SUDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

College of Engineering

Electrical Engineering

COORDINATION ON POWER SYSTEM PROTECTION

تنسيق أجهزة الحماية في منظومة القدرة

A Project Submitted in Partial Fulfillment for the Requirement of the Degree of B.Tech. (HONS) In Electrical Engineering

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الايـــــة

قال تعالى :

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ (1) الْحَمْدُ لِلَّهِ رَبِّ الْعَالَمِينَ (2) الرَّحْمَنِ الرَّحِيمِ (3) مَالِكِ يَوْمِ الدِّينِ (4) إِيَّاكَ نَعْبُدُ وَإِيَّاكَ نَسْتَعِينُ (5) اهْدِنَا الصِّرَاطَ الْمُسْتَقِيمَ (6) صِرَاطَ الَّذِينَ أَنْعَمْتَ عَلَيْهِمْ غَيْرِ الْمَغْضُوبِ عَلَيْهِمْ وَلَا الضَّالِّينَ (7)

صدق الله العظيم

سورة الفاتحة.(1-7)

DEDICATION

To

***My Mother**: A Strong and Gentle Soul Who Taught Me to Trust Allah Believe In Hard Work and the So Much Could Be Done With Little.*

***My Father**: For Earning an Honest Living for Us and For Supporting and Encouraging Me to Believe In Myself.*

***My Brothers and Sisters**: for their help and Passion.*

***My Friends**: a great people whose standing with me when I need support,*

Especially to Eng. Omer salama, Eng. abd alsalam, Eng. Mohammed Salah and Eng. Mustafa said basha.

***My Soul**: a beautiful woman that I love*

I Dedicate This Work

ACKNOWLEDGEMENT

All the thanks, praises and glorifying is due to Almighty ALLAH

I owe my deepest gratitude to my advisor Dr. MOHAMMED OSMAN HASSAN. First for accepting me as a student, then for the support and help he has given me throughout the project.

Many thanks to my colleagues and all the staff at the Department Of Electrical And Nuclear Engineering for the pleasant working atmosphere and your friendship.

Finally, I would like to thank all those who helped me supported me and lots of thanks to my family.

ABSTRACT

Continuous and reliable power supply is the main goal and target for power system networks. In this regard, many methods have been developed to enhance the performance of power supply systems.

The case study is initiated to investigate power system network by using ETAP software as analysis tool. The network was drawn. The data for each component in the network was entered.

After running the simulator, different fault scenarios were created to examine the existing protection system schemes and different miss-operations results were obtained as a response of protection system to the abnormal conditions.

A new coordination scheme is designed which starts first by coordinating the phase over-current elements, for different paths from furthest downstream up to the generators. Next the earth fault relays are coordinated for the same paths and finally the instantaneous element as a backup protection was applied successfully.

المستخلص

منظومة القوي الكهربية واحده من اهم واعظم المنظومات التي صنعها الانسان واكثرها تعقيداً، ويعتبر إمداد الطاقة بشكل مستمر وموثوق أحد أهم العوامل التي تؤثر علي كفاءة المنظومة ، لذلك تم إبتكار العديد من الأنظمة والطرق واستخدمت العديد من الوسائل من أجل تحسين آلأداء وضمان استمرار إمداد الطاقة بالصورة المطلوبة .

تم عمل هذا البحث لدراسة نموزج مصغر لمنظومة شبكة كهربائية باستخدام برنامج "إي تاب" كأداة للدراسة والتحليل ، تم رسم وتمثيل الشبكة ، ومن ثم تم إدخال البيانات الخاصة بجميع عناصر الشبكة فى البرنامج.

تم إختبار أنظمة الحماية الحالية عن طريق عمل سيناريوهات لأعطال كهربائية فتم الحصول على بعض الإستجابات الخاطئة من نظام الحماية لهذه الأعطال.

تم تقسيم الشبكة الي مناطق وصمم نظام تنسيق جديد للمرحلات ، هذا النظام يبدأ بتنسيق عناصر مراقبة التيار فى الطور الواحد وذلك للمناطق بالتتابع في مسارات الشبكة إبتداءً من أبعد نقطة فى الشبكة وصولاً إلى المولدات .

كذلك تم تنسيق مرحلات حماية الأعطال للخطأ الأرضى وذلك لنفس المسارات السابقة للشبكة ، وأخيرا تم تنسيق العناصر اللحظية كعناصر إحتياطية للحماية.

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List of ABBREVIATIONS

IEEE	Institute of Electrical and Electronic Engineering
SLD	Single Line Diagram
KVA	Kilo Volt Ampere
KW	Kilo Watt
KV	Kilo Volt
DMT	Definite Minimum Time
IDMT	Inverse Definite Minimum Time
OC	Over Current
CT	Current Transformer
VT	Voltage Transformer
CB	Circuit Breaker
IEC	International Electro-technical Commission
SI	Standard Inverse
VI	Very Inverse
ETAP	Electrical Transient Analysis Program
TMS	Time Multiplier Setting
OHTL	Over Head Transmission Line
MVA	Mega Volt Ampere
MW	Mega Watt

CHAPTER ONE

INTRODUCTION

1.1 Overview

In any power system network, protection should be designed such that protective relays isolate the faulted portion of the network at the earliest, to prevent equipment damage, in-jury to operators and to ensure minimum system disruption enabling continuity of service to healthy portion of the net-work. In case of failure of primary relays, back up relays operate after sufficient time discrimination. The protective relay should be able to discriminate be-tween normal, abnormal and fault conditions. The term relay coordination covers concept of discrimination, selectivity and backup protection. [1]

In modern era, the demand for electrical power generally is increasing at a faster rate in economically emerging countries. So the networks of electricity companies become very complicated. The exercise of load flow analysis, fault calculations and listing the primary and back-up pairs will be very tedious and several iterations would be required to calculate TMS of relays so that minimum discrimination margin as required is found between a relay and all its back-up relays in large electrical system. This is possible only through computer programming. [1]

1.2 Problem Statement

The improper relays setting led to uncontrolled faults and can cause service outage, as well as extensive equipment damage. There are many setting rules for calculating the setting values of the different protection zones. The overlap problems and under reach problem have been raised for most of these rules especially in the second and third protection zone.

1.3 Objectives

This project focuses on the following objectives:

1- To analyze the power system properties (e.g. load flow and fault analysis).

2- To apply the appropriate settings and coordination of the protection Devices.

3- To introduce the new improve setting and coordination of the case studies system.

1.4 Methodology

- Draw and analyze the power system Using ETAP [load flow and short circuit analysis].
- Understanding and analyzing Types of Faults, Zones of protection and Protection Devices.
- Use the TCC to coordination and improve setting Power System Protection.
- Ensure the correctness of coordination. extraction of final reports.

1.5 Project outlines

This project is organized as follows:-

Chapter one covers the Overview of the protection and coordination, problem statement, and objective of the project and expected results from the research and testing.

Chapter two presents the literature review of the protection on the power system, the Protection Equipment, Protection quality, basic requirements of protection and the desirable attributes of protection system.

Chapter three deliberates on the methodology of Coordination in power system protection and the Standards characteristic equations.

Chapter four reports and discusses on the results obtained from the test of the Protective devices due to the simulation using ETAP V16.0.0.

Chapter five will go through the conclusion and recommendation for future study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Protection Definitions

The definitions that follow are generally used in relation to power system protection.

2.1.1 Protection System

A complete arrangement of protection equipment and other devices required to achieve a specified function based on a protection principal.

2.1.2 Protection Equipment

A collection of protection devices (relays, fuses, etc.). Excluded are devices such as CT‟s, CB‟s, Contactors, etc. [2]

2.1.3 Protection Scheme

A collection of protection equipment providing a defined function and including all equipment required to make the scheme work (i.e. relays, CT‟s, CB‟s, batteries, etc.) In order to fulfil the requirements of protection with the optimum speed for the many different configurations, operating conditions and construction features of power systems, it has been necessary to develop many types of relay that respond to various functions of the power system quantities. [2]

2.2 Protection Quality

The basic function of electrical protection is to detect system faults and to clear them as soon as possible. For any one particular application, there are many ways to do this function, with varying degrees of effectiveness. The choice is influenced by the overall protection philosophy of the plant and the importance of the equipment or portion of the network to be protected, weighing cost against performance. The general philosophy of applying protection in a power network is to divide the network into protective zones, such that the power system can be adequately protected with the minimum part of the network being disconnected during fault conditions. The zones can either be very clearly defined, with the protection operating exclusively for that zone only as in differential protection,

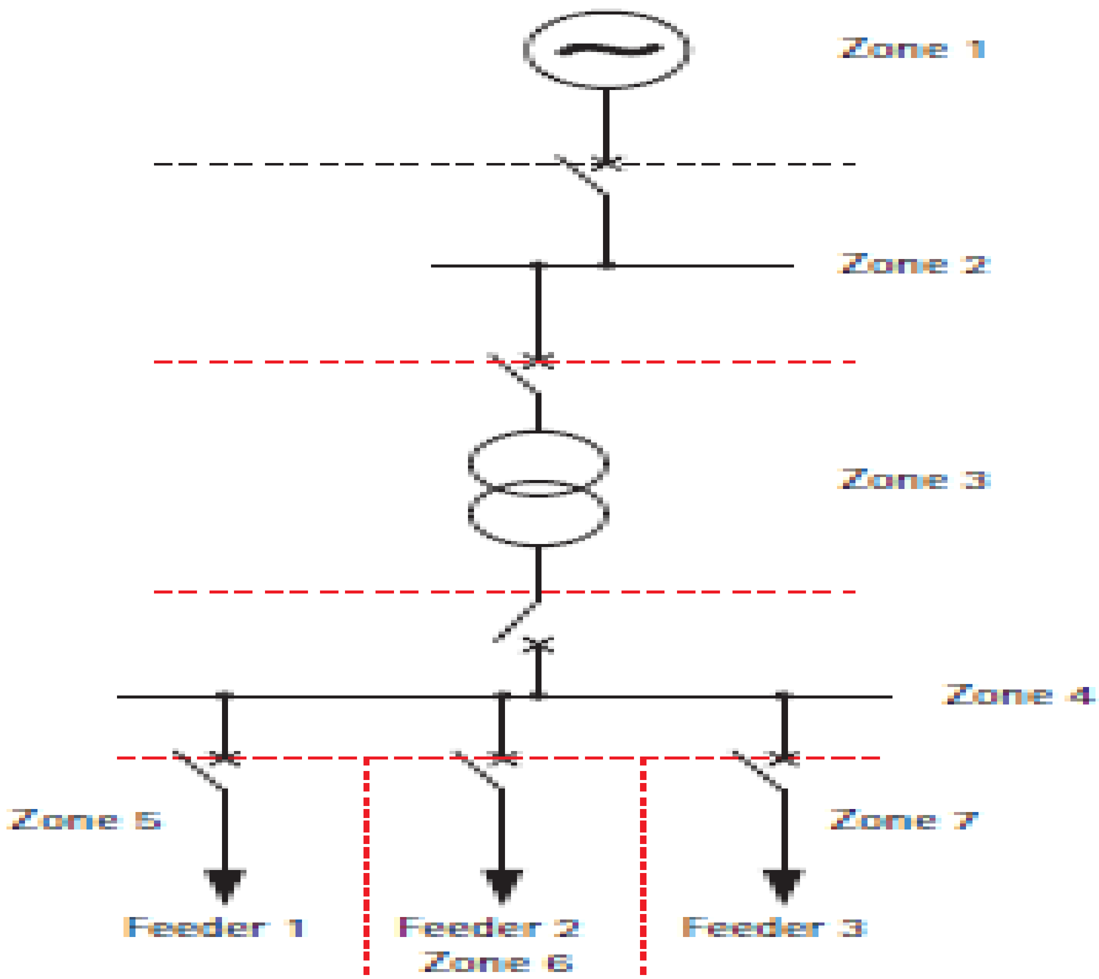

Figure 2.1: Zones of protection

Illustrated in Figure 2.1 or less clearly defined, with overlapping of the protection function between zones for example, over- current protection, as illustrated in Figure 2.2.

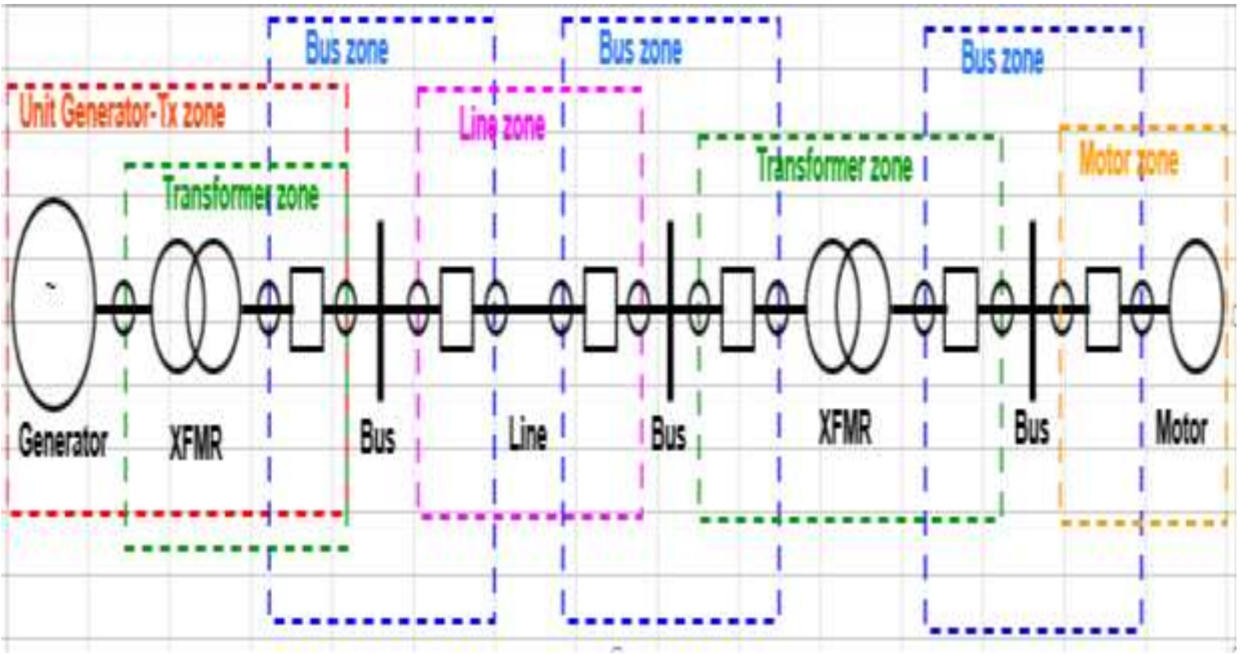

Figure 2.2: Overlapping of zones

2.3 Basic requirements of protection

A protection apparatus has three main functions/duties:

i. Safeguard the entire system to maintain continuity of supply.

ii. Minimize damage and repair costs where it senses fault.

iii. Ensure safety of personnel.

These requirements are necessary, firstly for early detection and localization of faults, and secondly for prompt removal of faulty equipment from service. In order to carry out the above duties, protection must have the following qualities.

2.3.1 Unit Protection (selectivity)

Selectivity or Discrimination is the ability of the protection to isolate only the faulted part of the system, minimizing the impact of the fault on the power network. Absolute discrimination is only obtained when the protection operates exclusively within a clearly defined zone. This type of protection is known as „unit protection‟, as only one unit is exclusively protected for example, a transformer, or a specific feeder cable. Unit protection can only be achieved when the following essentials are satisfied:

- Sensing or measuring devices must be installed at each (electrical) end of the protected equipment.
- There has to be a means of communication between the devices at each end, in order to compare electrical conditions and detect a fault when present.

The most common form of unit protection is current differential protection, whereby current values at each end of the protected equipment is measured and compared, and a trip signal is issued when the difference in measured values is more than a predefined threshold value.

The main Advantages of unit protection are:

i. Only the faulted equipment or part of the network is disconnected, with minimum disruption to the power network.
ii. Unit protection operates very fast, limiting damages to equipment and danger to human life. Fast operation is possible because the presence or absence of a fault is a very clear-cut case.
iii. Unit protection is very stable
iv. Unit protection is very reliable (provided the communication path is intact).
v. Unit protection is very sensitive.

The main Disadvantages of unit protection are:

vi. It is very expensive.
vii. It relies on communication between the relays installed at either end.
viii. It can be maintenance-intensive to keep the communication medium intact, depending on the application and environment.

The discrimination qualities of non-unit protection are not absolute, as the relay functions independently and will generally operate whenever it sees a fault, no matter where the fault is located. Therefore, to achieve proper discrimination for non-unit protection schemes, the principle of grading is applied. Consider the example, as illustrated in figure 2.3 where the protection consists of only over-current relays. If the relays in figure 2.3 were all of the same type, and no lower or upper restrictions

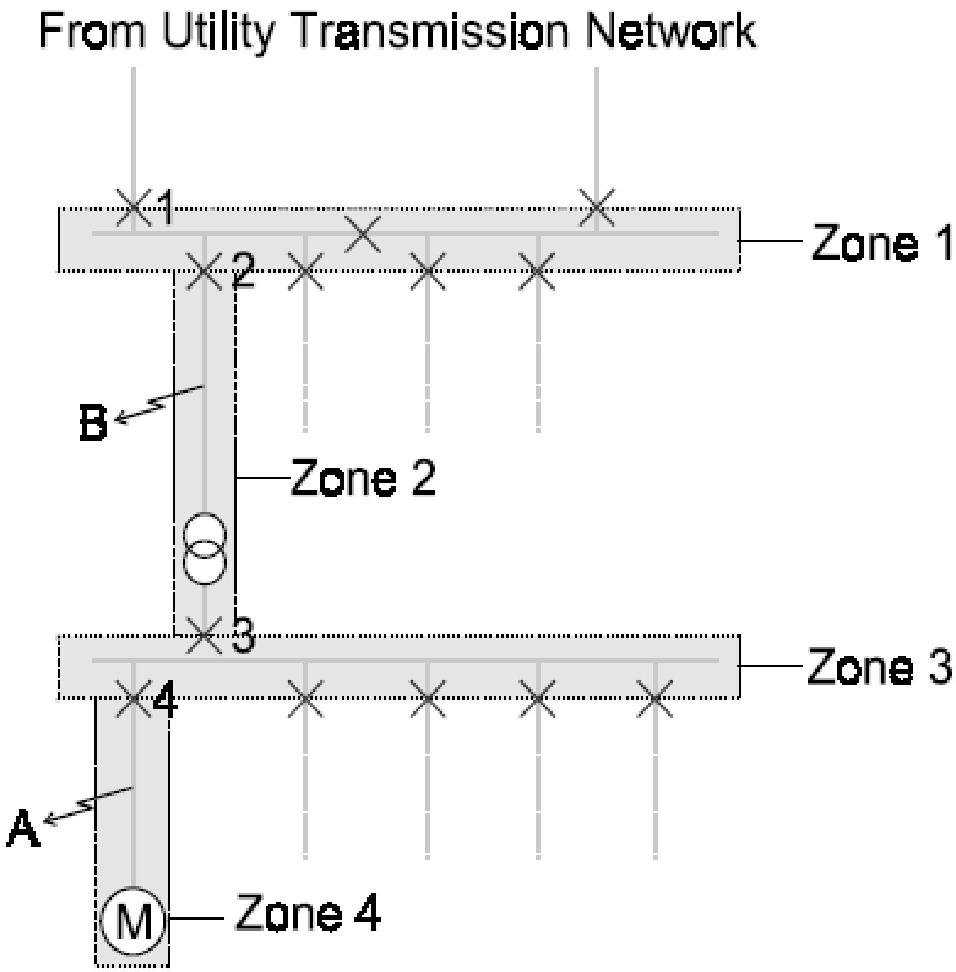

Figure 2.3: Application of principle of grading

Were placed on the grading, it would be quite simple, and the time–current would look something like the graph in figure 2.4.

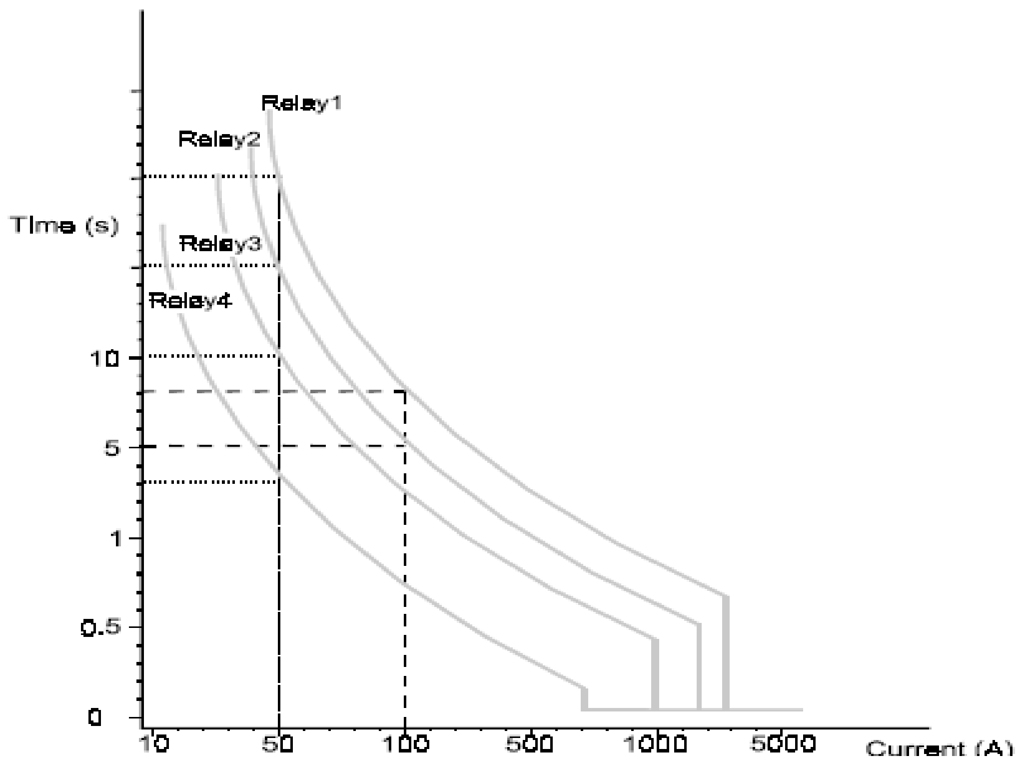

Figure 2.4: Over current time

2.3.2 Stability

Stability, also called security, is the ability of the protection to remain inoperative for normal load conditions (including normal transients like motor starting).Most stability problems arise from incorrect application of relays and lack of maintenance.

2.3.3 Reliability

Reliability, or dependability, is the ability of the protection to operate correctly in case of a fault. Reliability is probably the most important quality of a protection system.

2.3.4 Speed of operation

The longer the fault current is allowed to flow, the greater the damage to equipment and the higher the risk to personnel. Therefore, protection equipment has to operate as fast as possible, without compromising on stability. The best way to achieve this is by applying unit protection schemes. However, unit protection is expensive, hence the importance and cost of the equipment to be protected, and the consequences of an electrical fault, must be considered and weighed against the cost of very fast protection schemes.

2.3.5 Sensitivity

The term sensitivity refers to the magnitude of fault current at which protection operation occurs. A protection relay is said to be sensitive when the primary operating current is very low. Therefore, the term sensitivity is normally used in the context of electrical protection for expensive electronic equipment, or sensitive earth leakage equipment.

CHAPTER THREE

PROTECTION COORDNATION

3.1 The Importance of Coordination

A Coordination Study is critical for the safe, efficient, and economical operation of any electrical distribution system. Coordination Study will help to ensure that personnel and equipment are protected by establishing proper interrupting ratings. When an electrical fault exceeds the interrupting rating of the protective device, the consequences can be devastating, including injury, damaged electrical equipment, and costly downtime. A Coordination Study maximizes power system selectivity by isolating faults to the nearest protective device, as well as helping to avoid nuisance operations that are due to transformer inrush or motor starting operations.

3.1.1 Selective Coordination

Selective coordination is often referred to simply as coordination. Coordination is defined in NEC® 240.2 as: "The proper localization of a fault condition to restrict outages to the equipment affected, accomplished by the choice of selective fault-protective devices." It is important to note that the type of overcurrent protective device selected often determines if a system is selectively coordinated.

The figure below shows the difference between a system without selective coordination and a system with selective coordination. The figure on the left shows a system without selective coordination. In this system, unnecessary power loss to unaffected loads can occur, since the device nearest the fault cannot clear the fault before devices upstream open. The system on the right shows a selectively coordinated system. Here, the fault is cleared by the overcurrent device nearest the fault before any other upstream devices open, and unnecessary power loss to unaffected loads is avoided.

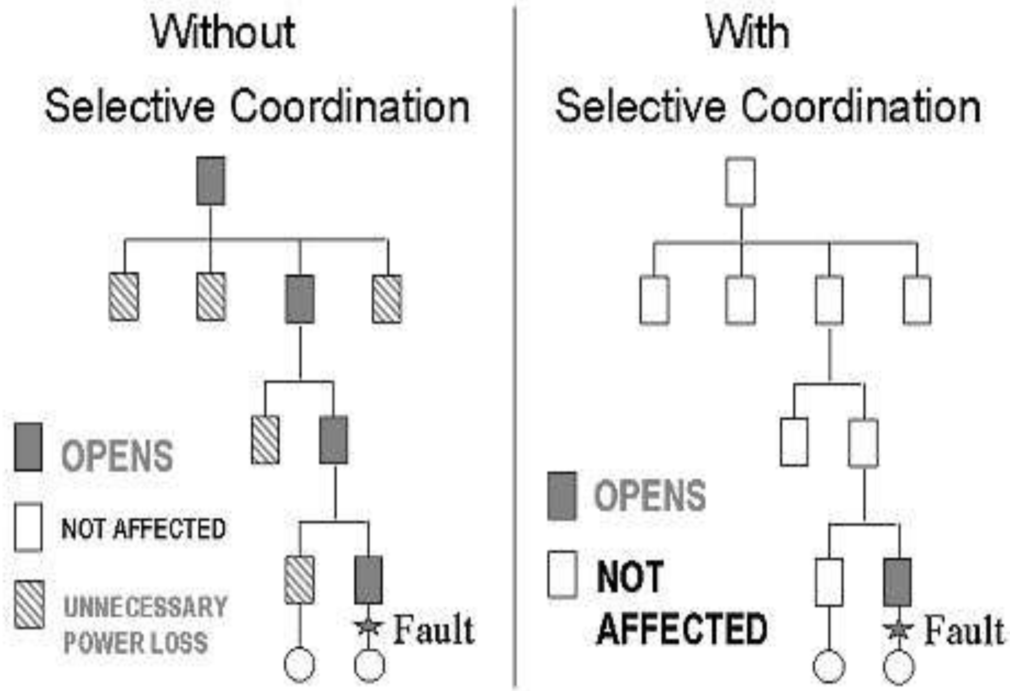

Figure 3.1: Selective coordination

3.2 Protective Device Coordination

Where there are two or more series protective devices between the fault point and the power supply, these devices must be coordinated to insure that the device nearest the fault point will operate first. The other upstream devices must be designed to operate in sequence to provide back-up protection, if any device fails to respond. This is called selective coordination. To meet this requirement, protective devices must be rated or set to operate on minimum overcurrent, in minimum time, and still be selective with other devices on the system. When the above objectives are fulfilled, maximum protection to equipment, production, and personnel will be accomplished. As will be seen later in this chapter, protection and coordination are often in direct opposition with each other. Protection may have to be sacrificed for coordination, and vice versa. It is the responsibility of the electrical engineer to design for optimum coordination and protection.

3.3 The Coordination Study

A coordination study consists of the selection or setting of all series protective devices from the load upstream to the power supply. In selecting or setting these protective devices, a comparison is made of the operating times of all the devices in response to various levels of overcurrent. The objective, of course, is to design a selectively coordinated electrical power system. A new or revised coordination study should be made when the available short-circuit current from the power supply is increased; when new large loads are added or existing equipment is replaced with larger equipment; when a fault shuts down a large part of the system; or when protective devices are upgraded.

Time-current characteristic curves. Time is plotted on the vertical axis and current is plotted on the horizontal axis of all time-current characteristic curves. Log-log type graph paper is used to cover a wide range of times and currents. Characteristic curves are arranged so that the area below and to the left of the curves indicates points of "no operation," and the area above and to the right of the curves indicates points of "operation." The procedure involved in applying characteristic curves to a coordination study is to select or set the various protective devices so that the characteristic curves are located on a composite time-current graph from left to right with no overlapping of curves. The result is a set of coordinated curves on one composite time-current graph. The following data is required for a coordination study:

* Single-line diagram of the system under study.
* System voltage levels.
* Incoming power supply data.
* Impedance and MVA data.

* X/R ratio.

* Existing protection including relay device numbers and settings, CT ratios, and time-current characteristic curves.

* Generator ratings and impedance data.

* Transformer ratings and impedance data.

* Data on system under study.

* Transformer ratings and impedance data.

* Motor ratings and impedance data.

* Protective devices ratings including momentary and interrupting duty as applicable.

* Time-current characteristic curves for protective devices.

* CT ratios, excitation curves, and winding resistance.

* Thermal (I-t) curves for cables and rotating machines.

* Conductor sizes and approximate lengths.

* Short-circuit and load current data.

* Maximum and minimum momentary (first cycle) short-circuit currents at major buses.

* Maximum and minimum interrupting duty (5 cycles and above) short-circuit

currents at major buses. The exact value of ground- fault current (especially

arcing ground-fault current) is impossible to calculate. Methods are available for estimating ground-fault current.

* Estimated maximum and minimum arcing and bolted ground- fault currents at major buses.

* Maximum load currents.

* Motor starting currents and starting times.

* Transformer protection points.

3.4 Coordination Procedures

The following procedure should be followed when conducting a coordination study:

* Select a convenient voltage base and convert all ampere values to this common base. Normally, the lowest system voltage will be chosen, but this may not always be the case.

* Indicate short-circuit currents on the horizontal axis of the log-log graph.

* Indicate largest (or worst case) load imparities on the horizontal axis. This is usually a motor and should include FLA and LRA values.

* Specify protection points. These include magnetizing inrush point and NFPA 70 limits for certain large transformers.

* Indicate protective relay pick-up ranges.

* Starting with the largest (or worst case) load at the lowest voltage level, plot the curve for this device on the extreme left side of the log-log graph.

Although the maximum short-circuit current on the system will establish the upper limit of curves plotted to the right of the first and succeeding devices, the number of curves plotted on a single sheet should be limited to about five to avoid confusion.

* Using the overlay principle, trace the curves for all protective devices on a composite graph, selecting ratings or settings that will provide over-current protection and ensure no overlapping of curves.

* Coordination time intervals. When plotting coordination curves, certain time intervals must be maintained between the curves of various protective devices in order to ensure correct sequential operation of the devices. These intervals are required because relays have over-travel and curve tolerances; certain fuses have damage characteristics; and circuit breakers have certain speeds of operation. Sometimes these intervals are called margins.

* Coordination can be easily achieved with low voltage current-limiting fuses that have fast response times. Manufacturer's time current curves and selectivity ratio guides are used for both overload and short-circuit conditions, precluding the need for calculating time intervals. For relays, the time interval is usually 0.3 to 0.4 seconds. This interval is measured between relays in series either at the instantaneous setting of the load side feeder circuit breaker relay or the maximum short-circuit current, which can flow through both devices simultaneously, whichever is the lower value of current.

The interval consists of the following components:

* Circuit breaker opening 0.08 seconds time (5 cycles).

* Relay over-travel - 0.10 seconds

* Safety factor for CT satu-0.22 seconds ration, setting errors, contact gap, etc.

* This safety factor may be decreased by field testing relays to eliminate setting errors. This involves calibrating the relays to the coordination curves and adjusting time dials to achieve specific operating times. A 0.355 seconds margin is widely used in field-tested systems employing very inverse and extremely inverse time overcurrent relays.

* When solid-state relays are used, over-travel is eliminated and the time may be reduced by the amount included for over-travel. For systems using induction disk relays, a decrease of the time interval may be made by employing an overcurrent relay with a special high-dropout instantaneous element set at approximately the same pickup as the time element with its contact wired in series with the main relay contact. This eliminates over-travel in the relay so equipped. The time interval often used on carefully calibrated systems with high-dropout instantaneous relays is 0.25 seconds.

* When coordinating relays with downstream fuses, the circuit opening time does not exist for the fuse and the interval may be reduced accordingly.

The total clearing time of the fuse should be used for coordination purposes. The time margin between the fuse total clearing curve and the upstream relay curve could be as low as 0.1 second where clearing times below 1 second are involved.

* When low-voltage circuit breakers equipped with direct-acting trip units are coordinated with relayed circuit breakers, the coordination time interval is usually regarded as 0.3 seconds. This interval may be decreased to shorter time as explained previously for relay-to-relay coordination.

* When coordinating circuit breakers equipped with direct-acting trip units, the characteristics curves should not overlap. In general only a slight separation is planned between the different characteristics curves. 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.

* When protecting a delta-wye transformer, an additional 16% current margin over margins mentioned previously should be used between the primary and secondary protective device characteristic curves. This helps maintain selectivity for secondary phase-to-phase faults since the per-unit primary current in one phase for

this type of fault is 16 percent greater than the per-unit secondary current which flows for a secondary three-phase fault.

Low-voltage coordination involves selecting feeder-breaker, tie-breaker, main-breaker, and transformer fuse ratings and settings that provide optimum protection of equipment while maintaining selective coordination among the low-voltage, protective devices. Total system coordination with upstream medium-voltage and primary protective devices must also be incorporated. Polarity and operation; and ground-fault protection systems should be performance tested.

3.5 The goals of Coordination

1. Maximum sensitivity.

2. Maximum speed.

3. Maximum security.

4. Maximum selectivity

3.6 IEC Inverse characteristic equations

The standard, very and extremely invers equation shone in equations (3.1_) to (3.3) respectively

$$t = TMS \times \frac{0.14}{(I/I_S)^{0.02} - 1} \quad (3.1)$$

$$t = TMS \times \frac{13.5}{(I/I_S) - 1} \quad (3.2)$$

$$t = TMS \times \frac{80}{(I/I_S)^{2} - 1} \quad (3.3)$$

3.7 IEEE Inverse characteristic equations

The moderately, very and extremely USC)* and USCO2 short time invers equation shone in equations (3.4_) to (3.8) respectively

$$t = \frac{TD}{7} \times \left[\left(\frac{0.0515}{\left(I/_{Is}\right)^{0.02} - 1} \right) + 0.114 \right] \tag{3.4}$$

$$t = \frac{TD}{7} \times \left[\left(\frac{19.61}{\left(I/_{Is}\right)^{2} - 1} \right) + 0.491 \right] \tag{3.5}$$

$$t = \frac{TD}{7} \times \left[\left(\frac{28.2}{\left(I/_{Is}\right)^{2} - 1} \right) + 0.1217 \right] \tag{3.6}$$

$$t = \frac{TD}{7} \times \left[\left(\frac{5.95}{\left(I/_{Is}\right)^{2} - 1} \right) + 0.18 \right] \tag{3.7}$$

$$t = \frac{TD}{7} \times \left[\left(\frac{0.02394}{\left(I/_{Is}\right)^{0.02} - 1} \right) + 0.01694 \right] \tag{3.8}$$

Normal range of (TD) is 0.15 to 15.

3.8 Steps for Hand Calculation of 3 Phase Short Circuit Current

MVAsc capacity of equipment is obtained by dividing MVA of equipment with

(%Z /100) of the equipment:

$$\text{MVAsc of an equipment} = \frac{\text{MVA} \times 100}{\text{Z\%}} \tag{3.9}$$

If the equipment's lie in parallel feeders, simply add the MVAsc of the equipment's to get resultant MVAsc.

$$\mathrm{MVAsc(res)} = \mathrm{MVAsc1} + \mathrm{MVAsc2} \qquad (3.10)$$

If the equipment lie on the same feeder, resultant MVAsc

$$MVAsc(res) = \frac{1}{\frac{1}{MVAsc1} + \frac{1}{MVAsc2}} \qquad (3.2)$$

Now, for the MVAsc capacity of the point where the fault occurs in the system, consider the path from where the fault current flows, and find resultant MVAsc using above formulas.

$$\text{Fault current at the point of fault} = \frac{\mathrm{MVAsc(res)}}{\sqrt{3}\mathrm{kV(L-L)}\text{of fault point}} \qquad (3.2)$$

CHAPTER FOUR

SIMULATION AND RESULTS

4.1 Introduction

The study considered is shown in Figure 4.1 includes grid power supply, generators, power transformers and induction Loads with primary protection (34.5kV), medium voltage protection (13.8kV), low-voltage overcurrent protection (480V), and low-voltage ground fault protection. Table 4.1 includes ratings and mode of generators, transformers and connected loads in the system with no coordination in protecting devices.

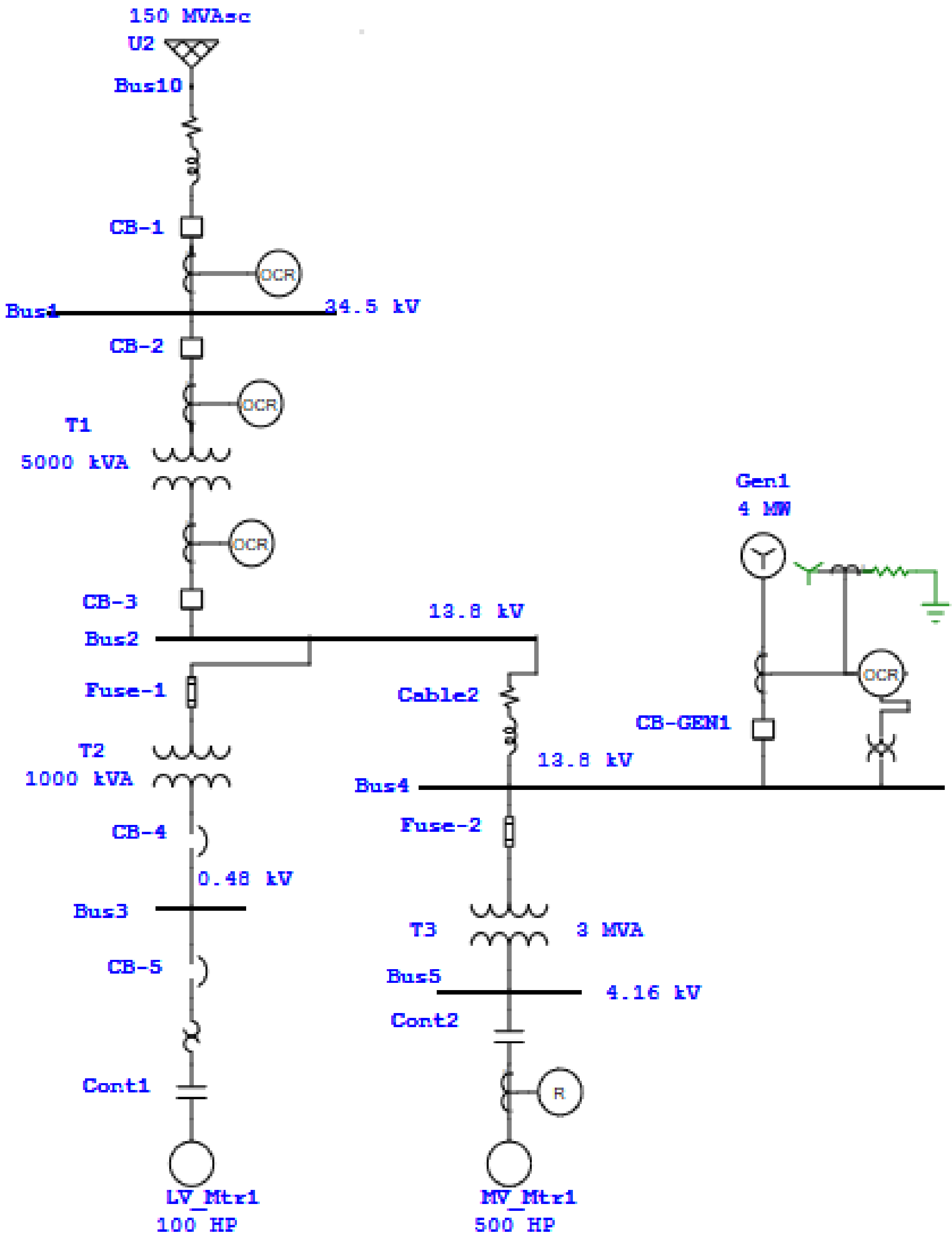

Figure 4.1: Single-line diagram

Table 4.1: Rating of generators and loads

Mode Of Operation	Swing	Voltage Control			Step Down 34.5 – 13.8 Kv	Stepdown 13.8 – 0.48	Step Down 13.8 – 4.16 Kv
Rating	35.5 Kv – 150mvasc	13.8kv – 4mw	0.46 Kv – 89.87 %Pf – 100 Hp	4 Kv – 92.75 %Pf – 500 Hp	5000kva Ansi Oa/Fa 55/65c	1000kva Ansi Oa/Fa 55/65c	3mva Iec Onwf/Onan 65c
Name Of Equipment	Power Grid	Generator	Induction Motor 1	Induction Motor 2	Power Transformers 1	Power Transformers 2	Power Transformers 3

4.2 Load Flow Analysis

Load flow analysis is performed using ETAP computer software that simulates actual steady-state power system operating conditions, enabling the evaluation of bus voltage profiles, real and reactive power flow and losses. Conducting a load flow analysis using multiple scenarios helps ensure that the power system is adequately designed to satisfy performance criteria. A properly designed system helps contain initial capital investment and future operating costs. A load flow analysis determines how the electrical system will perform during normal and emergency operating conditions, providing the information needed to:

- Optimize circuit usage.
- Develop practical voltage profiles.
- Minimize kW and kVar losses.
- Develop equipment specification guidelines.
- Identify transformer tap settings

A combination of relays, circuit breakers and current transformers are used in this system to achieve the desired coordination. Appropriate ratios of CTs are selected depending upon the load current through the primary of it. Table 4.2 shows the CT ratio of different current transformers connected in the system.

Table 4.2: Ratio of current transformers

Current Transformer	CT Ratio
CT 1	200 : 5
CT 2	350 : 5
CT 3	350 : 5
CT 4	350 : 5
CT 5	450 : 5
Potential Transformer	13.8kv : 120 V

4.3 Fault Analysis

To be able to determine device coordination, a short-circuit fault analysis must first be performed. Figure 4.2 illustrate fault in bus2 was faulted in ETAP under normal operating conditions and the results are shown in red.

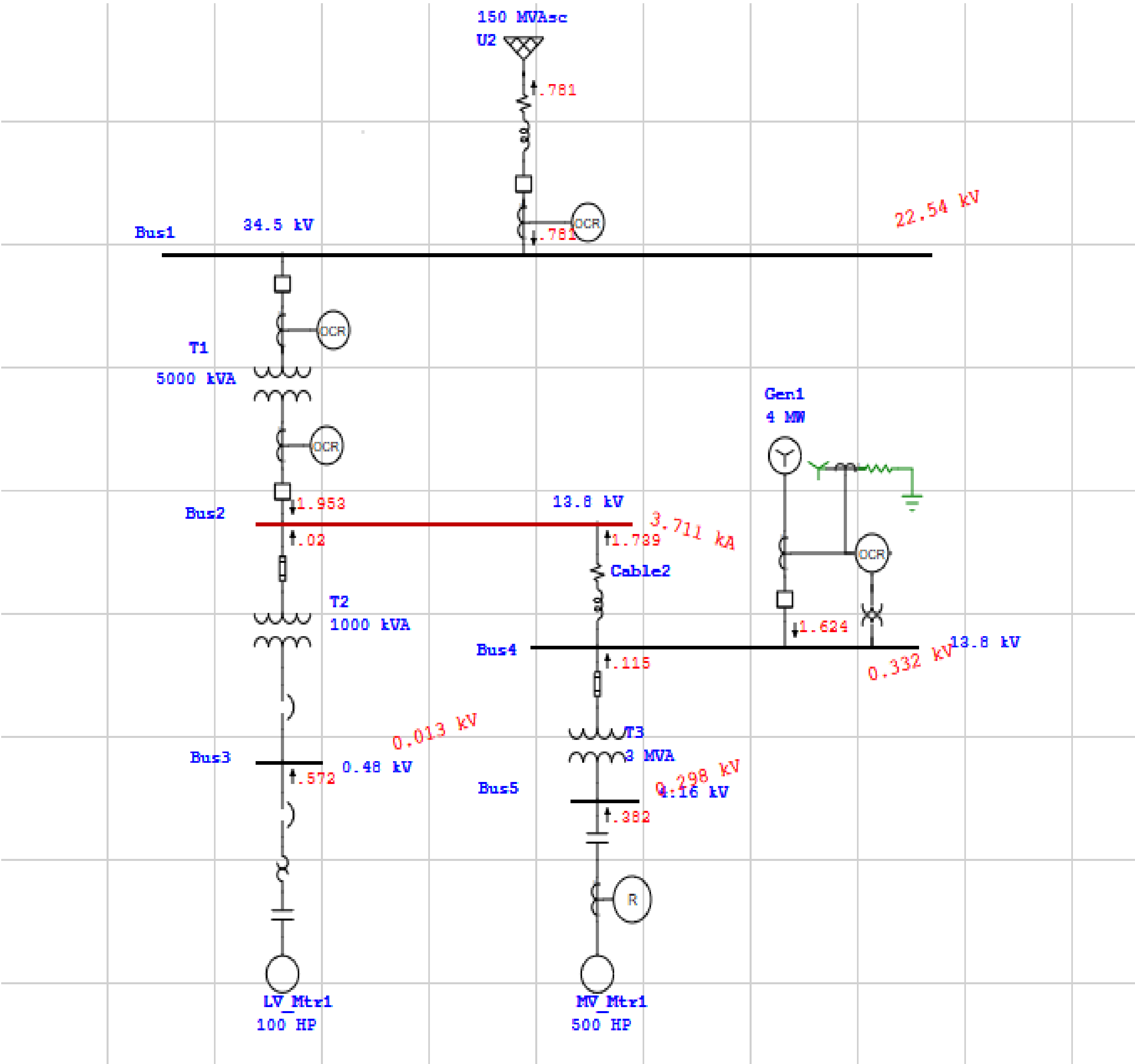

Figure 4.2: Short-circuit fault analysis

The goal of the short circuit studies is to find the maximum fault current which appears only whenever there is a fault in the circuit. Table 4.3 contains of Short circuit analysis of bus 1 to bus 5 during a symmetrical /unsymmetrical faults.

Table 4.3: Short circuit duty analyzer

ID	Nominal kV	Symm. kA	Asymm. kA	Peak kA	X/R Ratio
Bus1	34.5	2.696736	3.977404	6.737347	11.81916
Bus2	13.8	3.711046	5.724374	9.60672	16.91232
Bus3	0.48	18.07569	23.96067	41.2913	6.468542
Bus4	13.8	3.700619	5.94742	9.889345	26.86439
Bus5	4.16	4.678967	7.13483	12.00344	15.26694

4.4 Coordination Evaluation

In case of placing fault anywhere at the system , as soon as fault appears Relays senses the fault and sends a trip signal to circuit's breaker. The protection devices will isolate the place where the fault occurred; if the primary protection devices fail the backup devices must eliminate the danger but never make an action before the primary devices fail so it needs a delay time.

4.4.1 Case I: Fault at bus 1

Figure 4.3, showing fault in Bus 1 at area 1, the relay R1 senses the fault first and sends a trip signal to the circuit breaker 1, also the relay R3 senses the fault and sends a trip signal to the circuit breaker 3, and those relays are the primary protection. If they failed the backup protection must do action.

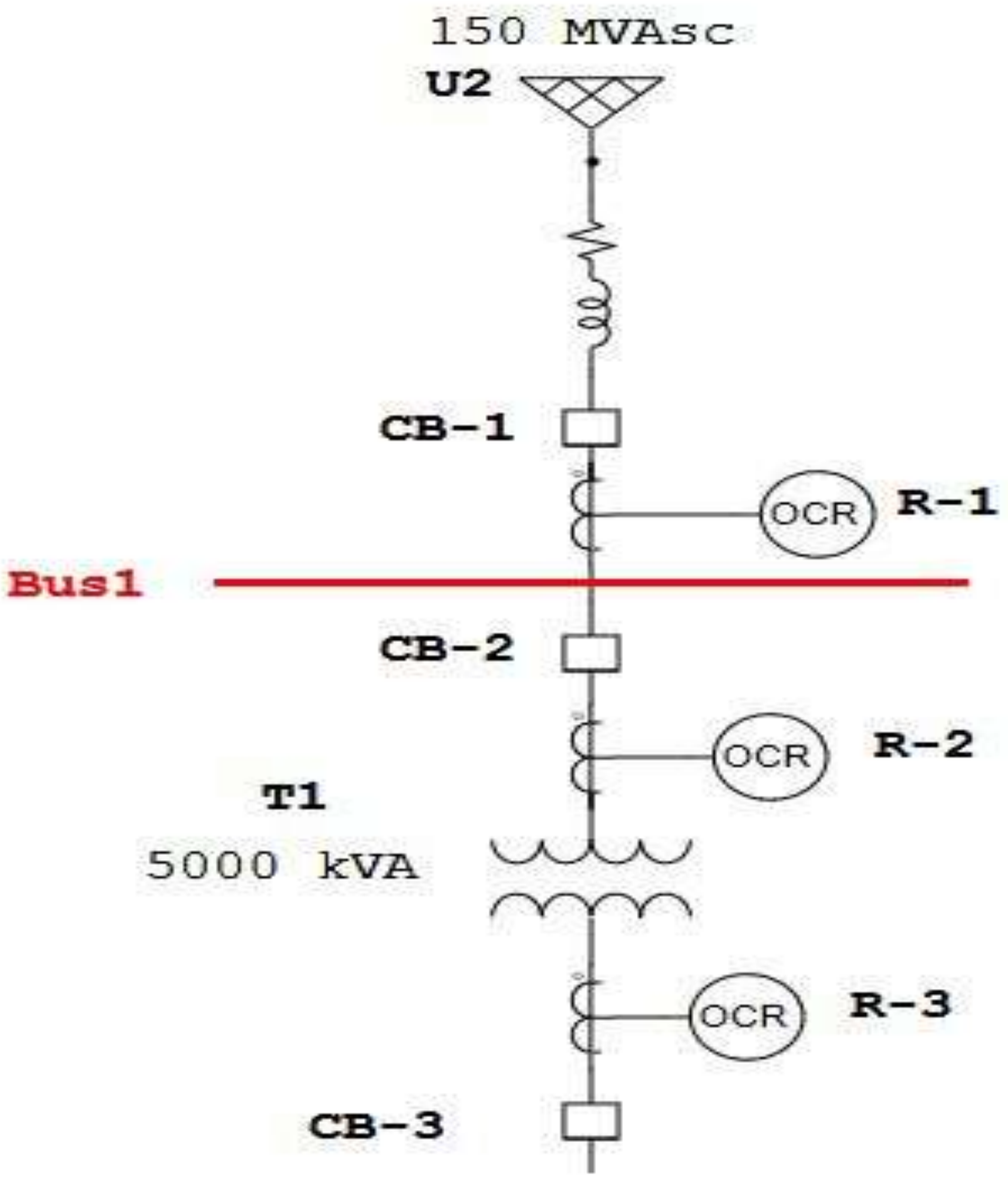

Figure 4.3: Area 1

Figure 4.3 represented the area 1 component, it consist a power transformer (T1), and Busbar (Bus 1) cable connect to power system rescores, CBs and relays.

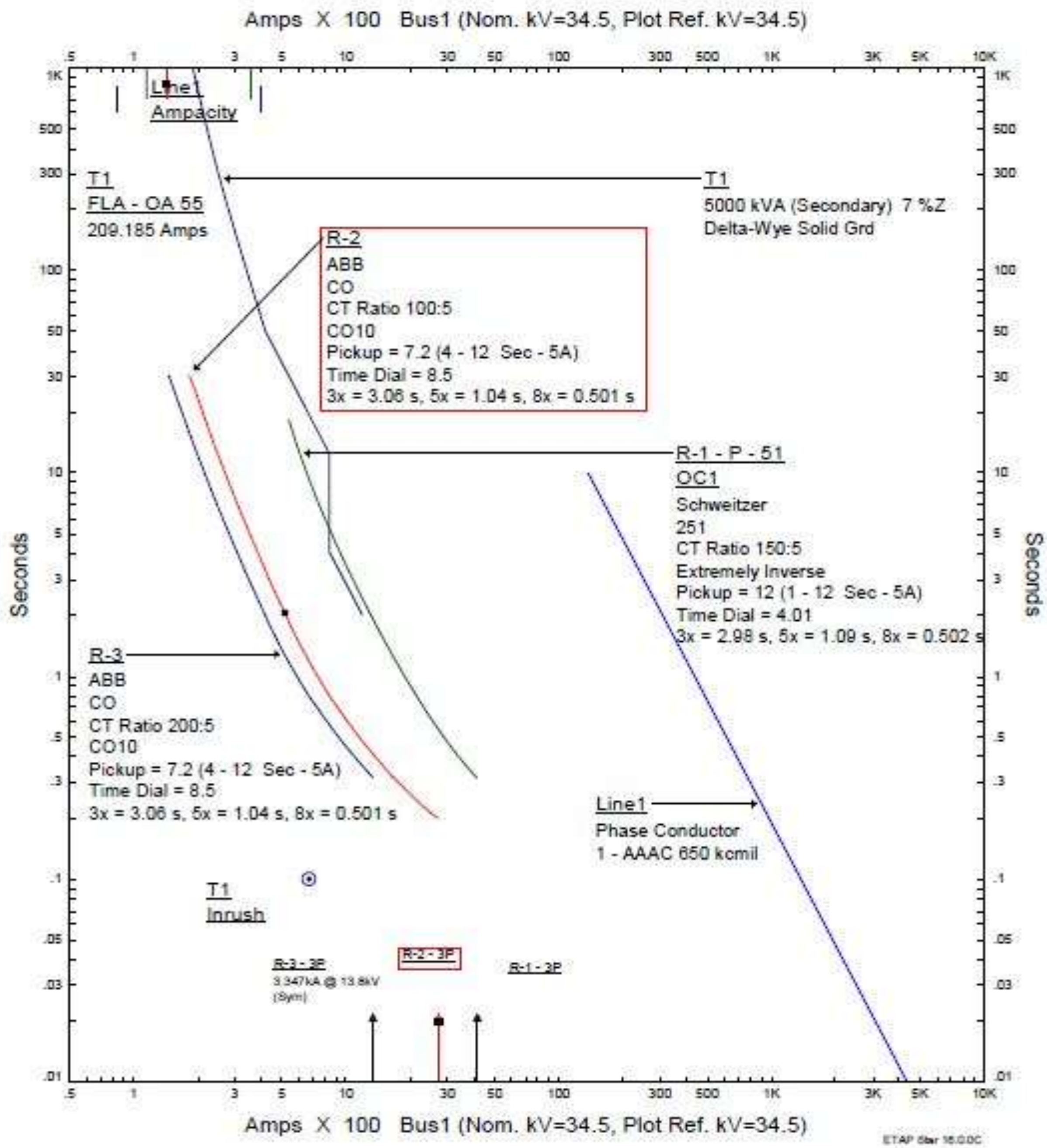

Figure 4.4 : TCC curve for CASE I

Figure 4.4 showing the relation between current (X-axis) and time (Y-axis). Lines 1 indicates Phase conductor (in blue), T1 indicates transformer characteristic (in black), R-1 (in green), R-2 (in red), R-3 (in black) indicate relay 1, 2 and 3 curve characteristics.

Adjustment made at figure 4.4 to obtain relays settings (Time delay and the Pickup current value) not to exceed FLA and not to drop below transformer inrush current.

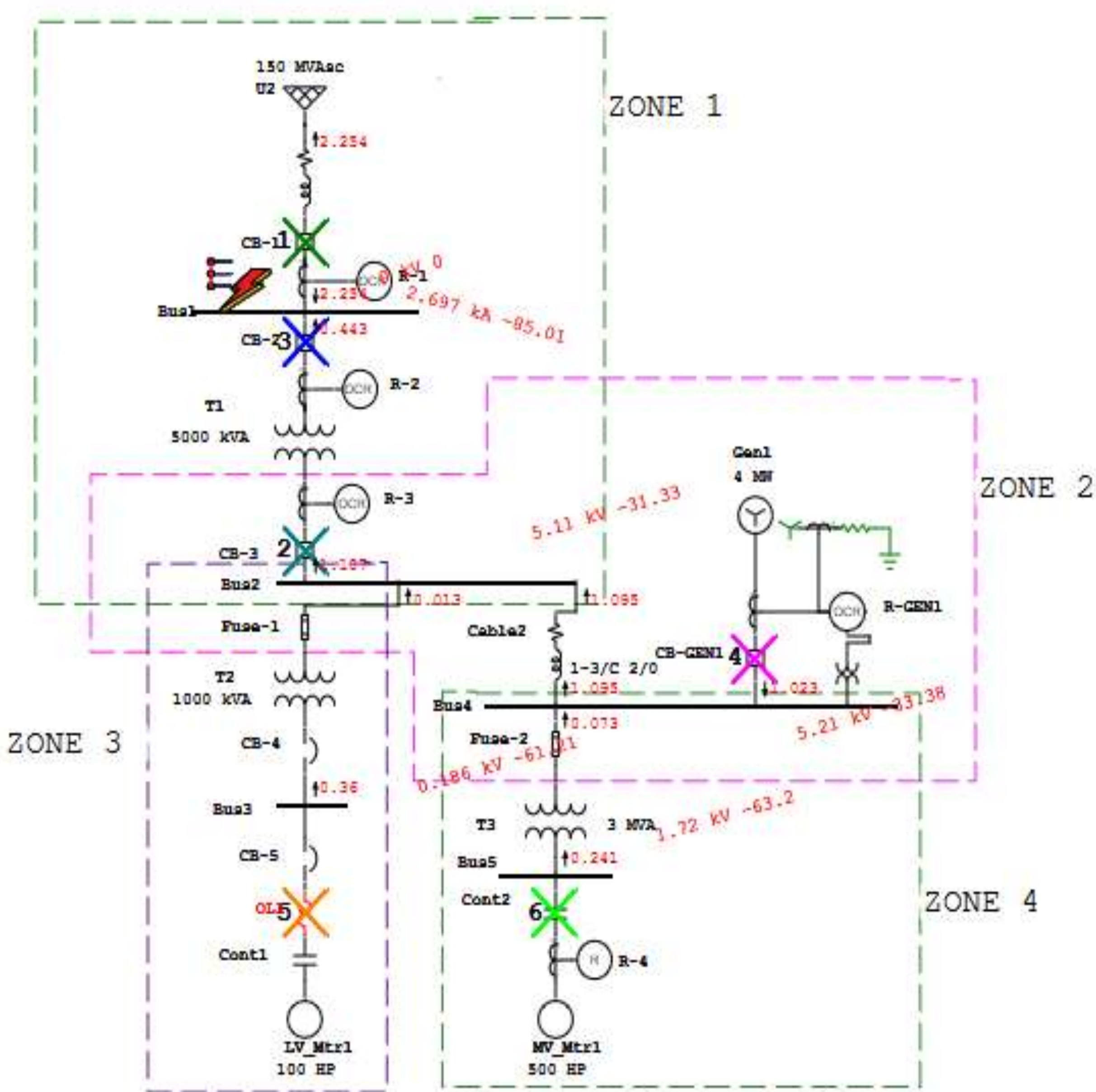

Figure 4.5: Protective devices in case I

Figure 4.5 showing protection devices operation sequence, CB 1 and CB3 work first as primmer protection devices if they fail CB 2 work as backup in case CB2 not work too the CB-GEN1 trip to element the Generator if all that protection devices fail the over load and contactor isolate the load as last protection devices. Table4.1 showing protection devices operation sequence, conditions and the magnetite of current vs time delay.

Table 4.4: Sequence of operation case I

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on bus: Bus1

Data Rev.: Base Config: Normal Date: 10-17-2018

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
736	R-1	2.254	736		Phase - OC1 - 51
820	CB-1		83.3		Tripped by R-1 Phase - OC1 - 51
1738	R-3	1.107	1738		Phase - OC1 - 51
1822	CB-3		83.3		Tripped by R-3 Phase - OC1 - 51
2874	R-2	0.443	2874		Phase - OC1 - 51
2958	CB-2		83.3		Tripped by R-2 Phase - OC1 - 51
5657	R-GEN1	1.023	5657		Phase - OC1 - 51
5740	CB-GEN1		83.3		Tripped by R-GEN1 Phase - OC1 - 51
35281	OL1	0.36	35281		
39340	R-4	0.241	39340		Overload Phase - Thermal
39473	Cont2		133		Tripped by R-4 Overload Phase - Thermal
293800	CB-4	0.36	72299	293800	

4.4.2 Case II: Fault at bus 2

Figure 4.5, showing fault in bus 2 at area 2, the relay R-GEN 1 senses the fault first and sends a trip signal to the circuit breaker CB-GEN 1, also the relay R 3 senses the fault and sends a trip signal to the circuit breaker 3, and those relays are the primary protection. If they failed the backup protection must do action.

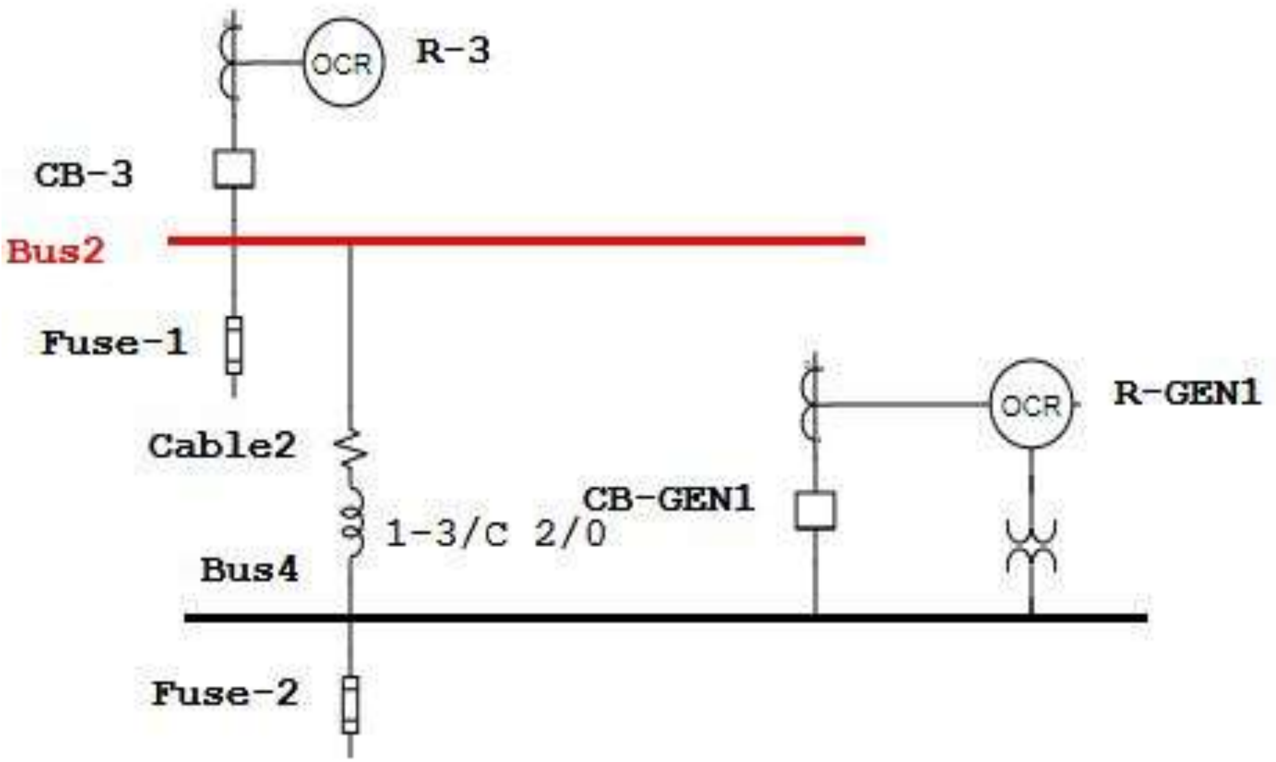

Figure 4.6: Area 2

Figure 4.6 represented the area 2 component, it consist a cable connect between (Bus 1and Bus2),VT,CBs, relays (R-3 and R-GEN1) and Fuses (fuse-1 and Fuse-2). Figure 4.7 showing the relation between current (X-axis) and time (Y-axis). Curve in brown indicates Cable 2 characteristic, curve in blue indicates relay R-3 characteristic, curves in Green indicates Relay R-Gen 1 characteristic, curves in bold blue indicates fuse-2 characteristic, curves in bold pink indicates fuse-1 characteristic. Adjustment made at figure 4.7 to obtain relays settings (Time delay and the Pickup current value)

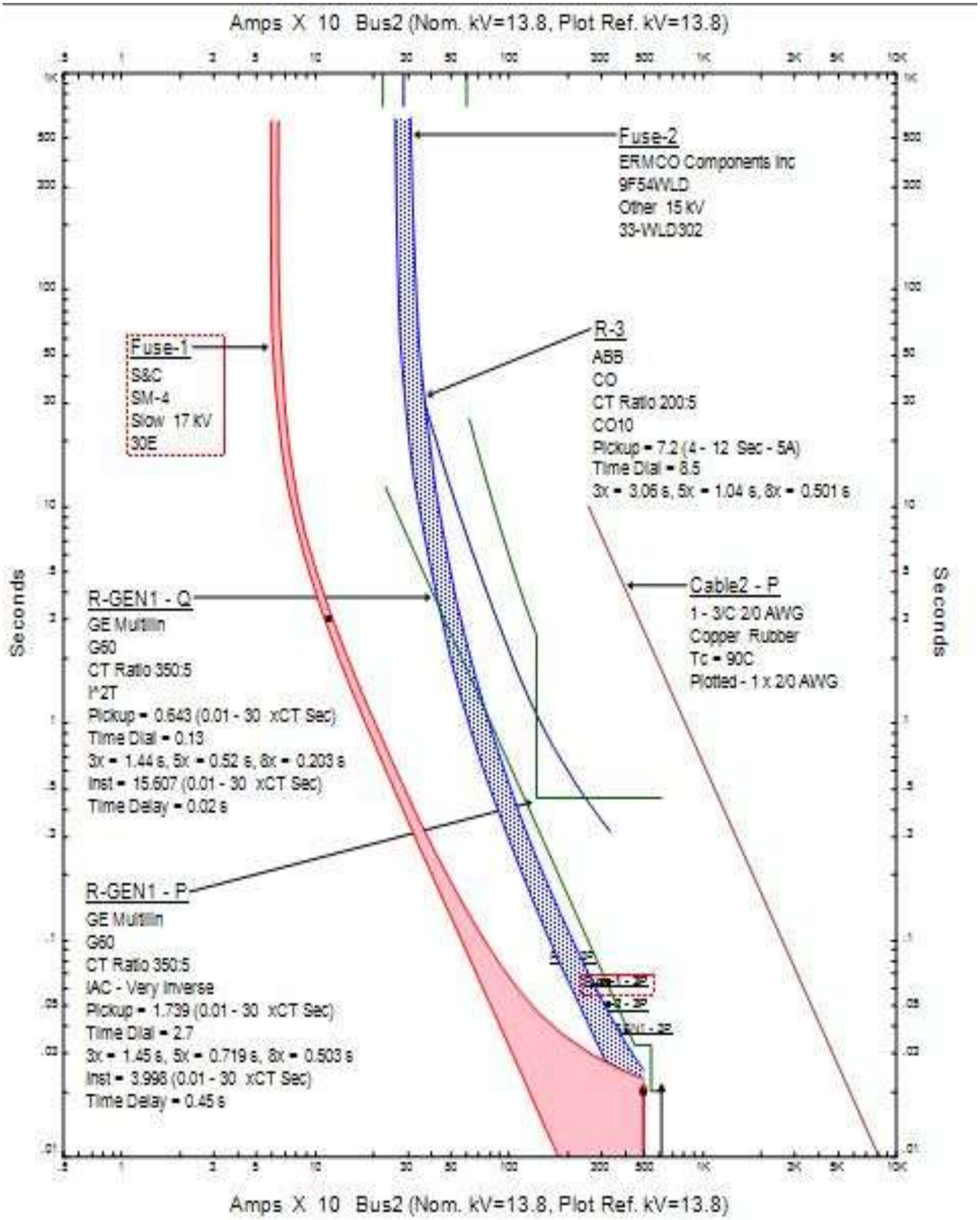

Figure 4.7: TCC curve for Case II

3Figure 4.8 showing protection devices operation sequence, CB-3 and CB-GEN1 work first as primmer protection devices if they fail CB-2 work as backup in case CB2 not work too the CB-1 trip to element the Generator if all that protection devices fail the over load and contactor-2 isolate the load as last protection devices.

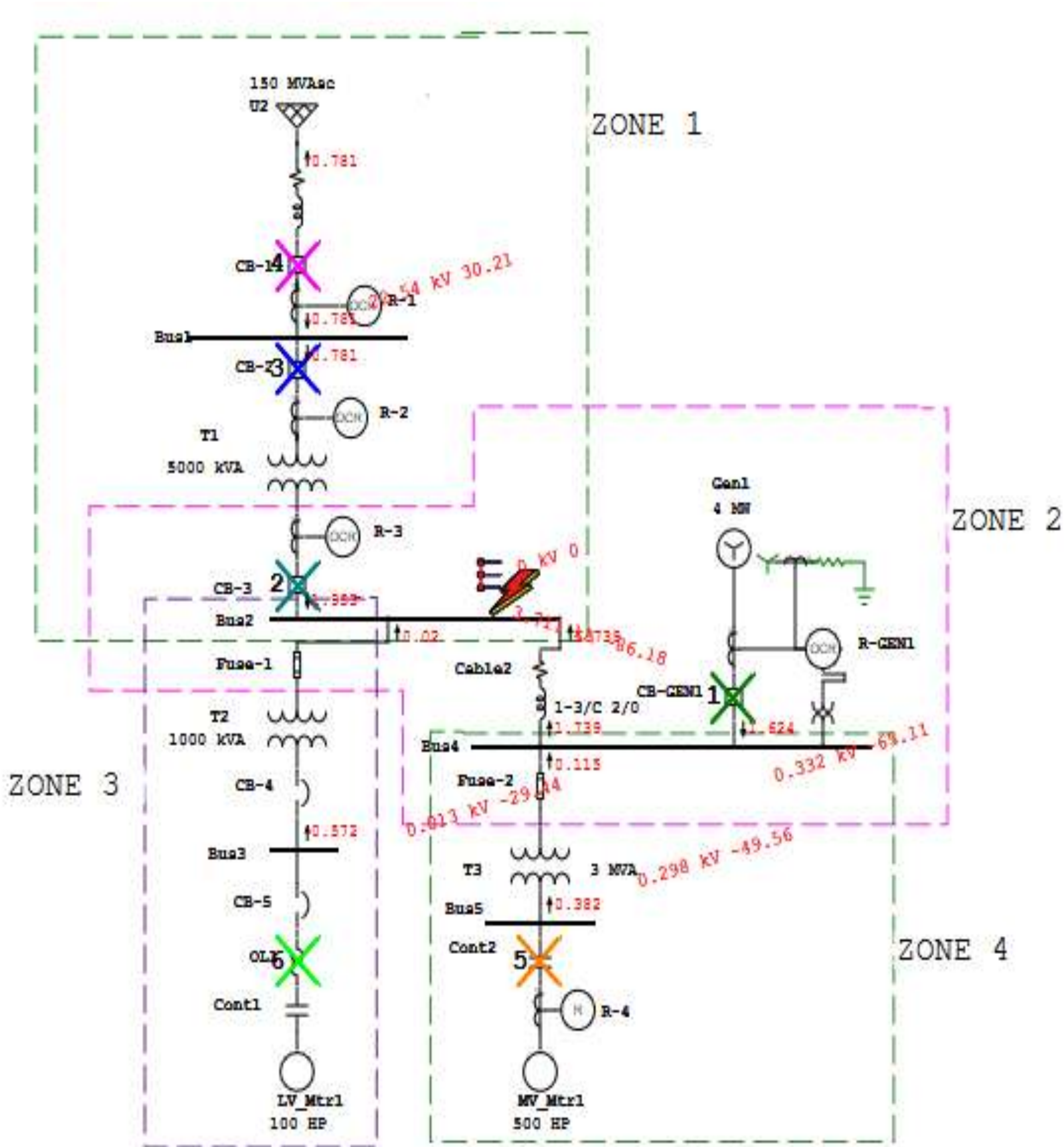

Figure 4.8: Protective devices operation case II

Table4.5 showing protection devices operation sequence, conditions and the magnetite of current vs time delay.

Table 4.5: Sequence of operation case II

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on bus: Bus2

Data Rev.: Base Config: Normal Date: 10-17-2018

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
450	R-GEN1	1.624	450		Phase - OC1 - 50
533	CB-GEN1		83.3		Tripped by R-GEN1 Phase - OC1 - 50
634	R-3	1.953	634		Phase - OC1 - 51
718	CB-3		83.3		Tripped by R-3 Phase - OC1 - 51
897	R-2	0.781	897		Phase - OC1 - 51
980	CB-2		83.3		Tripped by R-2 Phase - OC1 - 51
6273	R-1	0.781	6273		Phase - OC1 - 51
6357	CB-1		83.3		Tripped by R-1 Phase - OC1 - 51
9290	R-4	0.382	9290		Overload Phase - Thermal
9423	Cont2		133		Tripped by R-4 Overload Phase - Thermal
21036	OL1	0.572	21036		
117409	CB-4	0.572	38201	117409	

4.4.3 Case III: Fault at bus 3

Figure 4.9, showing fault in bus 3 at area 3, the circuit breaker CB 4 tripped as primary protection. If it failed the fuse 1 is a backup protection with the other protection devices. If they failed the backup protection must do action. Figure 4.9 represented the area 3 component, it consist a power transformer (T2), Busbar (Bus 3) Low voltage motor (LV_Mtr1), Fuse-1, contactor (CONT1) , circuit breakers (CB-4 and CB-5) and overload (OL1).

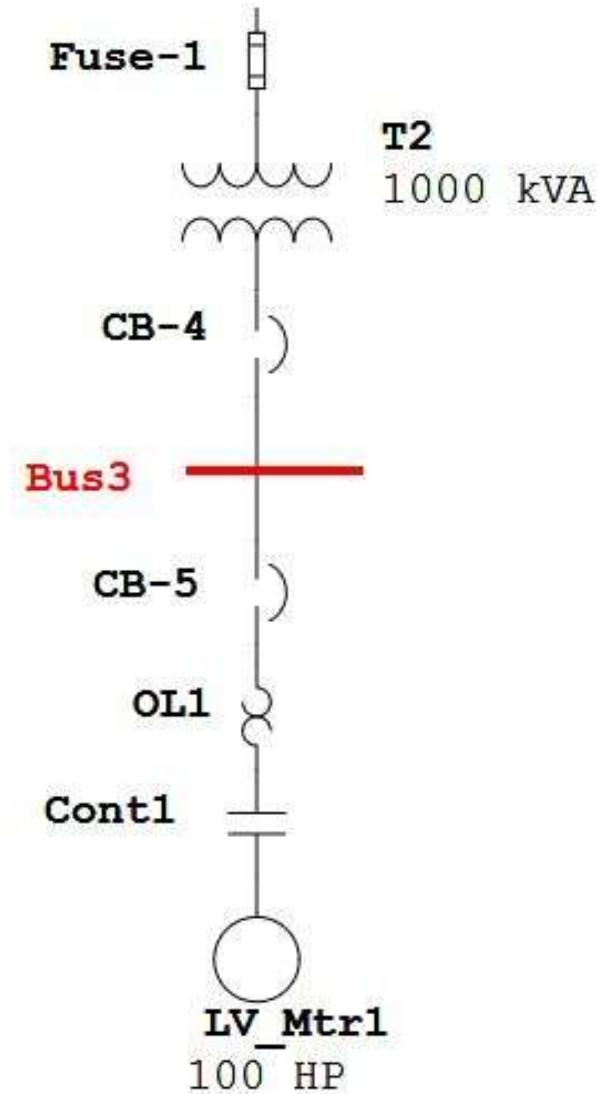

Figure 4.9: Area 3

Figure 4.10 showing the relation between current (X-axis) and time (Y-axis). Curve in brown indicates Cable 1 characteristic, curve in blue indicates fuse 1 characteristic, curves in Green indicates Over Load (OL1) characteristic, curves in bold blue indicates contactor (cont1) characteristic, curves in bold Gray indicates fuse-1 characteristic. Adjustment made at figure 4.10 to obtain relays settings (Time delay and the Pickup current value).

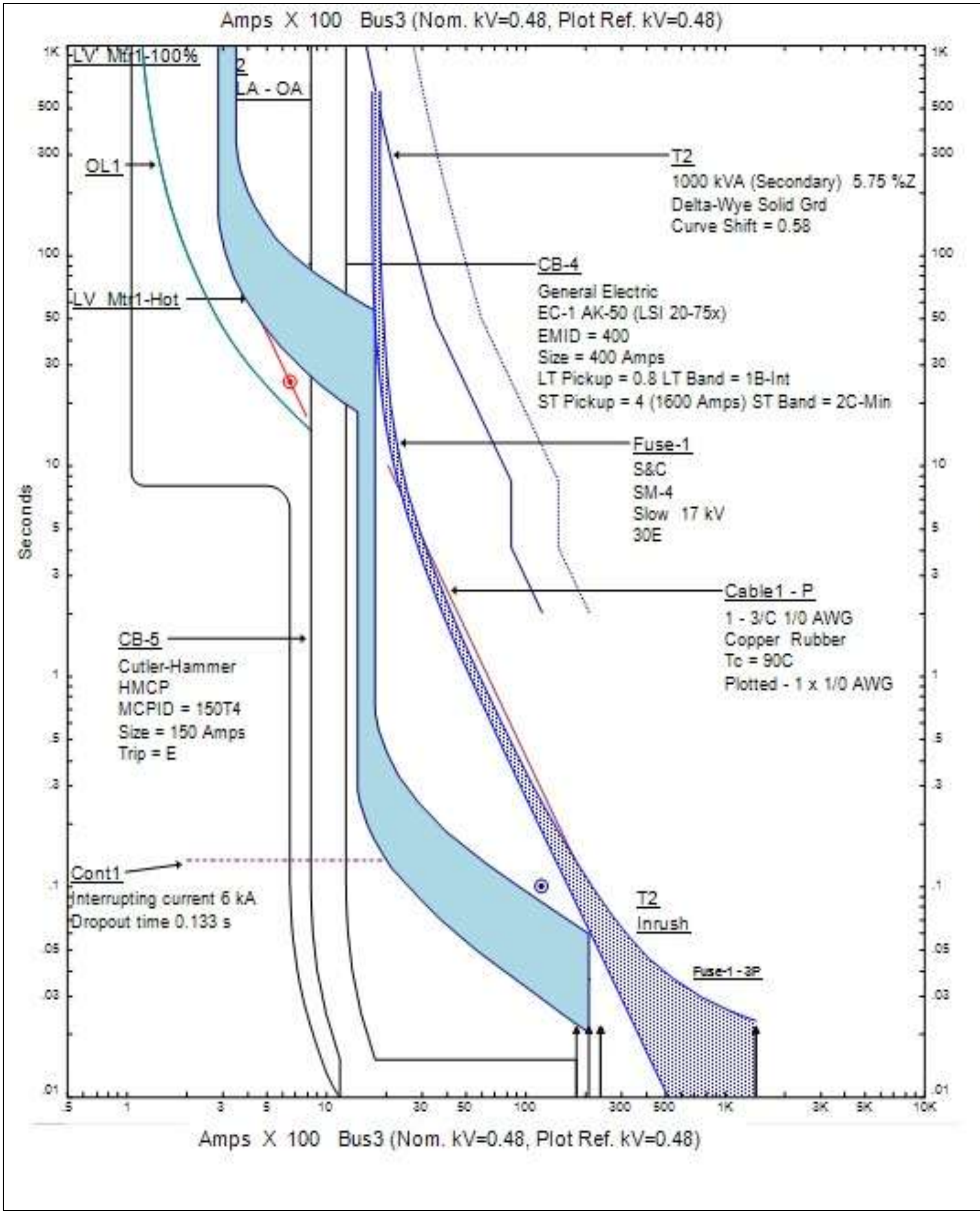

Figure 4.10: TCC curve for CASE III

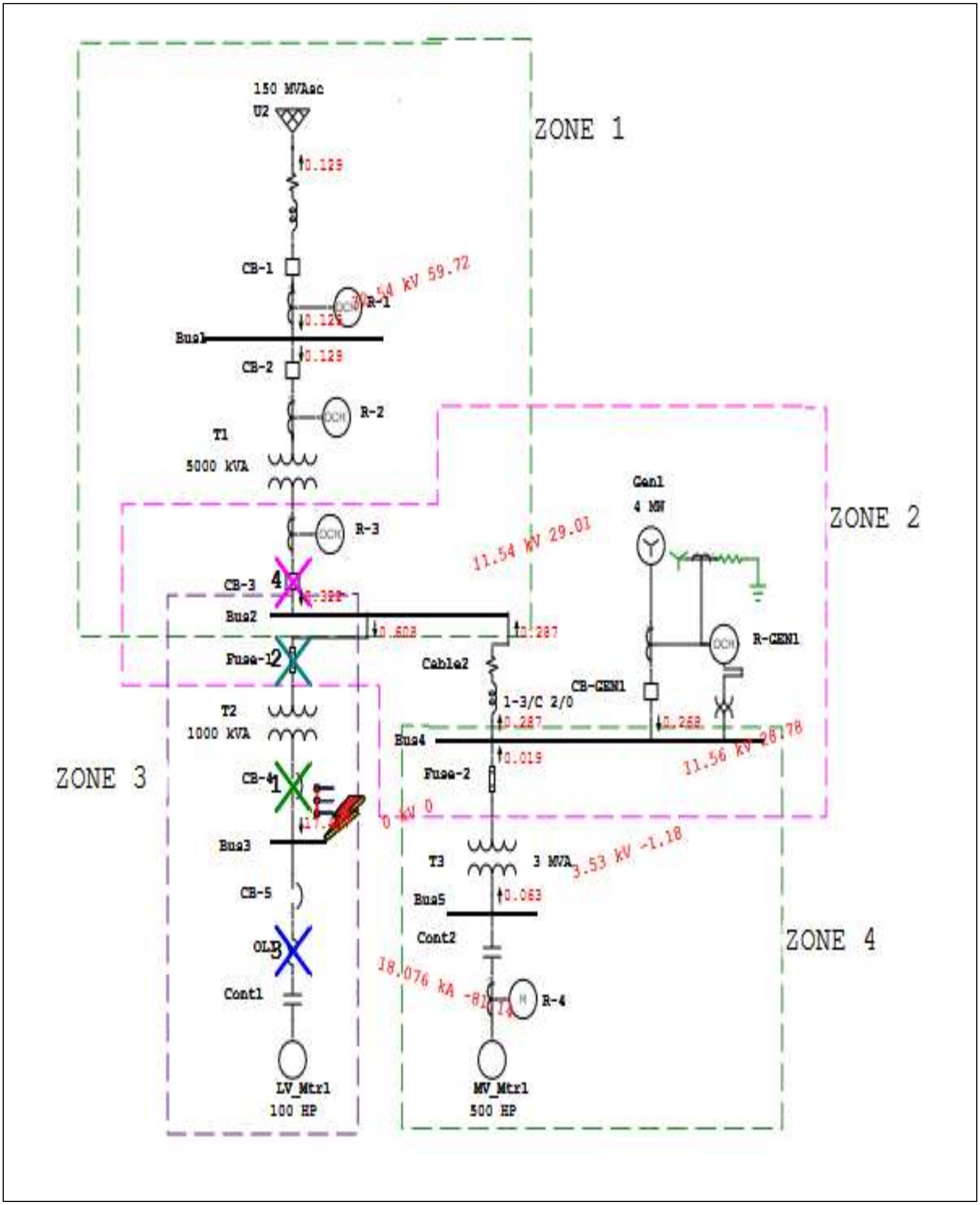

Figure 4.11: Protective devices operation case III

Figure 4.11 showing protection devices operation sequence,CB-4 work first as primmer protection device if it fail fuse-1 work as backup in case fuse-1 not work too the CB-3 trip to element the danger if all that protection devices fail the over load isolate the load as last protection devices. Table 4.6: showing protection devices sequence of operation and the magnetite of current vs. time delay.

Table 4.6 : sequence of operation case III

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on bus: Bus3

Data Rev.: Base Config: Normal Date: 10-17-2018

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
66.3	CB-4	17.487	22.6	66.3	
137	Fuse-1	0.608	87.8	137	
20460	OL1	0.589	20460		
30457	R-3	0.322	> 30457		Phase - OC1 - 51
30540	CB-3		83.3		Tripped by R-3 Phase - OC1 - 51

4.4.4 Case IV: Fault at bus 5

Figure 4.12, showing fault in bus 5 at area 4, the fuse 2 tripped as primary, the relay R-GEN 1 3 and R3 senses the fault and sends a trip signal to the circuit breaker GEN 1and CB 3 as a backup, If they failed the other protection devices must tack an action. Similar to other cases through the time characteristics shown in Figure 4.11 the time delay and the Pickup current value of the backup protection devices adjusted. Table 4.8 and Figure 4.12 shows the final Protection scheme, value and the sequence of the protection devices work when the fault is in bus 5

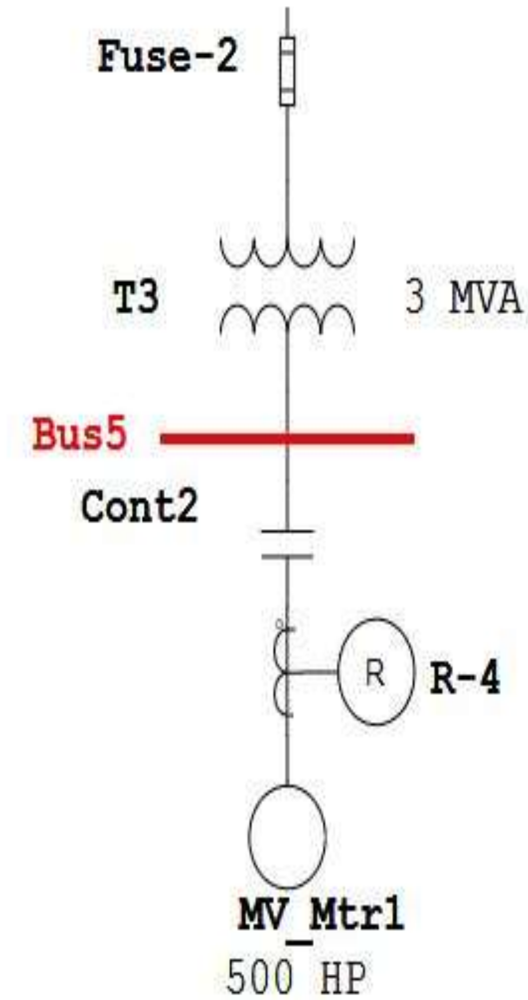

Figure 4.12: Area 4

Figure 4.12 represented the area 4 component, it consist a power transformer (T3), Busbar (Bus 5) Medium voltage motor (MV_Mtr1), Fuse-2, contactor (CONT2) and relay (R-4). Figure 4.13 showing the relation between current (X-axis) and time (Y-axis). Curve in brown indicates Relay (R-4) characteristic, curve in bold blue indicates fuse 2 characteristic, curves in Gray indicates contactor (cont2) characteristic, curves in blue indicates Transformer 3 characteristic. Adjustment made at figure 4.10 to obtain relays settings (Time delay and the Pickup current value)

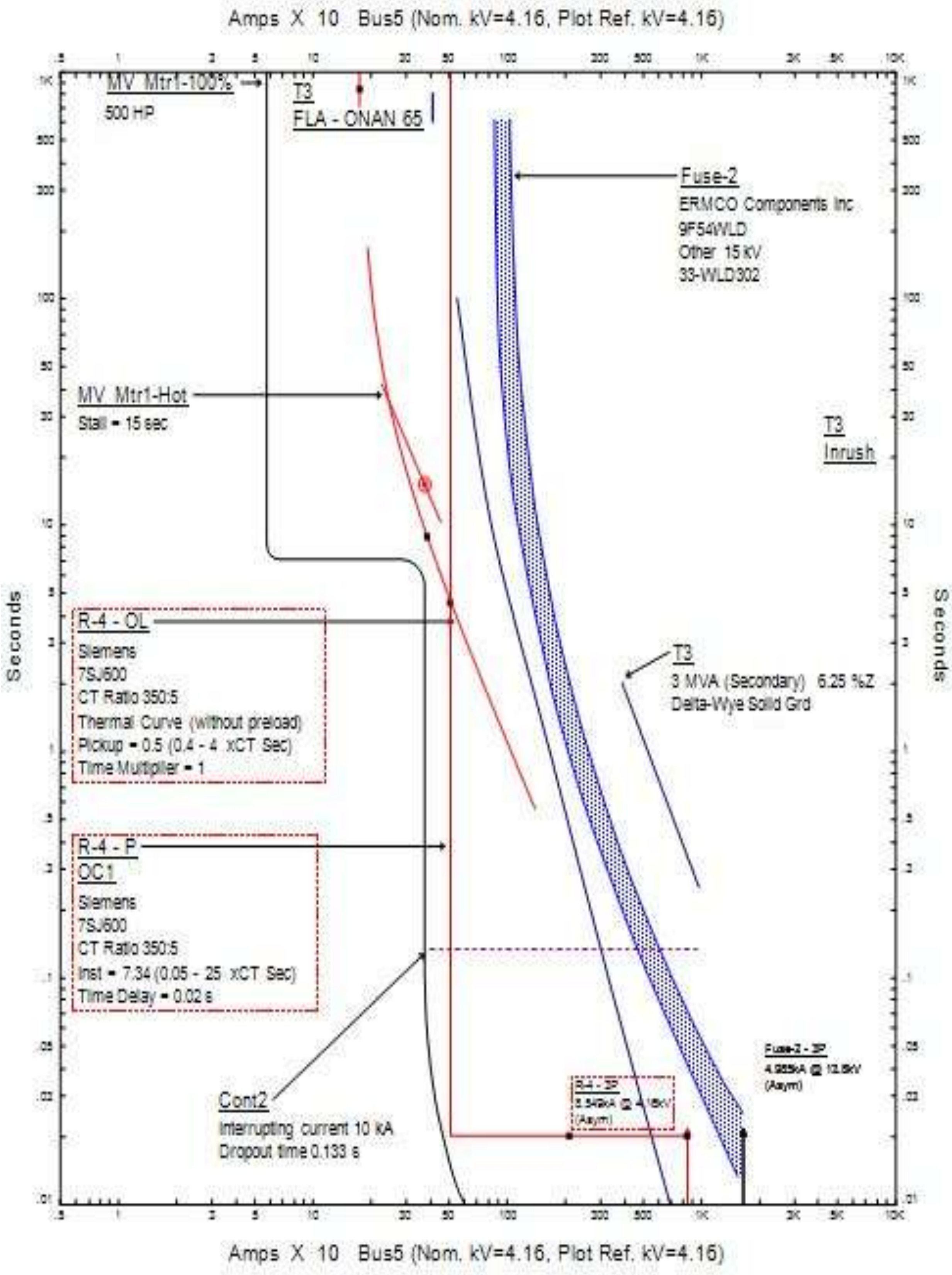

Figure 4.13: TCC curve for CASE IV

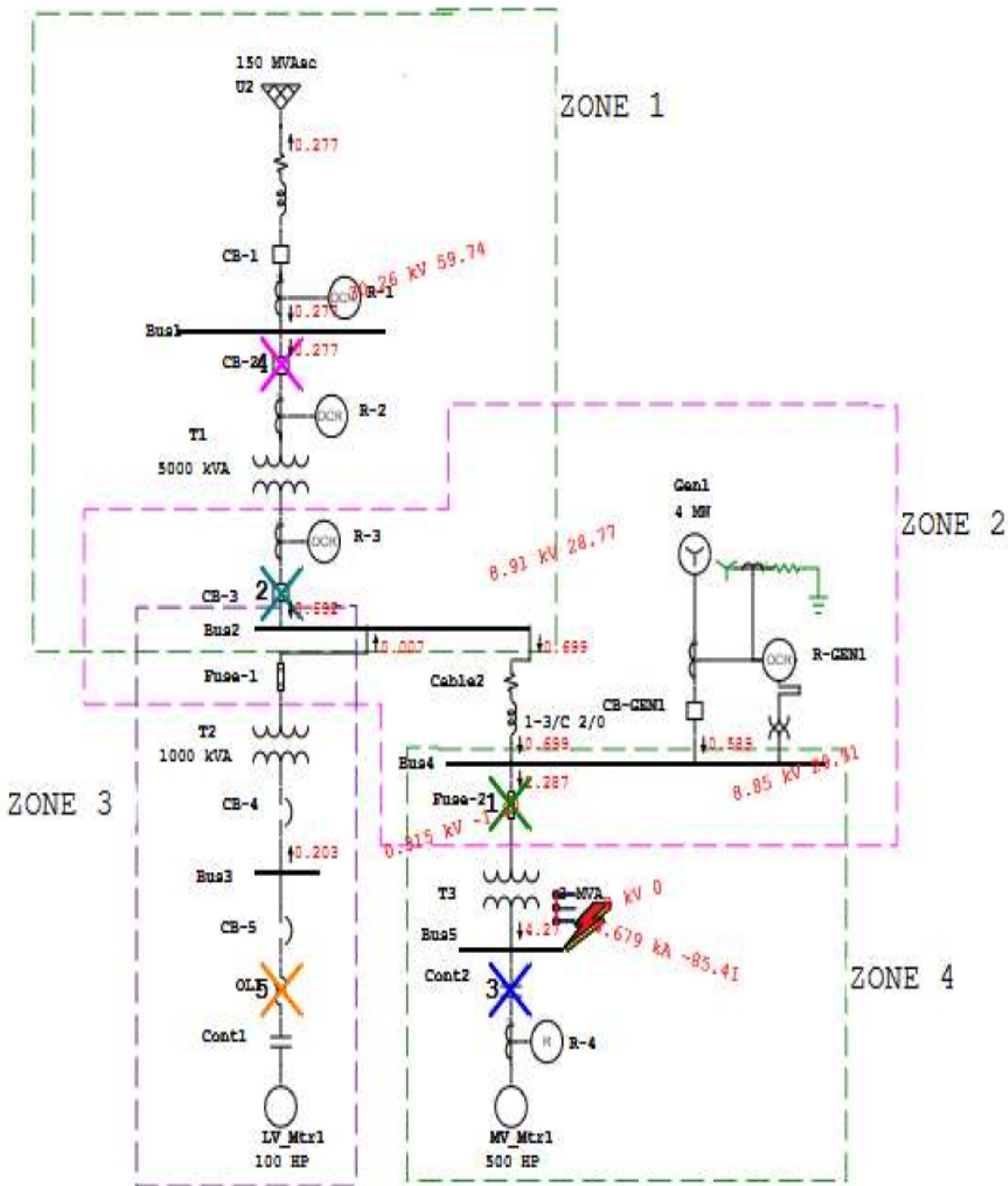

Figure 4.14: Protective devices operation case IV

Figure 4.14 Showing protection devices operation sequence, fuse-2 work first as primmer protection device if it fails CBs(CB GEN1 and CB-3) works as backup in case they don’t work too the CB-2 trip to element the danger if all that protection devices fail the over load and contactor-2 isolate the load as last protection devices. Table4.3 showing protection devices sequence of operation and the magnetite of current vs. time delay. Table4.7 showing protection devices sequence of operation and the magnetite of current vs. time delay.

Table 4.7 : Sequence of operation case IV

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on bus: Bus5

Data Rev.: Base   Config: Normal   Date: 10-17-2018

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
286	Fuse-2	1.287	166	286	
5247	R-3	0.692	5247		Phase - OC1 - 51
5330	CB-3		83.3		Tripped by R-3 Phase - OC1 - 51
7815	R-4	0.41	7815		Overload Phase - Thermal
7948	Cont2		133		Tripped by R-4 Overload Phase - Thermal
9379	R-2	0.277	9379		Phase - OC1 - 51
9462	CB-2		83.3		Tripped by R-2 Phase - OC1 - 51
99131	OL1	0.203	99131		

4.5 Entire coordination scheme

Figure4.15 showing the combination of final protection devices settings curves characteristic which represent the overlapping between the zones of protection and the coordination schemes. Time curve characteristic shown in figure 4.15 demonstrates the respond of protective devices for the current values against time at any moment. Through this step we can determine which and when the device is a primary protection or backup.

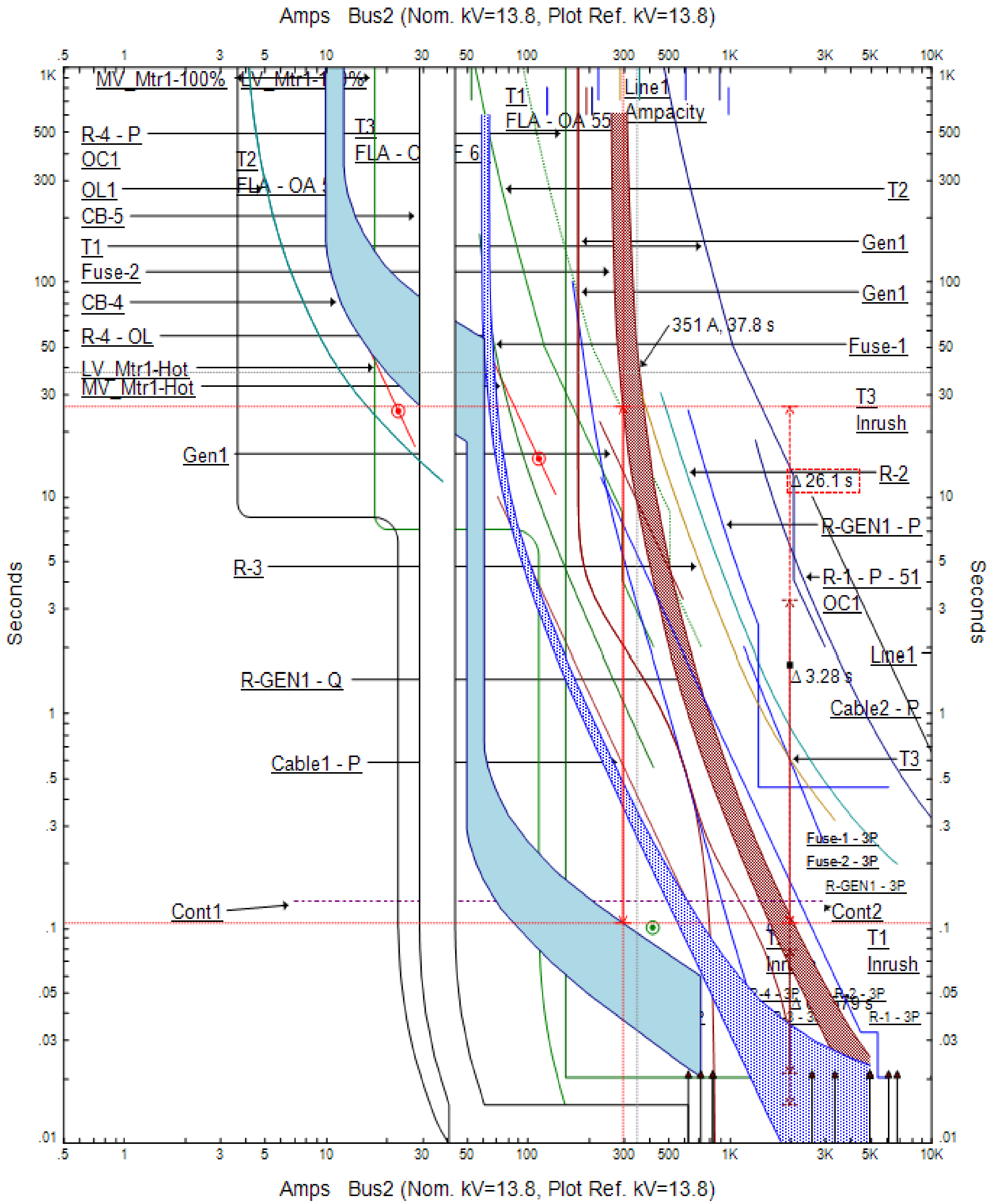

Figure 4.15: Final TCC curve

Table 4.8 : Protective Device Settings - Relay Test Points

Test Points - Trip Time at Multiply of Pickup	**10X**	0.447 s	0.386 s	0.386 s	0.13 s		0.0407 s	0.354 s	0.377 s	0.371 s	2.03 s	0.377 s
	8X	0.503 s	0.429 s	0.429 s	0.203 s		0.0569 s	0.556 s	0.501 s	0.502 s	2.37 s	0.501 s
	6X	0.612 s	0.499 s	0.499 s	0.361 s		0.0927 s	1 s	0.76 s	0.791 s	3.11 s	0.76 s
	5X	0.719 s	0.556 s	0.556 s	0.52 s		0.13 s	1.46 s	1.04 s	1.09 s	3.87 s	1.04 s
	4X	0.927 s	0.647 s	0.647 s	0.812 s		0.2 s	2.33 s	1.6 s	1.66 s	5.32 s	1.6 s
	3X	1.45 s	0.819 s	0.819 s	1.44 s		0.365 s	4.38 s	3.06 s	2.98 s	8.72 s	3.06 s
	2X	3.54 s	1.3 s	1.3 s	3.25 s		0.952 s	11.7 s	8.45 s	7.72 s	20.8 s	8.45 s
OCR (51, ST), OLR (49)	**Time Delay**	2.700	0.130	0.130	0.130		0.500	1.000	8.500	4.010	15.000	8.500
	Prim. Amps	608.650	26.250	26.100	225.050		17.500	175.000	288.000	360.000	7.500	144.000
	Pickup	1.739	0.075	0.058	0.643		0.050	0.500	7.200	12.000	0.250	7.200
Curve		IAC - Very	IEC - Curve A	IEC - Curve A	I^2T		ANSI - Extremel	Curve (without	CO10	Extremely Inverse	Very Inverse	CO10
Level/Stage		OC1	OC1	OC1	OC1	OC1	OC1		OC1	OC1	OC1	OC1
Trip Element		Phase	Neutral	Ground	Negative Sequence	Phase	Neutral	Overload Phase	Phase	Phase	Neutral	Phase
Device Function		Overcurrent	Overcurrent	Overcurrent	Overcurrent	Overcurrent	Overcurrent	Overload	Overcurrent	Overcurrent	Overcurrent	Overcurrent
PT	**CT Ratio**	350:5	350:5	450:5	350:5	350:5	350:5	350:5	200:5	150:5	150:5	100:5
Model		G60	G60	G60	G60	7SJ600	7SJ600	7SJ600	CO	251	251	CO
Manufacturer		GE Multilin	GE Multilin	GE Multilin	GE Multilin	Siemens	Siemens	Siemens	ABB	Schweitzer	Schweitzer	ABB
Relay ID						R-4	R-4	R-4	R-3	R-1	R-1	R-2

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The power system network is one of the most important life services facilities, and the protection of this network is a very tough job, it also needs to be very accurate and reliable with high selectivity to achieve the dependability on protection devices and the Stability on the power system networks.

The Conclusion of this project to coordinate the power system protection is:

- Analyze the power system properties (e.g. load flow and fault analysis) is more successful and reliable using ETAP software, it is faster than manual hand calculation method.
- Improve protection devices setting and coordination was achieved.

Overall this project was successful, it was chosen with the intention of Learning ETAP and using it effectively in obtaining protective devices coordination.

5.2 Recommendation

We recommend to:

- Use the newest ETAP software version. it performs numerical calculations with tremendous speed, automatically applies industry accepted standards and provides easy to follow output reports with other..
- Use distance relay.

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[8]	A.A.M. Hassana and Tarek A. Kandeel, Effectiveness of frequency relays on networks with multiple distributed generation. 2(1): 75-85 (2015)

Appendix A

LOAD FLOW ANALYZER REPORT

ETAP 16.0.0

A.1: System description

Buses	6
Branches	5
Generators	1
Power Grids	1
Loads	2
Load-MW	0.473
Load-Mvar	0.222
Generation-MW	0.473
Generation-Mvar	0.222
Loss-MW	0.0051
Loss-Mvar	0.0263
Mismatch-MW	0
Mismatch-Mvar	0

A.2: Bus data

Amp Loading	25.81	67.81	105.9	83.94	58.12	25.78
kvar Loading	217.4	184.2	38.46	160.5	156.9	205.8
kW Loading	1527.4	1609	78.81	2000	389.3	1526.8
Voltage	100.02	99.92	99.62	100	100.23	100
Amp Rating	0	0	0	0	0	0
Nominal kV	34.5	13.8	0.48	13.8	4.16	34.5
Bus ID	Bus1	Bus2	Bus3	Bus4	Bus5	Bus10

A.3: Branch data

kvar Losses	0.577	-11.59	33.19	0.439	3.64
kW Losses	1.4	0.578	2.73	0.0758	0.341
% Voltage Drop	0.08	0.02	0.1	0.3	0.23
% Loading		6.5	30.8	8.8	14
% PF	-99.6	-99	-99	89.69	92.46
Amp Flow	67.65	25.81	25.81	3.683	17.63
kvar Flow	-144.8	-217.4	-217.4	38.9	160.5
kW Flow	1610.4	1527.4	1527.4	78.88	389.6
Allowable	0 A	398.3 A	5000 kVA	1000 kVA	3000 kVA
Rating 2	1 - 3/C 2/0	650	5000 kVA	1000 kVA	3000 kVA
Rating 1	1000 ft	7920 ft	34.5 / 13.8 kV	13.8 / 0.48 kV	13.8 / 4.16 kV
Type	Cable	Line	Transf. 2W	Transf. 2W	Transf. 2W
To Bus	Bus4	Bus1	Bus2	Bus3	Bus5
From Bus	Bus2	Bus10	Bus1	Bus2	Bus4
ID	Cable2	Line1	T1	T2	T3

A.4 : Load data

Vtermal	103.95	104.23
% Loading	96.2	95.9
% PF	89.87	92.75
Amp	105.9	58.12
kvar	38.46	156.9
kW	78.81	389.3
Rated kV	0.46	4
Rating/Limit	100 HP	500 HP
Type	Induction	Induction
Terminal Bus	Bus3	Bus5
ID	LV_Mtr1	MV_Mtr1

A.5: Source data

% Generation	50	
% PF	100	-99.1
Amp	83.68	25.78
kvar	15.78	205.8
kW	2000	-1526.8
Rated kV	13.8	34.5
Rating/Limit	4000 kW	150000 kVA
Type	Synchronous	Power Grid
Terminal Bus	Bus4	Bus10

Appendix B

Protective Devices setting

ETAP
16.0.0C

OCR: R-1

MFR: Schweitzer Tag #:

Model: 251

	CT	Base kV	If (kA)
CT Input:	150/5	34.500	4.15 3 ph, Asym. (Calc.)
			4.06 LG, Asym. (Calc.)

OC Level: OC1

		Range	Setting
Phase TOC	Extremely Inverse		
	Pickup (Tap)	1 - 12 Sec - 5A	12.000
	Time Dial		4.010
Neutral TOC	Very Inverse		
	Pickup (Tap)	0.25 - 12 Sec - 5A	0.250
	Time Dial		15.000

OCR: R-2

MFR: ABB Tag #:

Model: CO

	CT	Base kV	If (kA)
CT Input:	100/5	34.500	2.72 3 ph, Sym. (Calc.)
			2.67 LG, Sym. (Calc.)

OC Level: OC1

		Range	Setting
Phase TOC	CO10		
	Pickup (Tap)	4 - 12 Sec - 5A	7.200
	Time Dial		8.500

OCR: R-3

MFR: ABB Tag #:

Model: CO

	CT	Base kV	If (kA)
CT Input:	200/5	13.800	3.35 3 ph, Sym. (Calc.)
			3.24 LG, Sym. (Calc.)

OC Level: OC1

		Range	Setting
Phase TOC	CO10		
	Pickup (Tap)	4 - 12 Sec - 5A	7.200
	Time Dial		8.500

OCR: R-4

MFR:	Siemens	Tag #:		CT	Base kV	If (kA)
Model:	7SJ600		CT Input:	350/5	4.160	8.55 3 ph, Asym. (Calc.)
						8.95 LG, Asym. (Calc.)

OC Level: OC1

		Range	Setting
Phase INST	Pickup	0.05 - 25 xCT Sec	7.340
	Time Delay	0 - 60 Sec	0.020
Neutral TOC	ANSI - Extremely Inverse		
	Pickup (Tap)	0.05 - 4 xCT Sec	0.050
	Time Dial		0.500
Neutral INST	Pickup	0.05 - 25 xCT Sec	25.000
	Time Delay	0 - 60 Sec	0.010

OCR: R-GEN1

MFR:	GE Multilin	Tag #:			CT	Base kV	If (kA)
Model:	G60	PT Phase Ratio:	13.800kV/120.0V	Phase:	350/5	13.800	6.18 3 ph, Asym. (Calc.)
							5.35 LG, Asym. (Calc.)
				GND:	450/5	13.800	5.35 LG, Asym. (Calc.)

OC Level: OC1

		Range	Setting
Phase TOC	IAC - Very Inverse		
	Pickup (Tap)	0.01 - 30 xCT Sec	1.739
	Time Dial		2.700
Phase INST	Pickup	0.01 - 30 xCT Sec	3.998
	Time Delay	0 - 600 Sec	0.450
Ground TOC	IEC - Curve A		
	Pickup (Tap)	0.01 - 30 xCT Sec	0.058
	Time Dial		0.130
Neutral TOC	IEC - Curve A		
	Pickup (Tap)	0.01 - 30 xCT Sec	0.075
	Time Dial		0.130
Neg-Seq TOC	I^2T		
	Pickup (Tap)	0.01 - 30 xCT Sec	0.643
	Time Dial		0.130
Neg-Seq INST	Pickup	0.01 - 30 xCT Sec	15.607
	Time Delay	0 - 600 Sec	0.020

Protective Device Settings

OLR: R-4

MFR: Siemens   Tag #:

Model: 7SJ600

	CT	Base kV	If (kA)	
CT Input:	350/5	4.160	8.55	3 ph, Asym. (Calc.)
			8.95	LG, Asym. (Calc.)

		Range	Setting
Thermal	Thermal Curve (without preload)		
	Trip	0.4 - 4 xCT Sec	0.500
	Multiplier		1.000

Fuse: Fuse-1

MFR:	S&C	Tag #:		3-Phase kA:	4.99 Asym. (Calc.)
Model:	SM-4	kV:	17.000	LG kA:	4.76 Asym. (Calc.)
Speed:	Slow	Int. kA:	12.500	Base kV:	13.800 (Calc.)
Size:	30E	Cont. Amp:	30.000		

Fuse: Fuse-2

MFR:	ERMCO Components Inc	Tag #:		3-Phase kA:	4.99 Asym. (Calc.)
Model:	9F54WLD	kV:	15.000	LG kA:	4.64 Asym. (Calc.)
Speed:	Other	Int. kA:	1.880	Base kV:	13.800 (Calc.)
Size:	33-WLD302	Cont. Amp:	104.000		

CB: CB-4

MFR:	General Electric	Tag #:		3-Phase kA:	20.82 (User Defined)
Model:	AK-50	Rating:	50 kA, 0.48 kV	LG kA:	18.00 (User Defined)
Size:	1600	Cont. Amp:	1600.000	Base kV:	0.480 (User Defined)

Electro-Mechanical Trip Device

MFR: General Electric

Model: EC-1 AK-50 (LSI 20-75x)

ID: 400

		Phase Setting
ong-Time	Pickup	0.8000
	Band	1B-Int
ort-Time	Pickup	4.0000
	Band	2C-Min

CB: CB-5

MFR:	Cutler-Hammer	Tag #:		3-Phase kA:	18.06 Sym. (Calc.)
Model:	HMCP-F	Rating:	100 kA, 0.48 kV	LG kA:	19.02 Sym. (Calc.)
Size:	150	Cont. Amp:	150.000	Base kV:	0.480 (Calc.)

Motor Circuit Protector Trip Device

MFR: Cutler-Hammer

OLH: OL1

MFR:	Allen-Bradley	Tag #:		Base kV	If (kA)
Model:	Bulletin520-TypeJ		Phase:	0.480	23.88 Asym. (Calc.)
Type:	In-Line		GND:	0.480	25.00 Asym. (Calc.)

Thermal Typical Curve - Class 20

Trip Amp 110.000