SELECTIVE COORDINATION FOR OVERCURRENT PROTECTIVE DEVICES: APPLICATIONS FOR BUILDINGS IN THE UNITED STATES

by

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ABSTRACT

The inclusion of Selective Coordination in the NEC since the 2002 revision and the expansion of applications for which coordination of Over-current Protective Devices is required have resulted changes in design approaches for electrical engineers. In order to meet the requirements of the NEC regarding Selective Coordination for secondary power systems within buildings, often, upstream protective devices need to be held-in to a short-circuit condition, thus increasing the Arc Flash Energy. Electrical engineers must understand the many aspects of Selective Coordination when approaching a project from the very beginning. Decisions made by the engineer regarding Selective Coordination will have influence on project cost, project timeline, robustness of the electrical equipment, and safety of personnel working near or on the electrical equipment.

The main objectives of this report are to convey an understanding of the following: recent changes in requirements for Selective Coordination, implications of short-circuit analysis, impacts of selectively coordinated systems on Arc Flash Energy, risks surrounding Arc Flash Hazards, and design processes regarding Selective Coordination.

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GLOSSARY OF TERMS

Bolted Fault Current

A short circuit or electrical contact between two conductors at different potentials in which the impedance or resistance between the conductors is essentially zero.

Down-stream device

The one of two devices farthest from the power source and closest to the load being supplied and protected.

Electronic Trip Unit

Electronic component that works in conjunction with a circuit breaker. Unit both sends signals to the breaker and can gather power related data about its respective circuit to send to a server for storage. Features and settings vary greatly from simple to very sophisticated depending on the application.

Emergency Systems

As defined by [2]: "Those systems legally required and classed as emergency by municipal, state, federal, or other codes, or by any governmental agency having jurisdiction. These systems are intended to automatically supply illumination, power, or both, to designated areas and equipment in the event of failure of the normal supply or in the event of accident to elements of a system intended to supply, distribute, and control power and illumination essential for safety to human life."

Essential Electrical Systems

As defined by [2]: "Those systems intended to supply power to public or private facilities or property where life safety does not depend on the performance of the system. Optional standby systems are intended to supply on-site generated power to selected loads either automatically or manually."

Electrical Hazard

As defined by [12]: "A dangerous condition such that contact or equipment failure can result in electric shock, arc flash burn, thermal burn, or blast."

Exposed (Live) Parts

As defined by [12]: "Capable of being inadvertently touched or approached nearer than a safe distance by a person. It is applied to parts that are not suitably guarded, isolated, or insulated."

Fault Current

A current that flows from one conductor to ground or to another conductor due to an abnormal connection (including an arc) between the two.

Fault Current Momentary Duty

The current capability, under maximum fault conditions, of the Overcurrent Protective Device (OPD) during the first cycle of the fault current.

Flash Hazard Analysis

As defined by [12]: "A study investigating a worker's potential exposure to arc flash energy, conducted for the purpose of injury prevention and the determination of safe work practices and the appropriate levels of Personal Protective Equipment (PPE)."

Flash-Protection Boundary

An approach limit at a distance, from live parts that are exposed, within which a person could receive a second degree burn. (*Syn:* **arc-flash protection boundary**).

Incident Energy

As defined by [12]: "The amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event." Incident energy is measured in joules per centimeter squared (J/cm^2) or calories per centimeter squared (cal/cm^2).

Interrupting Rating

Regarding over-current protective devices, namely circuit breakers, this rating indicates the maximum current level to which a device could be exposed and still operate as designed. Exposure to the very maximum current level may damage the device such that it would only provide needed operation during the one event and need to be replaced after.

Legally Required Standby Systems

As defined by [2]: "Those systems required and so classed as legally required standby by municipal, state, federal, or other codes or by any governmental agency having jurisdiction.

These systems are intended to automatically supply power to selected loads (other than those classed as emergency systems) in the event of failure of the normal source."

Unlatching Time

The amount of time, usually fractions of a second, in which a circuit breaker would experience a designated current level and begin to operate to open the circuit.

Up-stream device

The one of two devices closest to the power source and farthest from the load being supplied and protected.

Withstand Rating

Regarding over-current protective devices, namely circuit breakers, this rating indicates the maximum current level into which a device could be held and still operate as designed repeatedly.

Working Distance

The dimension between the possible arc point and the head and body of the worker positioned in place to perform the assigned task.

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ACKNOWLEDGMENTS

Patience is truly a virtue and is one which I have had the opportunity to learn throughout my experiences as a Master's student at Kansas State University. As exemplified by many of my instructors and especially by my Major Professor, Dr. Morcos, patience on their part was appreciated on many occasions. I would also like to express many thanks to my Advisory Committee, Dr. Pahwa and Dr. Starrett, for their time and efforts in helping develop this report. Also appreciated was the understanding of my friends and family during my studies and the long bouts of their own neglect. I thank my parents for always regarding higher education as a high priority in both their own lives and those of their children. And, thanks goes to my sister for her persistent belief in me and for always lending an understanding ear.

CHAPTER 1 – INTRODUCTION

Electrical engineers tasked with designing electrical distribution systems for buildings within the United States are faced with new challenges surrounding Selective Coordination in the last decade. Changes in the 2002 Revision of the National Electric Code (NEC) [1] have brought forth broader inclusions for coordination of Over-current Protective Devices (OPD) as well as made the requirements more stringent. While engineers are bound in their design by codes and standards, as well as local Authorities Having Jurisdiction (AHJ), their engineering judgment must also play a role in deciding on solutions for operable and safe designs.

As a result of recent Selective Coordination requirements, the knowledge base needed for selecting Overcurrent Protective Devices (OPD) features and setting has greatly broadened and the need for open communication and teamwork with the local AHJ has become essential. Also required is an in depth understanding of the consequences of a selectively coordinated system as the risk for a deadly Arc Flash event raises.

The purpose of this report is to evaluate the risks involved with selectively coordinated electrical distribution systems within commercial buildings in the U.S. Considered in this report are building electrical systems consisting of 600V or less. Commonly accepted codes and standards are used as references for this evaluation. Details about considerations and calculations that an electrical engineer must make to ensure a functional and safe electrical system are covered in this report. After reading this report, an electrical engineer will be able to make well-informed decisions about approaching a design which will entail Selective Coordination.

This report does not include information for buildings or structures with occupancy types other than commercial use. Neither does it include electrical systems over 600V nor components typically used within systems over 600V.

Information for this report was gathered by reviewing technical literature from recent reports and white papers. Code and standard requirements and recommendations were collected and included, as well as information from a technical seminar.

This report is organized into 7 chapters. First, the report discusses Selective Coordination; what it is and the applicable requirements. Second, an overview of short-circuit available fault current calculations and relevance is discussed. Third, the dangers and analysis of Arc Flash are included. Next, the report discusses common requirements for electrical engineers pertaining to collecting a permit for their design. The report then includes a chapter on the risks of implementing a design with selectively coordinated devices and concludes with suggestions for further work to support or reject the need for such requirements.

CHAPTER 2 - SELECTIVE COORDINATION

Electrical systems within buildings, in the simplest terms, are made up of busses, conductors, and protective equipment. The protective devices, also referred to as OPD, serve to both maintain the integrity of electrical busses and conductors, and to minimize injury or death to personnel. The OPDs achieve this by opening the circuit, thus stopping the flow of current, during events leading to conditions beyond the capacity of the electrical system.

When an upstream OPD and a downstream OPD work together in such a way that only the appropriate device opens during an overcurrent or fault event, the two devices are said to be coordinated. Their tripping characteristics complement one another in such a case. In recent years, the term Selective Coordination has become a buzz word within the Buildings Electrical Systems industry due to new requirements in the 2011 NEC [2]. Characteristics of devices which are selectively coordinated complement one another even in extreme cases of high overcurrent events. As a result, the system designer, usually an electrical engineer, must take into account factors and variables, such as device laboratory tests and increased Arc Flash Hazards, not necessarily considered before. The impacts to design considerations due to new Selective Coordination requirements are discussed in this chapter. Also discussed, the common types of OPD used to achieve Selective Coordination within buildings and how they perform in combination.

2.1 Overview

The purpose of Selective Coordination is to eliminate, or at least greatly minimize, the chance of an outage during a period in which the building is being electrically supported by a secondary power means falling under one of the three following system categories as defined by [2]:

- Emergency Systems
- Legally Required Standby Systems
- Essential Electrical Systems

A building’s primary source of electrical power is usually the local utility or an onsite power generation plant. In the case of an outage, the primary power source can no longer supply the electrical power for the building. In such a case, the building may be equipped with a secondary electrical power generation systems such as diesel generators or battery banks. Refer to [2] for requirements pertaining to when secondary systems are mandatory. These secondary systems can vary in capacity and duration based on the occupancy type and local code requirements.

For example, most hospitals have multiple generators that will act as a secondary source of power in the case that the utility or an on-site plant experiences an outage. The equipment fed by the generators is limited to those which are required by the NEC and local authorities. This equipment will include medical life support equipment, egress lighting, and some of the elevators. Selective Coordination is implemented to minimize any outages, with regards to the secondary sources, within the building due to overcurrent and/or fault events which may occur during this period of secondary power being supplied to the building.

Figure 2.1 illustrates the difference in operation of two systems which have the same configuration, but differ because the devices in the system on the left have been selectively coordinated. The fault causes much more disruption in the system on the right where none of the circuits continue to be fed. If considering the hospital example from above, any equipment needed for lifesafety systems would no longer continue to operate in the case on the right. In the system on the left, only operation of equipment fed by the bottom right circuit will be lost.

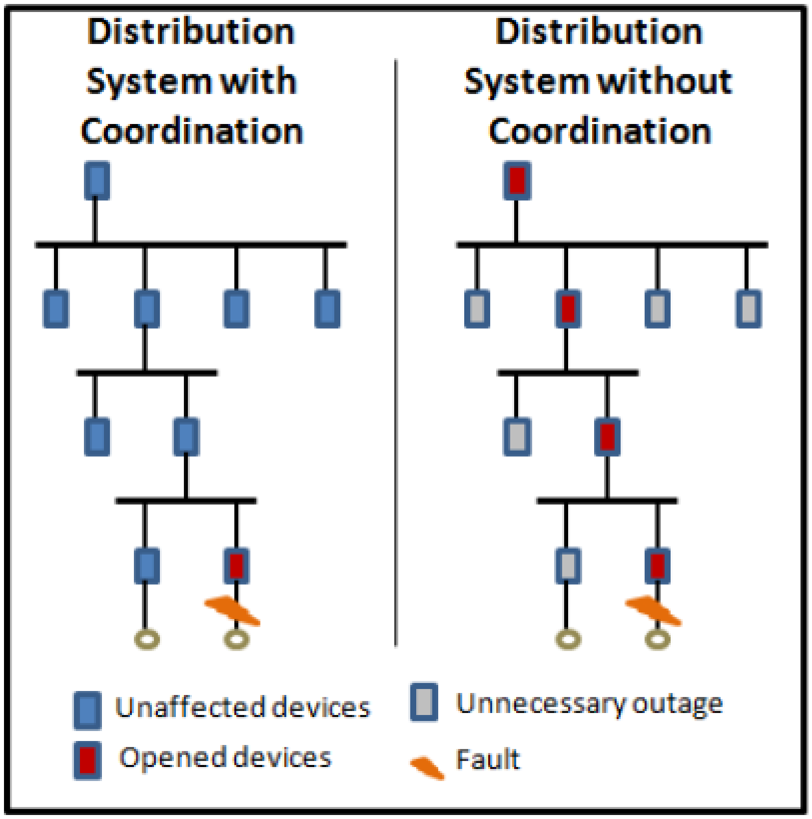

Figure 2.1. Electrical Distribution System with and without Selective Coordination [3].

2.2 The requirements

Earley and Sargent cover requirements for the installation of electrical equipment and raceways for public and private buildings and structures [2]. Electrical engineers in the buildings industry must design electrical systems to comply with the requirements from [2].

The NEC revision cycle takes three years. Between the 2002 [1] and 2005 [4] revisions, requirements for coordination of OPD started to become more stringent. In Reference [1] the definition of **Coordination** as listed in Section 240.2 is,

> *"The proper localization of a fault condition to restrict outages to the equipment affected, accomplished by the choice of selective fault-protective devices."*

Section 240.12 went on to say that the electrical system should be electrically coordinated in cases where an orderly shutdown is required in order to maintain safety for equipment and personnel.

Also, Section 620.62, which applies to motors for transportation systems in buildings such as elevators, Selective Coordination is required for cases when more than one machine disconnecting means are fed by one conductor. In these cases, each disconnect shall have its own OPD which is selectively coordinated with the conductor's upstream OPD. No selective coordination requirement for Emergency Systems, Legally Required Standby Systems, or Essential Electrical Systems was listed.

In [4], the term was moved to Article 100 and changed to **Coordination (Selective)** and the definition was changed to,

> *"Localization of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the choice of overcurrent protective devices and their ratings or settings."*

The requirements for Sections 240.12 and 620.62 remained the same as in they were in [1], but Sections 700.27, 701.18, and 708.18 were added to Reference [4] for secondary source systems. These sections read as:

> *<u>Section 700.27 Coordination (Emergency Systems)</u>*
> *"Emergency System(s) overcurrent devices shall be selectively coordinated with all supply side overcurrent protective devices."*

> *<u>Section 701.18 Coordination (Legally Required Standby Systems)</u>*
> *"Legally required standby system(s) overcurrent devices shall be selectively coordinated with all supply side overcurrent protective devices."*

In the 2008 revision of the NEC [5], requirements for Selective coordination were again revised. Exceptions were stated in Sections 700.27 and 701.18 for the OPD for the primary and secondary side of transformers, as well as OPD in series of the same size. Also, Article 708 for

Critical Operations Power Systems was added. The requirement for Selective Coordination is stated in Section 708.54.

<u>Section 708.54 Coordination (Critical Operations Power Systems)</u>
"Critical operations power system(s) overcurrent devices shall be selectively coordinated with all supply side overcurrent protective devices."

No exceptions were listed for this section.

Notice the clause in each of the three sections (700, 701, and 708) that reads, "…s*hall be selectively coordinated with all supply side overcurrent protective devices*" in the citations above. This statement is interpreted differently by different AHJ. Figure 2.2 shows an electrical distribution system with the utility supplying the primary source of electricity, and a generator serving as a secondary source of electricity. "…all supply side overcurrent protective devices…" can and has been interpreted as one of the following:

1) All OPD which are upstream of a load on the respective Secondary system
2) All OPD which are upstream of a load whether on the primary or secondary system

In the first case, as shown in Figure 2.2 with the dashed green line for the Secondary Source, only those OPD serving loads on the secondary system must be selectively coordinated. In the second case, a higher quantity of OPD are required to be selectively coordinated as OPD along both the green and blue dashed lines would need to be coordinated. This will cost the client in both materials and engineering fees. Because this point is open to interpretation, it is one of several topics which will need to be discussed with the AHJ early in the design process.

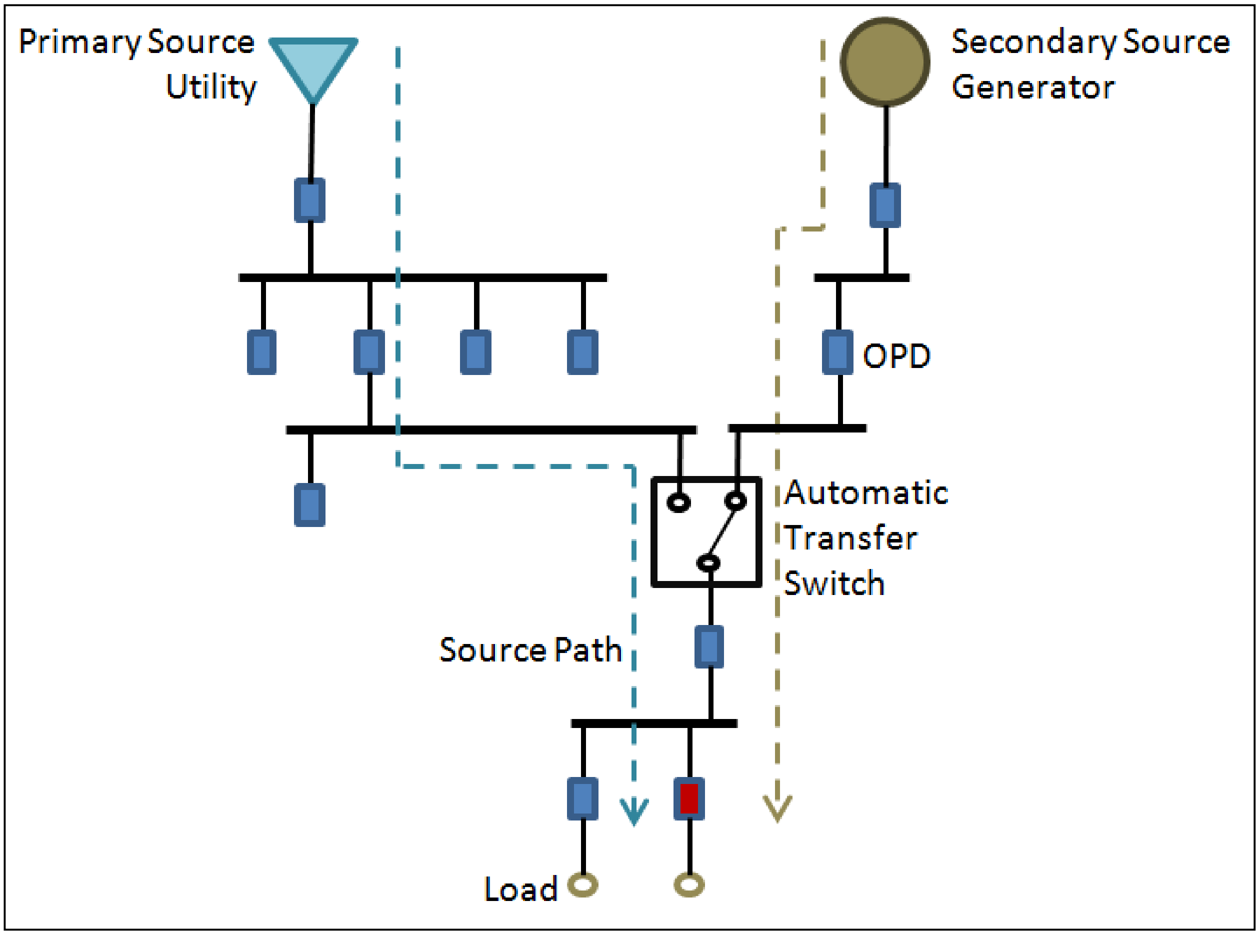

Figure 2.2. Supply side Over-current Protective Devices.

Beyond deciding to which OPD the NEC Selective Coordination requirements apply, the engineer must make decisions about what types of OPD's to use.

2.3 Overcurrent Protective Devices for Selective Coordination

Circuit breakers and fuses are the most common type of OPD for buildings. They operate differently from one another and thus have differing applications and react differently to overcurrent and fault events. Below is a discussion of the combinations of breakers and fuses used in buildings and the advantages and disadvantages of these combinations with regards to Selective Coordination.

2.3.1 Selective Coordination for Circuit Breaker Combinations

In the buildings industry, Selective Coordination is illustrated graphically by "white space" between two devices' Time Current Curves (TCCs). One of the many questions surrounding this widely accepted rule of thumb is, "How much space is enough?" A second question also arises for the application of circuit breakers in particular; "Can there be overlap in the instantaneous region?" Figure 2.3 illustrates why these two questions often arise for those designing the electrical distribution system for a building.

The TCC's are usually provided to an engineer by device manufacturers. The curves identify the properties and characteristics of the individual device model. These characteristics include information about how fast the device will react to different overcurrent levels.

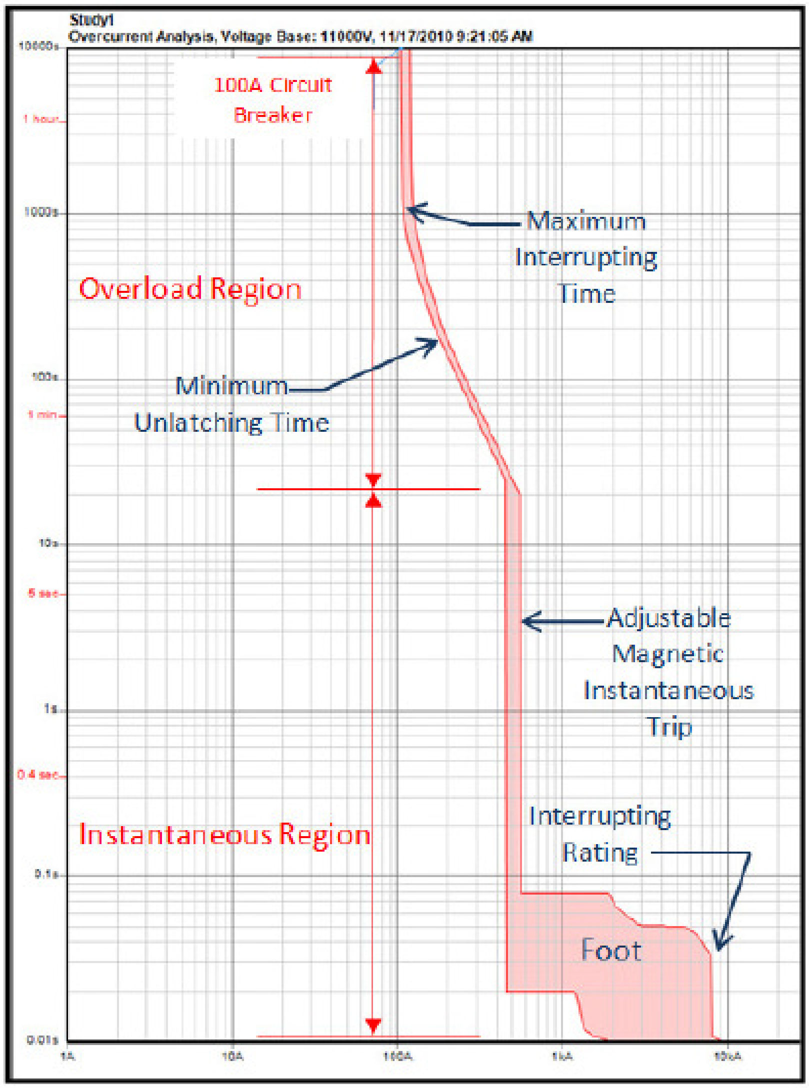

Figure 2.3 Circuit Breaker Time-Current Curve Components [3].

Figure 2.3 shows the TCC for a typical 100A MCCB. Two regions, the Overload Region and the Instantaneous Region, are indicated to highlight the different interrupting features of the breaker. Within the Overload Region, the curve describes how the device will operate during an overload. At 200A, the breaker will open the circuit within 190s. Within the Instantaneous Region, the curve is usually much steeper, if not completely vertical, until it meets the "Foot". Operation of the breaker in this region will be due to a short circuit event. During an overload current of 8kA, the device will open the circuit in 0.035s.

Notice that the curve is shown as a band rather than a line. This band represents the tolerance allowances for both manufacturing inconsistencies and operating functions within the device.

The left side of the band represents the Unlatching Time, while the right side represents the maximum Interrupting Time. When an overcurrent or short circuit event occurs, the breaker's contacts begin to separate or "unlatch", and then, any arc between the contacts is distinguished, opening or "interrupting" the circuit.

Reference [2] does not state a requirement for the gap or white space between the bands of two devices. The designer should check with the device's manufacturer for specific recommendations for the model they are specifying. The designer should also check if the AHJ has any requirements for the separation between curves. Regarding circuit breakers specifically, according to "IEEE Standard 242-1986: IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, [6]", "…only a slight separation is planned between the different characteristic cures. This lack of a specified time margin is explained by the incorporation of all the variables plus the circuit breaker operating times for these devices within the band of the device characteristic curve."

The most critical characteristic for an OPD is the Interrupting Rating. This is the absolute maximum current for which the device has been designed to operate. The Interrupting Rating is represented on the TCC with the vertical cut-off at the right hand side of the Foot. The designer will determine the system's Available Short Circuit (ASC) current at the device's location and choose a device with an Interrupting Rating not less than the ASC current. Refer to Chapter 3 for information pertaining to short circuit analysis.

For Selective Coordination to be achieved between two circuit breakers, the TCC's for the up-stream device and the down-stream device should not overlap. This requirement is a tall order for some circuit breakers due to their Instantaneous Region, particularly the Foot. Figure 2.4 illustrates this.

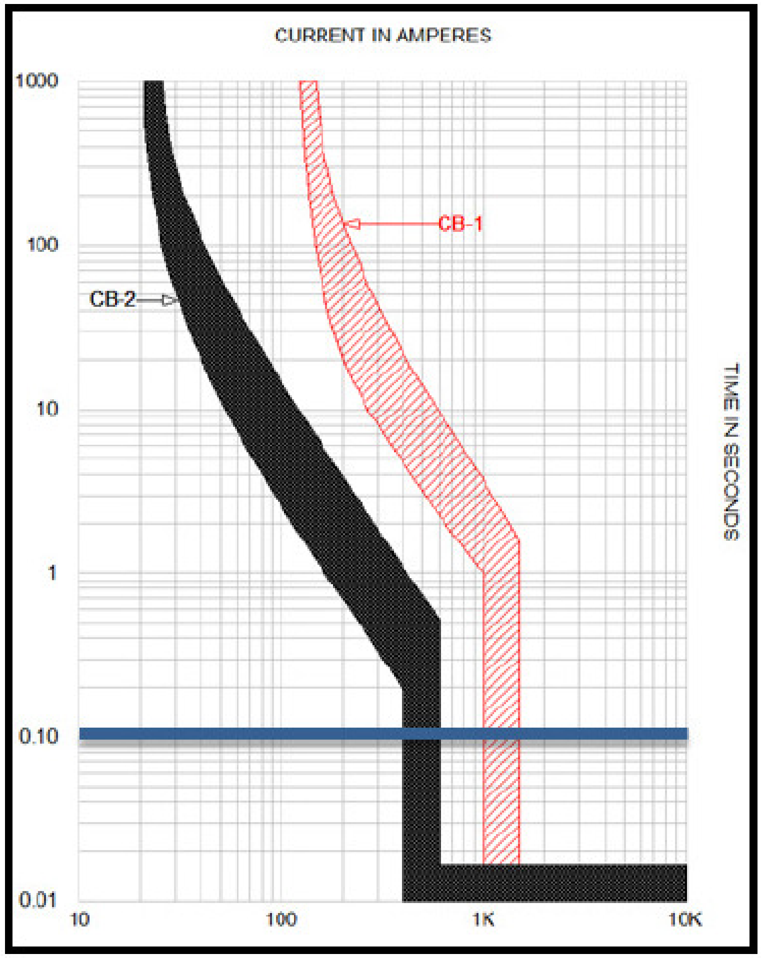

Figure 2.4 Circuit Breaker Time-Current Curve Components [3].

Circuit Breaker number 1 (CB1), on the left, and Circuit Breaker number 2 (CB2), on the right, are Molded Case Circuit Breakers (MCCBs). These two devices are coordinated from approximately 0.017s, 1kA and beyond, before which the Foot of each device overlaps. When an event occurs within the overlapping region at 1kA or higher, most likely, both devices will operate and open. In that case, the outage will not be limited to the down-stream circuit as illustrated in Figure 2.1.

One of the questions posed at the beginning of this section, "Can there be overlap in the instantaneous region?" is answered differently by different AHJ entities across the country. For example, according to Square D's "Guide to Power System Selective Coordination 600V and

Below [7]," The Florida Agency for Health Care Administration (AHCA) has its own answer for the design of electrical systems for hospitals in Florida. AHCA only requires OPD curves to be coordinated to 0.1s. This means that below the blue line drawn in Figure 2.4 AHCA does not require devices to be selectively coordinated. For most devices, the portion of the curve below 0.1s includes most of their Instantaneous Region. Therefore, the devices operate independently, depending on the location and current value except when the current is high enough to fall in the region below 0.1s operating time. Other jurisdictions in the U.S. have decided to use this rule as well. They include the City of Seattle, Washington and the State of California.

If the AHJ does require the designer to have a fully coordinated set of OPDs, meaning no overlap on the TCCs should be evident, the engineer will need to employ one or all of a few options to comply using circuit breakers. Varying the type of circuit breaker is the first option. The engineer can specify a Power Circuit Breaker, for example. The TCC characteristics on a Power Circuit Breaker can be manipulated via an adjustable electronic trip unit. By adjusting the trip unit, the curve shape can be changed. In particular, the instantaneous region can be manipulated to shorten or even eliminate the Foot of the curve and thus the overlap. The Power Circuit Breaker also has a Withstand Rating composed of two parts; 1) the Short-time Withstand Current and 2) the Withstand time. This rating, unlike the performance limit of the Interrupt Rating, represents a safety limit at which the device can remain held into a fault condition without damage to personnel or equipment. The Withstand Time is as high as 0.5s or 30 cycles for some devices.

However, the designer must understand that the longer the current is held by the breaker, the higher the energy becomes. Therefore, the designer must be mindful of increasing the Arc Flash Hazard if the Withstand Time is increased on a Power Circuit Breaker. Arc Flash Hazard is discussed in detail in Chapter 4.

A second option for the engineer to achieve Selective Coordination is to change the size of the circuit breakers rather than the type. However, the designer must keep in mind the NEC requirements for maximum and minimum overcurrent protection sizing which varies per load type.

If the engineer is in doubt about the coordination of two devices, he or she should consult with a representative from the device manufacturer. The manufacturer's data should be based on laboratory test results and devices that have not been tested together should not be specified for a Selective Coordination application. After running tests on their own devices, Schneider Electric published results in their data bulletin, "A Comparison of Circuit Breakers and Fuses for Low Voltage Applications [8]," stating that, "…previous published circuit breaker trip curves, due to dynamic impedance and current limiting effects, are actually somewhat conservative in the instantaneous region when considering selectivity between circuit breakers, and that many line/load combinations of circuit breakers actually do coordinate even if their trip curves indicate otherwise,". This quote exemplifies that it may be useful to contact the manufacturer directly to gain an understanding of their expectations for their products' performance. Yet another option for the designer is to change manufactures all together if he or she is not satisfied with the solutions one manufacture can provide. Refer to Appendix A for an example of the Selective Coordination process for a typical commercial system with circuit breakers.

2.3.2 Selective Coordination for Fuse Combinations

OPD manufacturers have been paying attention to applications for coordination with fuses for a much longer time than for circuit breakers. Fuses were the first form of circuit protection, dating back as far as the late 1800s. The TCC for a fuse is much simpler in appearance and thus easier to coordinate. Figure 2.5 is an example taken from Cooper Bussmann's "*Selective Coordination*" [9] of two fuses' TCCs. Figure 2.5 illustrates the relationship between two time-delay, dual-element fuses in series. The single line diagram for the system is shown in the upper right hand corner of the figure.

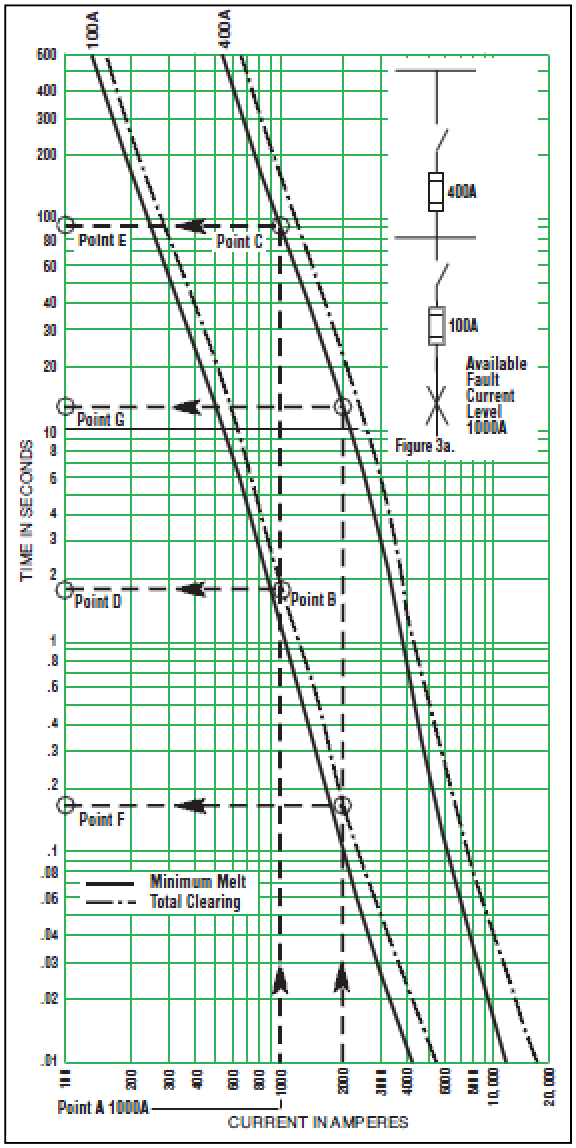

Figure 2.5. Fuse Time-Current Curve Examples (Recreated from [9]).

In the system shown in Figure 2.5, the available short circuit current is 1kA RMS symmetrical at the down-stream fuse. Follow a vertical line up from 1kA on the horizontal axis up to the intersection of the clearing time for the 100A fuse (from point A to B on the graph), then, from that intersection follow a horizontal line left to the vertical axis at point D. Point D tells the engineer how long the fuse will experience the short circuit before opening the circuit. Now, as stated previously, in a selectively coordinated system, only the down-stream device will operate. If a vertical line from B is continued up to the minimum melt curve (the left side of the band) to point C, then over to the left to point E, the minimum time to operate the up-stream, 400A fuse is found. The difference between the two is almost 88 seconds. Thus, Selective Coordination is insured with a 1000A short circuit event.

Besides the TCCs, fuse manufacturers publish ratio guides. The ratios listed are for those pairs of fuse models that have been laboratory tested together. The ratios convey the relationship between the ampere rating of the up-stream fuse and the down-stream fuse. If, for example, the ratio is 2:1, then the up-stream fuse ampere rating needs to be at least twice that of the down-stream fuse for coordination to be achieved. For example, in Figure 2.6, if a system has a line-side (up-stream) fuse that is a Cooper Bussmann 100A T-Tran JJN type, the designer could only expect to pick a load-side (down-stream) Fast-Acting Limitron RK1 type fuse with a ratio of 3:1 to maintain selectivity. Thus, the down-stream fuse should be rated at 30 amperes. If the load required higher than a 30 ampere fuse, the upstream fuse rating would have to be increased.

***Selectivity Ratio Guide for Blackout Prevention (Line-Side to Load-Side)**

Circuit					Load-Side Fuse									
Current Rating					601-6000A	601-4000A	0-600A			601-6000A	0-600A	0-1200A	0-600A	0-60A
Type					Time-Delay	Time-Delay	Dual-Element Time-Delay			Fast-Acting	Fast-Acting	Fast-Acting	Fast-Acting	Time-Delay
Trade Name					Low-Peak	Limitron	Low-Peak		Fusetron	Limitron	Limitron	T-Tron	Limitron	SC
Class					(L)	(L)	(RK1)	(J)	(RK5)	(L)	(RK1)	(T)	(J)	(G)
Cooper Bussmann Symbol					**KRP-C_SP**	**KLU**	**LPN-RK_SP LPS-RK_SP**	**LPJ-SP TCF[†]**	**FRN-R FRS-R**	**KTU**	**KTN-R KTS-R**	**JJN JJS**	**JKS**	**SC**
Line-Side Fuse	601 to 6000A	Time-Delay	Low-Peak® (L)	**KRP-C_SP**	2:1	2.5:1	2:1	2:1	4:1	2:1	2:1	2:1	2:1	N/A
Line-Side Fuse	601 to 4000A	Time-Delay	Limitron® (L)	**KLU**	2:1	2:1	2:1	2:1	4:1	2:1	2:1	2:1	2:1	N/A
Line-Side Fuse	0 to 600A	Dual-Element	Low-Peak (RK1)	**LPN-RK_SP LPS-RK_SP**	–	–	2:1	2:1	8:1	–	3:1	3:1	3:1	4:1
Line-Side Fuse	0 to 600A	Dual-Element	(J)	**LPJ-SP**	–	–	2:1	2:1	8:1	–	3:1	3:1	3:1	4:1
Line-Side Fuse	0 to 600A	Dual-Element	Fusetron® (RK5)	**FRN-R FRS-R**	–	–	1.5:1	1.5:1	2:1	–	1.5:1	1.5:1	1.5:1	1.5:1
Line-Side Fuse	601 to 6000A		Limitron (L)	**KTU**	2:1	2.5:1	2:1	2:1	6:1	2:1	2:1	2:1	2:1	N/A
Line-Side Fuse	0 to 600A	Fast-Acting	Limitron (RK1)	**KTN-R KTS-R**	–	–	3:1	3:1	8:1	–	3:1	3:1	3:1	4:1
Line-Side Fuse	0 to 1200A	Fast-Acting	T-Tron® (T)	**JJN JJS**	–	–	3:1	3:1	8:1	–	3:1	3:1	3:1	4:1
Line-Side Fuse	0 to 600A		Limitron (J)	**JKS**	–	–	2:1	2:1	8:1	–	3:1	3:1	3:1	4:1
Line-Side Fuse	0 to 60A	Time-Delay	SC (G)	**SC**	–	–	3:1	3:1	4:1	–	2:1	2:1	2:1	2:1

***Note:** At some values of fault current, specified ratios may be lowered to permit closer fuse sizing. Plot fuse curves or consult with Cooper Bussmann.
General Notes: Ratios given in this Table apply only to Cooper Bussmann fuses. When fuses are within the same case size, consult Cooper Bussmann.
[†] TCF (CUBEFuse) is 1 to 100A Class J performance; dimensions and construction are unique, finger-safe IP-20 design.

Figure 2.6. Selectivity Ratio Guide for Blackout Prevention (Line-Side to Load-Side) [9].

2.3.3 Selective Coordination for Fuse and Circuit Breaker Combinations

Breakers and fuses operate in different ways, thus, selective coordination between them can be difficult. In some cases a breaker/fuse combination may not work at all. Again, laboratory testing should be conducted and results published before a designer specifies a set of devices for selective coordination.

In cases where the circuit breaker is up-stream of the fuse, even when the plot of the TCC for both devices shows, graphically, that the devices are selectively coordinated, one cannot be sure without laboratory testing for the pair. Figure 2.7 shows a breaker/fuse combination.

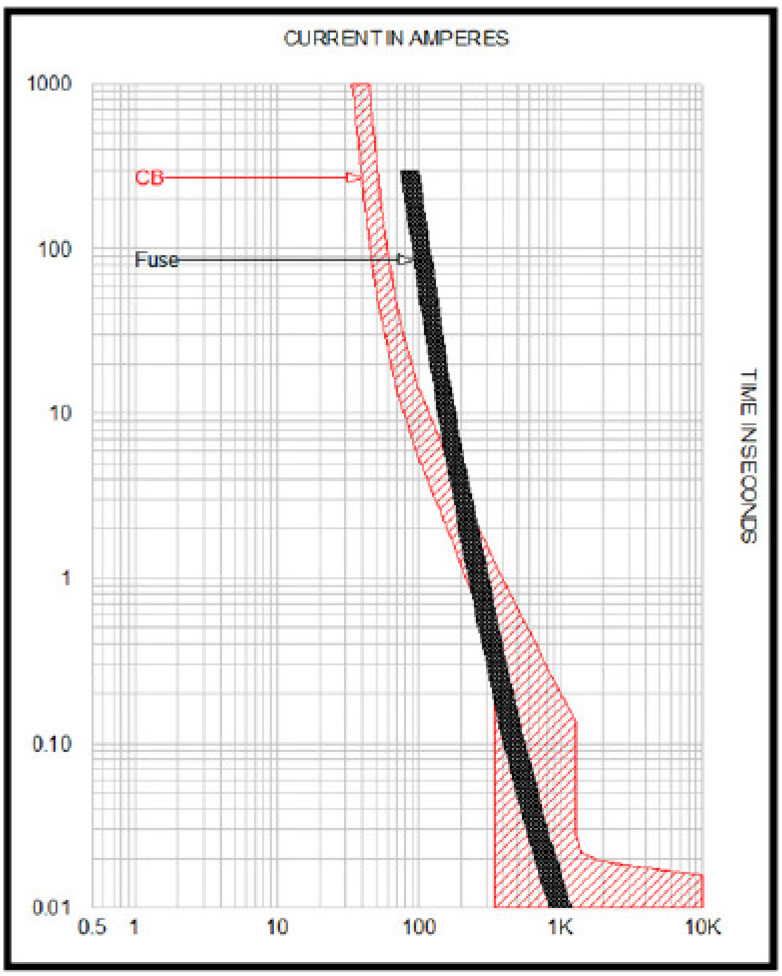

Figure 2.7. Fuse and Circuit Breaker Curves [3].

When a fuse is up-stream of a circuit breaker, selective coordination is merely impossible. Figure 2.7 illustrates this fact; the bottom of the fuse curve usually falls along the foot of the circuit breaker.

2.4 Ground Fault Protection

Ground Fault Protection (GFP) is required by [2] for particular instances, such as in Article 230.95 in [2] which requires GFP for solidly grounded wye electric service disconnects between 150 and 600V and rated at 1000A or greater. According to National Electrical Manufacturers Association's (NEMA) "*A NEMA Low-Voltage Distribution Equipment Section Document ABP 1-2010: Selective Coordination*" [10], faults to ground are the most common types of faults and the frequency of their having instigated building fires prior to the 1970's prompted the inclusion of requirements in the 1972 revision of the NEC. GFP is required due to the potential of an arc to ground for which the current value may be substantially lower than an arc between phases. With such a low current value, the fault may be maintained for long periods of time with typical OPDs. GFP equipment is usually in the form of dedicated relays or functions integral to circuit breaker trip units.

Both the NEC and the Underwriters Laboratory (UL) mandate requirements for the tripping function for ground fault protections according to [10]. Figure 2.8 illustrates how these requirements fit into a typically shaped ground fault protection device.

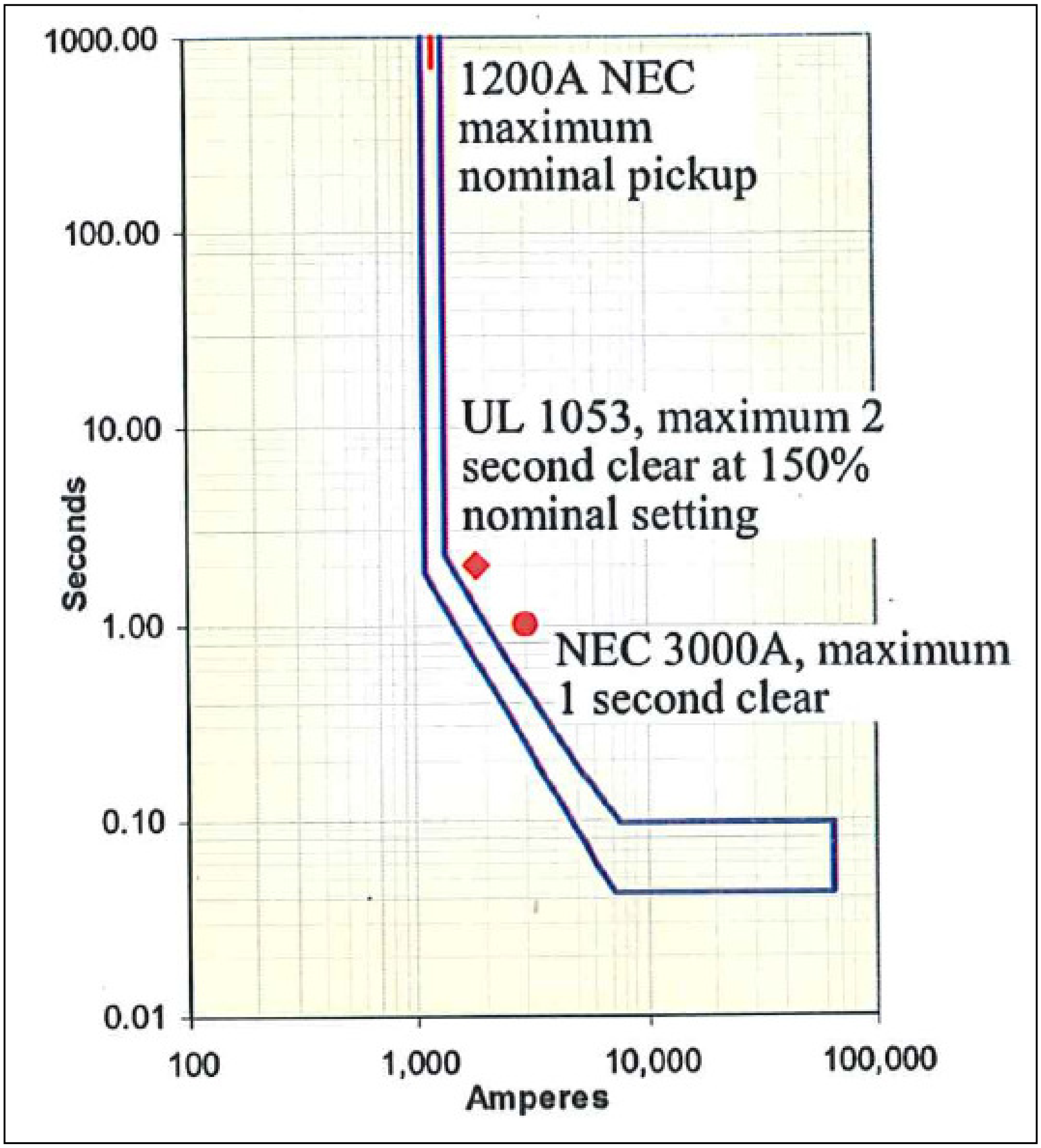

Figure 2.8. Typical Ground Fault Protection TCC (Reproduced from [10]).

The shape of the TCC for GFP devices is very limited unlike those of the phase protective OPDs. The sloped portion of the curve is commonly referred to as the "I^2t Slope" and provides some selectability to the user. It is the rigidness of these curves that can cause further challenge in developing a selectively coordinated system.

2.5 Design Impacts

The addition of the Selective Coordination requirements to the 2005 NEC has changed the design process for electrical engineers. More thought must be given to selecting OPDs. In recent decades, circuit breakers have become the common solution for circuit protection in commercial buildings. Breakers provide easy troubleshooting and are reusable, eliminating the need for on-site stockpiles. Designers must now, however, take a second look at fuses for some Selective Coordination designs where they would not have otherwise.

Since OPDs come in a variety of ratings and characteristics, the designer must consider each system as a unique case and the many factors must be considered.

Designers must also open the channels of communication with the AHJ earlier in the design process. Understanding the requirements upfront can be critical in achieving approval for a permit in a timely manner and saving the client money. Lastly, designers must also now consider hiring an expert where their own skills are exceeded. Many engineers specialize in coordination and base their entire career around this skill set.

Cost to the owner is yet another consideration for a selectively coordinated system. After the contractor has placed orders for components like OPDs, any changes in the orders are referred to as “Change Orders”. Finding out AHJ requirements after the contractor has placed orders could lead to Change Orders and will most likely result in higher costs to the contractor and consequently to the client.

CHAPTER 3 - SHORT-CIRCUIT AVAILABLE FAULT CURRENT

Short-circuit fault currents can be very destructive due to the heat and electromagnetic force that are released into the system during a short-circuit event. Short-circuit current calculations should be performed for every electrical distribution system design for commercial buildings. This calculation will tell the engineer if the specified equipment and components are robust enough to withstand the available fault current within the designed system.

The available fault current is different at every point along the electrical distribution system due to the additive effect of the impedance of the components between the source and the point in question. Thus, this calculation is essential in understanding not only the specifications for equipment at a specific location, but also in understanding how the arc flash potential will vary at each location. This chapter will outline the methods for calculating short-circuit available fault current and assumptions the engineer can make in order to gain an understanding of implications with regards to Selective Coordination for each OPD within the system. The calculation methods referenced in this chapter regarding short-circuit analysis are taken from the IEEE Standard 242-1986 [6].

3.1 The Calculation

In general, Reference [6] breaks down the short-circuit analysis into three tasks:

1) Develop a graphical representation of the system
2) Determine the total equivalent impedance between the source and designated points on the system
3) Calculate the short-circuit current at each point by dividing the voltage by the total impedance at that point

3.1.1 Graphical Representation

The first task entails developing a drawing, either by hand or with the assistance of a computer program, to identify where calculations are required. Often, engineers need to calculate available short-circuit current values at electrical equipment, such as panelboards, and at motors and generators. A graphical representation is also useful for recording all the information about each piece of equipment or each component in one location.

3.1.2 Total Equivalent Impedance

To determine the equivalent impedance between the source and the designated points of interest, a full understanding of each component along the path is necessary. Information about each component's impedance is needed. For different types of components, this information comes in different forms. For instance, for conductors, the impedance is often presented in milliohms per 100 linear feet. Thus, the engineer would need to know the length of the conductor to determine the impedance for a specific run of conductor. The impedance for the conductor would also vary by material. Reactance and resistance data can be gathered from the equipment manufacturer or, in the absence of such data, some values can be found in various codes and standards such as the tables in Chapter 2 of the Standard. Using data from the manufacturer is always a preferable method.

3.1.3 Short-Circuit Current Calculation

Reference [6] establishes a few assumptions which both simplify the calculation and ensure a conservative solution is achieved. First, the engineer should establish assumptions about the fault type. Reference [6] assumes that the short-circuit condition is being caused by a "**bolted fault**": a zero-impedance condition. Also, the fault should be assumed to be across all three phases as this usually results in a maximum fault current. Reference [6] states that, "Bolted line-to-line currents are about 87% of the three-phase value, while bolted line-to-ground currents can range from about 25-125% of the three phase value, depending on the system parameters. However, line-to-ground currents of more than 100% of the three-phase value rarely occur in industrial and commercial systems."

Secondly, further assumptions should be made regarding equipment that could contribute energy to or dissipate energy from the system during an event. These assumptions include the following:

- Load currents are ignored

- The source (usually the utility) is operating at nominal voltage values with no loads
- Motors are running at their rated voltage
- Transformer impedance values are equal to their actual percentages or within +/- 7.5% of nominal values
- Any source X/R ratios that are unknown are assumed to be at rather high values
- Equipment bus impedances are ignored

Reference [6] offers guidance for particular information that should be gathered for specific types of Fault Current Sources such as the utility, generators, and synchronous motors. Also explained: how the short-circuit current will vary over time.

Refer to Appendix B for a short-circuit analysis example from [6] using a Direct Method calculation approach.

The total short-circuit current is a summation of the contribution of all the components on the system. Figure 3.1 illustrates how different components may react after being exposed to a short-circuit condition and the shape of the resulting total short-circuit wave form. Only the symmetrical short-circuit currents are shown in this figure. Notice that the contributions from some sources decrease more quickly than others.

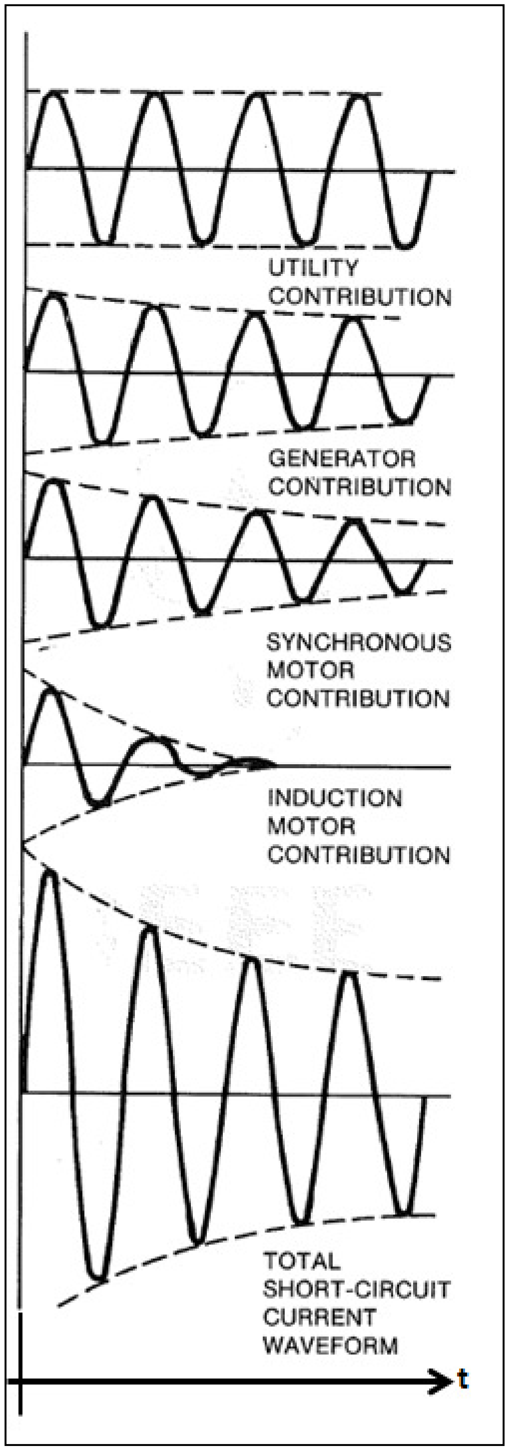

Figure 3.1. AC Symmetrical Contributions from Various Sources (Reproduced from [6]).

While Figure 3.1 is a good example of how the symmetrical contributions all influence the total short-circuit current waveform, most short-circuits are asymmetrical. The typical asymmetrical short-circuit waveform is a combination of the alternating current, symmetrical waveform and a direct current waveform as shown in Figure 3.2. Component "a" depicts the direct current component. The total short-circuit current is asymmetrical because the waveform is no longer symmetrical about the original axis.

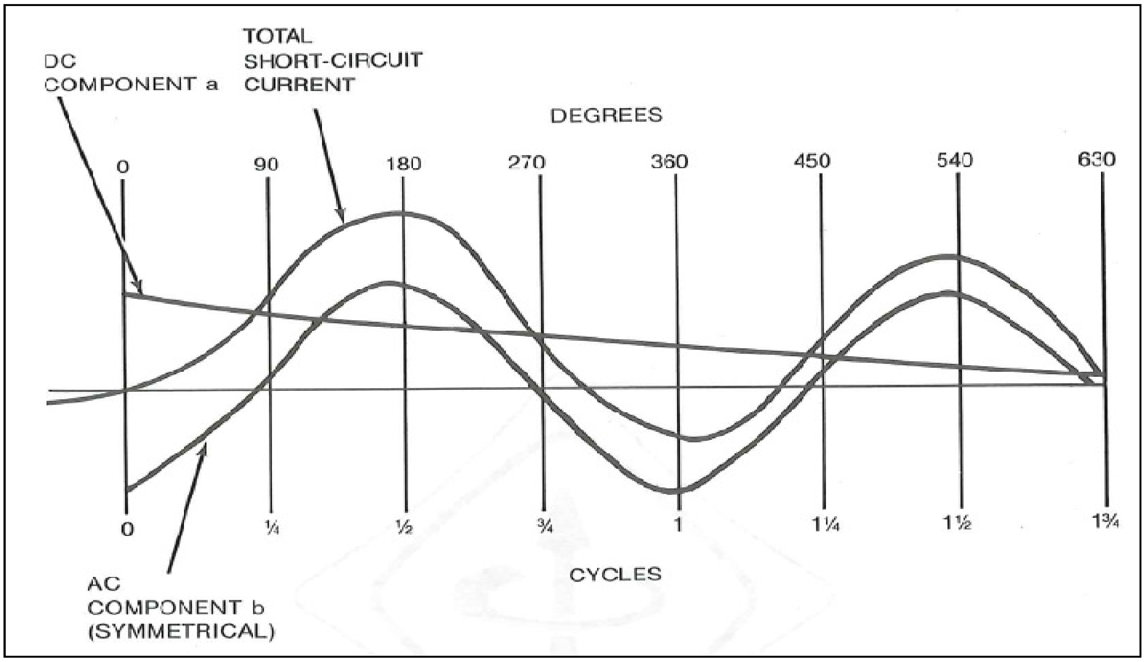

Figure 3.2. Total Asymmetrical Short-Circuit Current Waveform. (Reproduced from [6]).

As seen in Figure 3.2, the short-circuit current value changes over time. This fact plays an important role in regards to selective coordination. Not all of the OPDs within the system will operate at the same time. Some, in order for selectivity to be maintained, will operate within the first cycle of the fault. For these devices, an evaluation of the system as subject to the maximum values of short-circuit current, "the symmetrical RMS short-circuit of the alternating current" [6], will be sufficient. This is the most commonly needed evaluation for other types of equipment as well. Other OPDs will be held into the fault and trip at the lower level of short-circuit value; namely, time-delay fuses and circuit breakers with time-delay trip unit settings belong to this group. Thus, the device, even though held in for the maximum values of current, should be rated to withstand these maximum values. Calculations of lower levels short-circuit currents are needed as well to ensure that the held in devices will open the circuit when expected.

In general, after considering all of the above, the engineer will calculate the motor(s) and generator(s) total contribution for the first cycle of the short-circuit current at each bus, starting with the load and working upstream to the source. Then, considering one segment of circuit at a time, the total maximum, symmetrical short-circuit current at the up-stream and down-stream ends of the segment. Start working on segment closest to the source, working toward the loads.

3.1.4 Re-evaluating the system

After all calculations are completed, each piece of equipment/component, including OPDs, should be re-evaluated to ensure all ratings are appropriate for the level of short-circuit available at their respective locations. At this time, the engineer can re-evaluate the coordination of OPDs within the system. Reference [6] states that, "Two devices in series should be sized and set to coordinate up to the calculated maximum short-circuit current." If the two circuit breakers in Figure 3.3 are installed in series, and the maximum short-circuit current available at the bus where CB2 sits is 1kA, then selective coordination is still achieved. If however, the maximum ASC at the same bus is 2kA or higher, then it is possible that both devices will operate simultaneously, thus the two devices are not selectively coordinated.

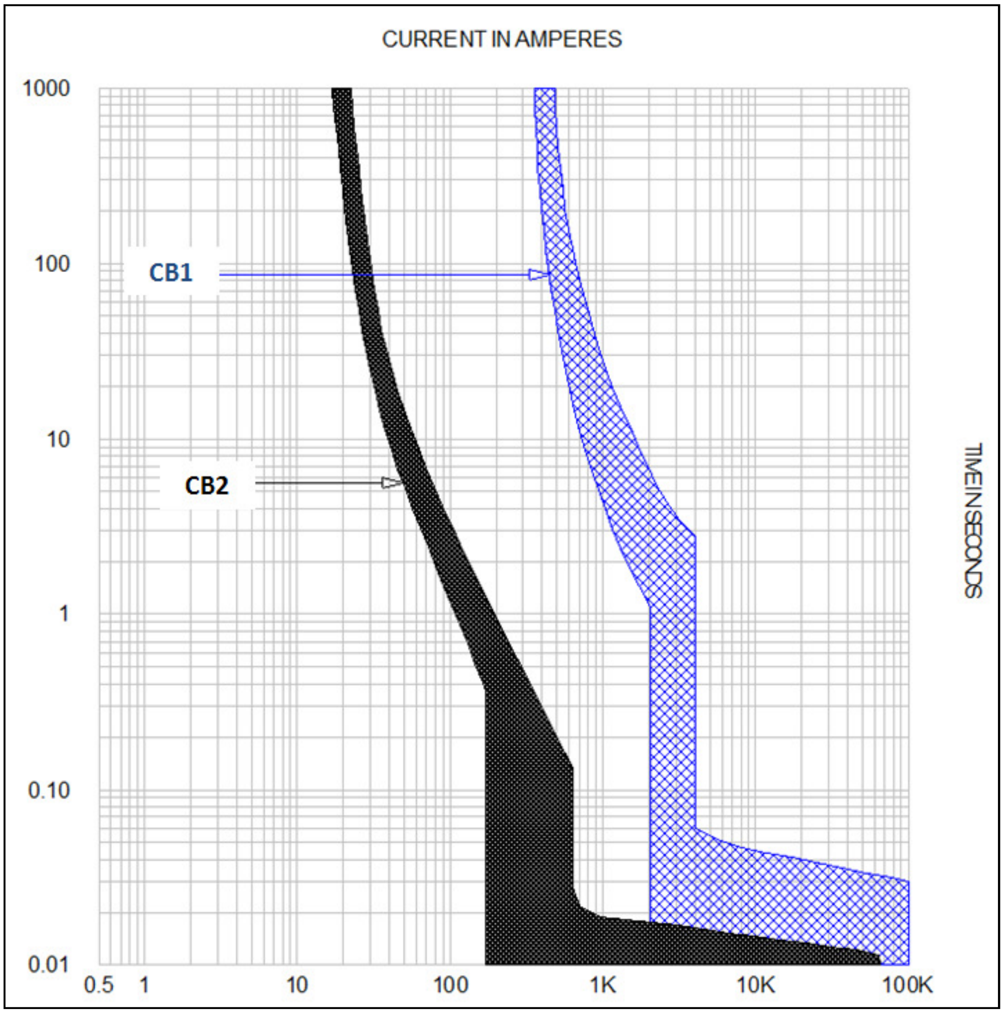

Figure 3.3. Maximum Short-Circuit for Coordination.

In some cases, however, two OPDs design with instantaneous trip settings could be selectively coordinated if the value of impedance between the two devices is significant. Either a transformer or a long run of conductor is an example of large impedance with which such coordination could be achieved. This type of situation would be unique and atypical for buildings applications.

CHAPTER 4 - ARC FLASH

One of the biggest debates surrounding the topic of Selective Coordination in the U.S. pertains to its effects on the available Arc Flash Energy in an electrical system. For a selectively coordinated system, some OPDs must be held-in to a fault condition to ensure the proper device opens as discussed in Chapter 2. Engineers specify this hold-in by picking certain characteristics for the devices and must be aware of the consequences when it comes to raising risk for those who will be asked to maintain and troubleshoot the systems once they are installed. This chapter describes the risks associated with the practice of selectively coordinating electrical distribution systems within buildings, as well as the measures that can be taken to minimize damage to equipment, and more importantly, minimize injury to personnel in systems with a high available fault which could result in Arc Flash. Also covered in this chapter are excerpts and summaries from several code and standards regulatory bodies which are commonly accepted by AHJ's in the United States pertaining to selective coordination and Arc Flash.

4.1 An Introduction to Arc Flash

An Arc Flash occurs when two electrodes are brought close enough to one another, but not touching, for electrical energy to be released and bridge the gap. The energy released during an Arc Flash event results in the liquifaction and vaporization of metallic materials in the vicinity. Because these materials change states so quickly, their volumes expand very fast creating an illuminous flash and sound blast. The hottest regions of the arc can reach up to 35,000 degrees Fahrenheit according to General Electric's paper "The Basics of Arc Flash" [11]. The surface of the Sun only reaches just less than 10,000 degrees Fahrenheit. All of the products of an Arc Flash, the energy, light, sound, and intense heat, can result in major damages to equipment and injuries or even death to personnel. The resulting shockwave can knock humans off their feet or even throw them across a room. The liquefied metallic particles thrown through the air can cause severe burns and start fires. The flash can be bright enough to cause temporary or permanent blindness and the sound loud enough to cause temporary or permanent hearing loss. According to the "NFPA 70E Handbook for Electrical Safety in the Workplace, Ed. 2004 [12]," "Arc flash incidents involving workers who are not properly protected results in more than 2000 workers being admitted to burn centers each year". Because such injuries, or even death, can result from arc flash incidents, engineers must understand the impact of their design decisions in regards to the Arc Flash Hazard.

4.2 Available Fault Current

The energy released during an arc flash event is dependent on the instantaneous available fault current at the event location and the time for which the fault is allowed to be sustained. The available fault current is the maximum current which could occur at a specific moment, at a specific location during a fault condition. The fault current level in an electrical system depends on many variables including the following:

- Available fault current at the electrical power source for the building
- Impedance of feeders and equipment throughout the building
- Distances between components and equipment being served in the building
- Types and quantities of equipment being served in the building

The amount of time the fault is sustained depends on the characteristics of the protective devices in the electrical distribution system. If short-time settings are increased and/or instantaneous settings are increased on an OPD, in the event of a fault, the amount of potential energy will increased.

4.3 Codes and Standards Applicable to Arc Flash Requirements

Many organizations and agencies have developed codes and/or standards for electrical design in the U.S. Many of these documents focus on predicting the severity of an Arc Flash and the protection of those who may be exposed. This section includes a brief overview of several of the codes and standards widely accepted and referred to by AHJs in the U.S. with respect to building electrical systems.

4.3.1 The Arc Flash Study

In general, an Arc Flash study is required in order to fully understand the risks for a particular system before workers are allowed to work on it while energized. Guidance for such a study is available from several sources; Reference [12] and *IEEE 1584: Guide for Performing Arc-Flash Hazard* Calculations [13] are two common resources. Using either, though the methods for calculations may differ, the algorithms are very similar according to the Arc Flash Information Resource Center's report, "Arc Flash Studies and Hazard Analysis [14]." Such an algorithm is presented below in Steps 1 through 5.

Step 1

The first step is to gather information about the system. Such data includes available short circuit currents, load specifications, and OPD types and settings. This first step will most likely take the most time and effort as it requires a lot of investigative work.

Step 2

After this data is collected an electronic model of the system can be developed for the second step. Calculations can be done by hand, but most engineers prefer electronic models as they provide a quicker and easier way to investigate several system configurations if needed. Building a model will require all the data from the first step to be input into a computer software program. ETAP and SKM are two commonly used software packages in the U.S. for arc flash analysis.

Step 3

The third step is to determine the arcing fault currents at each piece of electrical equipment. Using the bolted fault current and other variables, by applying formulas from [13], Arcing Fault Currents can be determined.

Step 4

Next, determine the Fault Clearing Times for the upstream OPDs and the resulting Incident energy. When the arc fault falls within the Instantaneous Region of the OPDs Time-Current Curve, even a small difference in the current value can result in a large difference in the clearing time; directly effecting the incident energy. The Incident energy can be calculated using the empirical formulas in [13] or the theoretical formulas of [14]. This calculation will include variables such as environmental conditions, equipment orientation, and distance between the equipment and the worker. Refer to Table 3 in [13] for common working distances for different types of equipment.

Step 5

Finally, the Flash Protection Boundary can be determined by referring to the Reference [12]. The engineer can use any of the three options for determining this boundary as outlined by this code.

Beyond performing calculations for the analysis, requirements and limitations are in place for defining when personnel can work on energized equipment, how that equipment should be labeled to convey the possible risks, and what Personal Protective Equipment (PPE) should be worn while work is being performed.

To better understand how each code or standard is applied to the algorithm outlined above, the following sections describe individual codes and standards in further detail.

4.3.2 National Fire Protection Association 70E

The National Fire Protection Association (NFPA) has developed [12] which includes regulations meant to ensure worker safety during the installation, maintenance, troubleshooting, and demolition of conductors and equipment in public and private buildings and structures. It defines a measure, with respect to the level of danger, personnel working on live parts might encounter, as well as the type of gear personnel should wear to protect themselves against bodily harm.

The measure regarding the level of risk is called, "**Flash Hazard**". According to [12], the definition of Flash Hazard is, "A dangerous condition associated with the release of energy caused by an electric arc."

Reference [12] lists two conditions under which taking the risk to perform work on energized, or live parts is acceptable as follows:

1) When taking energized equipment off-line will result in a higher hazard than when it is live
2) When taking energized equipment off-line is infeasible due to the limitations of the equipment or the task being performed

Under the first condition, the risk of working on live parts is deemed acceptable since the condition under which the loss of power to equipment such as life support equipment in a hospital or orderly shutdown in a nuclear power plant poses a higher risk than that of the work on energized electrical equipment itself. The second condition refers to infeasibility. The standard is clear in making a distinction between *infeasible* and *inconvenient*. Often, during unexpected equipment outages due to failure or need for repairs, a solution can only be drawn via troubleshooting. Troubleshooting investigations often need to be done on live equipment. In such cases, de-energizing the equipment becomes infeasible. If justification for work on live parts is made, for either condition, personnel can only carry out such work by first obtaining a "Work Permit". Refer to Section 130.1(A) of [12] for more details about obtaining a Work Permit.

In addition to the permit, Section 130.3 of [12] requires that a "Flash Hazard Analysis" also be carried out before work on live parts is undergone. The analysis' purpose is to, "…determine if a thermal hazard exists and to select protective equipment necessary to mitigate exposure to the hazard." This type of study investigates the potential for exposure to arc flash energy.

The Flash Hazard Analysis is performed to determine the incident energy on a surface at a specific distance away from the initiation location of an arc flash. The incident energy is commonly measured in calories per centimeters squared (cal/cm^2). As an example, the release of incident energy levels of 1.2 cal/cm^2 will most likely yield second-degree burns to human skin. Energy levels of 8 cal/cm^2 can yield third-degree burns [11].

The incident energy is inversely proportionate to the square of the working distance, and directly proportional to the available fault current and duration of an arc flash event [11]. Incident energy is discussed in greater detail below in Section 4.3.3. The short circuit available fault, cable size and length, and the OPD settings all influence the incident energy value as well. The OPD settings influence the duration of the fault contributing to the time variable.

A separate analysis could be done for equipment containing features that allow the worker to temporarily change OPD settings during periods of maintenance and troubleshooting. For instance, General Electric manufactures some equipment with a "Reduced Energy Let Through" (RELT) feature, as on their Entelliguard TU trip unit that allow a worker to change setting while they work, and then reinstate the operational settings when they are finished according to [11].

Once the Hazard Analysis is complete, a Hazard Risk Category can be determined per the incident energy level. The categories range from 1 to 4 plus a category called "Extreme Danger". Table 4.1 outlines the energy levels and their corresponding category.

Table 4.1. Hazard Risk Category and Incident Energy (Reproduced from [12]).

Hazard Risk Category	Incident Energy (cal/cm2)
0	N/A
1	4
2	8
3	25
4	40
Extreme Danger-No PPE Available	>40

NFPA 70E also defines the "**Arc Flash Protection Boundary**". This boundary represents the closest approach allowed before Personal Protective Equipment (PPE) must be worn. The PPE is meant to limit burns to 2^{nd} degree or less.

For example, the Flash Protection Boundary for a system of 600V or less, is 4ft if the product of the OPD clearing time and the available bolted fault current do not exceed 300kA-cycles (5000 ampere seconds) according to Section 130.3(A). As an example, a system with 50kA available fault current and a clearing time of 6 cycles would meet this criterion. This boundary distance is directly proportionate to the available fault current and the time the fault is sustained. Equations 4.1 and 4.2, used by this standard for systems that exceed the 300kA cycles product, are given below.

$$D_c = [2.56 \text{ x } MVA_{bf} \text{ x } t]^{1/2} \tag{4.1}$$

or,

$$D_c = [53 \text{ x } MVA \text{ x } t]^{1/2} \tag{4.2}$$

where:

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

MVA_{bf} =bolted fault capacity available at point involved (mega volt-amperes)

MVA = capacity rating of transformer (mega volt-amperes). For transformers with MVA ratings below 0.75, multiply the transformer rating by 1.25

t = time of arc exposure (in seconds) Reference [12].

Protective gear is a critical safety element in working on live equipment. Reference [12] has drawn conclusions about which types of PPE shall be worn based on the results of the Flash Hazard Analysis. The higher the hazard, the more gear required for the worker. The engineer should be aware that heavy, bulky equipment can be a nuisance and have adverse effects to the worker in some instances. Refer to the standard for specific details pertaining to the PPE requirements as this topic is outside the scope of this report.

4.3.3 IEEE 1548

As discussed above, Reference [13] provides engineers with one method for arc flash analysis and several of the variables for particular cases. The standard suggests that an analysis be done for both the minimum and maximum available arc flash fault values since the arc flash energy may be higher at reduced values of fault current due to longer operating times of an upstream OPD.

Reference [13] lists equations to be used for arc flash analysis for a very specific set of variables as used in laboratory tests. The results of the calculations performed, according to [13], are more accurate and specific to particular cases than those using methods from [12]. Reference [13] warns, however, that actual arc flash intensity in the field may vary from the results obtained during testing.

According to the Standard, "An arc-flash hazard analysis should be performed in association with, or as a continuation of, the short-circuit study and protective-device coordination study." Reference [6] contains methodology for calculating short-circuit currents and conducting coordination studies for OPDs respectively. The results of these two exercises yield the following:

- Fault current momentary duty, interrupting rating, and short-circuit (withstand) rating of electrical equipment
- Time required for OPD to react and isolate overload or short-circuit conditions.

In determining the arcing fault current levels, equations from [13] yield current values which are approximately 50% of a bolted fault current values. Using the calculated three-phase values for arc fault currents (I_a) is a conservative approach.

For systems under 1000V, I_a is determined as follows:

$$\lg I_a = K + 0.662 \lg I_{bf} + 0.0966V + 0.000526G + 0.5588V(\lg I_{bf}) - 0.00304G(\lg I_{bf}) \quad (4.3)$$

where:

lg is the $\log_{10}$

I_a is arcing current (kA)

K is –0.153 for open configurations and is –0.097 for box configurations

I_{bf} is bolted fault current for three-phase faults (symmetrical RMS) (kA)

V is system voltage (kV)

G is the gap between conductors [13].

Refer to the standard for equations applicable to systems over 1000V.

The Gap between Conductors (G), measured in millimeters, can be found Table 4.2.

Table 4.2. Factors for Equipment and Voltage Classes [13].

Table 4—Factors for equipment and voltage classes[a]

System voltage (kV)	Equipment type	Typical gap between conductors (mm)	Distance x factor
0.208–1	Open air	10–40	2.000
	Switchgear	32	1.473
	MCC and panels	25	1.641
	Cable	13	2.000
>1– 5	Open air	102	2.000
	Switchgear	13–102	0.973
	Cable	13	2.000
>5–15	Open air	13–153	2.000
	Switchgear	153	0.973
	Cable	13	2.000

[a]The distance x factor is used in 5.3 as an exponent.

Once I_a (the three-phase arcing current) is calculated, the operating time for a particular OPD can be determined. Reference [13] recommends calculating the fault-clearing time for both the 100% and 85% arc fault current values since the clearing time can vary a great deal with only a small change in current.

With the arc fault current known, the incident energy (En) can be calculated as Section 5.3 of [13] outlines. The equation given is, "based on data normalized for an arc time of 0.2 seconds and a distance from the possible arc point to the person of 610 mm."

$$\lg E\text{n} = K_1 + K_2 + 1.081 \lg I_a + 0.0011\, G \qquad (4.4)$$

where:

En is incident energy (J/cm2) normalized for time and distance

K_1 is –0.792 for open configurations (no enclosure) and

is –0.555 for box configurations (enclosed equipment)

K_2 is 0 for ungrounded and high-resistance grounded systems and

is –0.113 for grounded systems

G is the gap between conductors according to Reference [13].

Then:

$$E_n = 10^{\lg En} \qquad (4.5)$$

Finally, convert from normalized:

$$E = 4.184 C_f E_n (t/0.2)(610^x/D^x) \qquad (4.6)$$

where:

E is incident energy (J/cm2)

C_f is a calculation factor which equals:

1.0 for voltages above 1kV, and

1.5 for voltages at or below 1kV

E_n is incident energy normalized

t is arcing time (seconds)

D is distance from the possible arc point to the person in millimeters (see Table 4.3)

x is the distance exponent from Table 4, (see Table 5.2) [13].

The arc flash hazard distance is a measurement of the proximity with respect to electrical equipment that a worker could expect to experience the effects of an arc flash. The working distance, also defined in this standard in Table 4.3.

Table 4.3. Classes of equipment and typical working distances [13].

Table 3—Classes of equipment and typical working distances

Classes of equipment	Typical working distance[a] (mm)
15 kV switchgear	910
5 kV switchgear	910
Low-voltage switchgear	610
Low-voltage MCCs and panelboards	455
Cable	455
Other	To be determined in field

[a]Typical working distance is the sum of the distance between the worker standing in front of the equipment, and from the front of the equipment to the potential arc source inside the equipment.

Finally, the Flash Protection Boundary can be calculated.

$$D_B = [4.184\ C_f E_n\ (t/0.2)\ (610^x/E_B)\ ]^{1/x} \tag{4.7}$$

where:

D_B is the distance of the boundary from the arcing point (mm)

C_f is a calculation factor

1.0 for voltages above 1 kV, and

1.5 for voltages at or below 1 kV,

E_n is incident energy normalized20

E_B is incident energy in J/cm2 at the boundary distance

t is time (seconds)

x is the distance exponent from Table 4.

I_{bf} is bolted fault current

E_B can be set at 5.0 J/cm2 for bare skin (no hood) or at the rating of proposed PPE [13].

Formulae specific to certain types of current-limiting classes of fuses have been developed and can be referenced in the standard.

Similarly, circuit breakers of different ratings have different applicable equations. Reference [13] includes a convenient table which the designer can quickly reference to deduce the Incident energy and Flash Boundary. Included in this table are three types of circuit breakers; molded-case circuit breakers (MCCB), insulated-case circuit breakers (ICCB), and low-voltage power circuit breakers (LVPCB). Five types of trip units are listed; thermal-magnetic trip units (TM), magnetic (instantaneous only) trip units (M), electronic trip units have three characteristics that may be used separately or in combination (E), long-time (L), short-time and (S), and instantaneous (I). Some trip units are listed in combination with one another.

Table 4.4. Equations for incident energy and flash-protection boundary by circuit breaker type and rating [13].

Table 5—Equations for incident energy and flash-protection boundary by circuit breaker type and rating[a]

			480 V and lower		575–690 V	
Rating (A)	**Breaker type**	**Trip unit type**	**Incident energy (J/cm^2)[b]**	**Flash boundary (mm)**	**Incident energy (J/cm^2)**	**Flash boundary (mm)**
100–400	MCCB	TM or M	$0.189\ I_{bf} + 0.548$	$9.16\ I_{bf} + 194$	$0.271\ I_{bf} + 0.180$	$11.8\ I_{bf} + 196$
600–1200	MCCB	TM or M	$0.223\ I_{bf} + 1.590$	$8.45\ I_{bf} + 364$	$0.335\ I_{bf} + 0.380$	$11.4\ I_{bf} + 369$
600–1200	MCCB	E, LI	$0.377\ I_{bf} + 1.360$	$12.50\ I_{bf} + 428$	$0.468\ I_{bf} + 4.600$	$14.3\ I_{bf} + 568$
1600–6000	MCCB or ICCB	TM or E, LI	$0.448\ I_{bf} + 3.000$	$11.10\ I_{bf} + 696$	$0.686\ I_{bf} + 0.165$	$16.7\ I_{bf} + 606$
800–6300	LVPCB	E, LI	$0.636\ I_{bf} + 3.670$	$14.50\ I_{bf} + 786$	$0.958\ I_{bf} + 0.292$	$19.1\ I_{bf} + 864$
800–6300	LVPCB	E, LS [c]	$4.560\ I_{bf} + 27.230$	$47.20\ I_{bf} + 2660$	$6.860\ I_{bf} + 2.170$	$62.4\ I_{bf} + 2930$

[a] Refer to Annex E for Table 5 (Table E.1) in cal/cm^2.
[b] I_{bf} is in kA, working distance is 460 mm.
[c] Short time delay is assumed to be set at maximum.

Refer to Sections 5.6 and 5.7 of [13] for more details about the equations used to build Table 5.4.

4.3.4 National Electrical Code

While the document from [12] informs workers as to the hazard they may face while working on a live system, the NEC mandates electrical equipment be marked, indicating hazardous conditions, if the equipment will likely require maintenance or examination while energized. Section 110.16 of [5] requires that such electrical equipment be marked to warn qualified personnel of potential arc flash hazards.

4.3.5 Occupational Safety and Health Administration

The Occupational Safety and Health Administration (OSHA), has developed standards that must be acknowledged by workers and employees in the workplace. OSHA 29 CFR [15] limits instances when it is appropriate to work on energized equipment in Subpart S 1910.333. It states, "Live parts to which an employee may be exposed shall be deenergized before the employee works on or near them, unless the employer can demonstrate that deenergizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations."

Note that financial hardship due to deenergizing equipment is not mentioned among the adequate reasons to work on or near energized equipment.

4.4 Minimizing the Risk

So far, this chapter has outlined the types of risks associated with Arc Flash and the Codes and Standards which have been written with the intent to minimize risks for damage to equipment or injuries to workers. The topic of Selective Coordination becomes controversial at the conceptual intersection of keeping people and equipment safe during an outage of primary power and as a result increasing the risk of Arc Flash. This poses a contradictory problem for engineers.

Engineers must rely on engineering judgment to develop safe electrical distribution systems. Sometimes this may mean involving the local approval authorities for special cases in order to ensure that the system is designed, installed, and operated in an appropriate way.
Communication with the AHJ is covered in the Chapter 5.

CHAPTER 5 - PERMITTING PROCESS

When a client hires a design team, usually consisting of architectural and engineering members, to design a building, certain items require approval from the AHJ before the building is constructed. The architects and engineers must be aware of all requirements for the respective AHJs and understand how to present proof of compliance. Usually, municipality, county, and state AHJs require the design team to seek Building Permits for individual systems. For example, the lead electrical engineer for a design will need to provide documentation to prove to the AHJ that all requirements are met for an Electrical Permit before the electrical distribution system can be installed in the building. These requirements often include details for Selective Coordination. This chapter briefly explains the approval process and how Selective Coordination fits into that process.

5.1 Approval Process

In most cities within the U.S., those wishing to either construct a new building or renovate an existing one, need to pull a building permit from the local permitting office. In the City of Los Angeles, California, for instance, the Los Angeles Department of Building Safety (LADBS) is the permitting entity for the city. For new construction of commercial buildings, for example, a set of documents which have been stamped by a licensed Professional Engineer for many of the buildings systems will be needed to obtain a building permit. These systems include Structural, Mechanical, Plumbing, and Electrical. The electrical documents for LADBS must include a hard copy of the 2-dimensional drawings of each level, the Single Line Diagram of the entire electrical system, and calculations done, including a report outlining the coordination of the OPDs. All of these requirements are outlined on the LADBS form titled "*City of Los Angeles LARUCP Electrical Plan Check Correction List*" [16]. In Los Angeles, as part of the approval process, a "plan checker", employed by LADBS, will thoroughly check the plans for accuracy and code compliance. Reference [16] lists most electrical requirements that the plan checker will be looking at while reviewing the submitted documents. The plan checker will make notes by the items they feel are incomplete or need corrected. A plan checker in Los Angeles will be paying attention to item Q-13 and Q-17 when reviewing the Selective Coordination portions of the design. Item Q-13 tells the plan checker that selective coordination, as outlined by the California Electrical Code (CEC) [17], is required. Q-17 tells the plan checker that a study must be submitted for the electrical systems included in the CEC Articles 700.27 and 701.18. Excerpts of this form as pertaining to Selective Coordination are included in Appendix C.

The electrical engineer will make any necessary revisions based on the plan checker's comments and return the documents to LADBS once more. If no errors or omissions are found in the re-check, a permit is approved for that system and the client may pull that permit when they are ready to start construction.

In the above scenario, LADBS is the Authority Having Jurisdiction (AHJ). This is the entity that the engineer should be in contact with from very start of their involvement with the project. City, county, and state AHJs often adopt existing national or international codes for buildings. Examples of these would be the National Electric Code (NEC) or the International Electrotechnical Commission (IEC). The city, county, or state may then write their own additions, exclusions, or addendums to the adopted code. Each city, county, and state code regulation board has its own chronological cycle for adopting newer versions of the code and updating their own additions, exclusions, or addendums. For instance, the state of California adopts and amends the applicable revision of the NEC and issues the latest version of the CEC every three years.

5.1.1 Local Code Compliance

Regarding Selective Coordination, Reference [17] has been amended in the 2010 revision. As an example, Article 100 for both has been edited to change the definition of "Coordination (Selective)". The amendment is indicated by italic text below:

> **"Coordination (Selective).** Localization of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the choice of overcurrent protective devices and their ratings or settings, *[OSHPD 1, 2, 3, & 4] utilizing the 0.10 second level of the overcurrent protective device from the time current curve as the basis for the lower limit of the calculation method.*" [17]

Seattle, Washington presents another case where the NEC is adopted and amended by a local AHJ. The City of Seattle Electrical Code has, among other amendments, modified Article 700.27 by adding their own exception to the instances when Selective Coordination is required for Emergency Systems [18]. The added exception reads:

> *"Exception No. 2: When an electrical engineer provides stamped fault current calculations, the emergency system(s) overcurrent protective devices may be selectively coordinated with emergency system supply side over current protective devices for faults with a duration of 0.1 seconds and longer."*

The City of Seattle completely deleted the definition of "Coordination (Selective)" from Article 100.

Cities, counties, and states are not the only entities which go through such a process to enforce specific codes upon buildings. Federal government buildings, hospitals and schools, for instance, often have special governing bodies which have their own adopt-and-amend process for building codes. Such requirements are usually more stringent and in addition to the city or state requirements. The designer will need to be in contact with entities such as these as well from the beginning of the project. Some examples of specific requirements for specific building types include the following:

- General Services Administration (GSA) requirements for federal government projects
- Division of the State Architect (DSA) requirements for public schools in California
- Office of Statewide Health Planning and Development (OSHPD) requirements for hospitals in California.

Understanding the AHJ's current expectations for Selective Coordination compliance and documentation will be key in obtaining a permit in a thorough and efficient way. As stated in Chapter 2, Selective Coordination can become quite a cumbersome exercise and sometimes requires the skills of an expert. Most AHJ personnel are not experts in this skill set. Thus, clear and concise documentation can help the engineer relay their design intentions to the Plan Checker. And what's more, if the engineer has been in contact with the Plan Checker from the onset of the project, they will have a better understanding of what will be presented for their review.

5.2 Typical Documentation

Electrical documents submitted to the AHJ for approval, generally need to be stamped and signed by a licensed Professional Engineer (PE). They include plans, diagrams, and calculations. The Plan Checker is interested in seeing calculations that include a Short Circuit Analysis, Selective Coordination, and Arc Flash Hazard Analysis for the building. All three documents should be reviewed together, at the same time, since, as implied in previous chapters, they are interdependent. Calculations such as these are usually required to be submitted in hardcopy form on 8.5x11inch paper.

CHAPTER 6 - UNDERSTANDING THE RISKS

An important aspect of the decision making process for engineers is fact finding. Throughout their careers, engineers are expected to use their "engineering judgment" to make decisions about unique cases, sometimes for which no written code or industry standard may be available. Many building electrical engineers have found, and will continue to find themselves having to use engineering judgment when designing systems that are selectively coordinated. This topic, in particular, requires the engineer to weigh the risks of having a selectively coordinated system with higher Arc Flash Hazards against the chances of an overcurrent event during a primary power source outage. The engineer can make a better-informed decision if he or she understands the risks. This chapter highlights data and statistics that can be useful in making informed decisions about Selective Coordination.

6.1 Selective Coordination: Arc Flash Risks Exemplified

The purpose of this report is, in part, to raise awareness of the risks associated with selectively coordinated electrical distribution systems. Eaton Corporation, in their white paper, "Selective Coordination versus Arc Flash - The Great Debate and Update" use a simple example calculation of Arch Flash incident energy and Hazard Categories to demonstrate the impact on the Arc Flash risks associated with Selective Coordination. The paper states that, "… when larger frame MCCBs with higher instantaneous settings or PCBs with higher short delay time settings are required to meet NEC selective coordination requirements typically, considerably higher arc flash energy results."[19]

Reference [19] describes an arc flash study performed to 1584 guidelines to compare the results of a system with MCCBs meeting requirements before the 2005 NEC Selective Coordination requirements and MCCBs meeting requirements as set forth after the 2005 NEC Selective Coordination requirements. This study concluded that, "…the level of arc-flash for the selectively coordinated system is significantly greater than the initially designed system. In addition, instantaneous settings on the generator breaker and the opening times of the normal and emergency MCCBs are longer than 3 cycles, which may require specially rated electrical circuit components and special bus bracing…"[19]

The results of this study were tabulated to illustrate the differences in the system initially and then after the incorporation of selective coordination. Refer to Table 6.1.

Table 6.1. Arc Flash Calculations Results (Reproduced from [19]).

TABLE 3 ARC FLASH CALCULATIONS RESULTS					
		Initial Design		Total Selective Coordination	
Bus	Description	Incident Energy (Cal/cm2)	Required Protective FR Clothing Category	Incident Energy (Cal/cm2)	Required Protective FR Clothing Category
1	PD1 Line Side	78	Dangerous!	78	Dangerous!
2	Transfer Normal Side	0.46	Category 0	12	Category 3
3	Transfer Emergency Side	0.92	Category 0	4.1	Category 2
4	Panel EMD, 400A	0.43	Category 0	3.9	Category 1
5	Panel EMB, 100A	0.16	Category 0	2.4	Category 1
6	EM - SWB PD6 Line Side	22	Category 3	22	Category 3

The increase in both the incident energy and PPE category is significant. Table 6.1 very clearly shows the great risk to those working on live equipment that comes along with the practice of Selective Coordination.

6.2 Personnel Risk

Data gathered by the National Institute for Occupational Safety and Health (NIOSH) under the U.S. Department of Health and Human Services (DOHHS) has published in a report entitled, "Worker Deaths by Electrocution; A Summary of NIOSH Surveillance and Investigative Findings" [20]. This report covers the frequency and causes of death by electrocution in the work place. NIOSH states that between the years of 1980 and 1992, electrocutions across all industries were the 5^{th}-leading cause of death equating to "…7% of all fatalities and an average of 411 deaths per year".

The fatalities were grouped into categories based on causes. For the cases as pertaining to building electrical systems and the maintenance of the systems, the "contacted short-circuited, damaged, or improperly installed wire or equipment" category is the most applicable cause. This category only accounted for 3% of the fatalities. That equates to an average that would more likely be close to 13 fatalities per year. Other causes included boomed equipment and/or vehicles, which are not usually required for commercial building electrical system access.

To further understand the trends of worker safety regarding electrocution, Figure 6.1 illustrates the significant drop in worker fatalities over the 12-year period studied.

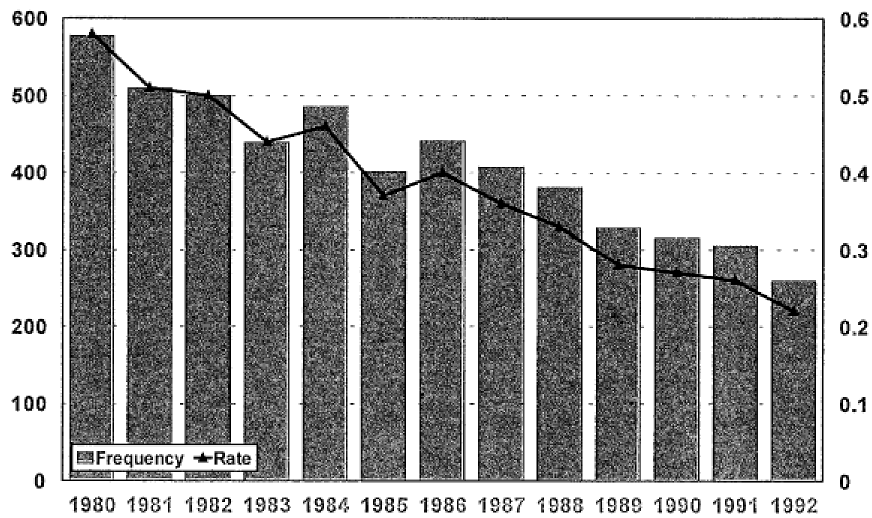

Figure 6.1. Frequencies and Rates of Electrocution Deaths Identified by NTOF by Year, 1980-1992 [20].

NIOSH also conducted a study focusing on 244 specific cases of electrocution in the work place over a time spanning from November 1982, to December 1994. Of the 244 cases studied, "Two incidents involved AC arcs [20]." This quantity is worth noting for two reasons; 1) AC Arc Flash is one of the greatest concerns to engineers when designing a selectively coordinated system, and 2) Selective Coordination as defined in the NEC today, was not a requirement during the time of this study. Also worth noting, NIOSH concluded, that for their study of the 244 cases, "Most of the 244 occupational electrocution incidents investigated … could have been prevented through compliance with existing OSHA, NEC, and NESC [National Electrical Safety Code] regulations; and/or the use of adequate … PPE.”

Statistics such as those listed in this section, based on installations within commercial buildings compliant with the newer Selective Coordination requirements, will be needed to understand the impact of their implementation in regards to worker safety.

6.3 Power Outage Frequencies

Yet another aspect to consider in designing selectively coordinated building electrical systems is the frequency of primary power source outages. Eaton Corporation releases an annual report about U.S. power outages entitled “Blackout Tracker” [21]. This report outlines the quantity, frequency, and causes of electric grid power outages. Since most commercial buildings use utility electricity as their primary source of power, understanding the real chances of an outage may provide the engineer with more data upon which to base his or her decisions in regards to Selective Coordination.

Eaton’s report lists which states have the most outages and the most common causes of these outages. For example, in 2010, California topped the list with 508 outages and that the average outage for the year was nearly 4 hours. Also, the report indicates that the predominate causes of outages across the U.S. are caused by weather and fallen trees, as well as equipment failure and human error as Figure 6.2 illustrates. In contrast, however, Figure 6.3 shows how two states, California and Kansas, for example, can have very different profiles even as compared to the U.S. as a whole.

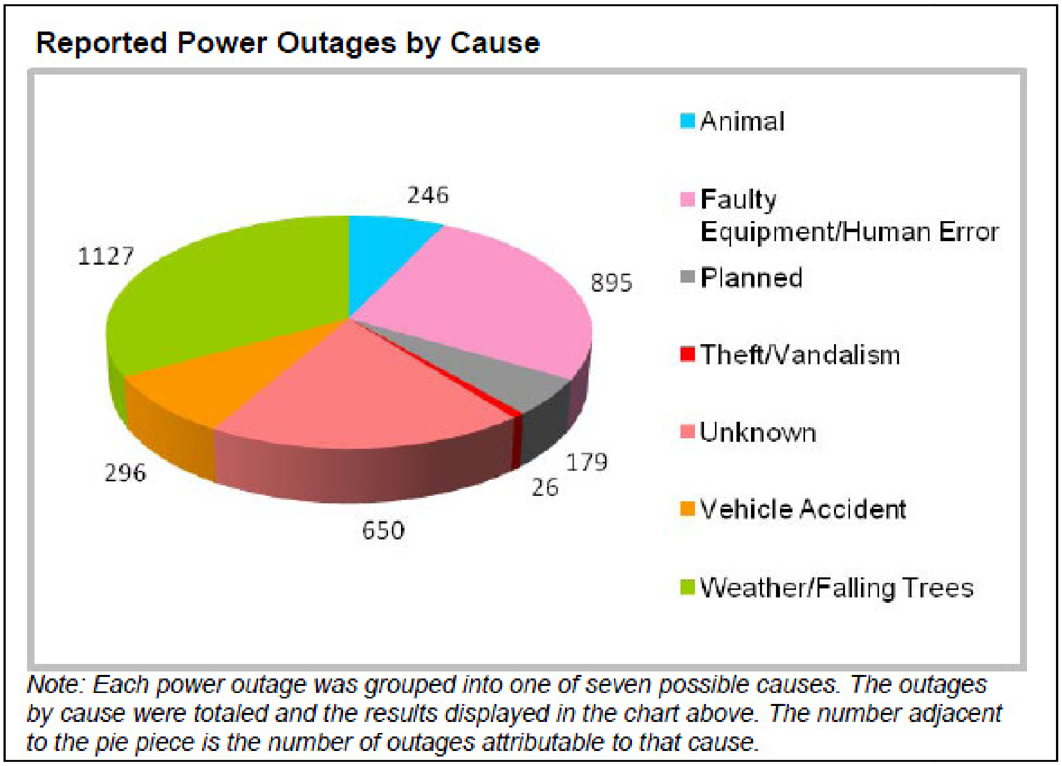

Figure 6.2. Reported Power Outages by Cause [21].

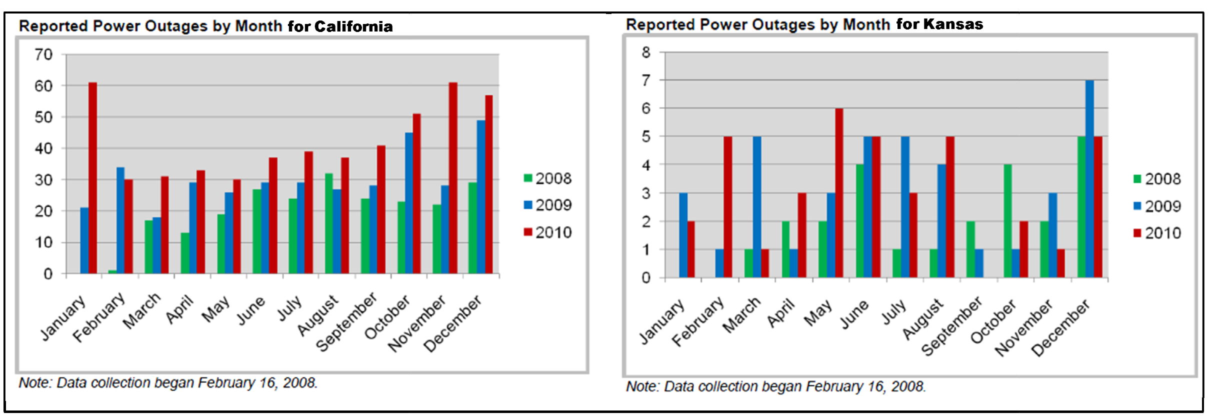

Figure 6.3. Reported Power Outages by Month for California (on the left), Kansas (on the right) [21].

The California and Kansas comparison shows that the frequency and duration of outages greatly varies by state and across each month. Design considerations could go as far as to include such variables in decisions about Selective Coordination.

CHAPTER 7 – CONCLUSIONS

Within the U.S., Selective Coordination has become a topic about which most electrical engineers have major concerns. These concerns have arisen in recent years due to changes in the NEC since the 2002 revisions. Electrical engineers are bound, in their designs, by a combination of national, state, and local codes and standards, as well as local AHJ requirements. Engineers must first understand the code and standard requirements for Selective Coordination and also establish a line of communication with the AHJ for each project early in the design phase in order to gain perspective on the AHJ's interpretations and requirements. What is more, the engineer must make judgment calls to fill the gaps left between codes and standards and the AHJ interpretations in order to deliver an electrical distribution system design that is both functional and safe.

Within a selectively coordinated system, choice of protective devices becomes very important. The engineer will need to fully understand the implications of each type of OPD and their individual features and settings. Circuit breakers and fuses have become the most common types of protective devices in commercial buildings, each having its own set of appropriate applications. These devices operate in different ways and the engineer will need to understand how each work and how they perform in combinations. The features and settings of each will allow for leniency in achieving coordination between two devices, but often at the cost of increasing the Arc-Flash Hazard.

A short-circuit study is needed to understand the available fault current at a given point within the distribution system. The engineer can reference [6] for a set of assumptions and calculation algorithms that will set him or her up with "best practice" results. The data obtained from the short-circuit study can be used to re-evaluate the robustness of the electrical equipment and components, making sure the Interrupting Rating for each OPD is appropriate.

Understanding the results from the short-circuit study is key in investigating the impacts of the system's design on the resulting Arc Flash Energy. Often when OPD are selectively coordinated, the up-stream device is held into the fault condition allowing energy to build; the more energy that builds, the higher the Arc Flash Hazard. When personnel are faced with working on or near live parts, their job becomes more dangerous with higher Arc Flash Hazard levels. This is why an Arc Flash Analysis is a critical task for the engineer.

Every AHJ can have a unique set of requirements regarding Selective Coordination. An open line of communication should be established early in the design process to determine the exact requirements for design and documentation before construction starts. After the contractor has placed orders for components like OPDs, any Change Orders will most likely result in higher costs to the contractor and consequently to the client.

The engineer must weigh the risks of having a selectively coordinated system with higher arc flash hazards against the chances of an overcurrent event during a primary power source outage. The engineer can make a better-informed decision if he or she understands the risks. While statistics show that the number of on the job electrocutions continues to fall, an engineer must now consider the fact that with a selectively coordinated system, a worker could have been exposed to a deadly Arc Flash that may have only been an electrical shock without selectivity.

Electrical engineers must not only understand the devices they specify and the applicable codes, understand interpretations by local AHJs, but also find a balance between developing a coordinated system and minimizing the risks that are inherent to such a design.

The influences that have driven the changes to the NEC are often speculated, but ultimately unknown. Statistics, such as those presented in Chapter 6, show the numbers of deaths by electrocution have decrease every year. Yet, now, electrical engineers are being required to design systems with higher levels of danger when it comes to working on or near live parts.

Future work for this topic should include data gathering about Arc Flash Energy increases due to selectively coordinated systems, as well as statistics about frequencies of primary power sources outages. What’s more, statistics should be gathered about how often workers are required to work on or near live parts during periods of primary power source outages. Selective Coordination requirements should be either justified or found unnecessary with such figures.

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APPENDIX A – SELECTIVE COORDINATION EXAMPLE

Appendix A exemplifies common steps that need to be taken through the course of achieving Selective Coordination. In this example, the assumption has been made that Selective Coordination requirements are applicable only to the secondary supply side of the system and that TCCs should only be required to be coordinated above 0.1 seconds.

The Single Line Diagram (SLD) in Figure A.1 illustrates the topology of the example electrical distribution system that includes equipment and arrangement that is typical to small commercial buildings in the U.S. As is often the case for commercial buildings, circuit breakers have been used as the OPD type. Also common in commercial buildings, the secondary source of power will be a back-up generator and for this example it will feed loads on an Emergency System as defined by [2].

Because the focus of this example is on the processes for selecting OPD which will result in a selectively coordinated system, details about conductors and their lengths have been neglected for simplicity. In practice, conductor data would be included in the short-circuit analysis and a plot of the conductors' fault current ratings would be include with the TCCs to ensure the OPD will protect the equipment/loads as well as the conductors.

Also, in practice, ground fault protection is required by [2] for particular instances as discussed in Chapter 2. Ground fault protection is outside the scope of this example.

SKM Power Tools Software (v. 6.5.2.6, Build 2) was used to develop the SLD as well as the TCC images and some of the tables that follow. The OPD selected for this example are from the choices available within the SKM electronic Library for devices manufactured by Square D. Table A.1 outlines the significant data for each piece of equipment included in the following analysis. Table A.2 summarizes the data for the initially designed OPD for the system.

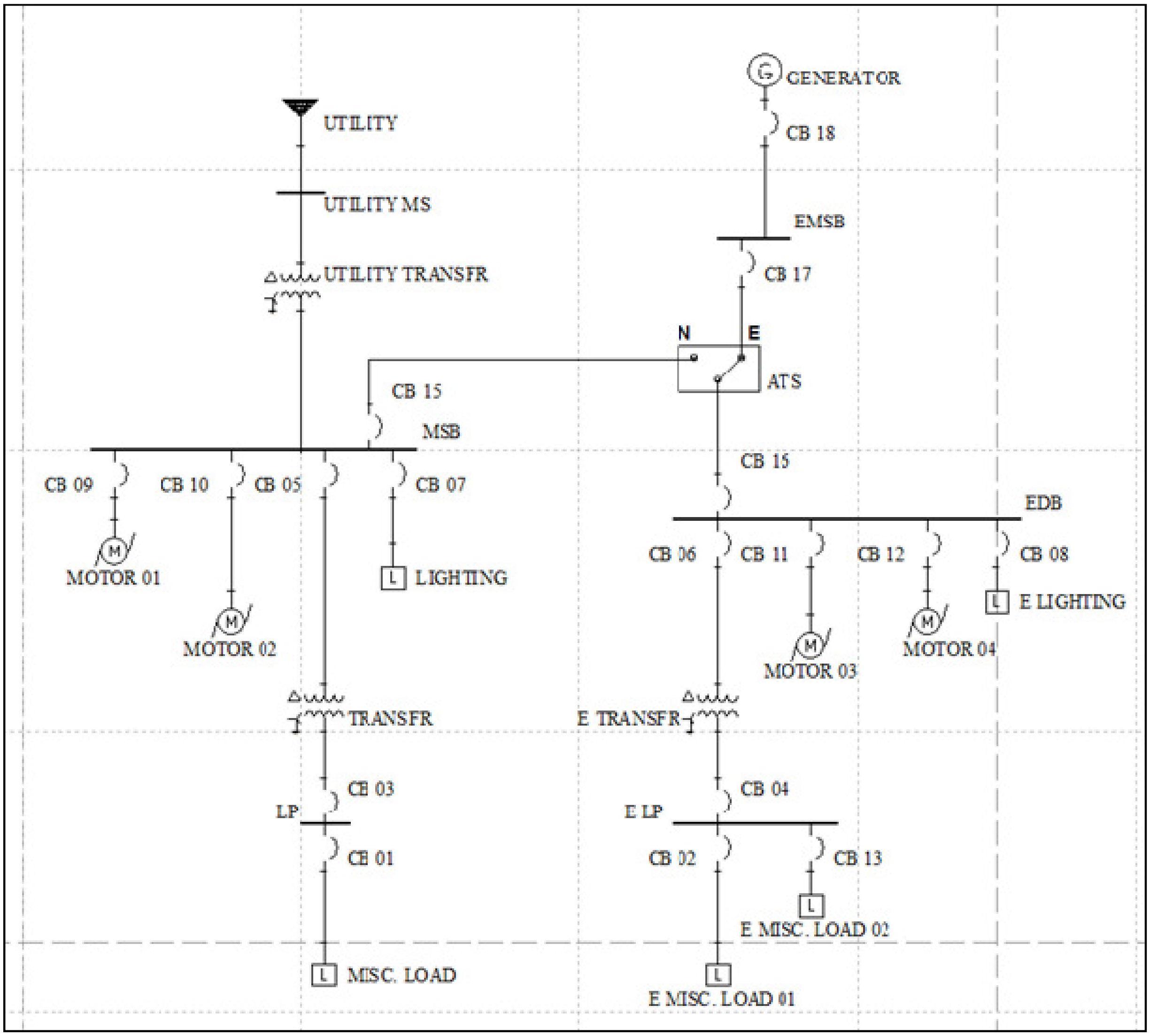


Figure A.1. Electrical Distribution System Single Line Diagram.

Table A.1. Initial Electrical Component Data.

Component Name	Equipment Type	System	Rating(s)
UTILITY	Primary Power Source- Utility Power Plant	Normal	5kV
UTILITY MS	Utility Installed Main Switch	Normal	5kV, 200A, 63kA
UTILITY TRANSFR	Utility Installed Transformer- Oil Filled, Air Cooled	Normal	750kVA, 5kV/ 480-277V, 3Ph, 4W
MSB	Main Switch Board	Normal	480V, 1200A, 200kA
MOTOR 01	Induction Motor Load	Normal	480V, 3Ph, 10Hp
MOTOR 02	Induction Motor Load	Normal	480V, 3Ph, 10Hp
LIGHTING	Lighting Loads	Normal	277V, 1Ph, 15kVA
TRANSFR	Transformer- Dry Type	Normal	75kVA, 480V/ 208-120V, 3Ph, 4W
LP	208V Panelboard	Normal	240V, 225A, 100kA
MISC. LOAD	Loads including receptacles and small equipment	Normal	208V, 30kVA
CB 01	Molded Case Circuit Breaker	Normal	125A F, 125A T
CB 03	Molded Case Circuit Breaker	Normal	400A F, 250A T
CB 05	Molded Case Circuit Breaker	Normal	225A F, 200A T
CB 07	Molded Case Circuit Breaker	Normal	30A F, 30A T
CB 09	Molded Case Circuit Breaker	Normal	25A F, 25A T
CB 10	Molded Case Circuit Breaker	Normal	25A F, 25A T
CB 15	Molded Case Circuit Breaker	Normal	150A F, 150A T
GENERATOR	Emergency Generator (Synchronous)	Emergency	500kW, 480v, 3Ph
EMSB	480V Emergency Main Switch Board	Emergency	480V, 800A, 200kA
ATS	Automatic Transfer Switch	Emergency	480V, 150A, 65kA
EDB	Emergency Distribution Board	Emergency	480V, 1200A, 100kA
MOTOR 03	Induction Motor Load	Emergency	480V, 3Ph, 15HP
MOTOR 04	Induction Motor Load	Emergency	480V, 3Ph, 5HP
E LIGHTING	Emergency Lighting Loads	Emergency	277V, 1Ph, 15kVA
E TRANSFR	Emergency Transformer- Dry Type	Emergency	45kVA, 480V/ 208-120V, 3Ph, 4W
ELP	Emergency Panelboard	Emergency	240V, 225A, 100kA
E MISC. LOAD 01	Emergency Loads including receptacles and small equipment	Emergency	208V, 20kVA
E MISC. LOAD 02	Emergency Loads including receptacles and small equipment	Emergency	208V, 20kVA
CB 02	Molded Case Circuit Breaker	Emergency	150A F, 150A T
CB 13	Molded Case Circuit Breaker	Emergency	70A F, 70A T
CB 04	Molded Case Circuit Breaker	Emergency	70A F, 70A T
CB 06	Molded Case Circuit Breaker	Emergency	225A F, 110A T
CB 11	Molded Case Circuit Breaker	Emergency	40A F, 40A T
CB 12	Molded Case Circuit Breaker	Emergency	15A F, 15A T
CB 08	Molded Case Circuit Breaker	Emergency	30A F, 30A T
CB 16	Molded Case Circuit Breaker	Emergency	150A F, 150A T
CB 17	Molded Case Circuit Breaker	Emergency	150A F, 150A T
CB 18	Molded Case Circuit Breaker	Emergency	800A F, 800A T

Table A.2. Initial Circuit Breaker Summary.

DESIGNATION		FRAME		TRIP UNIT				
Location/Name	Amps Frame	MFR	TYPE MODEL	Amps Sensor/Plug	Description	TYPE/MODEL	LT SETTING	INST SETTING
LP CB 01	125	SQUARE D	HJ	125 0	15-150A	HJ	Fixed	
E LP CB 02	70	SQUARE D	HJ	70 0	15-150A	HJ	Fixed	
LP CB 03	400	SQUARE D	LA	250 0	125-400A	LA	Thermal Curve	INST LO
E LP CB 04	150	SQUARE D	KH	150 0	70-250A	KH	Thermal Curve	INST LO
MSB CB 05	225	SQUARE D	LA	200 0	125-400A	LA	Thermal Curve	INST LO
EDB CB 06	225	SQUARE D	KI	110 0	110-250A	KI	Thermal Curve	INST LO
MSB CB 07	30	SQUARE D	FH	30 0	15-100A	FH	Fixed	
EDB CB 08	30	SQUARE D	FH	30 0	15-100A	FH	Fixed	
MSB CB 09	25	SQUARE D	25A	25 0	15-100A	FG	Fixed	
MSB CB 10	25	SQUARE D	25A	25 0	15-100A	FG	Fixed	
EDB CB 11	40	SQUARE D	40A	40 0	15-100A	FG	Fixed	
EDB CB 12	15	SQUARE D	15A	15 0	15-100A	FG	Fixed	
E LP CB 13	70	SQUARE D	HJ	70 0	15-150A	HJ	Fixed	
MSB CB 15	150	SQUARE D	KH	150 0	70-250A	KH	Thermal Curve	INST LO
EDB CB 16	150	SQUARE D	KH	150 0	70-250A	KH	Thermal Curve	INST LO
EMSB CB 17	150	SQUARE D	LH	150 0	125-400A	LH	Thermal Curve	INST HI
EMSB CB 18	800	SQUARE D	MG	800 0	300-800A	MG w/ ET1.0, 2-8x Inst.	Thermal Curve	INST 4

To begin the analysis, all the OPD TCCs had to be gathered. Figure A.2 shows all the TCCs for devices that would be in operation while the system's secondary source, the Generator, is supplying electrical power to the equipment being fed from EDB. Initially, the OPD are selected based on load type and size required per minimum and maximum limitations outlined in the NEC [2]. Even with these two criterions, there are many choices among many manufacturers for OPD. Thus, more than one right combination of devices exists. In most cases, an electrical engineer will begin by selecting devices all from one manufacturer, and within the same "family" or type when possible.

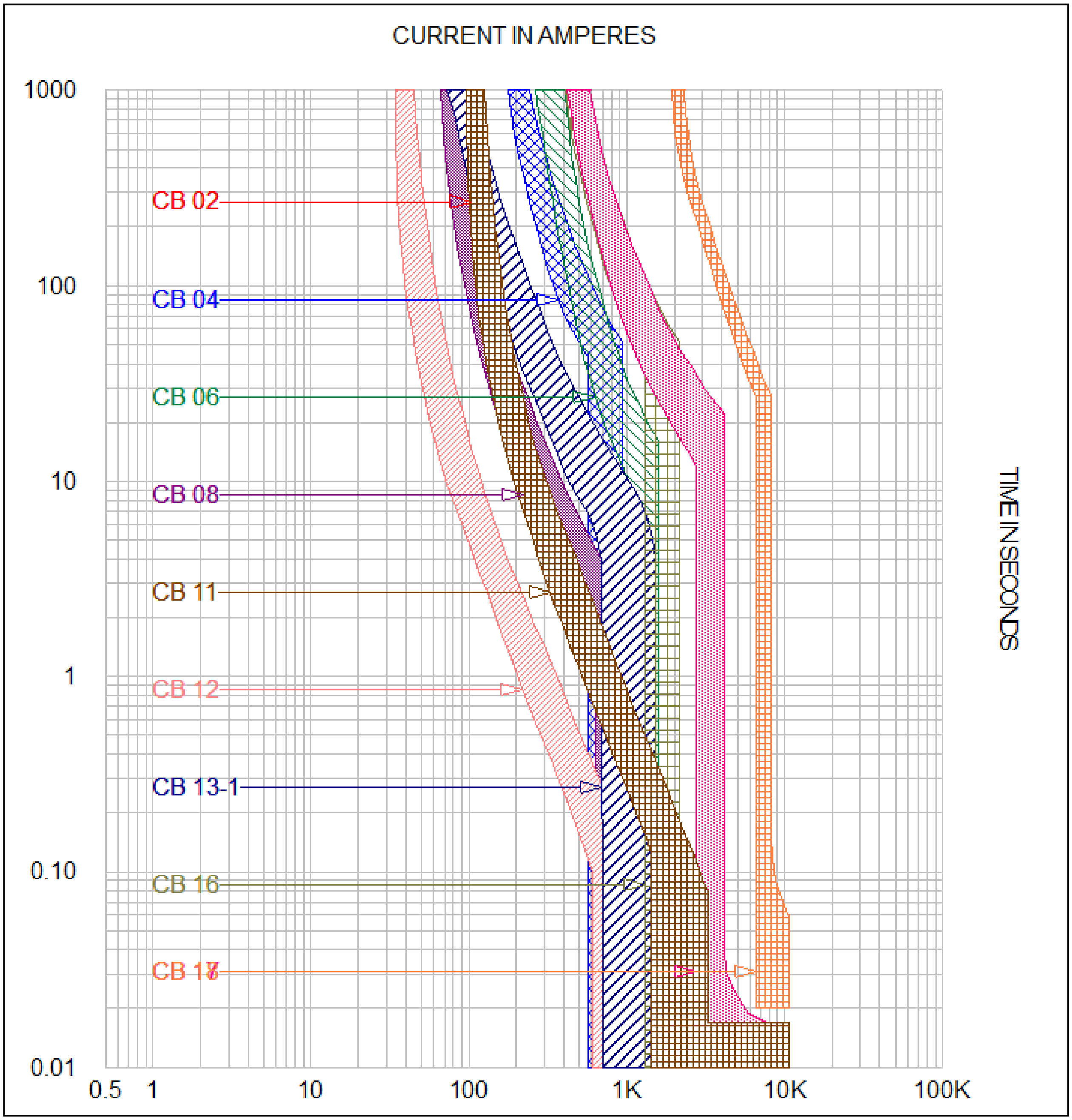


Figure A.2. Initial Emergency System TCC's.

Quickly, the engineer can observe from Figure A.2 that work is required in order to achieve Selective Coordination among the curves under consideration. The engineer should start by analyzing the TCCs for devices furthest down-stream and work upward to the source.

For this example, the following devices will be considered in order to exemplify the selective Coordination process:

- CB 02
- CB 04
- CB 06
- CB 16
- CB 17
- CB 18

Devices not included in this example would be handled in a similar fashion as those that are included.

Figure A.3 shows only the TCCs for CB 02 and CB 04 at the farthest down-stream point for the example system.

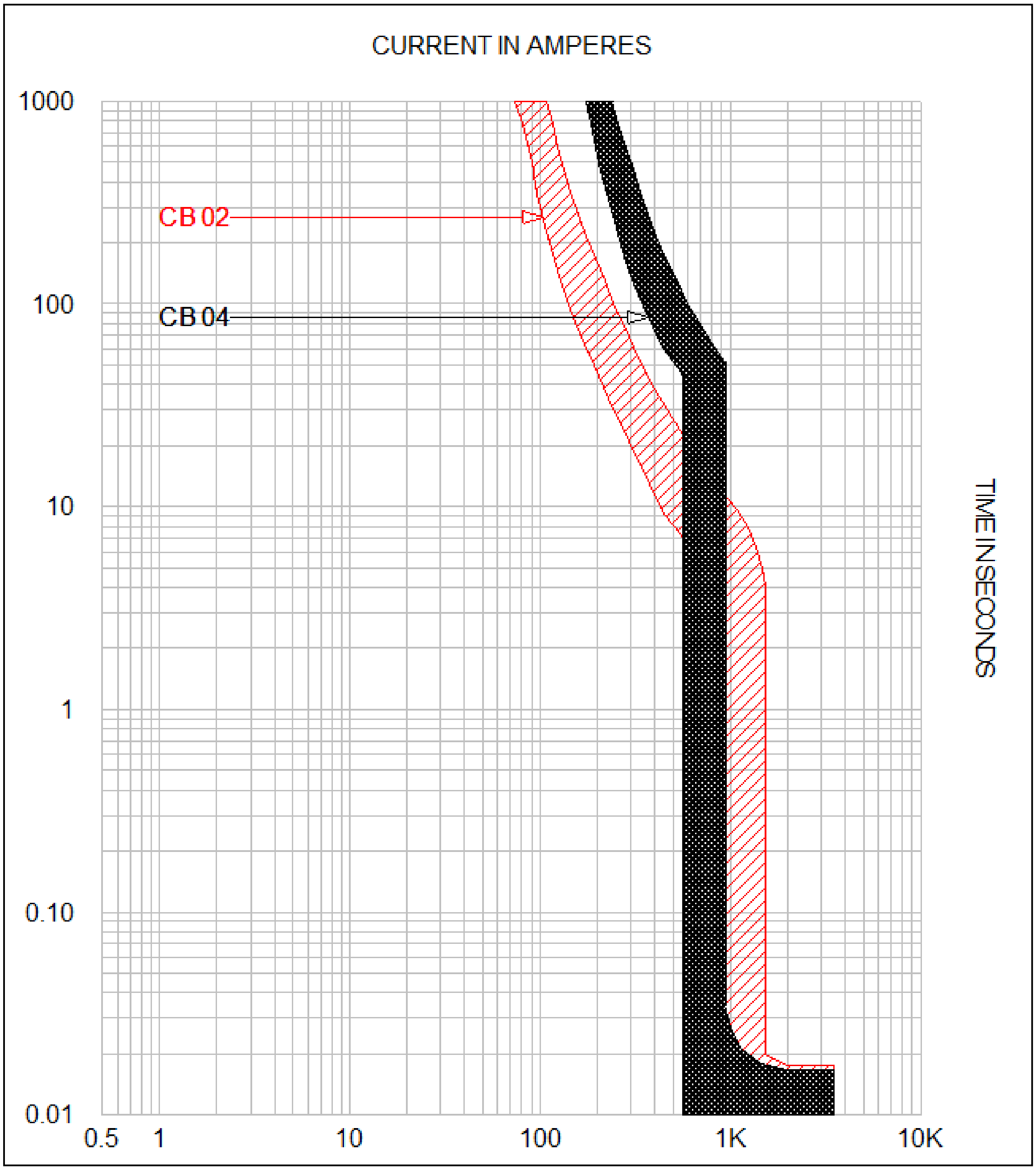


Figure A.3. Initial TCCs for CB 02 and CB 04.

The TCCs overlap for the entirety of their instantaneous regions. Either devices should be changed or, when possible, settings should be adjusted to move the curve for CB 04 to the right of CB 02 as to ensure that CB 02 operates before CB 04. For this example, the device had to be switched for CB 02 and the instantaneous setting for CB 04 had to be set to its highest set point for the two to coordinate. Figure A.4 shows the coordinated pair of OPD.

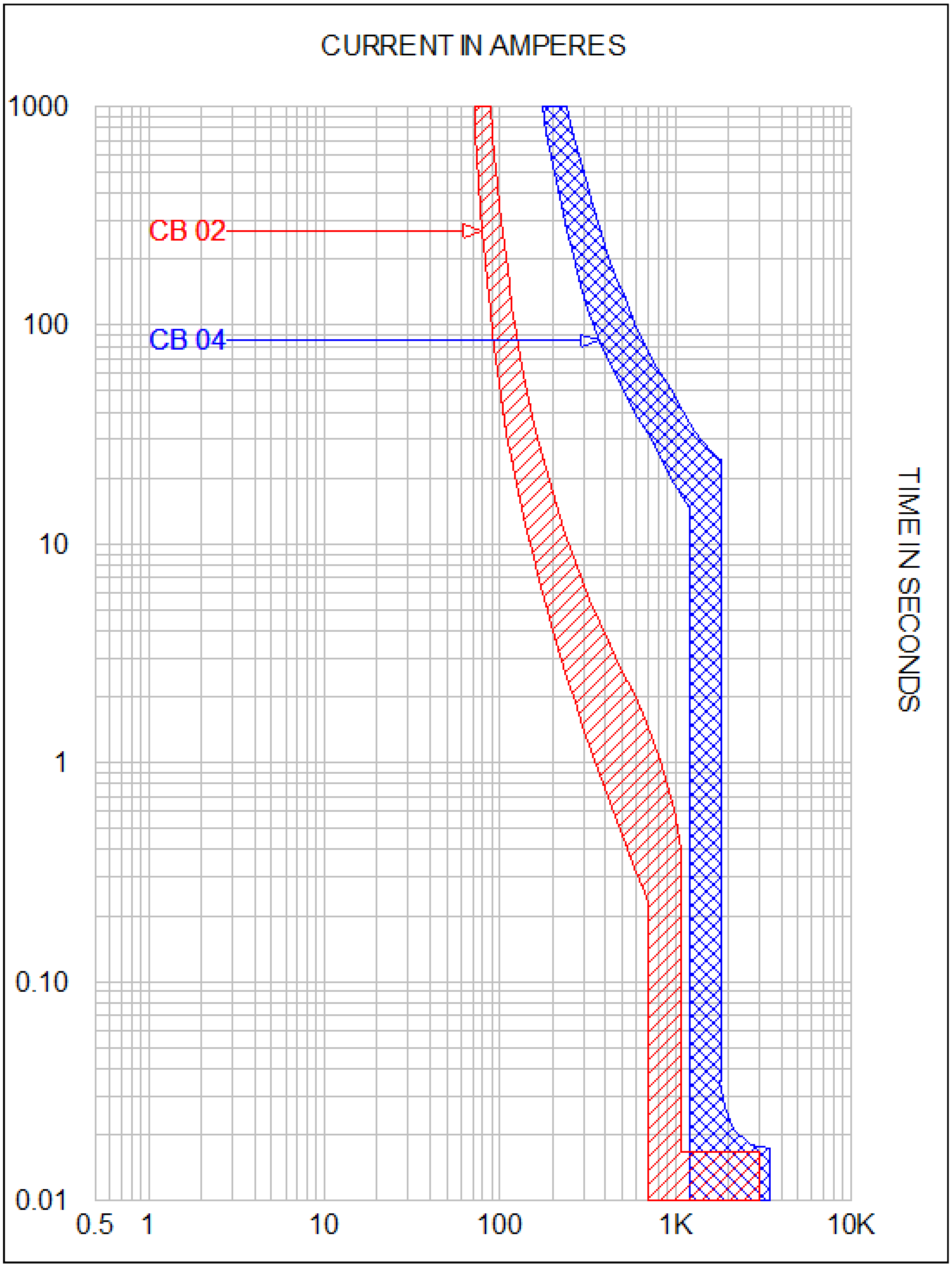


Figure A.4. Final TCCs for CB 02 and CB 04.

The same steps should be used to ensure selectivity for CB 13. Since the loads protected by CB 02 and CB 13 are the same, the same OPD can be used for CB 13 as was used for CB 02.

Next, the relationship between CB 04 and CB 06 was investigated. Per NEC Article 700.27 for Emergency Systems [2], the OPD on the Primary and Secondary sides of a transformer do not have to be coordinated since an open circuit due to either of the devices opening results in the same amount of equipment being isolated and disconnected from the source. The initial curves for CB 04 and CB 06 were fairly close to being coordinated before the coordination exercise began. Figure A.5 illustrates the initial TCCs for these two OPD.

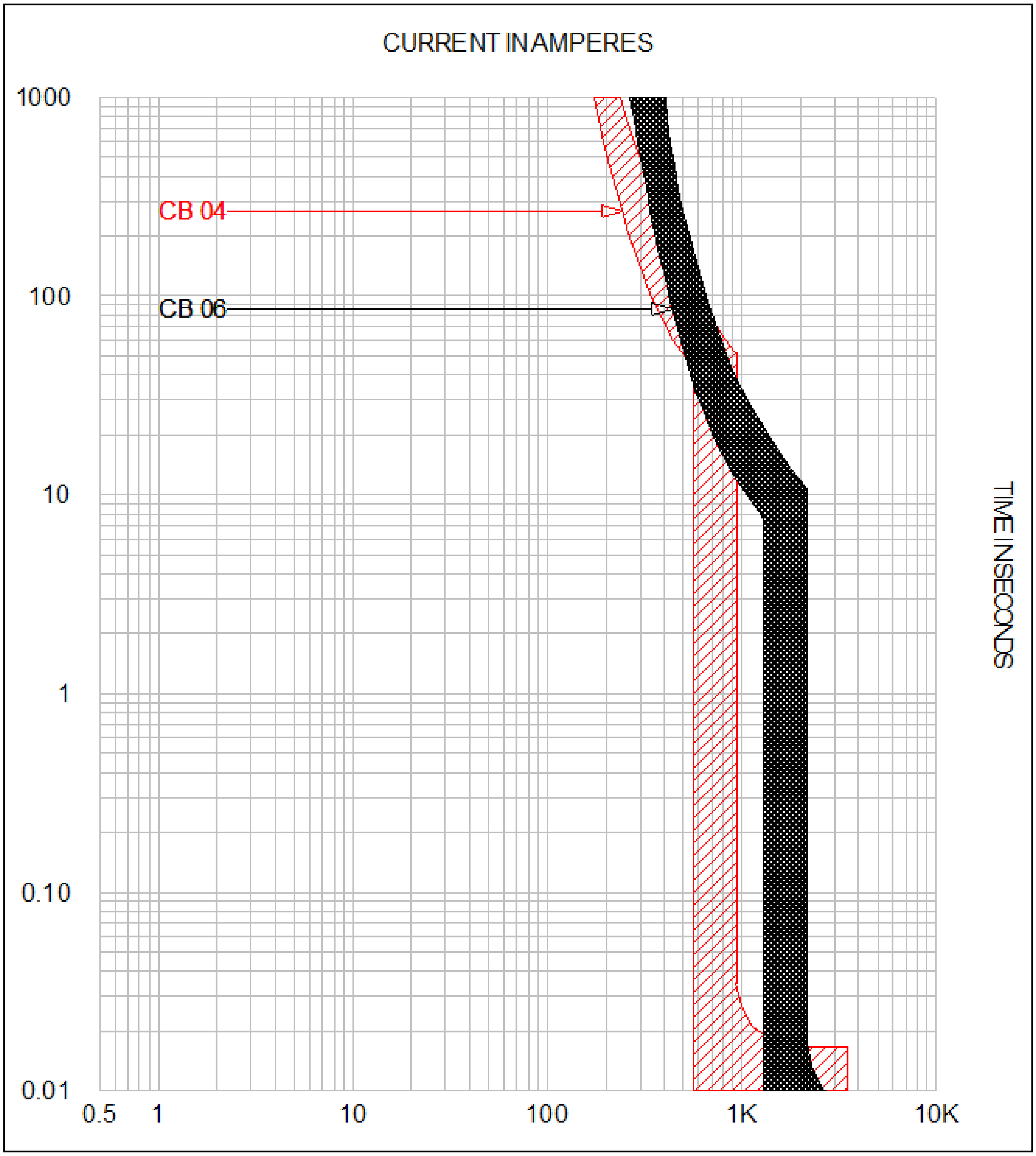


Figure A.5. Initial TCCs for CB 04 and CB 06.

Since CB 04 had to be changed to coordinate with CB 02, the relationship between CB 04 and CB 06 became less desirable. The curve for CB 04 actually moved to the right of CB 06 as shown in Figure A.6.

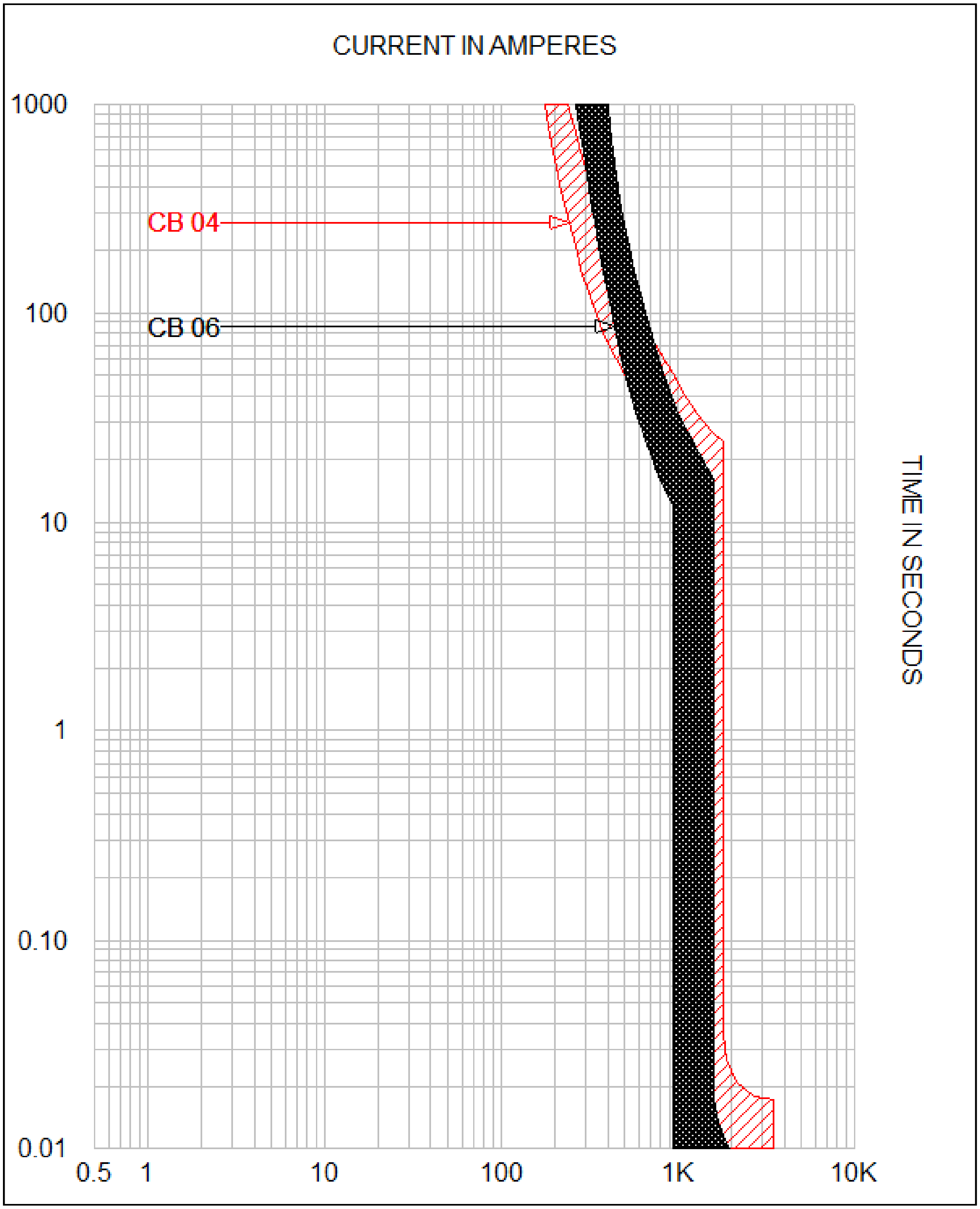


Figure A.6. Final TCCs for CB 04 and CB 06.

The same process is repeated for each OPD, as required, as the electrical engineer moves up-stream toward the source. The following figures show the initial and final relationships for adjacent OPD moving toward the generator.

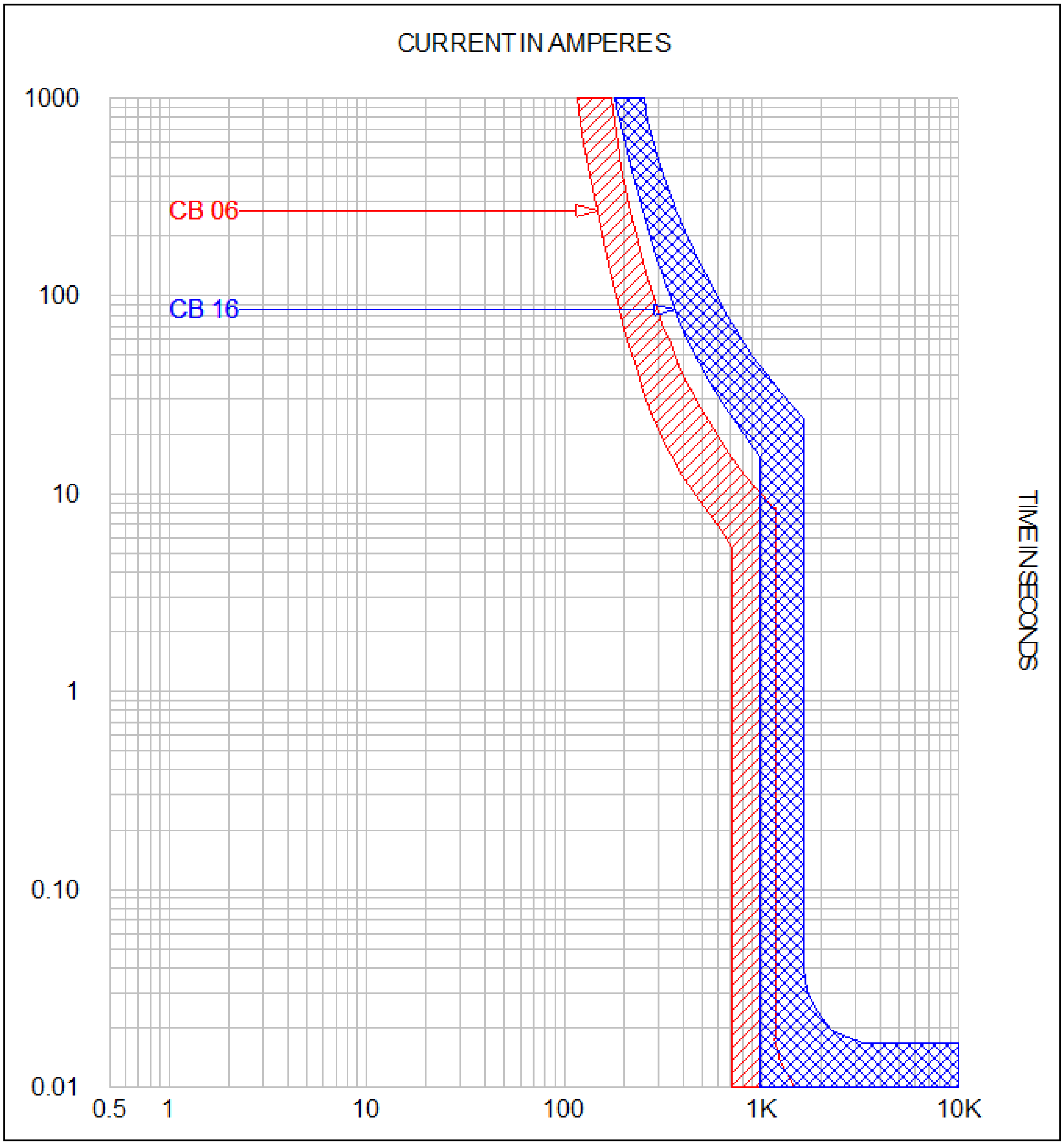


Figure A.7. Initial TCCs for CB 06 and CB 16.

Once again, the instantaneous setting for the upstream breaker, CB 16, in the case shown in Figure A.7, had to be set to the highest set-point available on the device. Figure A.8 shows the closest to "coordinated" that these two particular devices can be. Notice the top of the two curves is barely touching.

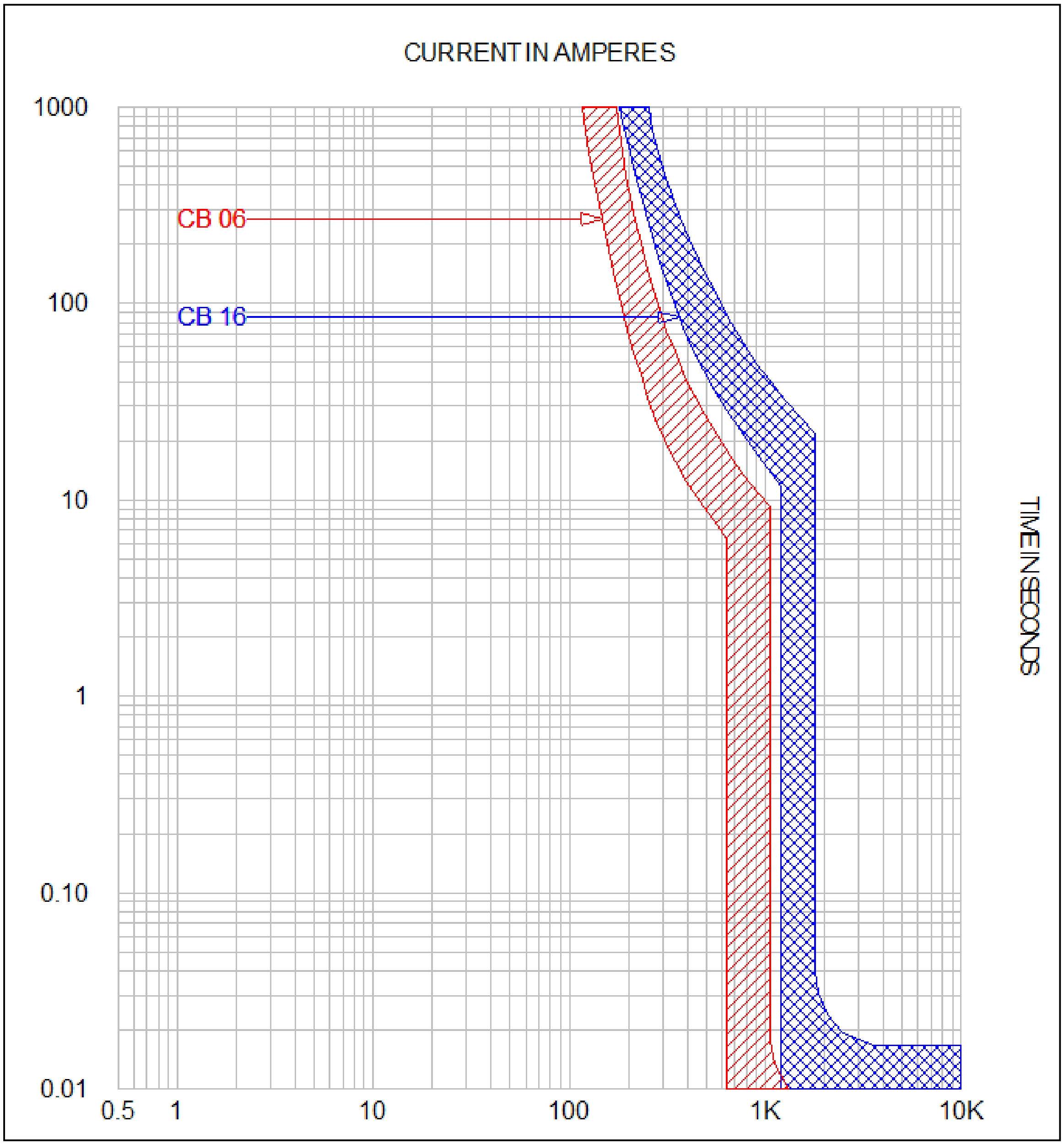


Figure A.8. Initial TCCs for CB 06 and CB 16 after adjustment to CB 16.

Figure A.9 shows just how little the two curves overlap.

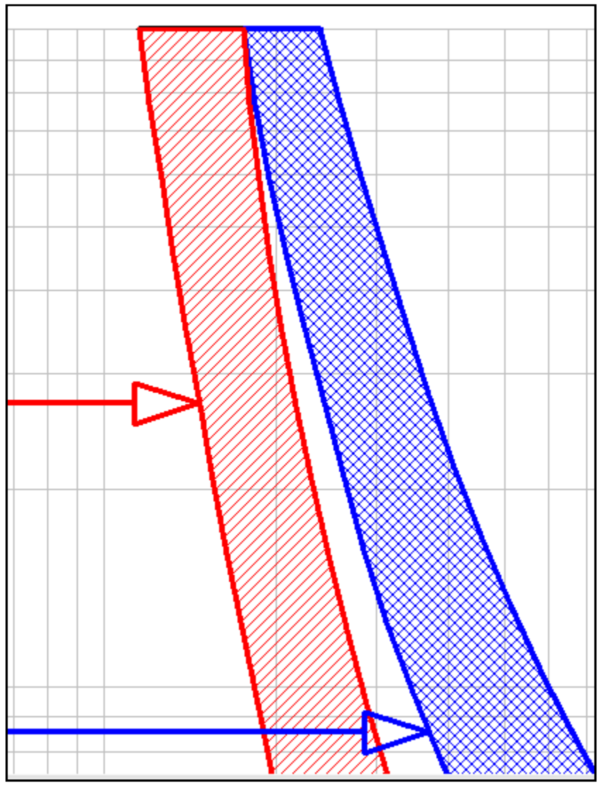


Figure A.9. Top of TCC for CB 06 and CB 16.

In the end, a new device has to be selected for CB 16 in order to ensure there is no overlap between the two curves. When curves like those shown in Figure A.9 are so close, it is best to consult with the device manufacturer. In this example, only one device existed that was any better fit as shown in Figure A.10. Figure A.11 shows that even these two devices nearly meet at the time of their curves.

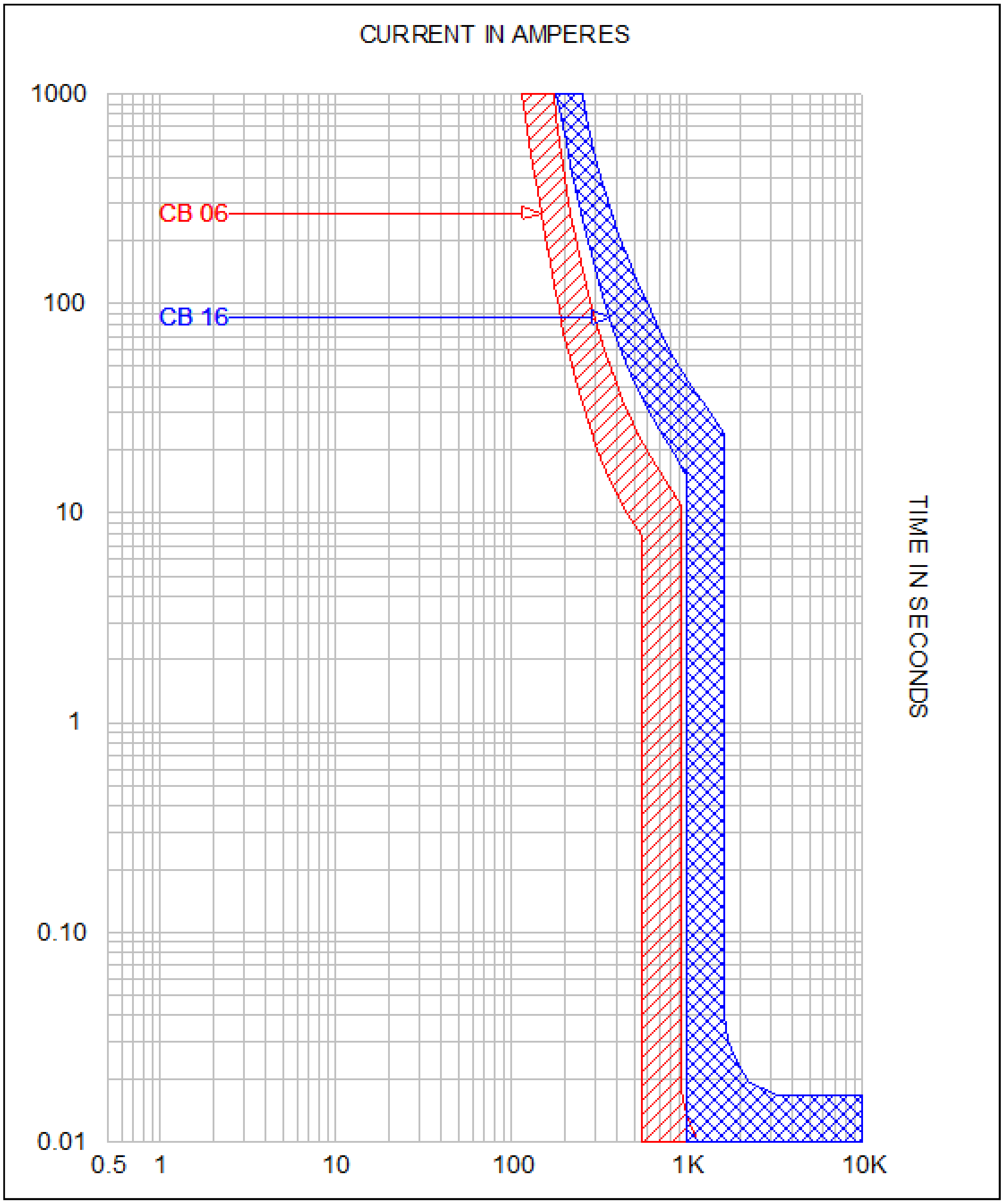


Figure A.10. Final TCCs for CB 06 and CB 16.

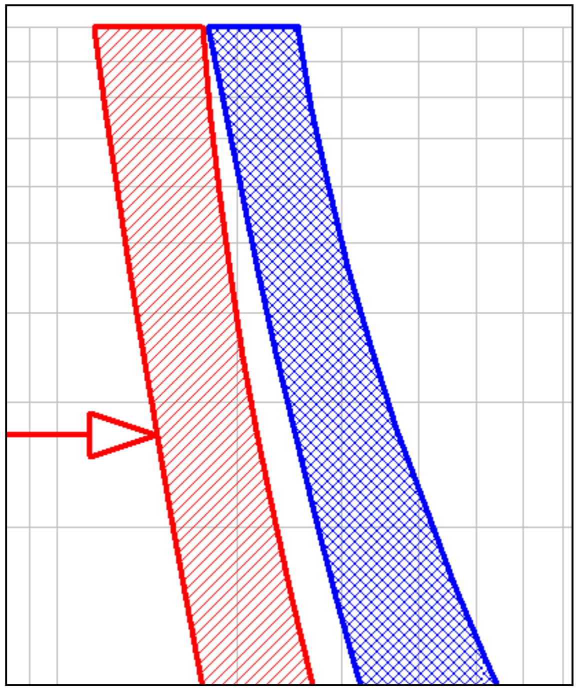


Figure A.11. Top of Final TCC for CB 06 and CB 16.

Achieving Selective Coordination for the devices at EDB exemplifies some of the challenges that engineers will face while completing such a task. As stated above, for this manufacturer's particular set of OPD, there were only two devices that would work for this exercise. The engineer has a few other options for solving this challenge. Fuses could be used, as they lend a TCC that is more easily coordinated. Also, the engineer could decide to do away with CB 16 all together. CB 16 is not required by code. It is a main circuit breaker for EDB and allows workers to de-energize the entire board with one device. Main breakers are common for safety reasons in commercial applications.

The next step would be to coordinate CBs 11, 12, and 08 with CB 16. This example does not cover these steps as the manufacturer would need to be consulted about the best options for OPD that will work together.

Coordination is not required for CB 16 and CB 17 per the exception listed in NEC [2] as was the case for the devices on either side of the E TRANSFR.

The next step would be to select devices that coordinate for CB 17 and CB 18. Figure A.12 shows the initial relationship between the two devices. The two devices seem to be coordinated to the 0.1 second level already. Thus, the devices do not need to be changed or adjusted.

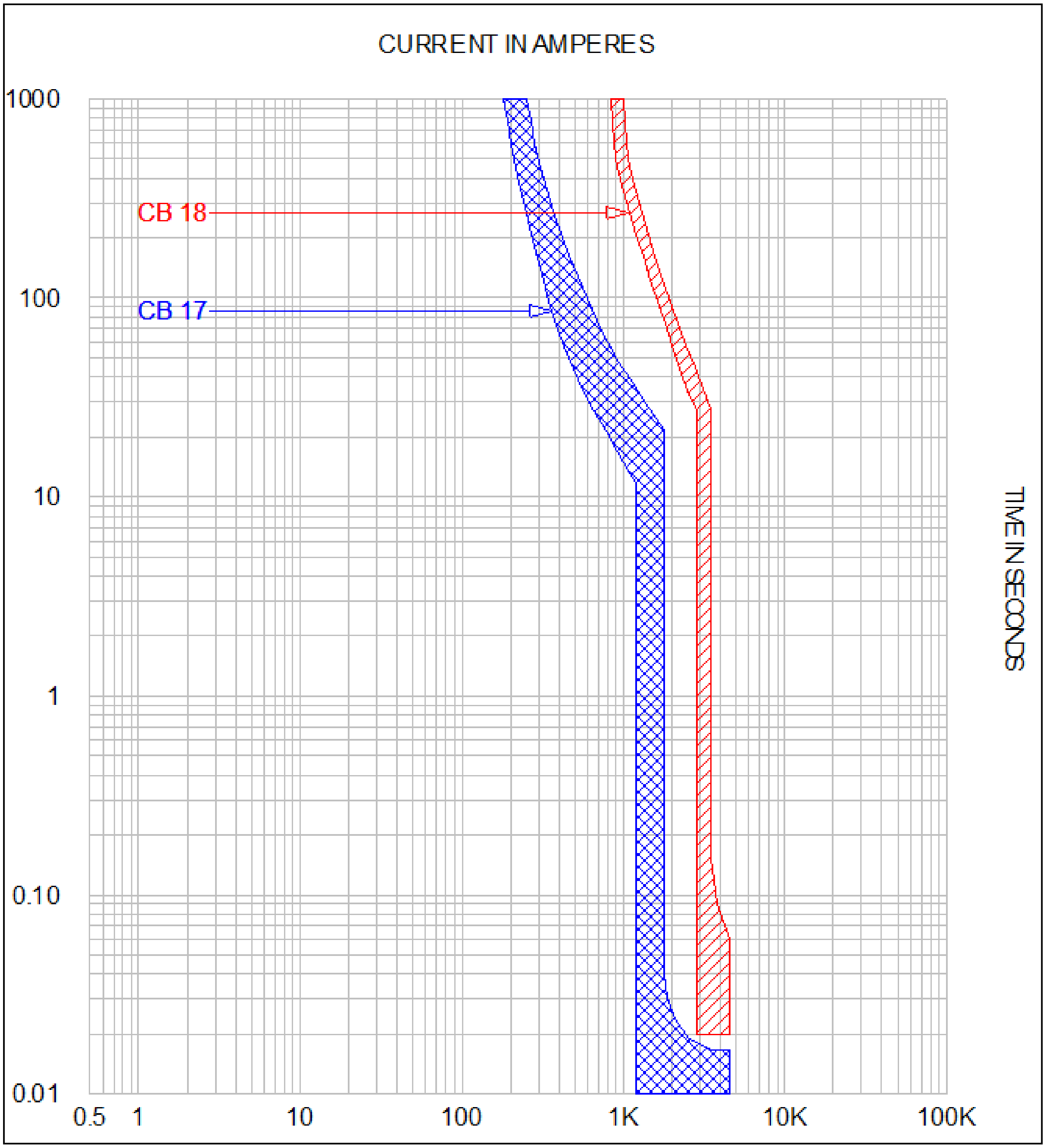


Figure A.12. Initial and Final TCCs for CB 17 and CB 18.

Finally, Figure A.13 shows the group of TCCs for the devices coordinated in this example. The OPD are, overall, coordinated to 0.02 seconds which is well below the 0.1 second requirement..

Notice that CB 04 and CB 17 seem to have very little or no white space between their curves. This is another instance when the device manufacturer should be consulted to ensure limited outages are experiences during a fault current event.

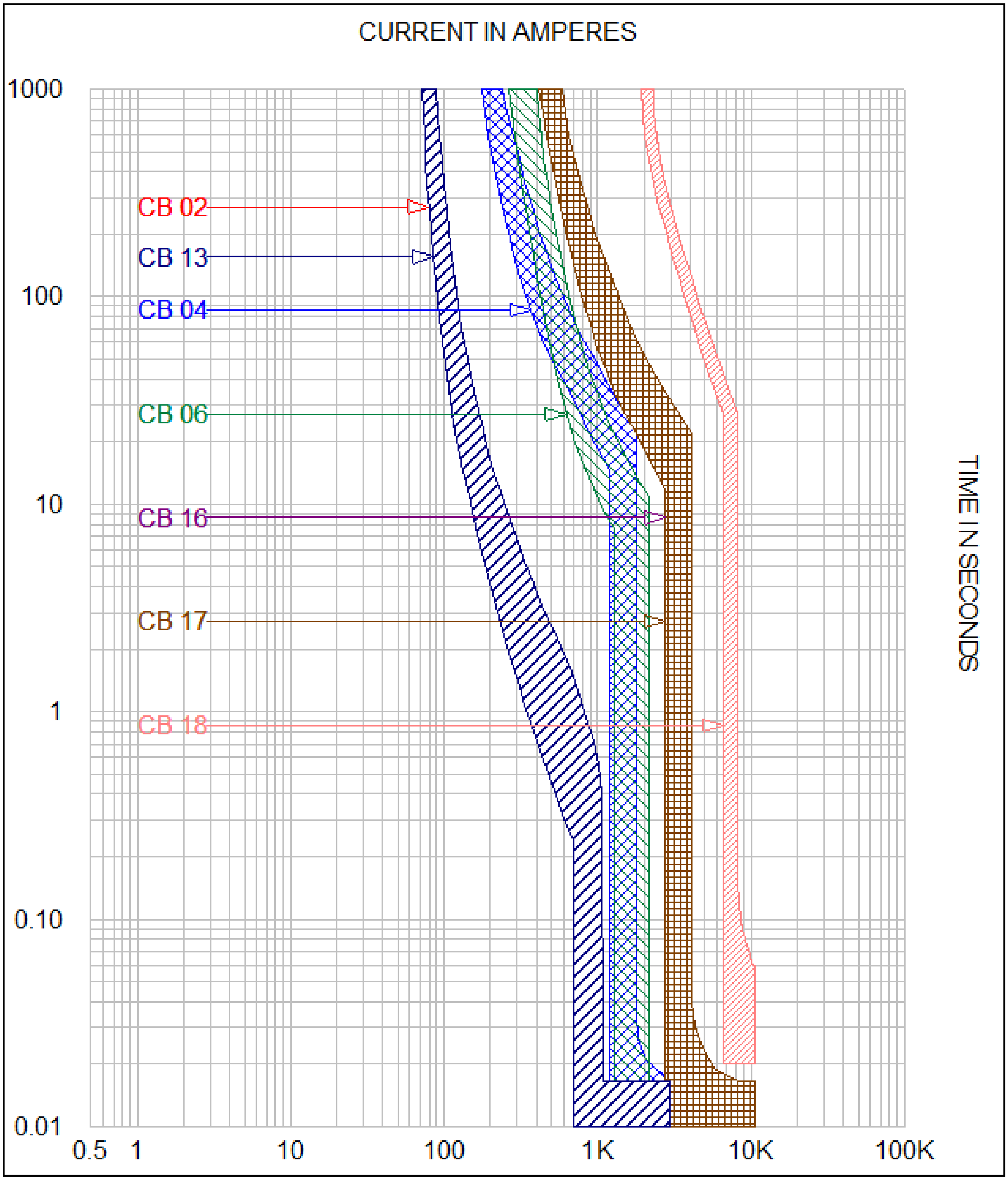


Figure A.13. Final TCCs for Emergency OPDs.

A final summary of the designed circuit breakers is provided in Table A.3.

Table A.3. Final Circuit Breaker Summary.

DESIGNATION		FRAME		TRIP UNIT				
Location/Name	Amps Frame	MFR	TYPE MODEL	Amps Sensor/Plug	Description	TYPE/MODEL	LT SETTING	INST SETTING
LP CB 01	125	SQUARE D	HJ	125 0	15-150A	HJ	Fixed	
ELP CB 02	70	SQUARE D	QOXD	70 0	16-100A	QOXD	Fixed	
LP CB 03	400	SQUARE D	LA	250 0	125-400A	LA	Thermal Curve	INST LO
ELP CB 04	150	SQUARE D	KH	150 0	70-250A	KH	Thermal Curve	INST HI
MSB CB 05	225	SQUARE D	LA	200 0	125-400A	LA	Thermal Curve	INST LO
EDB CB 06	225	SQUARE D	KI	110 0	110-250A	KI	Thermal Curve	INST 3
MSB CB 07	30	SQUARE D	FH	30 0	15-100A	FH	Fixed	
EDB CB 08	30	SQUARE D	FH	30 0	15-100A	FH	Fixed	
MSB CB 09	25	SQUARE D	25A	25 0	15-100A	FG	Fixed	
MSB CB 10	25	SQUARE D	25A	25 0	15-100A	FG	Fixed	
EDB CB 11	40	SQUARE D	40A	40 0	15-100A	FG	Fixed	
EDB CB 12	15	SQUARE D	15A	15 0	15-100A	FG	Fixed	
ELP CB 13	70	SQUARE D	QOXD	70 0	16-100A	QOXD	Fixed	
MSB CB 15	150	SQUARE D	KH	150 0	70-250A	KH	Thermal Curve	INST LO
EDB CB 16	150	SQUARE D	LH	150 0	125-400A	LH	Thermal Curve	INST HI
EMSB CB 17	150	SQUARE D	LH	150 0	125-400A	LH	Thermal Curve	INST HI
EMSB CB 18	800	SQUARE D	MG	800 0	300-800A	MG w/ ET1.0, 2-8x Inst.	Thermal Curve	INST 4

APPENDIX B – SHORT CIRCUIT ANALYSIS

The following example is taken from Chapter 2 of [6] and includes calculations using the Direct Method approach.

2.4.1 First-Cycle Motor and Generator Short-Circuit Contributions. The total motor and generator short-circuit contribution flowing toward the source must be determined first. The actual calculations for each bus are shown.

(1) *Busses 14 and 15.* No motor contribution.
(2) *Bus 13.* 100 kVA for 100 hp induction motor at 80% power factor.

$$\begin{aligned} SCA_M &= 5 \cdot I_{FL} \\ &= 5 \cdot \frac{100\ \text{kVA}}{\sqrt{3}\ \cdot\ 0.46\ \text{kV}} \\ &= 5 \cdot 125.5\ \text{A} \\ &= 628\ \text{SCA} \end{aligned}$$

(see Fig 9)

(3) *Busses 11 and 12.*

$$SCA_M = 2 \cdot 628\ \text{A} = 1256\ \text{SCA}$$

(4) *Bus 10.*

$$\text{transformer primary amperes} = \frac{750\ \text{kVA}}{\sqrt{3} \cdot 4.16} = 104.09\ \text{A}$$

$$\text{transformer rated secondary amperes} = \frac{750\ \text{kVA}}{\sqrt{3} \cdot 0.480} = 902.11\ \text{A}$$

$$\begin{aligned} SCA_M &= \frac{104.09\ \text{A}}{\frac{5.5\%}{100\%} + \frac{902.11\ \text{A}}{1256\ \text{A}}} \\ &= 135\ \text{SCA} \end{aligned}$$

(see Fig 11)

(5) *Bus 9.* No motor contribution.
(6) *Busses 7 and 8.* Generator contribution.

$$\text{generator rated amperes} = \frac{625\ \text{kVA}}{\sqrt{3} \cdot 4.16\ \text{kV}} = 86.74\ \text{A}$$

$$\begin{aligned} SCA_G &= \frac{86.74\ \text{A} \cdot 100\%}{9\%} \\ &= 964\ \text{SCA} \end{aligned}$$

(see Fig 7)

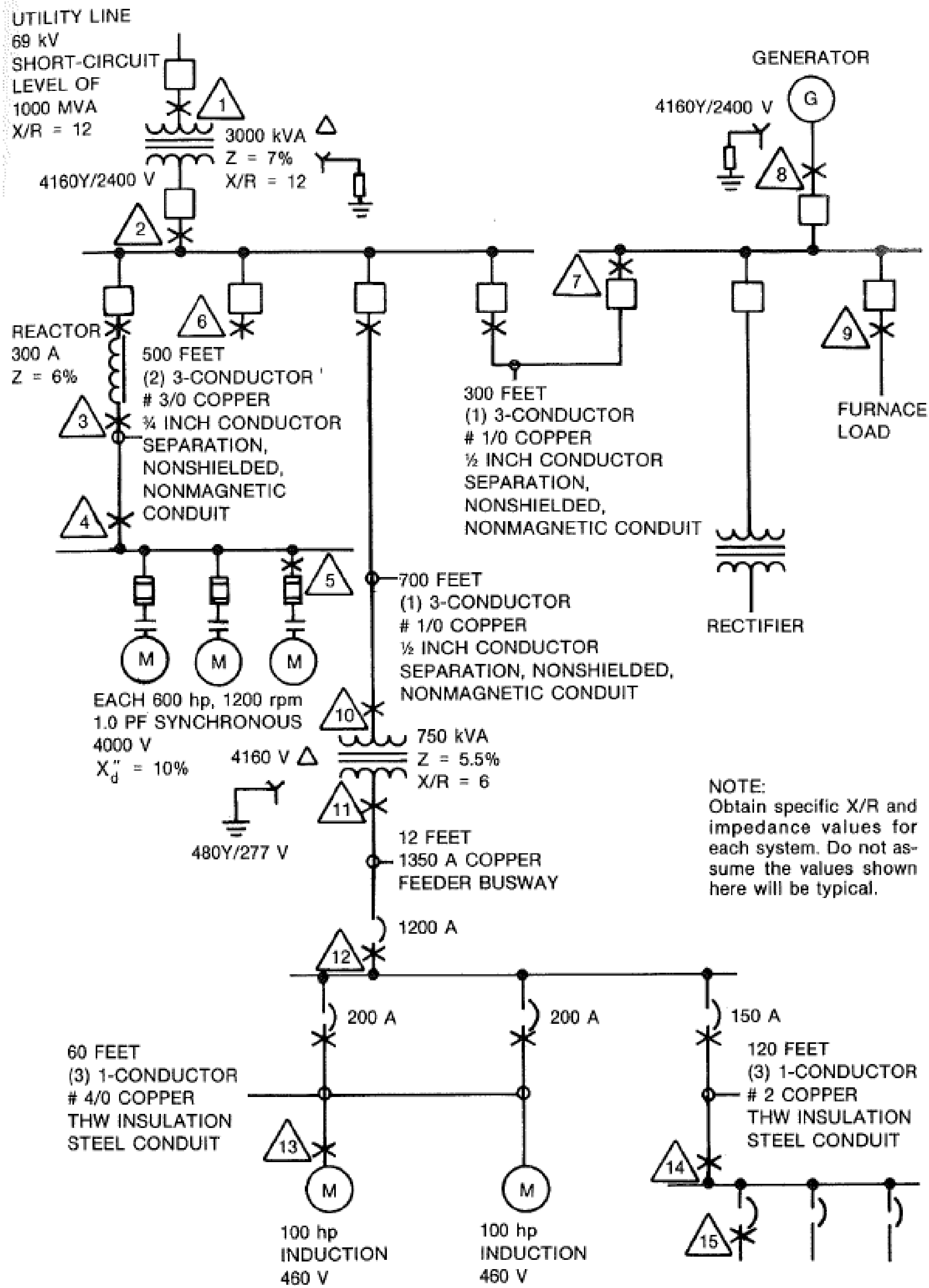


Fig 17
One-Line Diagram for Typical Industrial Distribution System

Fig 18

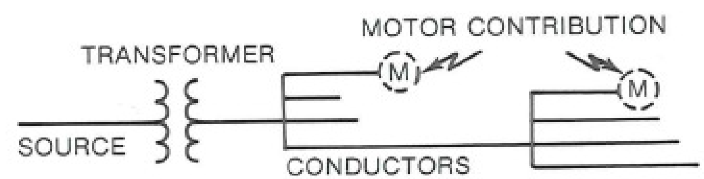
Sample Worksheet for Short-Circuit Calculations by Direct Method

Short-Circuit Calculation Sheet
(Three-Phase Fault)

A step-by-step procedure for calculating maximum short-circuit amperes (SCA) rms sym. in 3ϕ electrical systems. Applicable to medium-voltage source, transformer, and/or low-voltage circuits.

Simply fill in columns. "•" designates data obtained from system. "*" designates values calculated using functional "item letter" equations which are derived from more complex electrical equations. A calculator with sin, tan, arc/INV functions is required.

TRANSFORMER CIRCUIT SEGMENT (See Fig 13)		
Source:	Busses →	
• SCkVA	$c \cdot d \div 577.35 = a$	
• X/R Ratio	b	
• SCA rms sym.	c	
• Voltage (line-to-line)	d	
Transformer:		
• kVA 3ϕ	e	
• % Impedance	f	
• X/R Ratio	g	
• Secondary Voltage (line-to-line)	h	
Source:		
* Equivalent % X	$\sin(\arctan b) \cdot 100 \cdot e \div a = j$	
* Equivalent % R	$j \div b = k$	
Transformer:		
* % X	$\sin(\arctan g) \cdot f = m$	
* % R	$m \div g = n$	
At Transformer Secondary:		
* Total % X (Back to Source)	$j + m = p$	
* Total % R (Back to Source)	$k + n = q$	
* X/R Ratio (Back to Source)	$p \div q = r$	
* SCA from Transformer	$\sin(\arctan r) \cdot e \cdot 57\,735 \div h \div p = s$	



CONDUCTOR CIRCUIT SEGMENT (See Figs 14, 15, and 16)

	Busses →						
• Voltage (line-to-line)	a						
• Length in feet	b						
• Number of conductors/ϕ	c						
• X mΩ/conductor/100 ft	d						
• R mΩ/conductor/100 ft	e						
At finish of preceding upstream segment							
• SCA from preceding upstream segment	f						
• X/R Ratio back to Source	g						
* X mΩ back to Source	① (s ←) h						
* R mΩ back to Source	② (t ←) j						
At start of this segment							
• SCA motor contribution	k						
* SCA Total	f + k = m						
* X mΩ new (Back to Source)	h · f ÷ m = n						
* R mΩ new (Back to Source)	j · f ÷ m = p						
Conductor segment							
* X mΩ	b · d ÷ c ÷ 100 = q						
* R mΩ	b · e ÷ c ÷ 100 = r						
At finish of this segment							
* Total X mΩ (Back to Source)	n + q = s						
* Total R mΩ (Back to Source)	p + r = t						
* X/R Ratio (Back to Source)	s ÷ t = u						
* SCA from this segment	sin (arctan u) · a · 577.35 ÷ s = v						

① h = sin (arctan g) · a · 577.35 ÷ f
h = s of preceding upstream conductor segment (s ←)

② j = h ÷ g
j = t of preceding upstream conductor segment (t ←)

Fig 19
First of Two Pages showing Example Problem Solved By Direct Method

Short-Circuit Calculation Sheet
(Three-Phase Fault)

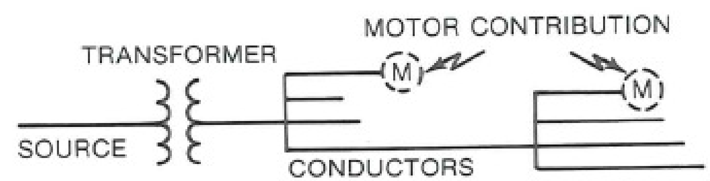
A step-by-step procedure for calculating maximum short-circuit amperes (SCA) rms sym. in 3ϕ electrical systems. Applicable to medium-voltage source, transformer, and/or low-voltage circuits.

Simply fill in columns. "•" designates data obtained from system. "*" designates values calculated using functional "item letter" equations which are derived from more complex electrical equations. A calculator with sin, tan, arc/INV functions is required.

MV Cable

Busses	Calculations
3-4	3.45 = (9.81 - 6.36) · 1
2-7	3.01 = (10.30 - 7.29) · 1

TRANSFORMER CIRCUIT SEGMENT (See Fig 13)		
Source:	Busses →	1-2
• SCkVA	$c \cdot d \div 577.35 = a$	1 000 000
• X/R Ratio	b	12
• SCA rms sym.	c	8367.4
• Voltage (line-to-line)	d	69 000
Transformer:		
• kVA 3ϕ	e	3000
• % Impedance	f	7
• X/R Ratio	g	12
• Secondary Voltage (line-to-line)	h	4160
Source:		
* Equivalent % X	$\sin(\arctan b) \cdot 100 \cdot e \div a = j$	0.299
* Equivalent % R	$j \div b = k$	0.025
Transformer:		
* % X	$\sin(\arctan g) \cdot f = m$	6.976
* % R	$m \div g = n$	0.581
At Transformer Secondary:		
* Total % X (Back to Source)	$j + m = p$	7.275
* Total % R (Back to Source)	$k + n = q$	0.606
* X/R Ratio (Back to Source)	$p \div q = r$	12
* SCA from Transformer	$\sin(\arctan r) \cdot e \cdot 57\,735 \div h \div p = s$	5703



CONDUCTOR CIRCUIT SEGMENT

	Busses →	2–3	3–4	4–5	2–6	2–7	7–8
• Voltage (line-to-line)	a	4160	4160	4160	4160	4160	4160
• Length in feet	b		500	0	0	300	0
• Number of conductors/ϕ	c		2			1	
• X mΩ/conductor/100 ft	d		3.45			3.01	
• R mΩ/conductor/100 ft	e		6.60			10.49	
At finish of preceding upstream segment							
• SCA from preceding upstream segment	f	5703	2885	2852	5703	5703	7014
• X/R Ratio back to Source	g	12	23.553	16.220	12	12	5.734
* X mΩ back to Source	① (s ←) h	419.69	831.88			419.69	
* R mΩ back to Source	② (t ←) j	34.97	35.32			34.97	
At start of this segment							
• SCA motor contribution	k	1099	0	1386	2551	1587	0
* SCA Total	f + k = m	6802	2885	4238	8254	7290	7014
* X mΩ new (Back to Source)	h · f ÷ m = n	351.88	831.88			328.33	
* R mΩ new (Back to Source)	j · f ÷ m = p	29.32	35.32			27.36	
Conductor segment							
* X mΩ	b · d ÷ c ÷ 100 = q	430.00	8.63	0	0	9.03	0
* R mΩ	b · e ÷ c ÷ 100 = r	6.00	16.50	0	0	31.47	0
At finish of this segment							
* Total X mΩ (Back to Source)	n + q = s	831.88	840.51			337.36	
* Total R mΩ (Back to Source)	p + r = t	35.32	51.82			58.83	
* X/R Ratio (Back to Source)	s ÷ t = u	23.553	16.220	16.220	12	5.735	
* SCA from this segment	sin (arctan u) · a · 577.35 ÷ s = v	2885	2852	4238	8254	7014	7014

① h = sin (arctan g) · a · 577.35 ÷ f
h = s of preceding upstream conductor segment (s ←)

② j = h ÷ g
j = t of preceding upstream conductor segment (t ←)

Fig 20
Second of Two Pages Showing Example Problem Solved by Direct Method

Short-Circuit Calculation Sheet
(Three-Phase Fault)

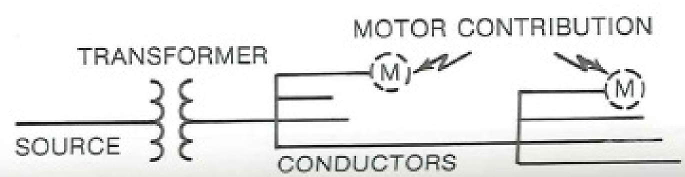
A step-by-step procedure for calculating maximum short-circuit amperes (SCA) rms sym. in 3ϕ electrical systems. Applicable to medium-voltage source, transformer, and/or low-voltage circuits.

Simply fill in columns. "•" designates data obtained from system. "*" designates values calculated using functional "item letter" equations which are derived from more complex electrical equations. A calculator with sin, tan, arc/INV functions is required.

MV Cable

Busses	Calculation
2-10	3.01 = (10.30 - 7.29) · 1

TRANSFORMER CIRCUIT SEGMENT (See Fig 13)		
Source:	Busses →	10-11
• SCkVA	$c \cdot d \div 577.35 = a$	52 325
• X/R Ratio	b	3.223
• SCA rms sym.	c	7262
• Voltage (line-to-line)	d	4160
Transformer:		
• kVA 3ϕ	e	750
• % Impedance	f	5.5
• X/R Ratio	g	6
• Secondary Voltage (line-to-line)	h	480
Source:		
* Equivalent % X	$\sin(\arctan b) \cdot 100 \cdot e \div a = j$	1.369
* Equivalent % R	$j \div b = k$	0.425
Transformer:		
* % X	$\sin(\arctan g) \cdot f = m$	5.425
* % R	$m \div g = n$	0.904
At Transformer Secondary:		
* Total % X (Back to Source)	$j + m = p$	6.794
* Total % R (Back to Source)	$k + n = q$	1.329
* X/R Ratio (Back to Source)	$p \div q = r$	5.112
* SCA from Transformer	$\sin(\arctan r) \cdot e \cdot 57\,735 \div h \div p = s$	13 031



(See 10-11 above)

CONDUCTOR CIRCUIT SEGMENT (See Figs 14, 15 and 16)							
	Busses →	7–9	2–10	11–12	12–13	12–14	14–15
• Voltage (line-to-line)	a	4160	4160	480	480	480	480
• Length in feet	b	0	700	12	60	120	0
• Number of conductors/φ	c		1	1	1	1	
• X mΩ/conductor/100 ft	d		3.01	0.65	4.14	4.49	
• R mΩ/conductor/100 ft	e		10.49	0.76	5.34	16.40	
At finish of preceding upstream segment							
• SCA from preceding upstream segment	f	7014	5703	13 031	12 974	12 974	8168
• X/R Ratio back to Source	g	5.734	12	5.112	5.024	5.024	1.043
* X mΩ back to Source	① (s ←) h		419.69	20.87	20.95	20.95	
* R mΩ back to Source	② (t ←) j		34.97	4.08	4.17	4.17	
At start of this segment							
• SCA motor contribution	k	964	2416	0	628	1256	0
* SCA Total	f + k = m	7978	8119		13 602	14 230	
* X mΩ new (Back to Source)	h · f ÷ m = n		294.80		19.98	19.10	
* R mΩ new (Back to Source)	j · f ÷ m = p		24.56		3.98	3.80	
Conductor segment							
* X mΩ	b · d ÷ c ÷ 100 = q	0	21.07	0.08	2.48	5.39	0
* R mΩ	b · e ÷ c ÷ 100 = r	0	73.43	0.09	3.20	19.68	0
At finish of this segment							
* Total X mΩ (Back to Source)	n + q = s		315.87	20.95	22.46	24.49	
* Total R mΩ (Back to Source)	p + r = t		97.99	4.17	7.18	23.48	
* X/R Ratio (Back to Source)	s ÷ t = u	5.734	3.223	5.024	3.128	1.043	1.043
* SCA from this segment	sin (arctan u) · a · 577.35 ÷ s = v	7978	7262	12 974	11 753	8168	8168

① h = sin (arctan g) · a · 577.35 ÷ f
h = s of preceding upstream conductor segment (s ←)

② j = h ÷ g
j = t of preceding upstream conductor segment (t ←)

(7) *Bus 6*. No motor contribution.

(8) *Bus 5*. 480 kVA (0.8 · 600) for 600 hp synchronous motor at 100% power factor.

$$SCA_M = \frac{100\%}{10\%} \cdot I_{FL} \quad \text{(Fig 9)}$$
$$= 10 \cdot \frac{480 \text{ kVA}}{\sqrt{3} \cdot 4.000 \text{ kV}}$$
$$= 693 \text{ SCA}$$

(9) *Busses 3 and 4*. 3 · 693 A = 2079 A

(10) *Bus 2*. Sum of feeder motor and generator contributions.

From Bus 3 through reactor:

$$Z_M = \frac{4.000 \cdot 1000}{\sqrt{3} \cdot 2079} \quad \text{(Fig 10)}$$
$$= 1.111\ \Omega$$
$$Z_R = \frac{6\%}{100\%} \cdot \frac{2400 \text{ V}}{300 \text{ A}}$$
$$= 0.480\ \Omega$$

SCA_M through reactor =

$$\frac{1.111}{1.111 + 0.480} \cdot 2079 \text{ SCA} = 1452 \text{ SCA}$$

Total SCA_M = 1452 SCA + 135 SCA + 964 SCA = 2551 SCA

(11) *Bus 1*. Calculation unnecessary.

2.4.2 First-Cycle Symmetrical Short-Circuit Calculations for Each Bus. The next step is to begin at the service point and make first-cycle symmetrical short-circuit calculations for each bus in the system. For convenience, the impedance of circuit breakers is neglected. The calculated values and equations are shown on the completed worksheets in Figs 19 and 20.

Note that total motor and generator short-circuit contribution at the start of a segment does not include load-side contribution. For example, the motor and generator contribution at the start of the segment from Bus 2 to Bus 10 is 2551 SCA − 135 SCA = 2416 SCA.

Additional calculations must also be made for the reactor as follows:

Z_R = 0.48000 Ω (see 2.4.1 item 10)
= 480.00 mΩ

Assuming X/R = 80.

$$Z \cong Z_R = 480.00 \text{ m}\Omega$$
$$R = \frac{480.00}{80} = 6.00 \text{ m}\Omega$$

APPENDIX C – LADBS ELECTRICAL PLAN CHECK CORRECTION LIST: SECTIONS PERTAINING TO SELECTIVE COORDINATION

CITY OF LOS ANGELES
ELECTRICAL PLAN CHECK CORRECTION LIST

DEPARTMENT OF BUILDING AND SAFETY

Plan Check/PCIS Application No.:____

Job Address: ____________________	**Expiration Date:** ______________
Applicant Name: ____________________	**Description:** ______________
Address: ____________________	**Phone:** ______________
City/State/Zip: ____________________	**E-Mail:** ______________
Plan Check Engineer: ____________________ **(Print first / last name)**	**Review Date:** ______________
Telephone: ____________________	**E-mail:** firstname.lastname@lacity.org

Your application for a permit, together with plans and specifications, has been examined and the issuance of a permit is withheld for the reasons set forth. The approval of plans and specifications does not permit the violation of any section of the Building Code, or other local ordinance or state law.

NOTE: Numbers in parenthesis ( ) refer to Code sections of the 2011 edition of the City of Los Angeles Electrical Code (based on 2010 California Electrical Code with adopted portions of 2008 National Electrical Code), 2008 and 2011 L.A. Building Code (LABC), 2008 and 2011 L.A. Mechanical Code (LAMC), 2007 National Fire Alarm Code (NFPA 72), 2011 L.A. Green Code (LAGC) and 2008 Title 24 California State Energy Regulations which was Effective January 1, 2010.

INSTRUCTIONS:

- Corrections with circled item numbers apply to this plan check.
- In the left hand margin of the circled corrections, please indicate the sheet number and detail or note number on the plans where the corrections are made. Resubmit marked original plans and one corrected set of plans, calculations and this plan review list.
- Incomplete or unreadable drawings or calculations will not be accepted.
- Incorporate all comments as marked on the checked set of plans and calculations and this corrections sheet.
- **Call the plan check engineer for appointment when the plans are ready for re-submittal.**
- **Appointments are required to schedule for conferences and verifications.**

PLEASE BRING THE MARKED UP PLANS TO THE VERIFICATION APPOINTMENT.

Your feedback is important; please visit our website to complete a Customer Survey at www.ladbs.org/LADBSWeb/customer-survey.jsf.

SEE MARKED UP PLANS FOR CLARIFICATIONS OF CORRECTIONS.

e. Accessory building to dwelling units with inhabitable room at or below grade level.

6. All 125 volts 15 and 20 ampere receptacles as required in Section 210.52 in dwelling units shall be tamper-resistance. ____ (406.11)

7. Provide show window lighting(s) and receptacle branch circuit(s). The receptacle outlets shall be within 18 inches from the top of a show window.________________ ________________________________ (210.62, 220.43(A))

8. A single receptacle installed on an individual branch circuit shall have an ampere rating of not less than that of the branch circuit. Indicate the receptacle rating. _______ (210.21(B)(1))

9. Provide receptacle outlets wherever cord connected equipment will be used. ____________________________ (210.50(B))

C. FEEDERS

1. A building or structure shall be supplied by one feeder or branch circuit.____________________________________ ____ ____ (225.30)

2. The following feeders are undersized. ________________ ____ ____________________ (225.5, 310.15, 110.14(c), 240.4)

D. BRANCH CIRCUITS & FEEDER CALCULATIONS

1. Branch circuit loads were incorrectly calculated or omitted: ____ ____ (220.14)

2. Feeder loads shall include 150 VA of load for every 2 feet of track lighting.______________________________________ ____(220.43(B))

3. Provide proper feeder, panel board and branch circuit ampacity for general lighting load as required for the particular occupancy. _______________________________________ ____ ______________________________(220.12, 220.40, 215.2)

4. Provide a dedicated branch circuit for exterior sign or outline lighting system calculated at a minimum of 1200 VA. _______ ________________________________(220.14(F), 600.5(A))

5. Provide a dedicated branch circuit for the light, receptacle(s), auxiliary lighting power source and ventilation on each elevator car. ______________________________________(620.22(A))

6. Provide a dedicated branch circuit for the air conditioning and heating units on each elevator car. ___________ (620.22(B))

7. Feeder loads were incorrectly calculated or omitted: _______ ____ ____ (220.40)

8. Provide a minimum of 200 VA for each linear foot of show window supplied by a branch circuit.__________________ ____(220.14(G))

9. Feeder and branch circuit rating shall be based on not less than noncontinuous loads and 125% of continuous loads. ____ ____ ____ ______________________________ (210.19(A), 215.2(A)(1))

10. Provide 180 VA of load for each general use receptacle. ____________________________________(220.14(I) & (L))

11. Small Appliance branch circuits shall be rated at 1500 VA each. ____________________________________(220.52(A))

E. SERVICES

1. Show the service conductor routing from the utility service point. ____ ____ ___________________________________(93.0207(o) & (n))

2. Provide a copy of the utility company's service report indicating the available fault current, voltage, amperes and phase at the service. ____ ______________________________________ (93.0207(k))

3. Provide an elevation drawing of the service equipment. Indicate dimensions and show each section, meter, and disconnect. ____ _______________________________________ (93.0207(k))

4. Service disconnect(s) shall be located nearest the point of entrance of the service conductors.__________________ ____ ____ (230.70(A))

5. No more than six service disconnecting means is permitted at any one location.________________________________ ____ (230.71(A))

6. The two to six disconnects as permitted in section 230.71 shall be grouped and each shall be marked to indicate the load served.____ ____ (230.72(A))

7. No more than one service disconnecting means is permitted for motor control centers. _____________________________ ____ (430.95)

8. The service equipment shall have a rating not less than the load served. This load shall be calculated per Article 220. ____ ____ (230.79)

9. Ground fault protection is required on each 1000 amperes or more, 4W, 277/480 volts wiring system of a service or a feeder disconnecting means.________________ ____________________________________ (230.95, 215.10)

10. Except as permitted in section 230.2(A), a building or other structure shall be supplied by only one service.___________ ____ ____ (230.2)

11. When more than one building or other structure is on the same property and under single management, each building or structure shall be provided with means for disconnecting all ungrounded conductors. ____________________________ ____ ____ (225.31)

12. Equipment shall not be connected to the supply side of the service disconnecting means. _________________ (230.82)

13. In a multiple occupancy building, each occupant shall have access to their service disconnecting means.______________ ____ (230.72(C))

14. Provide service load calculation. ______________________ __________________________________ (230.42, 93.0207(n))

15. Provide service load calculations for 120/240 V, 3 phase, 4W, delta system in accordance with Los Angeles Electrical Code (Excerpts Section). ________________________________ ______________________________________ (93.0207(n))

16. Service and feeder demand load calculation shall be in accordance with Article 220.87. _______________________

17. ____ ____

F. OVERCURRENT PROTECTION AND SHORT CIRCUIT PROTECTION

1. Submit overcurrent coordination study. __________________ ________________________ (240.12, 620.62, Table 685.3)

2. Indicate the provisions to ensure the proper operation of Ground Fault Protection equipment on a separately grounded service and generator system. ___________________________ ____________________ (215.10, 230.95(C), 240.13, 110.26)

3. Provide proper overcurrent protection for conductors on circuits: ____ ____ ____ (240.4)

6. Submit details of the natural or mechanical ventilation provided in garage area(s). ______________________________ ______________________________ (511.3(C), (D), or (E))
7. Provide GFCI protection for outlets in repair garages.______ ______________________________ (511.12)
8. Classify the pits in the garage areas. ________________ ______________________________ (511.3(B))
9. A manually operated remote control installed at an approved location shall be provided to shut off fans or blowers installed as part of ventilation system that are located in flammable vapor or dust systems. ____________________________ ______________________________ (LAMC 503.1)
10. Electrical equipment located in operations that generate explosive or flammable vapors, fumes or dust shall be interlocked with the ventilation system so that the equipment can not be operated unless the ventilation fans are in operation. __________________________ (LAMC 503.1)

O. CLINICS

1. Indicate type of clinic(s). ___________________________ ______________________________ (LABC 1226)
2. Provide a list of equipment to be installed. _______ (93.0207)
3. Equipment classified for life-support purpose shall be supplied from an essential system as required per sections 517.31 through 517.45.
4. Indicate if the clinic is or will be licensed by the State of California. __________________________ (LABC 1226.2)
5. Clarify if a generator is to be installed to supply all the loads in the ambulatory surgical clinics.____________ (517.45(D.1))
6. Clarify if wiring installation within an ambulatory surgical or hemodialysis clinics are in accordance with 517.45(F) and (G).
7. Provide a nurse call system in the birthing clinic. ______________________________ (LABC 1226.16)
8. Provide minimum of 100 fc at working surface in a birthing clinic.______________________________ (LABC 1226.16)
9. Operating room of a surgical clinic shall include a clock and elapsed timer and an x-ray film illuminator. (LABC 1226.17.1)
10. If Ethylene Oxide sterilizers are supplied from emergency power, the exhaust system shall also be supplied from the emergency power.__________________ (LABC 423A.4.4)

P. FIRE PUMP

1. Fire pump circuit conduits shall be encased in no less than 2 inches of concrete. _______________________________ ______________________________ (695.6)
2. Show the routing of the fire pump feeder. _______________ ______________________________ (93.0207, 695.6)
3. Overcurrent protection for fire pump services shall provide short circuit protection and shall be set to carry fire pump motor locked rotor current indefinitely.______________________ ______________________________ ______________________________ (695.4(B)(1))
4. Provide an emergency source of power for fire pump. ______ ______________________________ ______________________________ (695.3(B), 700.12)
5. No disconnecting means shall be installed within the fire pump feeder circuit. _________________________________ ______________________________ (695.4(A))
6. Transfer of power shall take place within the fire pump room. ______________________________ ______________________________ (695.12(A))
7. ______________________________ ______________________________ ______________________________

Q. EMERGENCY SYSTEMS

1. Provide (a) properly sized emergency power source(s) for required emergency load(s). _______________________ ______________________________ (700.5)
2. A completely independent raceway, switchboards and wiring system shall be installed for emergency circuits including generator control wiring.______________________ ______________________________ (700.9)
3. The means of egress illumination level shall not be less than 1 foot-candle at the walking surface level. _____ (LABC 1006.2)
4. Emergency lights shall be provided in all means of egress as defined in section 1006.3. _________________________ ______________________________ (LABC 1006.3)
5. The emergency luminaires shall provide an initial average illumination level of at least 1 foot-candle but at any point it shall not be less than 0.1 foot-candle along the path of egress at floor level. ________________________ (LABC 1006.4)
6. At the end of the required emergency source time duration, the emergency luminaires shall provide an average illumination level of at least 0.6 foot-candle but at any point it shall not be less than 0.06 foot-candle along the path of egress at floor level. ______________________________ (LABC 1006.4)
7. The emergency illumination level shall have a minimum-to-maximum emergency illumination uniformity ratio that does not exceed 40 to 1. ______________________ (LABC 1006.4)
8. Emergency exit illumination shall be supplied from:

   a. generator, b. storage battery, c. UPS, d. Fuel Cell with storage battery, or e. unit equipment. (LABC 1006.3, 700.12)
9. Provide exit signs. ____________________ (LABC 1011.1)
10. Provide low level exit path marking. __________________ ______________________________ (LABC 1011.6)
11. Provide battery capacity calculation. ________________ ______________________________ (700.5, 700.12(A))
12. Storage batteries shall comply with Article 480. __________ ______________________________
13. Provide selective overcurrent protection. _______________ ______________________________ (700.27)
14. Exit signs shall be supplied by two circuits, one from normal source and one from emergency source. ______________ ______________________________ _________ (700.17, 700.3, 110.3, LABC 11011.4 & 1011.5.3)
15. Provide a lock-on device for circuits supplying emergency unit equipment. ____________________ (700.12(E) Exception)
16. The branch circuit feeding the unit equipment (emergency light with self-contained rechargeable battery) shall be the same branch circuit as that serving the normal lighting in the area and connected ahead of any local switches or time clocks. Indicate the correct circuit wiring diagram on the plans._____ ______________________________ ______________________________ (700.12(F))
17. Provide Coordination study for all emergency and legally required standby systems overcurrent protective devices. ______________________________ (700.27, 701.18)
18. Provide 4 pole automatic transfer switch to transfer normal to emergency power under any of following conditions:

    a. Ground fault protected service or feeder supplying the transfer switch. ___________________________ (700.27)

    b. Ground fault indicating for the emergency source and Ground fault protected service or feeder. ________ (700.6) **or**

    c. Two levels of ground fault protection on normal supply side. ______________________________ (700.6)
19. Emergency generator(s) shall not be located in a room or an area used for any other purpose other than equipment and controls related to the generation and distribution of emergency power. This room shall be separated from the remainder of the building by a one-hour fire barrier, or two hours if installed in a new high rise building. ____________ ______________________________ ______________________________ __________________ (LABC 432.2.1, 432.2.3, 403.4.7.1)