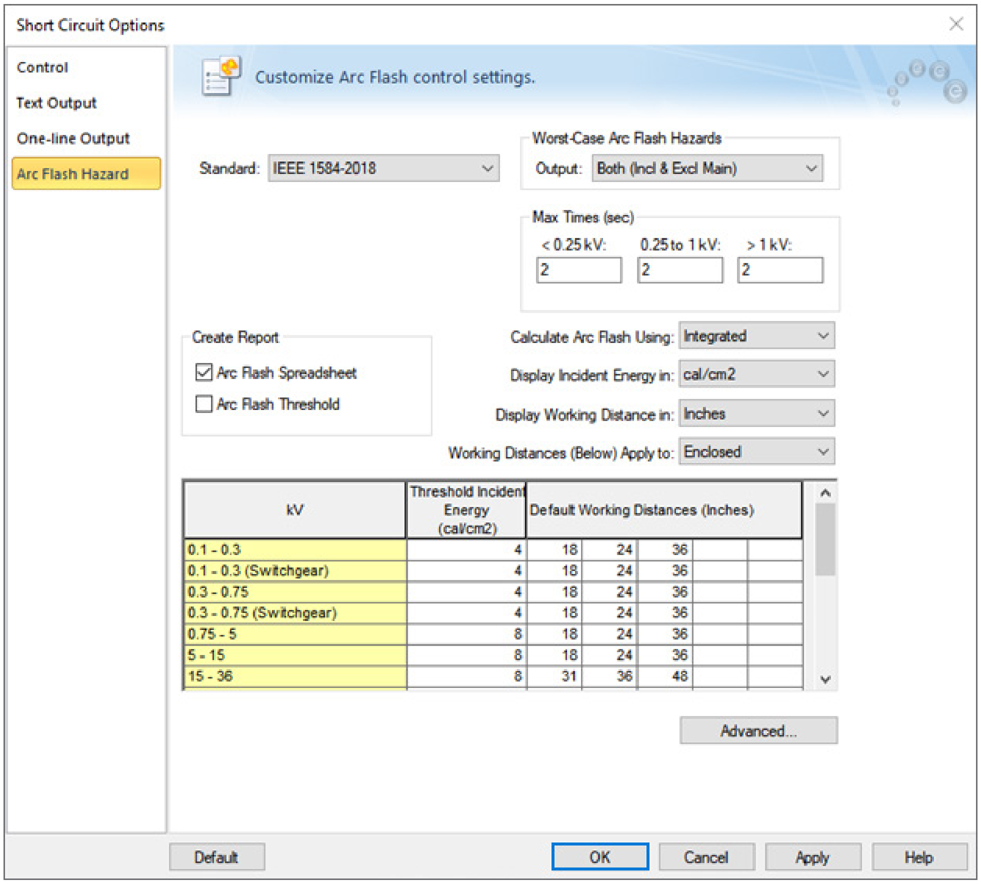


Figure 8.54: Short Circuit Options – Arc Flash Hazard Tab

3. Click **OK** to save the changes.

Displaying Detailed Output and the Arc Flash Spreadsheet

Double-click BUS-3 to fault only that bus, and then click **Arrange for Arc Flash** to view the Arc Flash Hazard report.

This displays a detailed set of arc flash results for the arcing fault. The results on the downstream feeder breakers represent the hazards one would incur when working just downstream of those breakers.

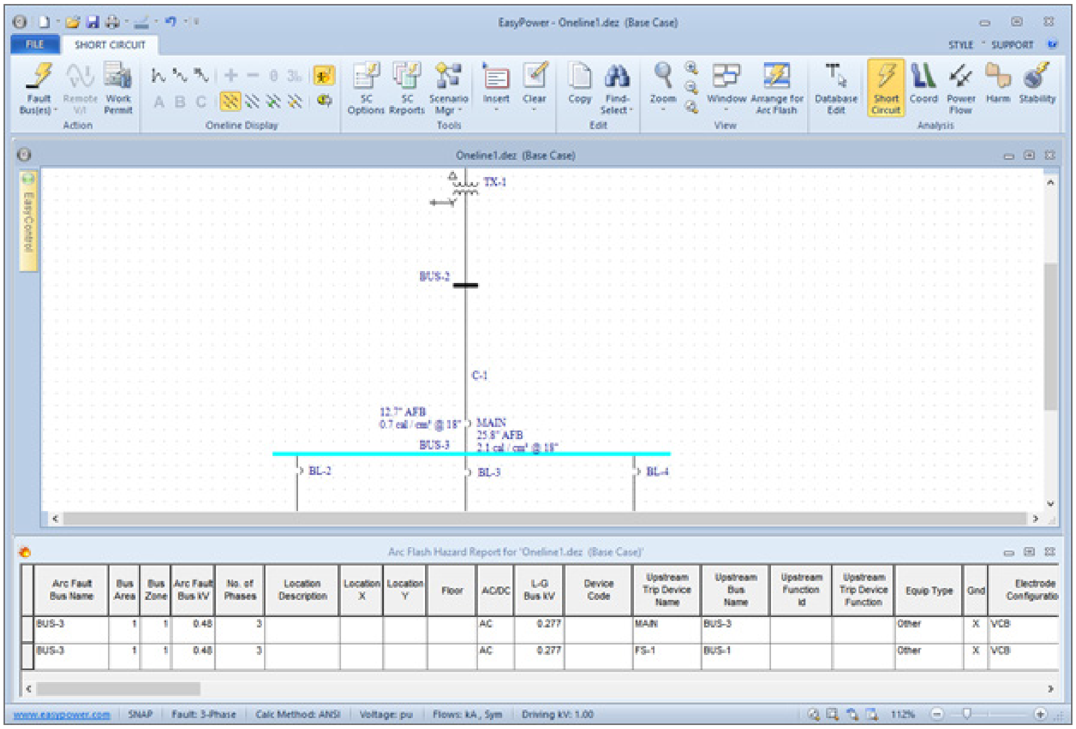


Figure 8.55: Arc Flash Results with the Arc Flash Hazard Report Displayed

Print the Arc Flash Hazard Labels

You can print arc flash hazard labels directly from the Arc Flash Hazard report. First, select the spreadsheet report window, and then click **Label**.

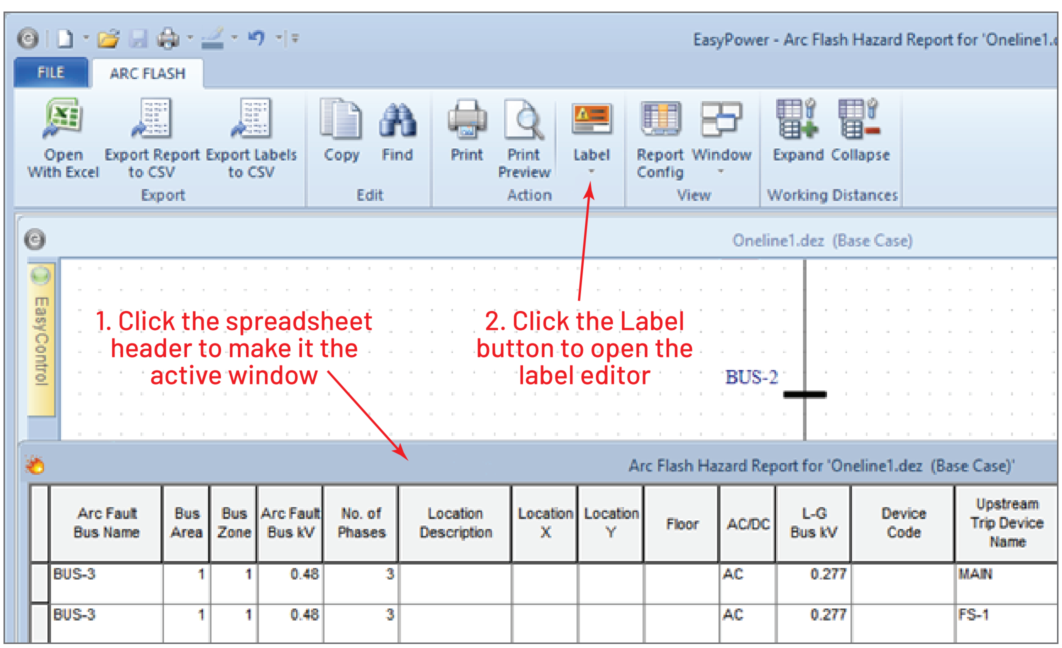


Figure 8.56: Printing Arc Flash Hazard Labels

A preview of the label appears. We can select different templates and layouts, select the devices for which we want to print labels, and add comments that will appear on all the labels. When we have the label we want, we can print it.

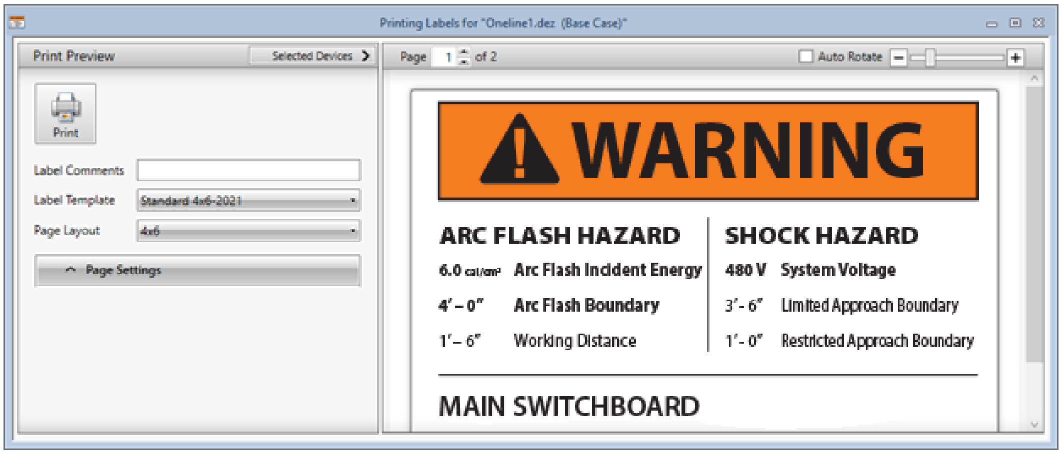


Figure 8.57: Printing an Arc Flash Hazard Label

Arc-Flash Label Printing & Placement

CHAPTER 09

Arc-flash labels of some kind have been required by NFPA 70E for many years, with labeling requirements now appearing in Article 130.5(H). Labels are generally produced in a standard format from ANSI Z535, to meet OSHA's requirements for accident prevention signs. Most arc-flash labels are printed on specialized label stock with industrial printers.

Introduction

Arc-flash warning labels are an important part of any electrical safety program. Signs or labels that describe a hazard will provide a clear reminder to follow safe work practices; they also help keep unprepared workers at a safe distance. Effective warnings can give actionable information, allowing workers to verify that they are ready to perform their tasks in a safe way.

Arc-flash labels also serve a compliance purpose. The NEC includes some basic requirements for these warnings in certain circumstances, meaning that these labels may be needed simply to bring an installation up to code. In workplaces, OSHA regulations call for several protective measures (such as warnings about electrical hazards, and information about necessary PPE) which are most effectively addressed with these labels.

Figure 9.1: Arc-Flash Labels in an Industrial Environment

Notes in the NEC, as well as enforcement guidelines from OSHA, refer to NFPA 70E as recommended practice for the information to be provided on arc-flash warnings. They also refer to ANSI Z535.4 as recommended practice for the design and layout of warning labels in general. These standards provide the framework for creating effective arc-flash warning labels.

Criteria for Labels

Because of the importance of these labels, it's worthwhile to give them special attention as part of an overall arc-flash analysis. There are some basic criteria that these labels need to meet in order to be effective. To summarize Article 110.21(B) of the NEC, these labels should:

- Use good design practice (as described in ANSI Z535.4) to give an effective warning,
- Be firmly and reliably fixed in place, and not simply handwritten, and
- Be made with materials and printing methods suitable to survive the intended environment.

Satisfying these criteria is not difficult if you plan ahead. The first point simply requires attention to the way labels are designed, often easiest when using pre-generated templates such as those included in the EasyPower software. The other two points require attention to the materials and processes used to actually create the labels.

Good Label Design with ANSI Z535

The ANSI Z535 standard for signage gives a consistent and effective way to communicate about safety. It includes several general guidelines, and a few more specific details. It also describes a standardized category system for signs that address hazards, using boldly colored headers and keywords.

ANSI Z535.4 provides the consensus standard used in North America for safety labels. Deviation from this standard is allowed, but courts will rule that Z535 is the minimum acceptable standard. This means that deviation from this standard requires that you prove increased effectiveness is provided by your equipment labeling program.

In general, safety signs should be visible and legible before the reader is exposed to the hazard — that is, the worker should be able to read the warning before work begins. Additionally, the reader of a sign should be able to understand what the hazard is, and what they need to do about it. For arc-flash warnings, this often means a brief statement that an arc-flash hazard is present, and that appropriate PPE is needed. The exact text and presentation will vary for different circumstances, and there is a lot of leeway for customization.

The most recognizable element of ANSI Z535 is the bold header along the top of each sign, which is more clearly defined. Different headers are used for different kinds of hazards; “Caution,” “Warning,” and “Danger.”

- **Caution** labels have a yellow header, with a safety alert symbol (the exclamation point in a triangle) and the word “CAUTION” in black. These signs indicate that personal injury is possible, but are not meant for situations where the injuries could be severe or life-threatening. Because arc flash is such a powerful phenomenon, Caution signs are almost never appropriate for arc flash.

- **Warning** labels have an orange header, with the safety alert symbol and the word "WARNING" in black. Warning signs describe a hazard that could result in serious injury or death if the sign is ignored. Most arc-flash labels, and most electrical hazard labels in general, should use the Warning format.
- **Danger** labels have a red header, with a safety alert symbol and the word "DANGER" in white. These signs are for the most severe hazards, where serious injury or death are practically certain unless the instructions are followed. Some jurisdictions use more specific definitions; for example, California's General Industry Safety Orders, in section 3340, rule that "Danger" should only be used "where an immediate hazard exists" (and not where there is only the potential for a hazardous condition such as arc flash).

Historically, some facilities have used Danger for arc-flash labels where energized work was not meant to be allowed at all, or where the calculated incident energy was above a certain threshold value (often 40 cal/cm^2). If the effective jurisdiction permits such a choice, keep signage consistent within the facility.

We have seen more than one facility color code labels based on PPE levels. Red=Extreme danger (> 40 calories), Orange =PPE Category 4 (> 25 calories), Yellow = PPE Category 2 (> 8 calories), and Green= PPE Category 1 (<1.2 calories). Because ANSI has selected three colors to denote specific levels of hazard, we do not recommend color coding AFH labels based on PPE level. Company defined color coding confuses the basic ANSI color coding and subjectively encourages levels of danger in the facility. In reality, an arc flash of 8 calories can have the same life changing impact as that of a 15 calorie event. Additionally, color coding any AFH label with green conveys the message that there are no potential hazards in this equipment, since green is the universal color for "go" or "safety."

Figure 9.2: Pre-Printed Label Stock

The EasyPower software includes a variety of label templates that follow the ANSI Z535 recommendations, including these standard headers. Label stocks intended for this application may even have the headers pre-printed.

The following label is an example of a thorough ANSI Z535 AFH label.

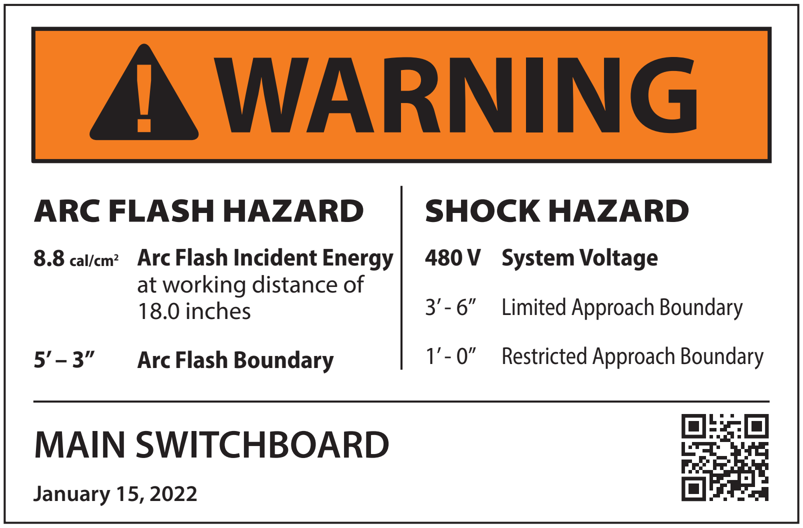


Figure 9.3: ANSI Z535 Arc-Flash Label Example

ANSI Z535 labels are the most recognized safety label in North America. Using standardized labels minimizes safety training requirements for both employees and contractors, thereby reducing liability on the part of the facility. Custom labels will require specialized training not only for your company employees, but also for every contractor coming on site. Note: Labels that display company logos, flashy colors, or vendor advertising should be avoided, as they distract from the warning!

Label Materials and Processes

The standards require clean, legible, and durable signage. If a sign is faded, damaged, missing, or otherwise can't be read when it's needed—it doesn't serve its purposes for safety or compliance.

Consider the intended lifespan of the label. If the facility is routinely reorganized or expanded, labels may only be accurate for a few years, and may need to be replaced after that time. In many cases, however, there will be no specific plan to change the equipment or installation; the labels you apply today may still be accurate long into the future.

Think about the environment where the sign will be placed. For outdoor equipment, the sign may need to withstand sun and rain. In some facilities, the equipment and signage will need to endure chemical exposure in the forms of occasional splashes or persistent fumes.

High quality labels will resist fading or smudging, stand up to wear and weather, and won't accidentally peel or tear away. Instead of replacing labels every few months, you should expect a replacement cycle measured in years; ideally when new labels are needed anyway to account for changes in the equipment, installation, or relevant standards.

In general, the best long-term labeling solutions will use materials and printing processes that are well adapted for permanent signage in industrial applications. The best printers for these applications use a printing process called "thermal transfer," in which a solid resin (or "ink") is transferred from a supply ribbon onto a label stock, which is often made from a vinyl or polyester material with a permanent adhesive backing. This gives an extremely long-lasting print with excellent resistance to abrasion, water, chemical exposure, and temperature variation, while being virtually immune to fading and UV exposure.

The DuraLabel line of printers from Graphic Products make use of this thermal transfer process. These printers were designed to make it cost-effective for users to create custom labels on-site and on-demand. The same printers can also be used for other signs and labels, from general safety signage to voltage markings and storage labeling.

For arc-flash labels, these systems can be connected to a standard PC just like an ordinary office printer, and the labels can be designed in the EasyPower software using automated templates and the calculated details from your analysis. Once the designs are ready, they can be printed directly to the DuraLabel printer; in a few seconds, you'll have finished labels ready to apply, and they'll be bold and readable for years.

Figure 9.4: Example of Arc-Flash Labels Applied to a Distribution Board

Printing Arc Flash Labels in EasyPower

Printing arc-flash labels begins with performing arc-flash hazard analysis in EasyPower's Short Circuit focus, through which arc-flash hazards are analyzed and reported on the Arc-flash Hazard Report and displayed on the one-line diagram. The interactive interface of the Arc-flash Hazard Report is the platform from which Arc-flash Labels can be printed in EasyPower.

Label printing involves many different variables as illustrated here.

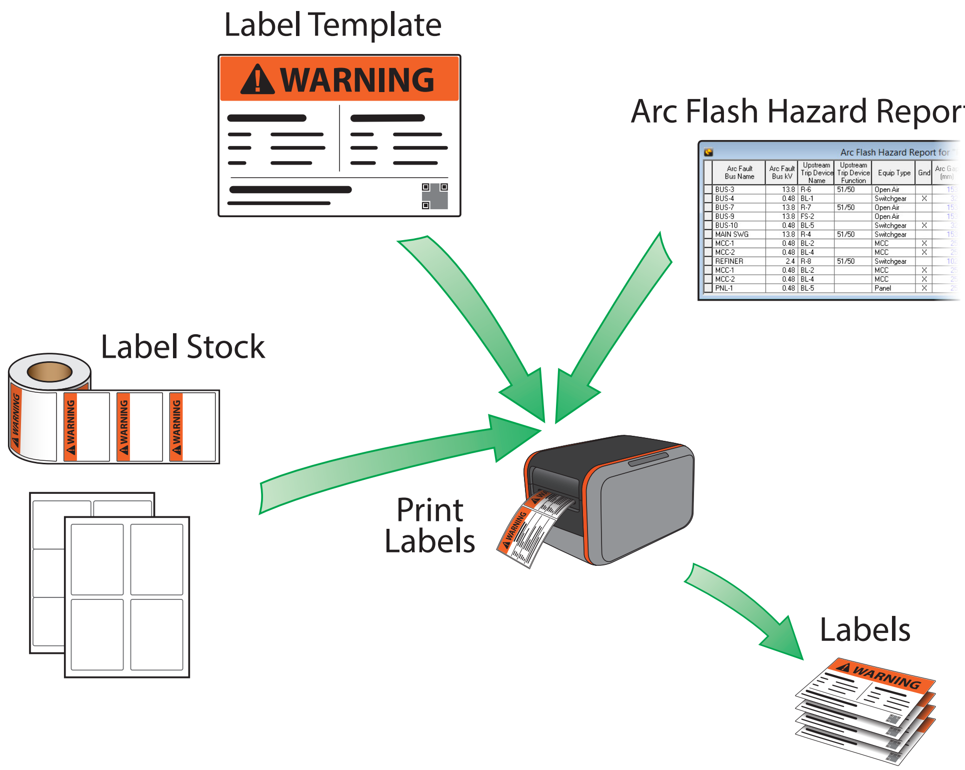


Figure 9.5: Arc-Flash Label Printing Workflow

- **Arc-flash Hazard Report** – analysis results flow from this report into the printed labels.
- **Label Template** – the template controls how labels are printed. Several templates are provided with EasyPower to address different scenarios.
- **Label Stock** – blank or partially pre-printed labels come from label manufacturers such as Graphic Products DuraLabel. Some label stock comes die-cut in rolls for a thermal printer, while some comes in sheets intended for use in a label printer. Several pre-measured page layouts are available when printing labels which match common label stock.

EasyPower's intuitive label designer also enables the customization of a label template to meet your specific needs.

Why Use EasyPower Label Printing and Design?

EasyPower's arc-flash label printing functionality pulls data directly from arc-flash analysis, ensuring you can be confident that information printed on labels comes from industry standard calculations built into EasyPower. The label design tool allows you to customize the printed labels including layout, fields, text, fonts, colors, and images. This gives you full control on how labels appear, to ensure your labeling requirements are met.

How to Print Arc-Flash Labels

From the Arc-flash Hazard report, you can preview and print the labels from two different paths.

- Using the toolbar button:

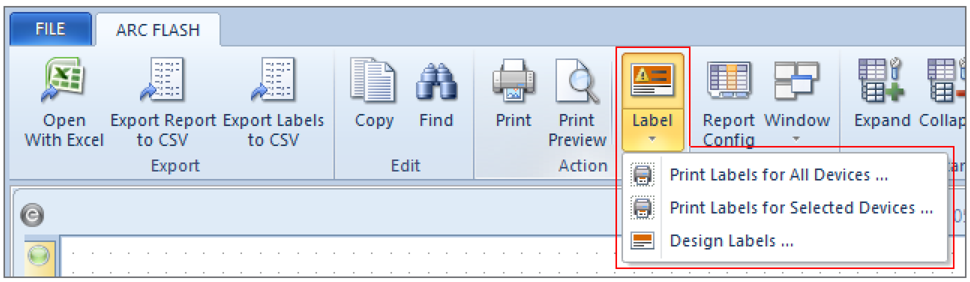


Figure 9.6: Accessing the Arc-Flash Label Editor

  - Clicking on the **Label** button will display the label preview window with all of the devices in the Arc-flash Hazard Report.
  - Clicking on the down arrow of the **Label** button provides different options of what to print, including printing only the selected labels. Only the label rows which are highlighted in the Arc-flash Hazard Report will print if this option is chosen.
- Using the Arc-flash Hazard Report context menu:

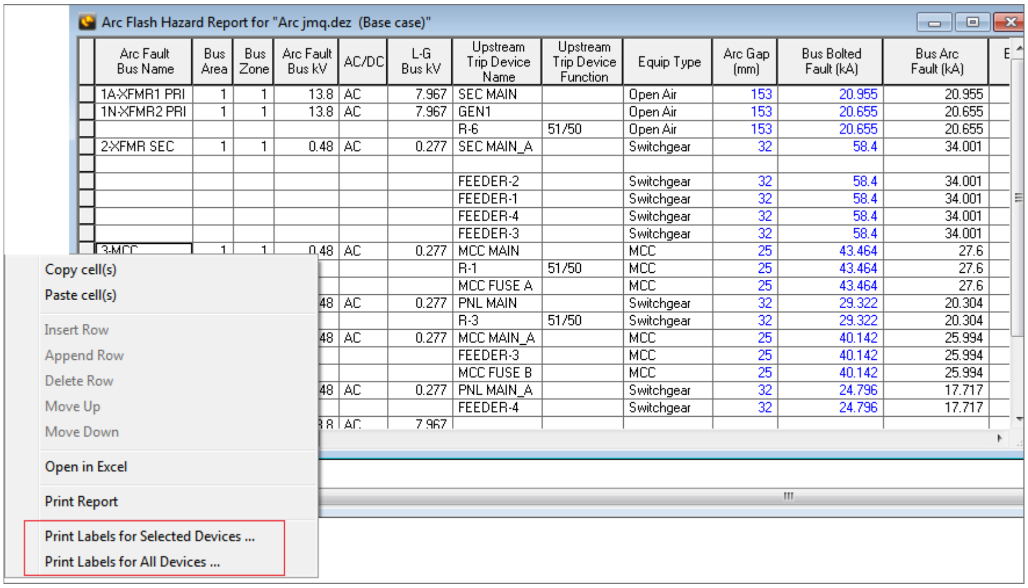


Figure 9.7: Label Printing from the Arc-Flash Report

To display the context menu, right-click on the hazard report. From the context menu, you can choose to print labels for all devices or only for the selected device.

After choosing to print labels, the label **Print Preview** window is displayed. From this window you may choose which label template you want to use when printing your labels, and choose a page layout which matches your label stock. Each label template is slightly different and includes fields from the Arc-Flash Hazard Report.

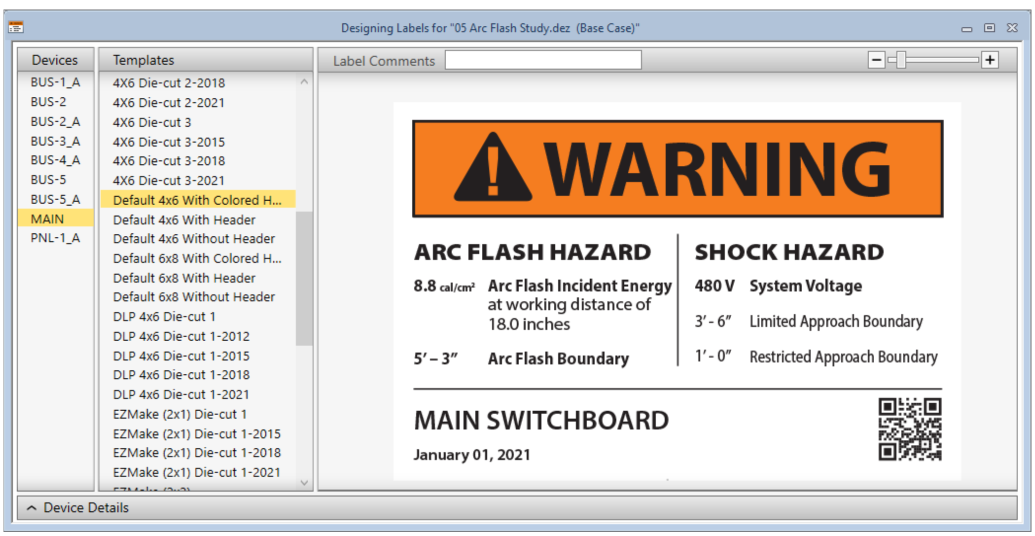


Figure 9.8: Arc-Flash Label Window

Pressing the **Print** button will allow you select the printer and send your label run to the printer.

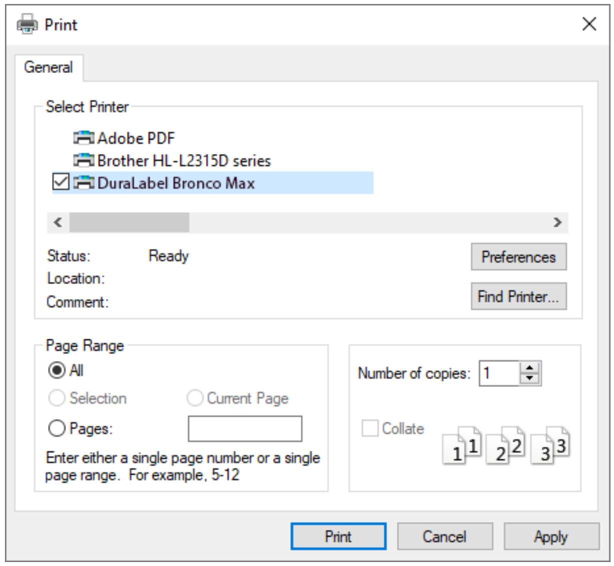


Figure 9.9: Arc-Flash Label Print Dialog

Label Print Preview Window

The label print preview window is designed to help you quickly and easily print labels based on the devices in the Arc-flash Hazard Report.

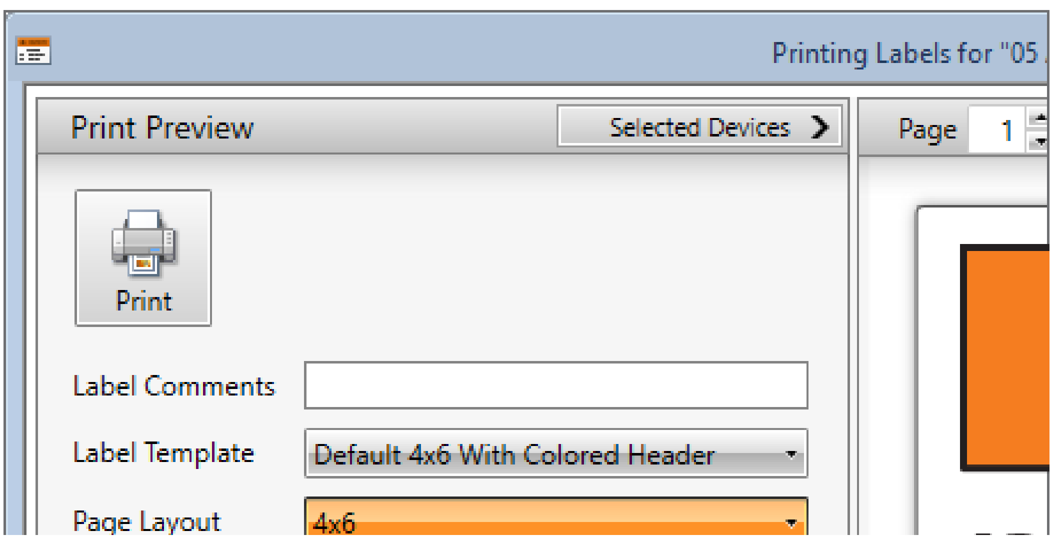


Figure 9.10: Arc-Flash Label Print Preview

Label Print Preview Window Reference

Table 9.1: Print Preview Window Options

Option	Description
Print Button	Prints the label(s)
Label Comments	Comment to use on each label
Label Template	Selects template to use from the current label template folder. The folder can be changed by pressing the **Load Templates** button on the toolbar, or by changing the setting in **File Locations**.
Page Layout	Selects how to layout labels on printed page. Use this field to choose from several predetermined page layouts from different label manufacturers, or choose custom to match printer and label stock that is not included in the list. Some label print stock comes on one label per page, while others come with multiple labels on the same page.
Selected Devices	Shows the list of devices that will be printed. Any devices with check marks will be printed; otherwise, nothing prints. You can use “All” or “None” or select individually. You can also override the number of copies of labels to print for each device.
Page	Indicates the page number of the labels that will be printed and allows you to select which page you are previewing. Depending on the devices selected and how many of the devices templates can fit into a page or label, the number of pages can dynamically shrink or expand accordingly.
Page Settings	Page settings give you control over the layout of your label stock to ensure that you can reliably print your labels on your printer. See the section “How to Print Custom Label Stock” for more details on items below. • **Page Size**: Allows you to change the width and height to match the actual page or spool size you will use to print the labels. • **Label Size**: The actual size of each label on the page. The label may be inset from the edge of the page by some margin. • **Page Layout**: If your label stock includes more than one label per page, use this field to specify the number of rows and columns of labels on each page. • **Scale to Fit**: If the template you chose does not match the size of the label indicated in page settings, this box can be checked to scale the label template to fit the actual label size. • **Center Label**: By default, printing starts based on measurements from the top left corner of the label. Check this box to center the printed out- put within the label. • **Label Outline**: Check this box to display guides of where the labels are on the page based on the specifications above. • **Units**: Units used for page layout measurements above. • **Labels to Print**: When label stock includes multiple labels on the same page, these check boxes can be used to control how the first page prints. This allows for reusing a sheet of label stock if only some of the labels were used in the last print run.

Print Labels Toolbar

When this window is active, the **Print Labels** toolbar is displayed.

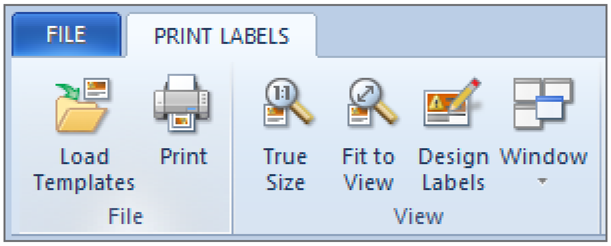


Figure 9.11: Print Labels Menu

Action Buttons On the Print Labels Toolbar

Table 9.2: Print Labels Tab Options

Action	Function
Load Templates	Loads pre-existing templates from your hard drive or network drive. You can use this button to load templates from pre-existing versions of 9.0 or later.
Print	Prints the label(s)
True Size	Changes the print preview to represent the actual size that will be printed.
Fit to View	Changes the drawing to best fit the real estate of the drawing panel.
Design Labels	If the current label template needs to be modified before printing, you can access the label designer through this button. The print preview window will be closed.
Window	Use this button to activate a different window within EasyPower, such as the Arc-flash Hazard Report window.

How to Print to Custom Label Stock

EasyPower ships with several pre-configured page layouts which match common label stock, but you can use a label stock which is not already built-in. In this case, you need to specify a custom page layout to match your label stock and this tutorial guides you through that process.

In this example, we will look to configure a page layout using an 8.5 x 11 inch page containing six 4 x 3 inch labels. Below is a picture of the layout of labels on the label stock that we will match with our page layout controls.

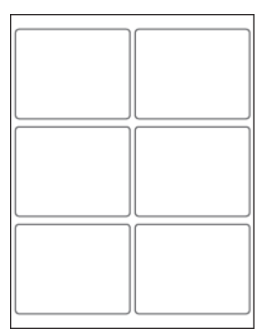


Figure 9.12: Custom Label Stock

1. From the label print preview window, select the **Custom** option from the **Page Layout** drop-down list.

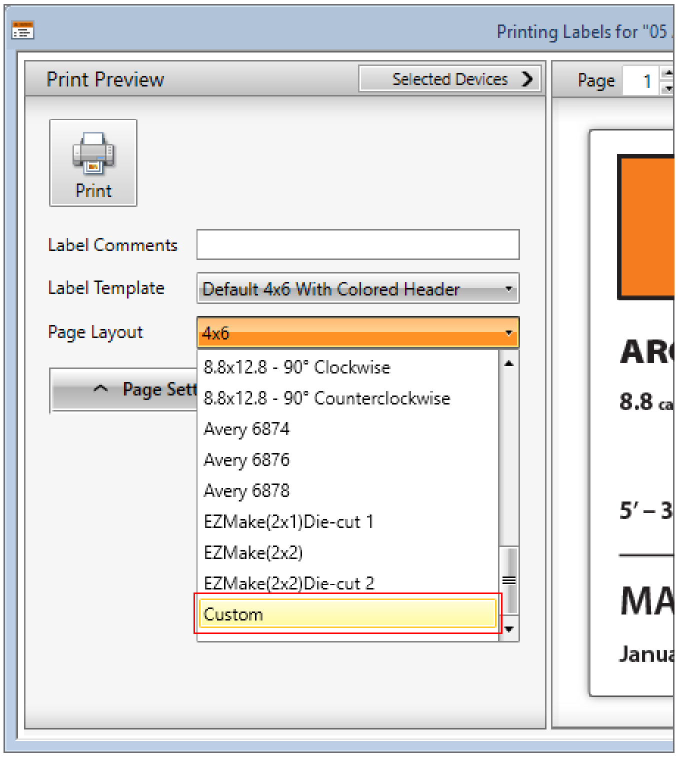


Figure 9.13: Arc-Flash Label Custom Layout

2. Click on the **Page Settings** button to expand the **Page Settings** pane.

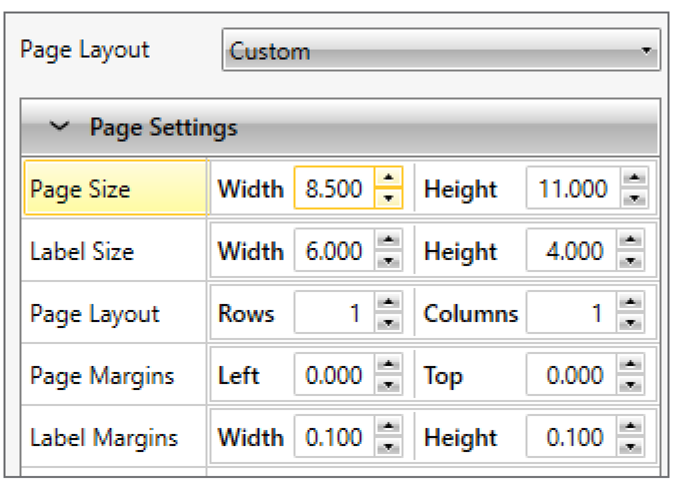


Figure 9.14: Arc-Flash Label Page Size

3. Specify the size of each page of labels in the **Page Size** fields. In this case, we are configuring a page which is 8.5 inches wide and 11 inches high.
4. Specify the size of the label itself. In this case, we will specify 4 inches wide by 3 inches high.
5. Specify the number of rows and columns of labels. In this case we have 2 columns and 3 rows.
6. The page margins, or margins from the outside edge of the page to the edge of the label, are .2 inches on the left and .75 inches from the top.
7. The label margins, or spacing between labels, is a width of .1 inches and a height of .3 inches.
8. Set **Center Label** and **Scale To Fit** to determine how you want the selected template to fit within the printed label.
9. To check how the template will be printed within your label area, select the **Label Outline** check box. This will add a green dashed line onto the preview illustrating where the labels are on the page. This outline will not actually be printed. The preview should look similar to the following:

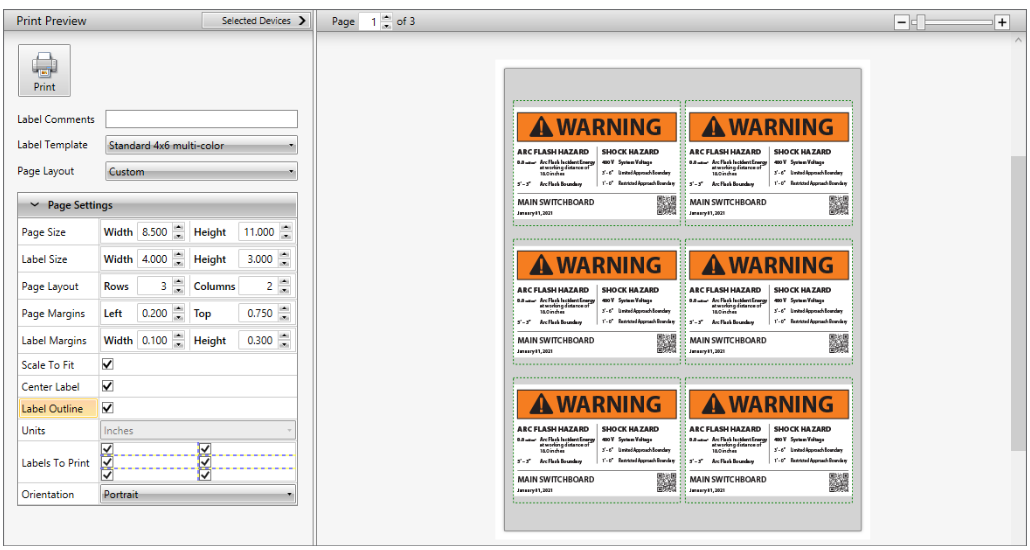


Figure 9.15: Arc-Flash Label Page Size

EasyPower remembers your custom page layout and uses it the next time you print.

Arc-Flash Hazard Labeling Do's and Don'ts

With industry adopting NFPA 70E, and Canada's Z462 as the consensus electrical safety standard, North American facilities and many of their counterparts worldwide are performing arc-flash hazard studies to label their electrical equipment for safety. The requirement for arc-flash hazard labeling is found in the National Electrical Code, Article 110.16 for new equipment, NFPA 70E-2021 Article 130.5(H) for existing equipment, and OSHA 1910.335(b)(1) for general electrical safety hazards.

There are as many different ways to label equipment as there are engineers and electricians in industry. Unfortunately, many of the methods being used are not recommended and may actually decrease worker safety, while increasing your company's liability should an accident occur. This section supplies a safe-approach reference developed through years of experience working with engineers and electricians on their arc-flash hazard projects. The viewpoints expressed in this section are provided as a guide to industry, recognizing that the NEC, NFPA, and OSHA set the standards but do not cover the myriad of questions associated with labeling the different types of electrical equipment in industry.

Common Terms:

- **AFH**: Arc-Flash Hazard
- **NFPA 70E**: National Fire Protection Association – Standard for Electrical Safety in the Workplace
- **OSHA**: Occupational Safety and Health Administration
- **CSA Z462**: Canadian Standards Association - Standard for Electrical Safety in the Workplace
- **PPE**: Personal Protective Equipment
- **NEC**: National Electrical Code
- **ANSI**: American National Standards Institute

Don't Label for Energized Work – Do Label to Warn of Hazards

In the majority of facilities hoping to obtain NFPA 70E compliance, the most prevalent mistake we see is performing an AFH study for the sole purpose of labeling equipment. Following the study, the plant continues the same day-to-day operations, only now the electricians wear PPE as labeled on the equipment.

Two myths need to be dispelled: 1) Arc-flash hazard labeling alone does not provide 70E or OSHA compliance and 2) Labeling does not eliminate the requirement for work permits, safety programs, or training and planning when working on energized equipment. What this means in simplified terms is that a facility cannot perform energized work based solely on the fact that the equipment is labeled and the worker is wearing the appropriate PPE as designated on the label.

Labels should not be used to "assess" a hazard, select PPE categories, or perform energized work based on the information provided on the label.

Arc-flash hazard labels should be applied to warn personnel of a potential hazard. Labels should not be used to "assess" a hazard, select categories, or perform energized work based on the information provided on the label. These tasks are part of the planning, documentation and work permit process required by NFPA 70E 130.2. Arc-flash hazard information such as PPE category, incident energy, and boundary information shown on many labels should only be used as a cross-check with the information provided in the work permit process.

Label Worst Case

NFPA 70E-2021 Article 130.5(H) requires AFH labels to show the nominal system voltage, arc-flash boundary, and at least one of the following:

- Available incident energy and the corresponding working distance, or the arc flash PPE category in Table 130.7(C)(15)(a) or Table 130.7(C)(15)(b) for the equipment, but not both
- Minimum arc rating of clothing
- Site-specific level of PPE

Whatever options you select, the listed incident energy or PPE should be the "worst" case for that equipment.

Many companies choose to label switchgear, for instance, with a working distance of 24-36 inches. They do this based on the assumption that the only work being done on the equipment is racking out the breaker. However, that is not a realistic assumption. What happens if the breaker racking mechanism sticks and the electrician positions himself/herself closer to fix the mechanism? What if there are other work tasks that require a closer working distance?

Other factors contribute to "worst" case results such as generators being turned on or off, motors being turned off or on during a shutdown condition, etc. These variables must be considered in a "worst" case calculation.

AFH labeling with values less than "worst" case requirements will increase your company's liability, should there be an arc-flash accident. The attorneys working for the injured parties will easily prove that a higher incident energy existed at a standard working distance of 18 inches or with a different mode of operation, and show the equipment label did not warn the party of potential increased danger, concluding pure and simple negligence. This is not to say that you cannot rack a breaker out using the calculated incident energy at a longer distance, say 36 inches. The important point to note is that each work permit and planning procedure documents a specific work task and its associated requirements. If that task or working distance changes, a new work permit is required along with the possible need for new safety procedures. The employee will be properly briefed and protected if this procedure is followed.

Label with Only One Working Distance and PPE Requirement

When equipment has multiple AFH labels with different working distances, and different PPE categories, it is a recipe for disaster in the making. With multiple options, workers now have the opportunity to select the label/PPE of their choice without management oversight. It is human nature for all of us to assume there will not be an incident. It usually goes something like this.

The worker looks at the front side label and reads an incident energy of 12.4 cal/cm2. The backside label (breaker terminals) is labeled 4.6 cal/cm2, due to the feeder breaker instantaneous trip units. The employee thinks: 1) "Man it's really hot today. I bet the humidity is 95%." 2) "I've done this same task for the past 26 years without an incident." 3) "It's almost time to go home. I really don't want to go back and get in that stupid tank suit."

When given the choice, most people are going to take what they perceive as the easy way out. If this worker initiates an arc-flash incident wearing inadequate PPE and ends up with third degree burns over half his body, who will be blamed and found liable? The objective reader may easily point the blame at the worker for being lazy or lacking intelligence. However, his attorney is going to claim: 1) The labeling process was confusing. My client could not tell which label applied to which area of the equipment. 2) The labels did not denote specific work tasks for the equipment, and they did not segregate boundaries on the equipment for their application. 3) My client was not properly trained by the company to distinguish how different labels apply to manufacturer XYZ's equipment. In any arc-flash hazard lawsuit, if there is any doubt regarding whether or not the corporation followed the industry mandates, the court jury or judge will rarely side with the corporation. In spite of the fact that the worker was incorrect or broke company policy, the jury will see a traumatized man with multiple skin grafts, scarred for life and unable to ever work again.

It is critical to label the equipment using only one (worst case) energy PPE category or incident energy and one working distance per equipment. Following this procedure will minimize training requirements, confusion, and liability. Additionally, we strongly recommend standardizing on an 18 inch working distance for all equipment. Considering every enclosed equipment type from 120 V through 34.5 kV, there will always be some work task that will put a worker in the 18 inch range. Labeling some equipment for 24 or 36 inches, and others for 18 inches adds confusion to your safety program. If workers want to manage down the PPE requirement for a "specific task" by working from an increased distance, this is properly done by a detailed Article 130.2 work permit combined with proper work procedures and training.

The only exception to this rule might be for isolated and barrier protected main breakers in a switchgear lineup. Many facilities prefer to label the incoming switchgear breaker separately from the bus and feeder breakers. This allows work on the feeder breakers to be conducted under the lower incident energy conditions provided by the main breaker. The problems with this approach are threefold. 1) Workers could follow the ratings on the lower rated bus label beginning their work in the appropriate area and either accidentally, or intentionally, transition to the main breaker compartment where the AFH energy will typically be "extreme danger." 2) This method promotes work on the bus and feeder breakers using only a label, potentially bypassing the necessary Article 130.1 work permit requirements. 3) This method can only be done on isolated and barrier protected main devices. In most facilities this applies only to a minor portion of equipment; therefore, additional training will be required to ensure all workers understand the specific restrictions for this particular labeling method.

How Many Labels per Equipment?

A frequently asked question is how many labels are enough? Obviously if one is good, more is better – right? This philosophy has both positive and negative aspects that must be considered. The more labels used the higher the visibility factor. However, too many labels clutter the objective and cause workers to ignore the warning.

Figure 9.16

For the MCC above, a simple one-word "warning" label was used without providing specific PPE, boundary information, or hazard levels. This minimizes clutter, however, if you take a step back and see 50-75 of these labels the clutter becomes obvious. The clutter is even more prevalent and confusing if the standard AFH information is included on the labels. The worker looking at the MCC must then determine 1) Which label is important? 2) If the labels are different, what information applies to this task? 3) How do I react to these circumstances?

When deciding quantity, another factor to consider is the cost of replacing the labels when system changes take place or when calculation or labeling standards are updated. Re-labeling an entire facility is time consuming and expensive.

A common sense approach to labeling seems to make the most sense for general applications. Labeling with one high profile 4x6 inch or 6x8 inch label front-side and back-side should be sufficient for most switchgear, switchboard, and panelboard applications. For larger equipment such as long switchboards, two labels should be sufficient. Labels should be placed where clearly visible; the top is preferable when equipment type allows. See examples below.

Note: Size and depth of an enclosure, as well as electrode configuration, has an effect on incident energy. As such, in some cases depending on the situation and the specific calculations that have been completed, using one label per compartment may be advisable and necessary.

For feeder bus duct, labeling every 15-25 feet with the bus duct "worst case" label, provides sufficient warning of the potential hazard. It is not necessary or recommended to label each plug-in for the reasons already stated.

For some equipment, additional labels should be considered at potential entry or work points. Examples might include open bus vaults or large junction boxes where access can be obtained from several sides.

Examples

This section provides multiple labeling examples for different types of electrical equipment, which can be modified or extrapolated to fit your system. For some equipment types, multiple options will be provided.

Panels

Panels are typically of box construction with a fixed backing plate attached to a beam, or wall mounted. The front of the panel, which provides opening access, is bolted in place. The front cover typically has a hinged opening, which allows viewing and operation of the breakers. For standard 42 circuit lighting panels, the typical labeling procedure is one label on the main cover, top center. See Figure 9.17.

Figure 9.17

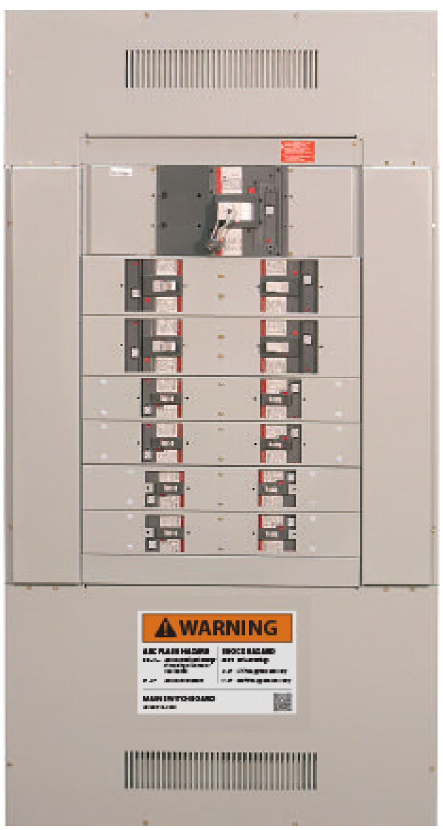


Figure 9.18

Panelboards

Panelboards, sometimes called distribution panel boards (DPB), or distribution boards are larger than a standard panel and may range from 400-1200 A. They are typically standalone, but smaller units may be wall or beam mounted. Larger units may be accessible front and back side via bolted covers. For standard DPB's, typical labeling procedures is one label on the main cover, top center. For the example shown in Figure 9.18, the label was moved to the bottom to prevent covering the cooling vents. Panelboards do not have isolated and barrier protected main breakers unless specially ordered and should always have only one label.

Dry Type Transformers

Dry type transformers typically have a bolted-on face plate section with exposed terminals behind the face plate. Since this is the main access point, it is usually not necessary to label the other sides.

Figure 9.19

Figure 9.20

Larger units may have two or more cubicles and can be labeled with one or multiple labels.

Variable Frequency Drives and Control Cabinets

Variable frequency drives and control cabinets are typically hinged front opening units with an open, exposed incoming main breaker. The incoming breaker or fuse is typically not isolated or barrier protected from the other sections and therefore cannot be used for AFH protection. Like other cabinets, one "worst case" label is typically sufficient. See Figure 9.21.

Figure 9.21

In the example of Figure 9.22, the incoming line section (upper left section) is not isolated from the main SCR/reactor compartments. Therefore, any arc initiation will propagate instantly to the incoming protection and prevent its operation.

Figure 9.22

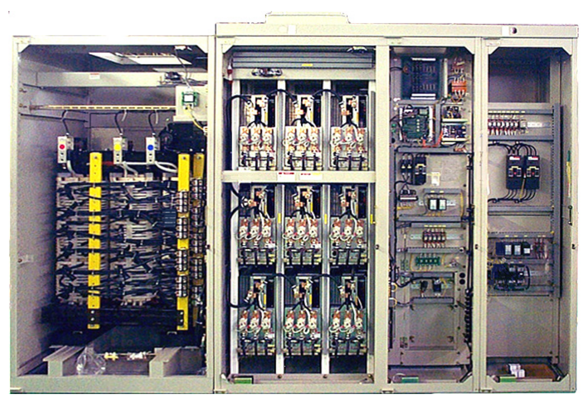


Figure 9.23

In the drive example shown in Figure 9.23 to the right, the incoming main breakers shown in the right side cubicle appear to be properly isolated by a section divider. Once this has been verified by the facility, the lower value incident energy/ PPE category can be labeled on the other sections. Facilities employing this approach assume the three liabilities listed in the previous section entitled, "Label with only one working distance and one PPE requirement." We recommend that only the "worst case" label for the complete equipment be used. If they are not working in the main incoming section, we recommend that users manage down the required PPE category via work permit and strict safety procedures.

Switchboards and Switchgear

Figure 9.24

Switchboards and switchgear are the standard for low voltage distribution equipment. Switchgear by definition has isolated and barrier protected cubicles, rack-in air frame breakers/switches, and isolated bus. Switchboards may have similar attributes but will most likely be equipped with molded case or insulated case breakers, or fuses in non-isolated cubicles with non-isolated bus work. By special order, the main breaker/switch can be isolated, enhancing arc-flash protection.

For a typical 4 section or less switchgear lineup, only one label (worst case) on the front side is necessary. See Figure 9.24. For longer sections, additional labels can be applied every 5-10 feet. Since both front and back-side switchgear covers are hinged, the back-side covers should also be labeled.

For switchboards, the back-sides are typically open exposed bus with bolted covers, which should prevent access. Labeling should be optional since access is not easily obtained.

If the user prefers to label the main breaker section separately, thereby providing a lower PPE category label for the bus and feeder breakers, the main incoming section should be sectioned off to clearly demark the switchgear. The main section will most likely be labeled "Extreme Danger" unless specialized relaying has been implemented, and the feeder breaker/bus section will typically have a lower incident energy. See Figure 9.25. One label on each side of the demarcation is typically sufficient, although the back-side should also be labeled if it is hinged and easily opened.

> ***Note:*** *EasyPower recommends "worst case" labeling for all switchgear and does not advocate demarcation lines to sectionalize equipment with different labels. The procedure shown here is presented only to show the proper method for demarcation. EasyPower recommends NFPA 70E Article 130.1 Work Permits, safety procedures, and proper planning for reduced PPE level work on different sections.*

Figure 9.25

Some switchgear line-ups come in combination units with a connected transformer and high voltage primary switch. These should be sectionalized with a clear demarcation line for section labeling. The preferred method is shown in Figure 9.26, where the "worst case" low voltage arc-flash results extend from the transformer section through the low voltage switchgear. This method can be applied to all switchgear, switchboard, and panelboard combination units, with or without main breakers. Note that the transformer HV terminals would actually be labeled with the higher incident energy value LV label, since the HV terminals are in the same cabinet as the LV terminals. The HV fused switch terminals should be labeled separately.

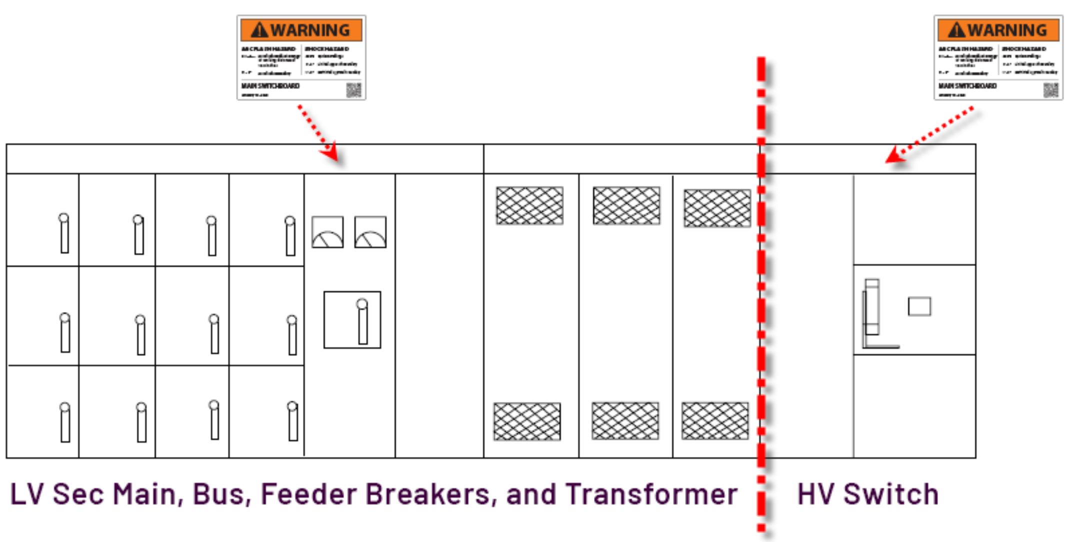


Figure 9.26

For switchgear with an isolated and barrier protected main breaker, the bus and feeder breaker section can typically be sectionalized with a lower incident energy label. Once again, clear demarcation and additional training is required. See Figure 9.27. This same labeling method can also be applied to enclosed high voltage switchgear and fused disconnects.

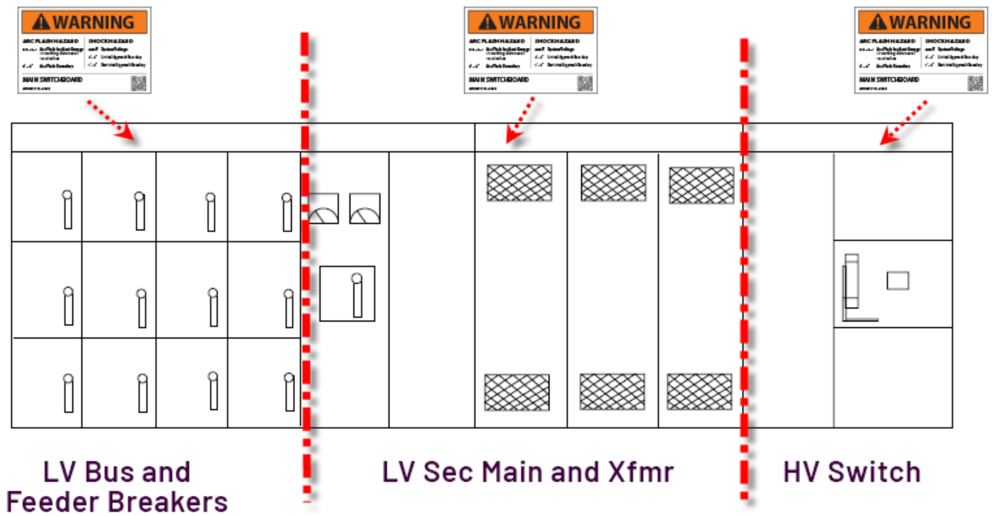


Figure 9.27

Feeder Bus Duct

Low voltage feeder bus duct has become the standard for many manufacturing facilities where production requirements require frequent machine tool change out, updating assembly lines, etc. The ease of simply plugging in a new feed for a different machine tool has many advantages. The disadvantages of feeder bus duct are that the phase conductors are typically not insulated, the bus structure can flex and become misaligned creating a hazard when plugging in or removing plug-ins, and the long lengths of some runs create short circuit disparities between the beginning and end sections, which create protection difficulties. All three of these issues relate directly to the best method for labeling a feeder bus duct. It is beyond the scope of this paper to explain the proper procedure for calculating the worst case PPE category or incident energy for a feeder bus duct. However, it should be sufficient to recognize that there can typically be several different PPE categories along a feeder bus duct length, due to the changing impedance and varying short circuit levels.

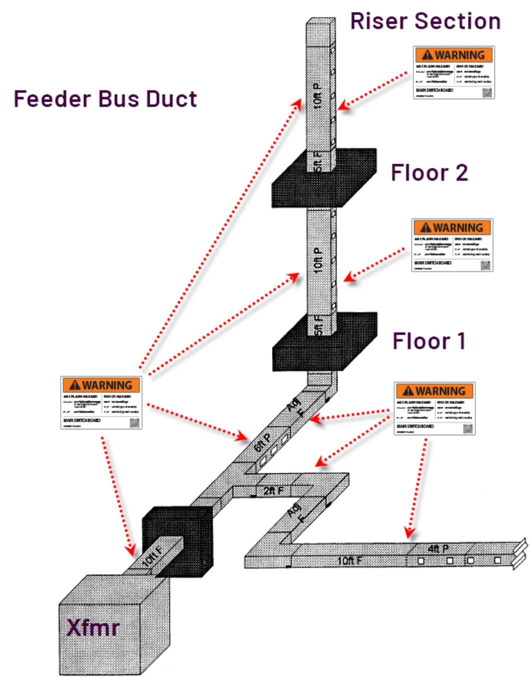


Figure 9.28

We recommend that the worst case PPE category or incident energy of the entire bus duct length be used to label the entire bus duct. We do not recommend different labels for different plug-ins, or the need to label each plug-in. A 4"x6" or 6"x8" label every 10-20 feet should be sufficient. See Figure 9.28.

Often, bus duct can have multiple bends which can hide a label from view. Consideration should be given to labeling these sections if there is potential for plug-ins. For vertical riser sections, it is probably only necessary to label at each floor level where plug-ins occur. Labeling should include both front and back sides of all runs.

Motor Control Centers

Motor control centers raise more labeling questions than almost any other type of equipment. The reason for this is the number of individual buckets or units in the equipment. Does each bucket require a label, or can the equipment be labeled using the same procedures as described for other equipment?

Figure 9.29

The key factor in labeling MCCs is understanding that the breaker/fuse in the individual motor starter bucket will not protect the worker if they initiate an arc flash in that bucket. The initial arc caused by the worker will instantly ionize the air in the bucket. This will propagate the arc to the breaker/fuse primary terminals, which will sustain the arc and prevent device operation. Therefore, the arc energy for each individual bucket is controlled by the remote tripping of the breaker/fuse that feeds the MCC. This is the same issue found in panelboards, switchboards, etc. Since there is only one arc energy for the entire MCC, we recommend labeling in the same manner as the other equipment – one "worst case" label as shown in Figure 9.29.

Size and depth of an enclosure, as well as electrode configuration, has an effect on incident energy. As such, in some cases depending on the situation and the specific calculations that have been completed, using one label per bucket may be advisable and necessary.

If the MCC extends more than 3-4 sections, additional labeling can be applied as necessary. MCCs are manufactured with bolted-on side and back sections, preventing inadvertent exposure of the main and vertical buses. Additionally, most MCCs are located either back-to-back in the center of the room or against the wall preventing opening of the MCC back panels. Therefore, labeling the side and back sections of an MCC is typically not required.

Junction Boxes and Miscellaneous Equipment

Junction boxes come in many forms, from standard conduit interconnections, to motor terminal connections. In a typical facility, there could be hundreds or thousands of boxes with accessible electrical wires. NFPA 70E 130.2 indicates it is imperative to train all workers that every electrical equipment is a potential AFH that requires a work permit before any equipment is opened, including junction boxes.

The key factor in deciding labeling protocol for junction boxes may come down to how frequently are they opened? If they are never opened, the need for labeling would follow the guidelines as provided for the back of an MCC or switchboard lineup. However, if they are opened on a routine basis, labeling is appropriate and necessary. According to Article 130.2, either option still requires a work permit.

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THIRD EDITION

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Written and compiled by

Bentley Systems,

developers of **EasyPower** software

EasyPower is Part of Bentley Systems

Power made easy.

ISBN 9780997102611

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9 780997 102611

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