People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University M'Hamed BOUGARA – Boumerdes

Institute of Electrical and Electronic Engineering

Department of Power and Control

Final Year Project Report Presented in Partial Fulfilment of the Requirements for the Degree of

MASTER

In **Electrical and Electronic Engineering**

Option: **Power**

Title:

Design a Protection Scheme Using ETAP

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Registration Number:………/2023

Abstract

This master report focuses on the design of a comprehensive protection scheme for industrial distribution systems, with a specific emphasis on the SCMI "GICA" factory. Using ETAP software, the report aims to develop and simulate an efficient protection scheme. The primary objective is to improve selectivity by replacing the definite time curve with the Inverse Definite Minimum Time (IDMT) curve, combining time selectivity and current-based methods. This approach effectively addresses challenges related to transient response and undesired tripping during high-current faults, particularly between successive short lines. Furthermore, the thesis proposes innovative solutions to mitigate the motor contribution during short circuits. The protection scheme design includes the meticulous selection and calibration of protective relays and current transformers (CTs) for various electrical elements such as transformers, motors, and busbars. Through extensive testing and validation using ETAP simulation, the proposed protection scheme and solutions demonstrate their effectiveness and reliability. This research significantly contributes to the field of industrial distribution system protection scheme design, particularly in terms of selectivity improvement, transient response handling, and motor contribution mitigation. The successful implementation and simulation of the proposed protection scheme highlight its practicality and efficiency in real-world applications. The findings provide valuable insights for professionals involved in designing protection schemes for similar industrial distribution systems.

DEDICATION

Every challenging work needs self-efforts as well as

guidance of elders those who were very close to our

heart.

My humble effort I dedicate to my sweet and loving **Mother** and my **Family members**,

whose affection, love, encouragement and prays of day and

night made me able to get such success and honor.

Along with all **my friends**, **hardworking** and respected **teachers.**

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful
Alhamdulillah, all praises to Allah for the strengths and the blessings He gave us to complete this project.

I would like to express our deepest and sincere gratitude to our project supervisor Dr. M.BOUCHAHDANE, We have been very fortunate and honored to work and study under your supervision, I would like also to thank Engineer Mr. S.NAYEB and PhD student Mr. O.MERABET and other teachers for their precious help during our work. Thank you very much.

Last but not least, we are infinitely grateful to our family members, particularly our parents for their patience, unwavering support, continuous encouragement, and belief in us throughout our whole lives. We would have never made it this far without them beside us every step of the way.

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List of abbreviation

ANSI-American National Standards Institute

CB-Circuit Breaker

CT-Current Transformer

CTI-Coordination Time Interval

DPZ-Differentiel Protection Zone

IDMT-Inverse Definite Minimum Time

IEC-International Electrotechnical Commission

OFAF -Oil Forced Air Forced

OFWF -Oil Forced Water Forced

ONAF- Oil Natural Air Forced

ONAN- Oil Natural Air Natural

ONWF -Oil Natural Water Forced

TDS- Time Dial Setting

VT-Voltage Transformer

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General introduction

Since the inception of electrical grids, power system protection has played an indispensable role as a vigilant watchdog, guarding against any abnormal conditions that may occur within the system. It is widely recognized as the most critical aspect of the entire power system, as failures in other subsystems can be mitigated if the protection system operates effectively. Conversely, a failure in the protection system itself can lead to severe losses, making it crucial to design and implement a robust protection scheme.

The protection system consists of three key components: instrument transformers for accurate measurement of current and voltage, circuit breakers as actuators to open circuits, and the protective relay, which serves as the heart of the system. Protective relays are fundamental to the power protection system, and designing and applying a proper protection scheme relies heavily on their selection, coordination, and configuration, along with the associated current transformer (CT) class and circuit breaker (CB) sizing.

This master report focuses on explaining the process of designing a proper and robust protection scheme for the SCMI factory. It is organized into five chapters, each serving a specific purpose to achieve the research objectives.

Chapter one provides a theoretical background on various protection functions, such as overcurrent and differential protection, and introduces the concept of selectivity. It explores different selectivity techniques and methodologies, which play a crucial role in designing an effective protection scheme.

Chapter two presents a general overview of the distribution system, discussing its components, structure, and characteristics. Understanding the system's architecture is essential for developing a protection scheme that caters to its specific requirements and challenges.

Chapter three delves into the methods employed for designing the protection scheme. It explores different protection philosophies, coordination techniques, and relay settings, with a focus on addressing the SCMI factory's unique needs.

Chapter four focuses on the implementation of the designed protection scheme using ETAP software. It allows for comprehensive simulation and analysis to validate the scheme's performance and effectiveness in various fault scenarios.

Lastly, chapter five presents and discusses the results obtained from the implementation and simulation of the protection scheme. It evaluates the scheme's performance in mitigating faults and abnormal conditions, highlighting its strengths and areas for potential improvement.

Chapter one:Theoretical background

Distribution system protection :

1.1introduction

In this chapter we will talk about distribution system protection and it's characteristics , components and structure After that we see main protections function like overcurrent protection and differential protection and philosophy after each function.

In second part of chapter we will talk about selectivity and how to set protective relay in order to achieve relays coordination.

1.2Definition :

Distribution system protection are essential to ensure the safety and reliability of power delivery to customers. They are designed to detect and isolate faults, prevent equipment damage, minimize service interruptions, and coordinate with other protection devices

1.3Characteristics of Distribution system protection

The following requirements define a protective system:
- Reliability: The capacity of a security system to function properly. Dependability—the ability of a protection system to unquestionably operate during failures for which it is responsible—and security—the capacity of a protection system to avoid erroneous operation during faults for which it is not responsible—are the two components of reliability [8] [9].
Speed: The capacity of a protection system to eliminate a fault as quickly as feasible in order to reduce through-fault damage to the apparatus.
-Selectivity: A protection system's capacity to only disconnect the smallest portion of the network required for fault clearing in order to maintain service continuity for the greatest number of customers.
Low cost is preferred.

1.4Structure of Distribution system protection

A transmission or distribution network's primary protection system component is a safeguarding relay. The protective relay is described by IEEE as "a device whose job is to detect to identify any abnormal or dangerous power system situations, such as broken lines or equipment, and to start the necessary management measures. Considering how they were built, the relays
categorized as being used for power system protection include:
- Electromechanical Relays: These relays, which have electrical, magnetic, and mechanical components, were the first to be widely used in industry. They function by producing a mechanical force that moves the relay contacts.
- Digital relays: These relays sample the analog input signals and generate digital signals using an analog-to-digital converter (ADC). Incorporating digital impulses into a

microprocessor, which contains the protection algorithm(s) and processes the input data to produce a digital output.

Numerical relays: Actually, these are modern digital relays with enhanced processing and communication capabilities. It is possible to classify numerical relays as intelligent electronic devices (IEDs).

Increased reliability, the capability of self-diagnosis for internal failures, the support of multiple protection functions, the adaptive protection feature (modification of protection settings depending on the system conditions), and the capacity to create records of events are some of the standout features of digital and numerical relays.

Figure 1-REF615 protective relay from ABB

A protection system also contains a current transformer (CT) and/or a voltage transformer (VT), in addition to the protective relay. It turns out that they are step-down protection transformers, which are necessary to shield the protection equipment from the high AC currents and voltages of the power system and provide the relay with suitable (lower-magnitude) analogue inputs. Since current measurements are frequently required in a protective system, a CT is frequently necessary. On the other hand, a VT is required when the protection principle being used calls for voltage measurements (such as in undervoltage, distance, or directed overcurrent protection). The protected system's conditions determine whether to use a CT or VT ratio.First of all, the current rating of the CT's primary winding is chosen so that [1]:
i) The primary winding of the CT is being used at a higher current than the maximum load current.
ii) in order to prevent measurement inaccuracies, the short-circuit current flowing through the CT's primary winding cannot cause the transformer's core to become saturated.
The secondary winding of a CT has a specified current rating of 1 A or 5 A. It should be noted that the CT ratios are uniformed in accordance with the pertinent IEEE [26] and International

Electrotechnical Commission (IEC) standards. Assuming a secondary rating of 5 A, a few standard ratios of multi-ratio CTs (MRCTs) are described in Table.
The nominal voltage of the protected network is used to determine the voltage rating for the primary winding of the VT. The secondary of the VT has a standard voltage rating of 100

MRCT	600:5	1200:5	2000:5	3000:5
Ratios	50:5	100:5	300:5	300:5
	100:5	200:5	400:5	500:5
	150:5	300:5	500:5	800:5
	200:5	400:5	800:5	1000:5
	250:5	500:5	1100:5	1200:5
	300:5	600:5	1200:5	1500:5
	400:5	800:5	1500:5	2000:5
	450:5	900:5	1600:5	2200:5
	500:5	1000:5	2000:5	2500:5
	600:5	1200:5	-	3000:5

Figure 2-standard ratios of multi-ratio current Transformers

A protective relay can decide when and whether it needs to activate to fix a defect, but it cannot isolate the problematic area of the network. A circuit breaker (CB) in a protective system is now necessary in this situation. The CB is placed in a way that allows it to influence the primary circuit under protection. The CB opens and breaks the circuit after receiving a trip signal from a relay that identifies a failure. Depending on the technology used by the CB, the interruption normally happens between 2 and 5 cycles [9].
A CB can trip the three phases simultaneously (three-pole tripping) or only one phase. Depending on the type of fault occurring (for example, for single-pole tripping), the protected circuit may trip.The general structure of a protection system including all the above-described elements (relay, CT/VT and CB) is illustrated in the single-line diagram of Fig11 [2]

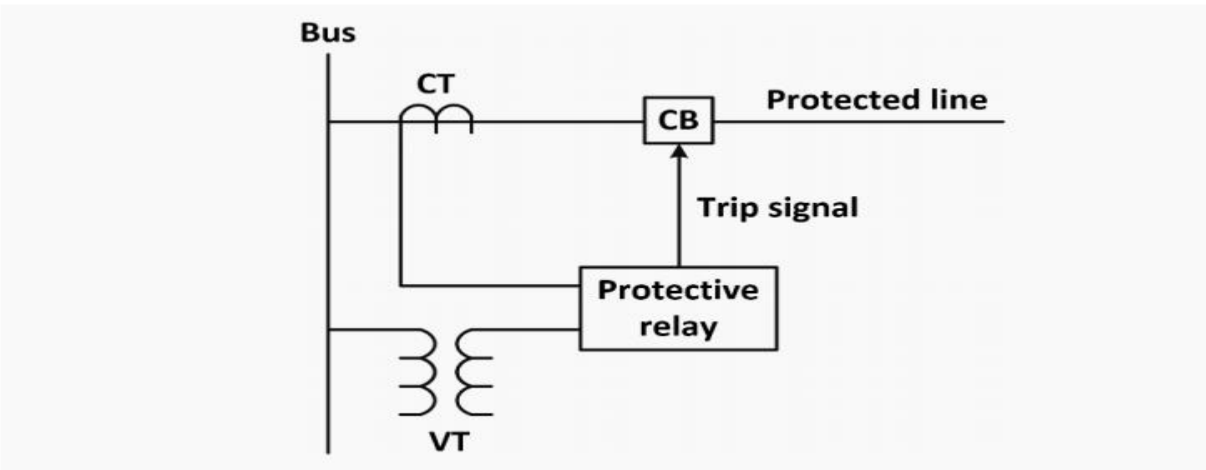


Figure 3-single line diagram of a generic protection system

Last but not least, we need to talk about the idea of primary and secondary protection.

The security strategy that is primarily in charge of securing a portion or component of the network is referred to as primary protection. In other words, the primary protection mechanism should be activated first to fix the fault if it occurs in this section or element.

The protection measure [9] that is programmed to take effect if the primary protection measure fails for any reason is referred to as secondary or backup protection.

Security used as a backup can be local or remote. Local backup protection would be possible by implementing a second protection system inside the same substation. This approach is frequently employed, although it obviously increases the cost of the protection program. Breaker-failure (BF) protection, which opens the appropriate nearby CB(s) to isolate a defective network portion in the event that the primary CB fails to open, is another form of local backup protection.

1.5Overcurrent protection

1.5.1Conventional overcurrent protection :

Fuse, overcurrent relays (OCRs), and overcurrent reclosers/reclosing relays are the most popular types of protection for MV power distribution networks under the conventional overcurrent protection theory.

OCRs (Overcurrent Relays) or reclosers are used to protect the main distribution feeder as well as occasionally provide lateral protection. In contrast, because of their affordability, fuses are frequently utilized for lateral protection in medium-voltage (MV) distribution networks.

The element that makes up a fuse is heated by the short-circuit current (ISC) that passes across it. The element melts when the current exceeds a certain value for a predetermined period of time. It is anticipated that choosing the right fuse will quickly cut off the protected circuit by melting the element and getting rid of the accompanying arc. The inverse time-overcurrent characteristic can be used to describe how a fuse operates. The operating time decreases (and vice versa) as the current flowing through the fuse increases. The minimum melting (MM) and total clearing (TC) curves make up the fuse characteristic. The fuse melts after the amount of time corresponding to the point where the MM curve intersects the root-mean-square (RMS) value of the current when it reaches a certain level.

the arc is extinguished, and the fault is completely cleared after the time indicated by the intersection point with the TC curve. [1]

The type of the fuse and its current rating, which sets its minimum intersecting current, both affect the precise form of that feature. Fast-blow (K-type) or slow-blow (T-type) fuses are frequently utilized in MV distribution networks [10].In comparison to T-type fuses of the same rating, K-type fuses typically have shorter clearing periods. How two succeeding fuses communicate with one another is depicted in Fig. 1.8a. For this reason, taking a proper CTI into account, the TC curve of the downstream fuse must be lower than the MM curve of the upstream fuse (at least for the projected short-circuit current range). In general, a fuse is selected to work in harmony with the downstream protective measures and not melt under normal load levels.

The most popular method for safeguarding primary feeders in MV distribution networks is OCRs. If the RMS current detected by these relays exceeds a certain value for a certain time delay, they are meant to send a trip order to their companion CB. The protection engineer sets both of these thresholds in advance. OCRs' operational characteristics can be divided into definite-time and inverse-time categories. [8]

A definite-time overcurrent element (applying a definite-time characteristic) operates based on two programmable settings: a pickup current setting I_{pickup} and a time delay setting t_d.

Once the current measured by the relay exceeds I_{pickup} (which is set greater than the maximum normal load current) a trip command is issued after a time duration equal to t_d expires. If t_d is set equal to zero, the relay operates instantaneously, as only the inherent response time of the relay (less than 50 ms [2]) must expire in order for a trip command to be issued. The basic drawback of definite-time overcurrent elements is that a single fixed time delay setting is only applicable. For this reason, they are not flexible in achieving a good compromise between selectivity and speed. To put it another way, if a fairly long time delay is specified for coordinating with the protection mechanisms of surrounding protection zones, the same time delay will also be used when faults occur in the relay's primary protection zone. the coordination of two definite-time overcurrent properties while taking into account a suitable CTI. [8]

OCRs employ inverse time features to produce a more controllable coordination with adjacent protection measures. Although a single curve is used in this instance, the fundamental theory behind these qualities is still quite similar to that of a fuse. [3]:

with dashed line, an inverse-time overcurrent element is often combined with a definite time (instantaneous) overcurrent element, in order to achieve definite-time-delayed (instantaneous) fault clearance in case of severe faults close to the relay (resulting in high For significant short-circuit currents, it is possible to quickly coordinate with an upstream relay. Two coordinated inverse time-overcurrent characteristics are shown in Fig.

In the time-current diagram, the characteristic of the former (either definite-time or inverse-time) must be set above the TC characteristic of the latter, at least during the expected short-circuit current range during lateral faults, in order to coordinate an OCR with a downstream lateral fuse.

Given that CB-interruption or other relay-related delays do not occur when the fault is cleared by a fuse, it should be noted that the CTI considered in this scenario may be lower than the CTI considered for relay-relay coordination. [11]

All of the information above will be summed up in the following numbers:

features of overcurrent protection for:

(a)TCC characteristics for Fuse :

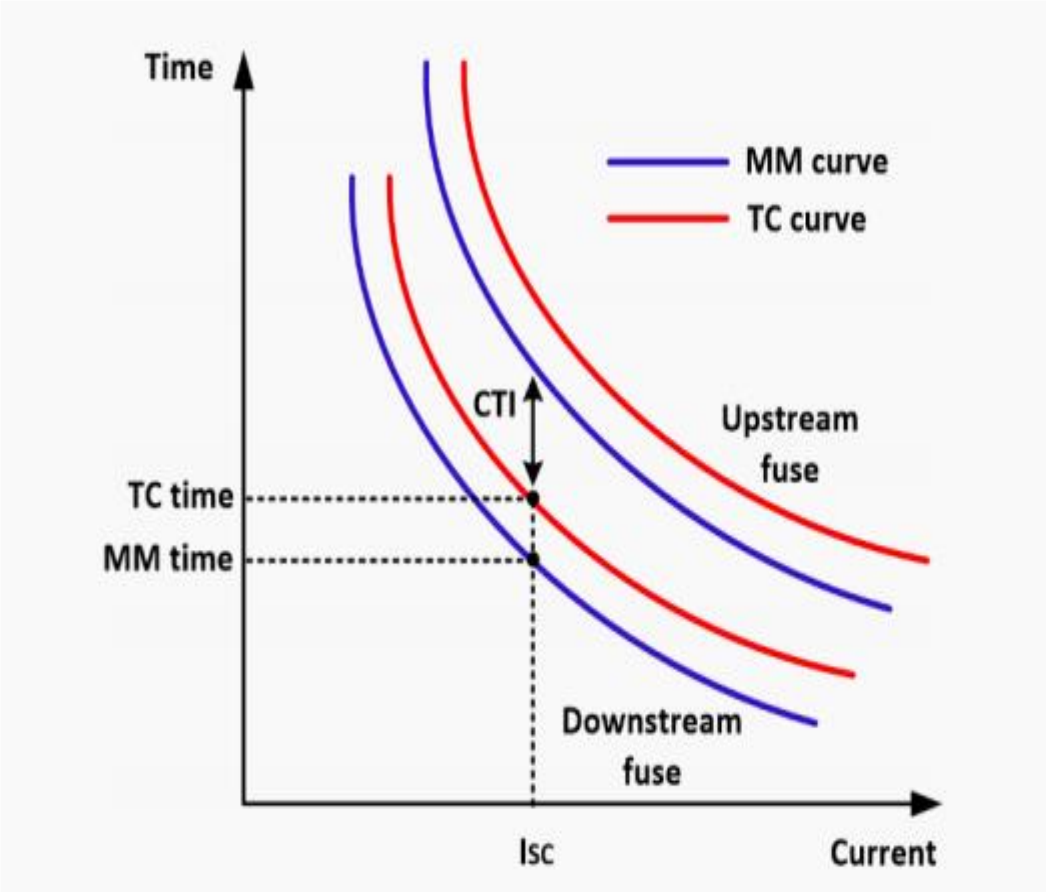


Figure 4-TCC characteristics for Fuse

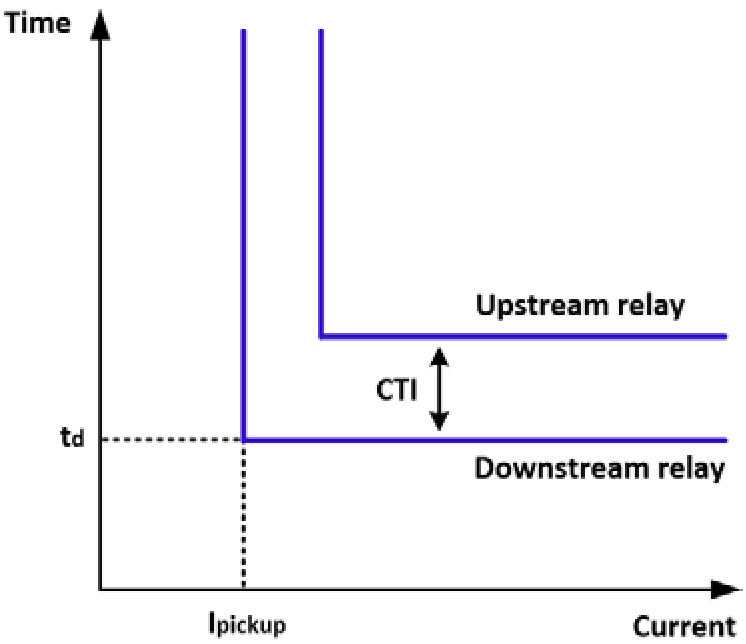


Figure 5-TCC characteristics for Definite-time relay

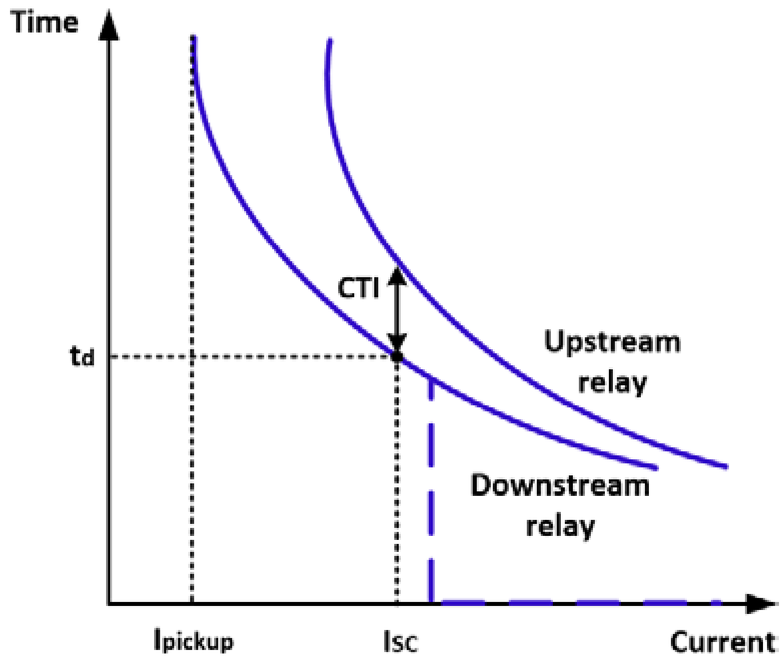


Figure 6-TCC characteristics for Inverse-time relay

Commercial OCRs frequently have separate overcurrent components (either definite-time or inverse-time) for phase and ground faults, it should be highlighted. These components' functional differences include the former's monitoring of phase currents and the latter's monitoring of residual current 3I0 or zero-sequence current I0. [2]

The major feeder of an overhead distribution network is often protected by one or more reclosing relays and/or pole-mounted reclosers, as opposed to a standard OCR. These reclosing relays and pole-mounted reclosers shall be collectively referred to as overcurrent reclosers or just reclosers from now on. Reclosers are functionally equivalent to OCRs, but they additionally have the capacity to carry out automatic reclosing operations. To put it another way, a recloser starts a set series of interruptions and re-energizations in the protected circuit when it detects a defect, and it keeps doing so until the fault is no longer there. After performing these steps, if the fault still exists, the recloser enters a "lockout" condition, permanently cutting off the circuit. Reclosers are used in classic overhead distribution networks because the vast majority of failures there (80–95%) are transient, lasting only a few cycles or seconds. As a result, the opening-reclosing process avoids the needless permanent disconnect of customers. [8]

1.5.2Directional overcurrent protection

By using traditional (non-directional) overcurrent protection, network segments may be disconnected needlessly since directional overcurrent protection is only implemented when bidirectional short-circuit-current flow is detected in the protected network. This could occur in networks with various power sources, including meshed and ring-type networks.

The same functional features as traditional OCRs are present in directional overcurrent relays (DOCRs). The distinction in this instance is because the relay additionally has a directing element that controls the short-circuit current's direction. Whenever the overcurrent component and the directional element asserts, then a trip command is issued for the CB. The directional element determines the fault direction by examining the phase angle of an operating quantity,with respect to a polarizing quantity [4]. The operating quantity is the measured short-circuit current I_{op}, whereas the measured voltage V_{pol} is usually set as the polarizing quantity. In phase directional overcurrent elements, it is common to use the short-circuit current phasor of the faulted phase as I_{op} and a proper phase-phase voltage phasor as V_{pol}. Specifically, the phase-phase voltage phasor which does not involve the faulted phase is used in each case For example, if the phase-a current phasor is used as I_{op}, the b-c voltage phasor is used as V_{pol}. This practice reduces the possibility of a considerably low V_{pol} magnitude during phase faults, which would be insufficient for reliable fault direction determination. In case of ground faults, ground directional overcurrent elements can be applied, using the opposite residual voltage phasor -$3V_0$ and the residual current phasor $3I_0$, or the respective zero-sequence phasors -V_0 and I_0, as V_{pol} and I_{op}, respectively. [2]

First, an operate and a non-operate zone are defined, each corresponding to half of the plane, to demonstrate the operation concept of the directional element. The line separating these two areas is known as the zero-torque line, and the line parallel to the zero-torque line is known as the maximum-torque line. However, next-generation relays have also embraced this phrase, which was originally used for electromechanical relays.

When Iop is in the operate zone, the directional element decides a forward fault; however, when Iop is in the non-operate zone, it determines a reverse fault. We must be noted that Vpol determines the position of Iop. The maximum-torque line is moved with regard to Vpol, in order to accurately define the operational zone of the directional element. Maximum-torque angle (MTA) is the term used to describe the shift angle. The moment Iop departs from Vpol by MTA, the operational torque reaches its maximum. Here is where the directional element's minimum pickup is defined. The maximum-torque line leading Vpol, common values for MTA in phase directed overcurrent elements are 30o and 45o. An MTA of 60o Vpol, on the other hand [2] .

For determining the direction of ground faults, current polarization can be also applied. In that case, $3I_0$ or I_0 is used as the polarizing quantity. The MTA typically applied in this case is zero, which means that maximum operating torque occurs when the residual current is in phase with the short-circuit current I_{op} of the faulted phase. [2]

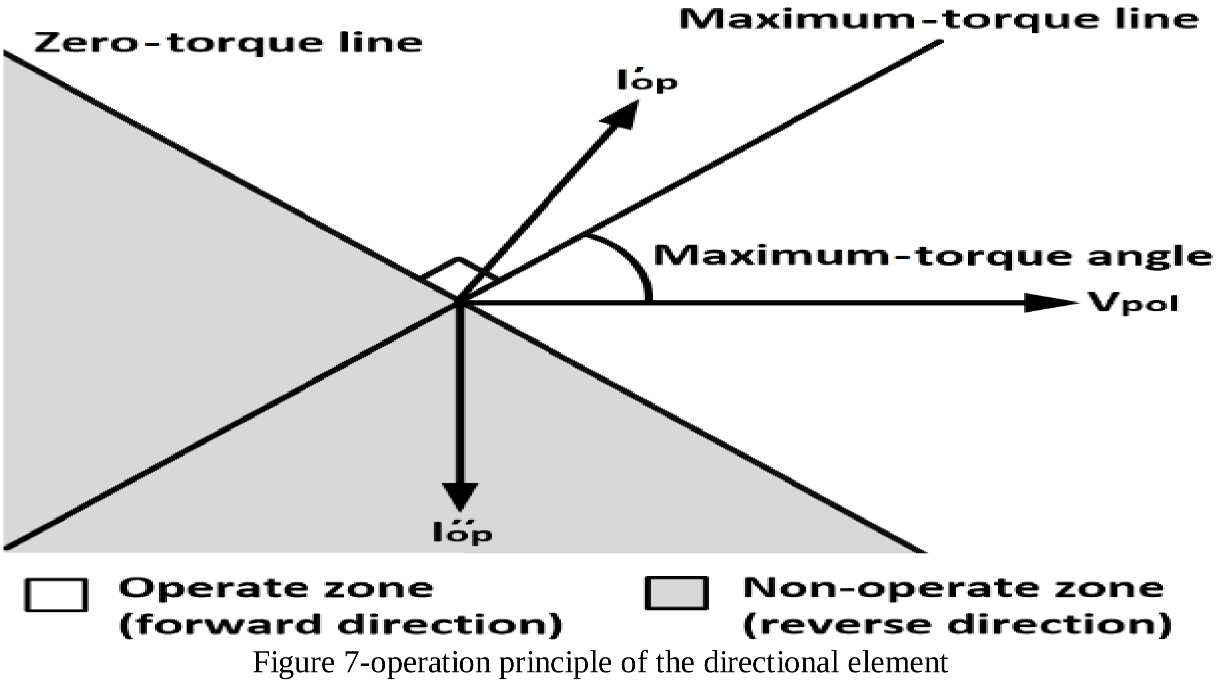


Figure 7-operation principle of the directional element

In general, correctly defining the operate zone of the directional element depends on the fault/system conditions. Hence all the possible fault cases in the protected network must be considered, in order to identify the expected range of short-circuit current phase angles. Based on this information, the best possible compromise should be made when determining MTA, so as for the direction of all the expected faults to be determined correctly. It is noted that, besides MTA, the angle limits of the operate zone can be also modified in modern DOCRs, by properly adjusting the zero-torque lines. [5, 2]

1.6Differential protection

Fig. 16 illustrates the basic operation principle of current differential protection, assuming a two-terminal differential protection zone (DPZ). CTs (CT_1 and CT_2) are installed at both terminals of the protected element (e.g. generator/motor, transformer, bus, or line), accompa nied by CBs (not depicted for illustration simplicity). A current differential relay continuously measures the currents flowing at the terminals of the DPZ ($I_{diff,1}$ and $I_{diff,2}$) and calculates their vectorial sum. Since the currents at the two terminals would flow in the same direction under normal system conditions or external faults (i.e. faults outside of the DPZ), the aforementioned vectorial sum should be zero (or nearly zero) according to Kirchhoff's laws. In contrast, because the currents at the two terminals would flow in the opposite directions during internal faults (i.e., faults within the DPZ), this vectorial sum should be higher than zero. The differential relay detects an internal failure in the latter scenario and trips the CBs at the DPZ terminals. According to the convention used here, the current entering the DPZ is positive whereas the current leaving the DPZ is negative. This is practically accomplished by making the right choice.

Based on the above, a differential protection element in its simplest form should operate when [6]:

$$I_{diff,op} = \left| I_{diff,1} + I_{diff,2} \right| > I_{diff,p}$$

where $I_{diff,op}$ is the operating differential current and $I_{diff,p}$ is the pickup differential current.

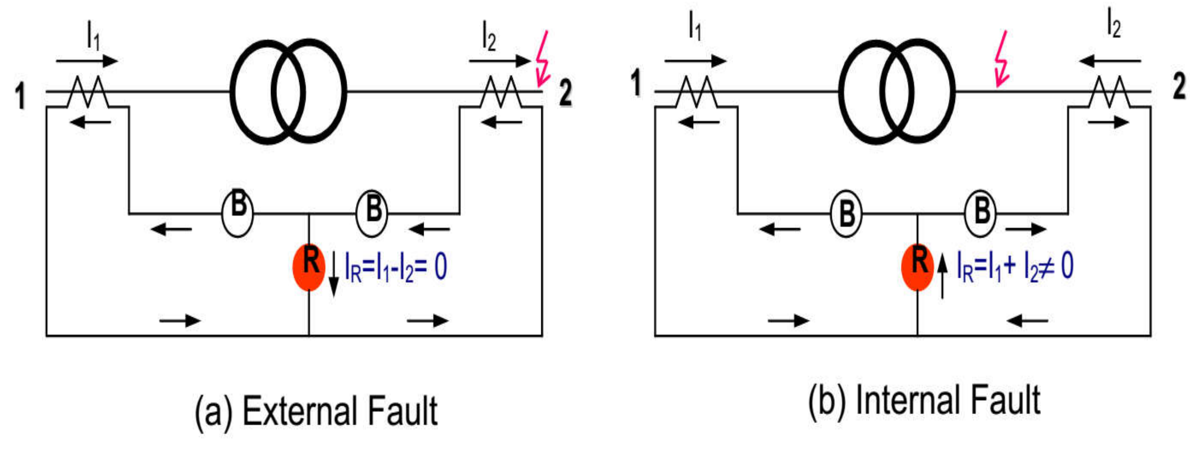


Figure 8-diffrential protection principle

The pickup differential current $I_{diff,p}$ cannot be practically set equal to zero. This is because,

a differential current might appear even during normal system conditions, or during an external fault, due to the following reasons [6] :
-**Current measuring errors:** Due to CT transformation, false differential current may arise. errors, whether they occur under normal or fault conditions. CT saturation may result in an incorrect differential, particularly when failures are accompanied by a significant short-circuit current. operation of the relay under external faults.

-**Intermediate outfeed/infeed:** The presence of intermediate loads or generators inside a DPZ may result in a differential current during normal system conditions or external faults.
-**Line charging current:** The capacitance of a line results in the flow of charging current, which appears as an erroneous differential current in the differential protection scheme protecting this line.
-**Excitation current:** The current flowing into the excitation branch of a power transformer produces an erroneous differential current for the differential relay protecting the transformer.

Actual differential relays do not operate solely based onInstead, they operate based on a characteristic, which is formed by $I_{diff,op}$ and restraint current $I_{diff,res}$. Referring to the example of Fig., modern numerical differential relays commonly define $I_{diff,res}$ as:

$$I_{diff,res} = \left|I_{diff,1}\right| + \left|I_{diff,2}\right|$$

The differential relays that operate according to the aforementioned theory are known as "percentage or biased differential relays." In Fig. 1.12a, the applied characteristic is depicted. On the Idiff,op - Idiff,res plane, this characteristic defines an operational zone and a restraint region as indicated. As long as the measured Idiff,op is followed by an Idiff,res, a fault within the operational region is detected, and the differential relay trips. It is evident that as through current (represented by Idiff,res) grows, the differential relay's pickup threshold rises as well. This offers excellent security against significant short-circuit currents that could result in CT saturation and erroneous relay operation, as well as high sensitivity during normal system conditions and internal defects accompanied by modest short-circuit currents. [14]

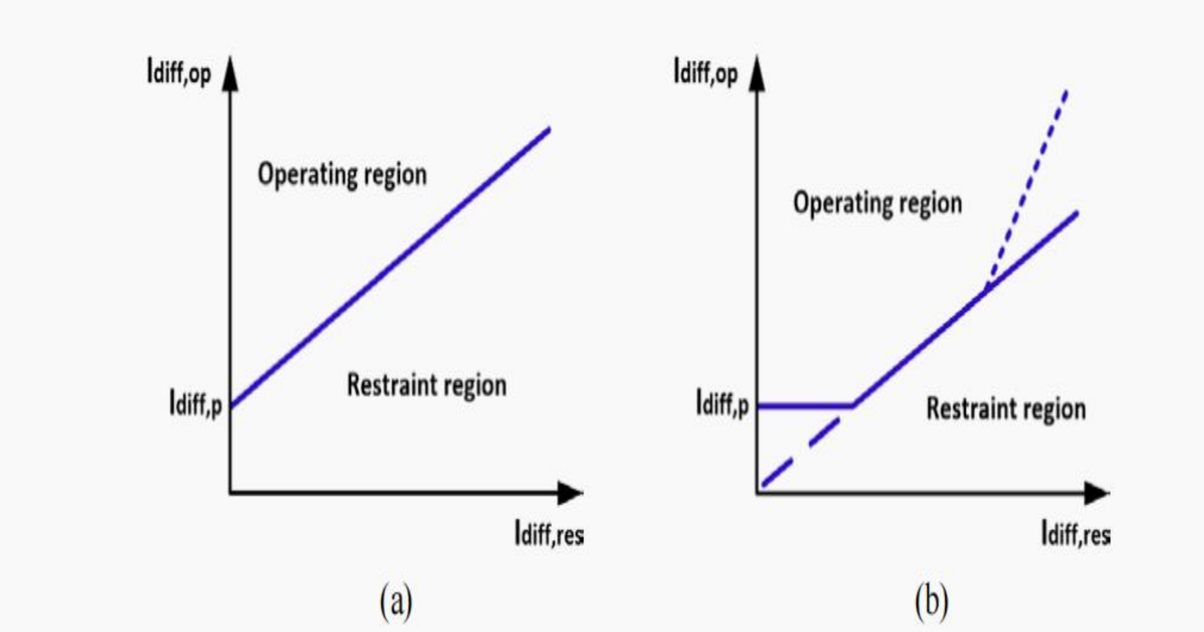


Figure 9-percentage differential relay characteristics

Based on the above-described characteristic, the differential relay operates when [6]:

$$I_{diff,op} > I_{diff,p} + k_{bias} I_{diff,res}$$

where k_{bias} is a bias factor which determines the slope of the characteristic. In this case, the $I_{diff,p}$ setting determines the starting point of the characteristic, and is typically set greater than the expected differential current during normal system conditions. It is noted that several percentage differential relays examine the pickup differential current and restraint current conditions separately, i.e. they operate when the next two conditions are simultaneously true [6]:

$$I_{diff,op} > I_{diff,p}$$
$$I_{diff,op} > k_{bias} I_{diff,res}$$

The origin of the Idiff,op - Idiff,res plane serves as the starting point for this feature, whereas Idiff,p is a separate pickup setting. Fig. 1.12b shows this trait. Additionally, the scenario of a dual-slope characteristic is shown in this image (dotted line). This feature allows for more freedom when determining the operating and constraint regions and is present in a number of differential relays. In that situation, there should be two bias factors defined, one for each slope.

Given that it exclusively reacts to internal faults (i.e. problems within the specific DPZ), differential protection's key benefits are its great dependability and quickness. Therefore, there is no requirement for time grading with additional protection methods, at least not in ordinary differential protection applications. As opposed to that, issue,commercial differential relays must include additional time-graded protection functions, such as overcurrent or distance protection functions [6].

The single-line diagrams of Fig. 2.9 depict how differential protection is ap-plied to a transformer.

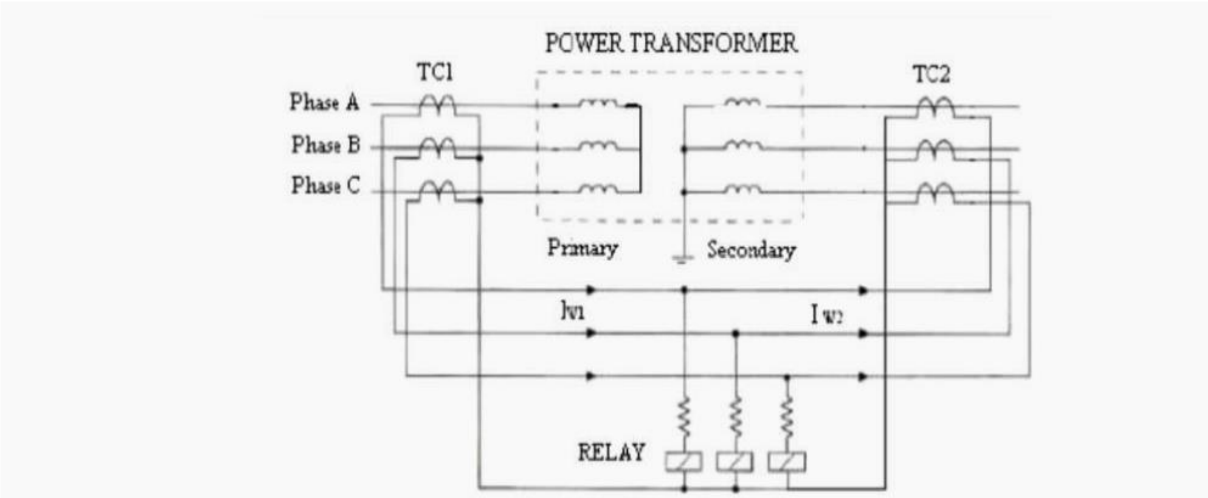


Figure 10-power transformer differential protection scheme

1.7Undervoltage protection

If the measured voltage drops below a set threshold, an undervoltage relay triggers. It is frequently employed to offer protection in the event of unusual low-voltage conditions (i.e., when voltage falls below the lowest permitted system operation voltage). Along with this Given that a voltage decrease is anticipated in such instances, undervoltage protection is used against abnormal events brought on by short-circuit defects. In particular, it is taken into account for interconnection protection and short-circuit fault detection in a multifunctional distribution network protection scheme.

As regards interconnection protection in particular, undervoltage protection trips a unit as soon as the measured voltage at PCC drops at a specific level, for a predetermined time duration. This is mainly to prevent unintentional islanding conditions in the hosting network, after the line protection trips. Voltage drop can be used as a tripping criterion in this case, since unbalance between the generated power and the served load inside the formed island may result in low-voltage conditions (as well as in high-voltage and low-/high-frequency conditions, which are supervised by dedicated protection functions). Moreover, undervoltage protection is used to trip a DG unit during network short-circuit faults, in the case where the short-circuit current contribution of the generator is low (e.g. as regards IIDG units) and overcurrent protection is not reliable . Conventional DG undervoltage protection is typically applied with the use of two definite time undervoltage elements. [7]

It should be mentioned that in addition to undervoltage protection, various other protective functions are frequently used for DG protection. However, the reason for concentrating on the latter protection principle in this thesis is that it is directly related to both the LVRT requirements, which are crucial for the involvement of DG units in fault events, as well as network short-circuit faults (which regard the scope of this thesis). [15]

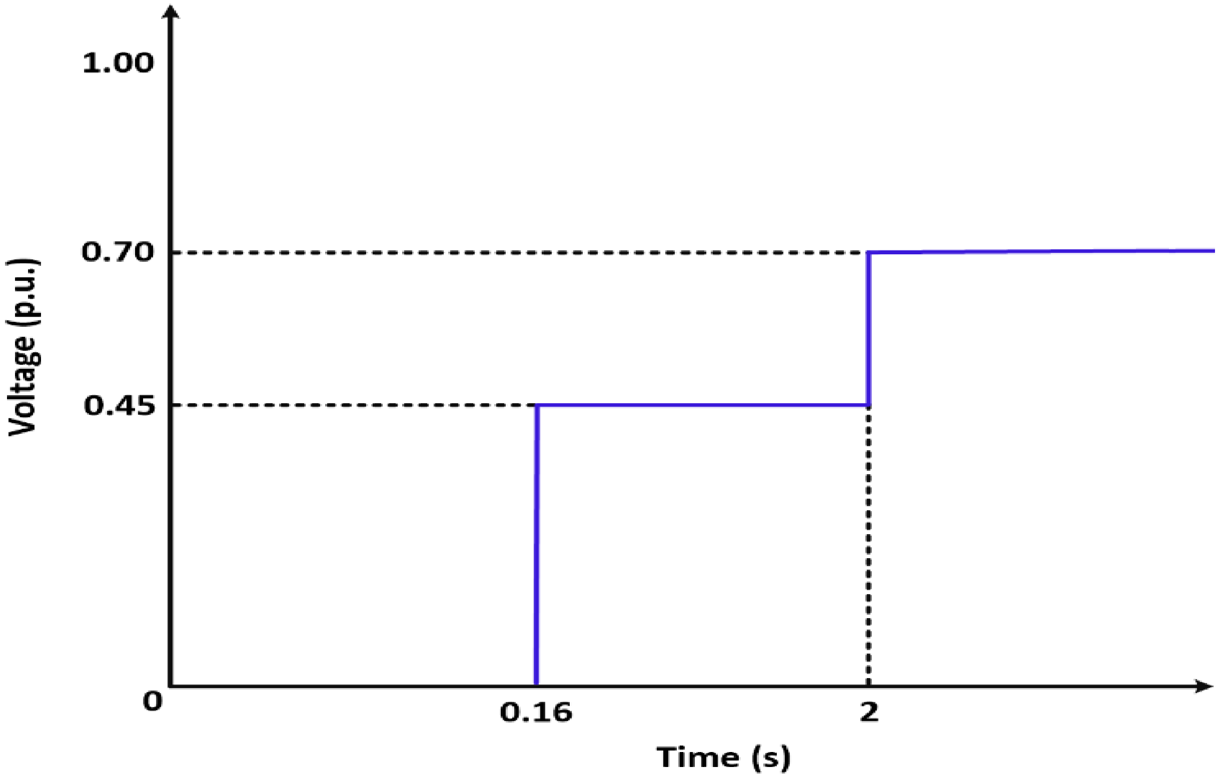


Figure 11-conventional under voltage protection curve

1.7Selectivity(discrimination)

1.7.1Overview: Discrimination, is the practice of selecting protective devices and adjusting their settings in order to limit interruption to electrical installations under fault conditions. When the devices in a distribution path are 'coordinated' it reduces nuisance tripping and makes it easier to identify where a fault has occurred. Hence, why it is also referred to as Selective Co-ordination.

In a nutshell, selective coordination is an electrical system design practice that improves reliability. The methodology increases uptime by limiting power outages to the branch of an electrical system where a fault appears without knocking out other areas of the grids. When a problem occurs, the closest overcurrent protective unit opens, either a or a fuse, circuit breaker, ensuring that any faults do not cascade upstream

Very important terms such as partial and total selectivity must be addressed for thorough investigation. The definitions of the total selectivity and partial selectivity are given in the same Standard IEC 60947-2 "Low voltage Equipment – Part 2: Circuit-breakers". Basically, total protection discrimination preserved when there is selectivity for any overcurrent possible value in the installation.

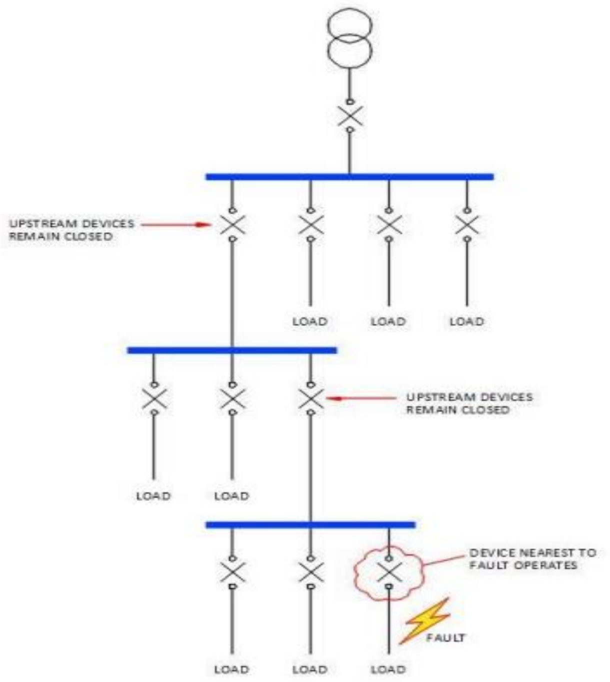


Figure 12-concept of selectivity

Proper discriminating tripping, besides limiting an outage to the shorted or overloaded branch circuit, facilitate investigation causes of faults, identification of underrated or overloaded equipment, and applying corrections. Power can typically be restored faster than when upstream breakers are tripped, mainly if a panel board has been taken down.

Most common challenge is to capacity to discriminate between untypical but tolerable situations and fault conditions within its competence zone in favor of avoiding unneeded trips which result unjustified outage of a sound part of the installation. Such cases are depicted in the Figure. 1.1. At the same time, circuit breakers must trigger as fast as possible to curb harm for the apparatus. [8]

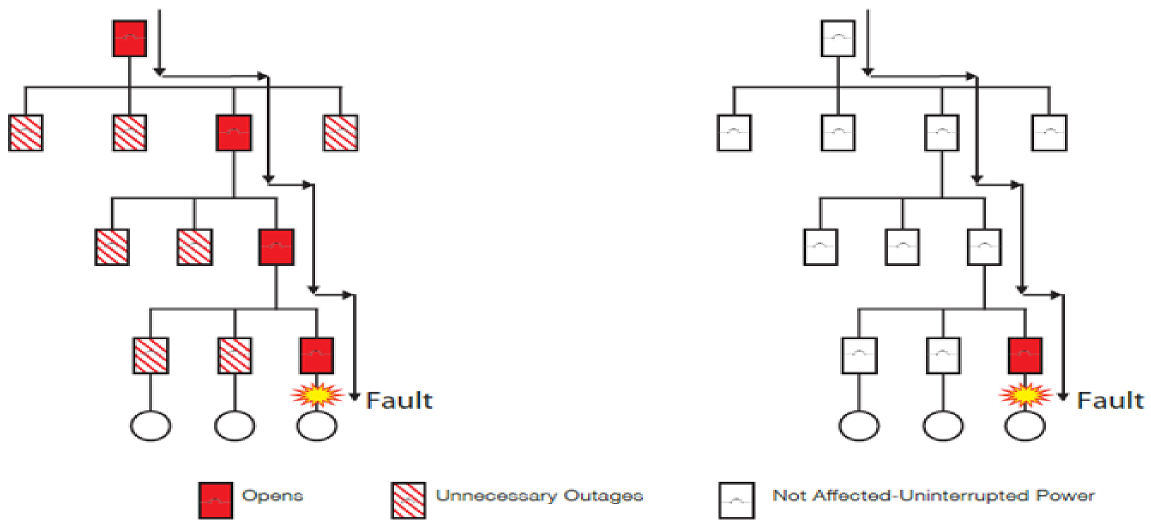


Figure 13-Illustrative example of a) absence and b) presence of actual

Selectivity.

1.7.2Overload and short-circuit zone :

First, the terms "overload zone" and "short-circuit zone" must be introduced in order to understand the discriminating protection system. Figure 22 depicts the key characteristics of these sectors.

The conventional method for determining selected coordination involves comparing the time-current properties of two or more overcurrent protection devices on a single graph. The degree of coordination can be demonstrated by the relative placement of each device tolerance bands on a time-current curve, and it is typical for the instantaneous trip characteristics to overlap.

The phrase "overload zone" describes the range of current values where the circuit breaker tripping curves gradually approach the circuit breaker's rated current, but not by more than 8 to 10 times the magnitude of the C-type protection curve. In this area, the protection device responds with a delay because it is not instantaneous. The long-time and short-time segments of the breaker's time-current curve make up this component. Thermomagnetic releases and L protection are frequently used for electronic releases to handle the "overload zone." Reliable non-instantaneous coordination is achieved by achieving a separate ampere rating or long-time pick-up between connected breakers. Working with electronic trip devices, which have tighter tolerance bands than thermal-magnetic automated, makes non-instantaneous coordination easier. [9]

By “short-circuit zone” one means the ranges of current values, and therefore the relative part of the trip curves of the protection device, which are more than 8-10 times of the rated current .In this case, circuit breaker opening is initiated without any intentional delay.

In this section a protective response provides the desired fastest protection in the presence of higher-level fault currents. [9]

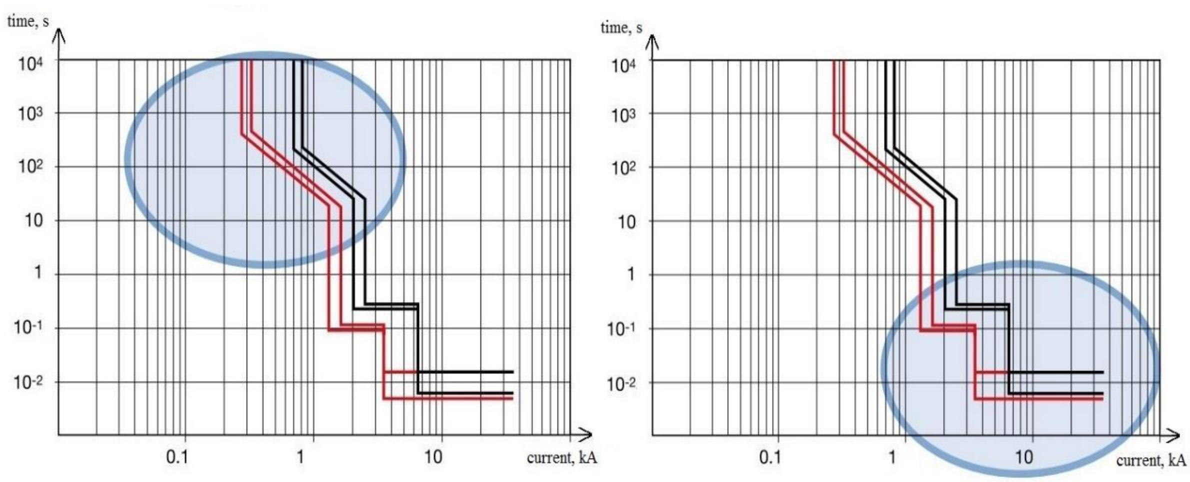


Figure 14-Illustrative example of “Overload” and “Short-circuit” zones

1.7.3Time-current selectivity technique

In general, the protection against overload have a definite time characteristic, whether they are made by means of a thermal-magnetic releaseor by means of function L of an electronic release.

A typical tripping coordination between upstream (A) and downstream (B) circuit breakers is shown in Figure 23. Due to its inexpensive cost and comparatively high dependability, this type of protective coordination is primarily used. Time-current curves (TCC) for over-current protective devices are well known to indicate how long the device will take to operate under overcurrent situations. Typically, these curves are created by running interruption tests on test devices at different overcurrent levels, including overload and fault currents.. [10]

To reduce the total working time of primary relays, the protection coordination problem can also be stated as a restricted non-linear programming problem (NLP). The time multiplier setting (TMS) and plug setting (PS), which are the two decision-making factors for the overcurrent relay. Relay operation time depends on TMS, PS, and current sensed by the relay. Equation 2 provides the operating duration of. [8]

$$t= TMSX(\frac{\beta}{(\frac{Ia}{Is})^{\alpha}-1})$$

where α ,β the constants representing the overcurrent relay characteristic in a mathematical form

I_a is actual current and I_s are setting current.

It is assumed that inverse-definite minimum time (IDMT) type overcurrent relays are used.

According to IEC standards, the,, constants are taken to be :

Sl no.	Curve Type	β	α
1	Normal Inverse	0.14	0.02
2	Very Inverse	13.50	1.00
3	Extremely Inverse	80.00	2.00
4	Long time inverse	120.00	1.00

respectively, for the usual IDMT characteristic. However, time-current curves are more easily used and visually appealing from a practical standpoint. [16]

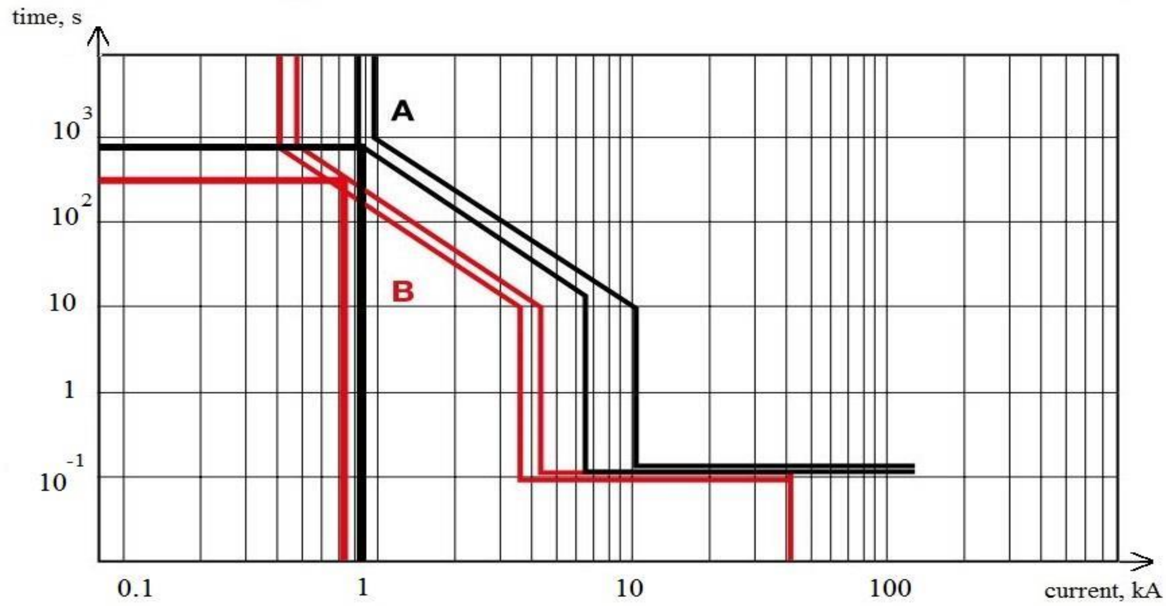


Figure 15- Time current curves

The time-current protection method has a number of serious shortcomings. In most circumstances, increasing the size of the circuit breaker frame and switching from a molded case to an electronic trip type with higher short time settings are necessary to achieve selected coordination.

Both techniques may lengthen the time protective devices take to clear an arcing fault, increasing the incidence energy from arc flash.To make matters worse, the TCC ignores the dynamic nature of the impedance imposed by arc and transient components. [8]

Also instantaneous coordination performance of two breakers in series is not necessarily determined by evaluating the relationship between their time current curves . In many cases, the time current curve analysis under-predicts the actual instantaneous coordination capability.

The dynamic operation of the downstream breaker, however, affects the fault current experienced by the upstream breaker as the load-side breaker starts to open when two breakers are connected in series. When the downstream breaker's instantaneous trip is quicker than the upstream breaker's, this interaction tends to be more noticeable. Manufacturers' published time-current curves frequently fail to reflect the true current limiting nature of breakers with this attribute, which furthers the difference between instantaneous coordination predicted by time-current curve analysis and actual performance.

1.7.4Current selectivity technique

This kind of selection is based on the observation that the short-circuit current increases with the distance between the problem spot and the installation's power source.

As a result, by altering the instantaneous protections' current values, it is feasible to distinguish the zone in which the fault occurred.

Total selectivity is typically only possible in rare circumstances when the fault current is low, a component with high impedance (such as a transformer, a very long cable, a cable with a small cross-section, etc.) is placed between the two protections, and there is a significant difference in the short-circuit current values.

Because of the low rated current and short-circuit current levels as well as the high impedance of the connection cables, this form of coordination is consequently most frequently utilized in distribution

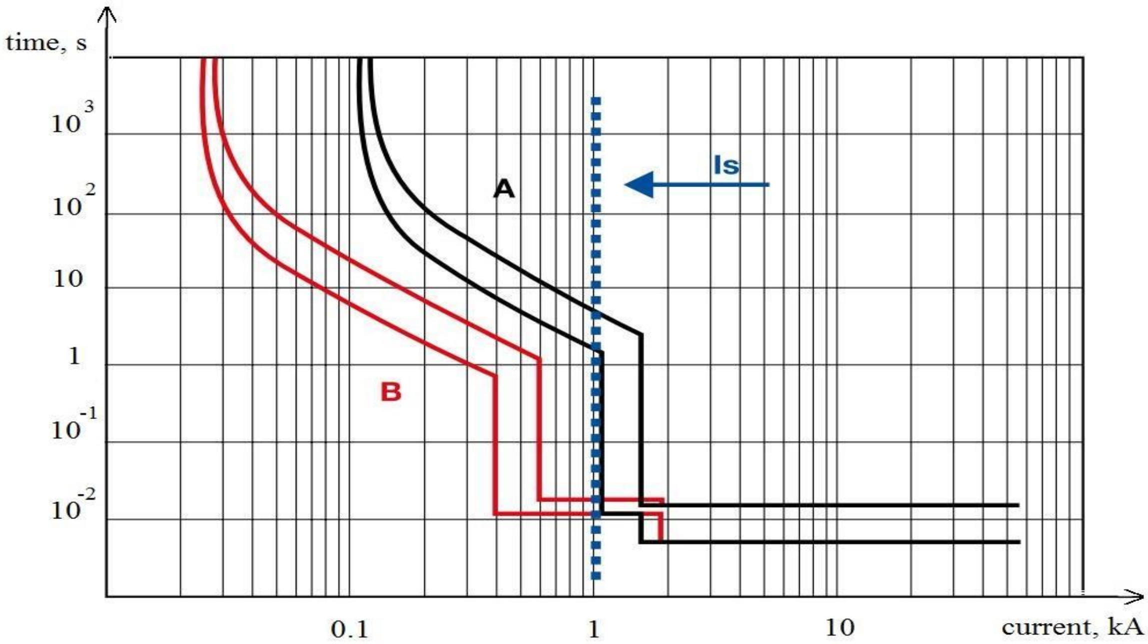


Figure 16 –TCCs of current selectivity

The Advantages of the current selectivity technique are [8] :

-Simplicity in realization

-Low cost implementation

The Drawbacks of the current selectivity technique are [8]:

-Relatively low level of ultimate selectivity current, which often make selectivity only partial

-Rapid increase of overcurrent setting level for the protection devices

1.7.5Time selectivity technique

The earlier form of selectivity evolved into this one. In this kind of coordination, in addition to the trip threshold in terms of current, there is also a trip time defined: at a given current value, the safeguards trip after a specified amount of time, allowing any protections installed closer to the fault to trip.

Therefore, the setting technique is to gradually raise the current thresholds and trip delays as one approaches the power supply sources. In other words, the hierarchical level closely correlates with the setting level. The tolerances of the two protective devices and the effective currents that flow through them must be taken into account when determining the delayed trip thresholds.

The difference between the delays specified for the protections in series must take into account the device's load-side fault detection and elimination durations as well as the supply-side device's supply-side inertia time or overshoot.

As in the case of current selectivity, the study is made by comparing the time-current trip curves of the protection devices. It is a type of selectivity which can also be made between circuit-breakers of the same size, equipped with electronic releases with delayed protection against short-circuit. [8]

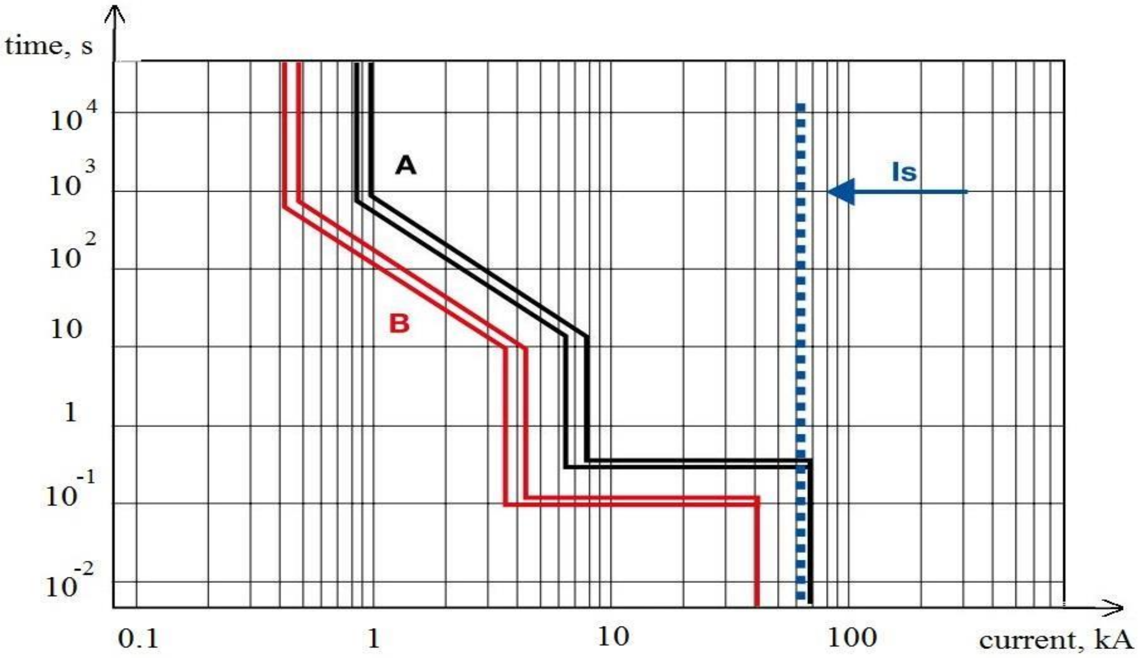


Figure 17– TCCs of time selectivity

The Advantages of the current selectivity technique are [8] :

-Simplicity in realization

-Low cost implementation

-Possibility of achieving high selectivity current limits

-Redundancy of supplying functions

The Drawbacks of the current selectivity technique are [8]:

-High level of trip times and energy levels let through by protection devices which are close to the source.

It worth to mention that There are an other techniques such as zone selectivity and energy selectivity but it will not discuss in this thesis.

1.8Protection scheme for power transformer

Overview: Transformer Protection's main goal is to both be immune to faults that are external to the transformer, or through faults, and to detect internal faults in the transformer with a high degree of sensitivity and induce a subsequent de-energization. Limiting fault damage and consequently required repairs is made possible by sensitive detection and deenergization. However, it should be able to offer backup protection in case of system through faults, as these could cause deterioration and accelerated aging, as well as failure of the insulation on the transformer windings due to overheating and high impact forces caused in the windings as a result of high fault currents. In addition to internal errors, unusual system circumstances include excessive excitation, excessive voltage, and loss of.

Transformer protection can be broadly categorized as electrical protection implemented by sensing mainly the current through it, but also voltage and frequency and, as mechanical protection implemented by sensing operational parameters like oil pressure/ level, gas evolved, oil & winding temperature.

Transformer protection basically divided into two types. One is Electrical Protection and it is designed based on Electrical parameters like Current, Voltage, Frequency, and Impedance. The second type of protection is Mechanical Protection and it is designed based on Mechanical parameters like Temperature, Pressure, Density, etc [11].

1-Transformer-Electrical Protection Types [11]:

-Over Current/Earth Fault-50/51Protection

-Under Impedance/Distance relay Protection-21

-Differential Current Protection-87

-Restricted Earth fault Protection-64H

-Three Phase Overload Protection-49

-Over Fluxing Protection-24

-Over Voltage-59/Under Voltage-27 Protection

2-Transformer-Machanical Protection Types [11]:

-Oil Temperature Indicator-26

-Winding Temperature Indicator-49

-Oil Pressure Relief-PRV-63PRD

-Gas Accumulation using Gas Accumulation Relay (Buchholz Relay)-63

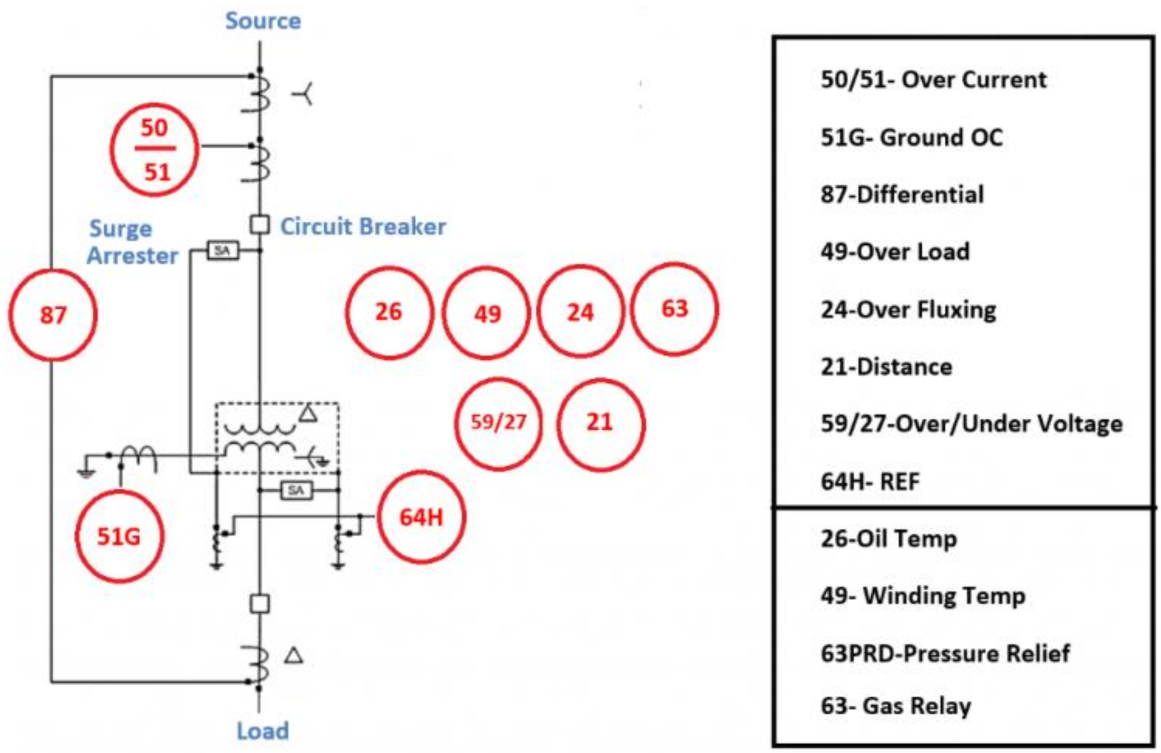


Figure 18-transformer protection scheme

1.9Motor protection scheme

Overview: Motor Protection There is a wide range of motors in existence for various purposes. However, the fundamental problems affecting the choice of protection are independent of the type of motor and the type of load to which it is connected. The motors under discussion here are a.c. motors which include synchronous motors and induction motors.

Types of Faults: Types of electrical faults in motors are similar to those of generators. Motors therefore in general are protected against the following faults:

-Stator Protection: The stator can experience short circuits to the earth or between phases. Thermal or dash, pot type overcurrent tripping devices that have an inverse time-current characteristic and typically give instantaneous tripping at high current are used to protect the motor from these failures. For motors with higher ratings (often more than 50 HP), instantaneous overcurrent relays are supplied from CTs. Two high-set instantaneous relay elements that are configured so that they are substantially over the maximum beginning current provide phase-fault prevention. A straightforward instantaneous relay with a setting of roughly 30% of the motor's full load current in the residual circuit of three CTs provides earth-fault protection for a motor operating on an earthed neutral system. Operation [12]

-Rotor Protection: Any type of imbalance, whether it be in the loading pattern or the supply voltage, will result in negative sequence currents flowing in the stator, which will produce high frequency currents in the rotor. These rotor currents have a frequency that is (2 - S) times higher than the supply's nominal frequency. While the heating impact on the rotor windings of the negative sequence component of the stator current is proportional to (2 - S) f (about 100

Hz) a.c. resistance value, the rotor heating caused by the positive sequence component of the stator current is proportional to d.c. resistance value. Positive phase sequence current obviously has a stronger heating impact than negative phase sequence current. This is something that Motor Protection must consider if it wants to [12]

Overload protection: It is exceedingly challenging to cover all types and ratings of motor with a given characteristic curve due to the huge variety of motor duties and motor designs. The overload protection is made to mirror the heating curve of the majority of motors as closely as feasible. The motor protection characteristic should be located directly below the motor's heating curve. The protection should ideally have configurable features so that it may be applied to various motor types and tasks. In order to avoid potentially disastrous outcomes, the protection should not permit the motor to be restarted after tripping while the winding temperature is still high. Therefore, for a protection to be successful, it needs not only match the thermal characteristic of. [12]

For these uses, induction overcurrent relays with the appropriate type characteristics are best, For overload protection, a typical setting is 120% of the full load current. The present setting is 120% of full load, yet tripping won't occur with a beginning current of 6 times full load for 30 seconds. Without changing the current setting, the operating time at high overcurrent values can be modified to meet the motor starting characteristic with the aid of the time multiplier setting. Overload protection can be achieved with just one phase-connected relay element, but two can also offer single phasing protection.. [12]

Under voltage protection: Undervoltage operation of a motor will typically result in overcurrent, which can be prevented by overload or temperature-sensitive devices. To guard against a three-phase voltage drop or an attempt to start with low voltage on all phases, a separate single-element under voltage relay that is powered by phase-earth or phase-phase voltage can be provided. Typically, a time delay is added to prevent tripping due to a brief voltage decrease.. [12]

1.10Feeder protection scheme:

Overview: Feeder protection is defined as the protection of the feeder from the fault so that the power grid continue supply the energy. The feeder injects the electrical energy from the substation to the load end. So it is essential to protect the feeder from the various type of fault. The main requirement of the feeder protection are;

-During the short circuit, the circuit breaker nearest to the fault should open and all other circuit breakers remain in a closed position.

-If the breaker nearest to the fault fails to open then, backup protection should be provided by the adjacent circuit breaker.

-The relay operating time should be small to maintain the system stability without necessary tripping of a circuit.

Time Graded Protection :

This is a scheme in which the time setting of relays is so consecutive that in the event of a fault, the smallest possible part of the system is isolated. The applications of time graded are explained below. :

Protection of Radial Feeders: A radial system's defining feature is that electricity only flows in one direction, from the generator or supply end to the load end. Its disadvantage is that, in the event of a problem, supply continuity cannot be managed at the load end.

When the number of feeders are connected in series as shown in the picture, a radial system is used. The least amount of the system should be off, if at all possible. By using time-graded protection, this is easily accomplished. The over current system should be set up so that the amount of time it is in operation decreases with the distance of the relay from the producing station.

The relay OC5 should operate when a fault on the SS4 occurs, not any other relays; in other words, the time needed to run the relay OC4 must be shorter than the time needed to operate the relay OC3, and so on. This demonstrates the need for appropriately graded time setting for these relays. The smallest space of time that can be permitted between two adjacent circuit breakers is determined by their own clearance times, plus a little extra time for a safety margin. [13]

The discriminating time between adjustment breakers should be at least 0.4 seconds with a regular circuit breaker in operation. The time parameters will be 0.2 seconds, 1.5 seconds, 1.5 seconds, 1.0 seconds, 0.5 seconds, and instantaneous for relays OC1, OC2, OC3, OC4, and OC5. It is crucial that the time of operation for the severe fault should be shorter in addition to the grading system. Utilizing a time-limiting fuse in tandem with the trip coils will accomplish this. [13]

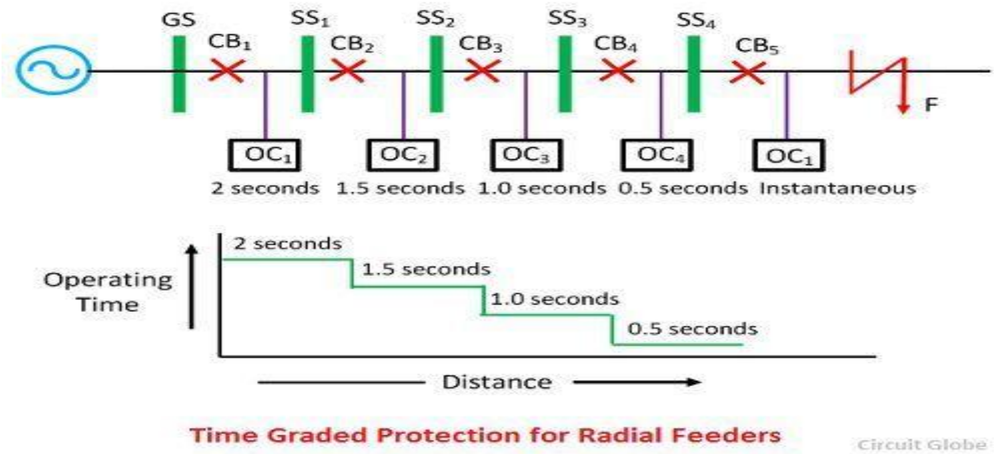


Figure 19-radial feeder protection coordination

Protection of Parallel Feeders: In order to share the load and ensure supply continuity, the supply is connected in parallel. When the protective feeder develops a malfunction, the protective device will choose and isolate the problematic feeder while immediately assuming the increased load on the other.The time graded overload relay, as shown in the picture below, is one of the most straightforward ways to protect the relay. It has an instantaneous reverse power or directional relay at the receiving end and an inverse time characteristic at the transmitting end.Both the transmitting end and the receiving end of the line feed electricity into the heavy fault F when it occurs on either one of the lines. The flow of power will be determined by. [13]

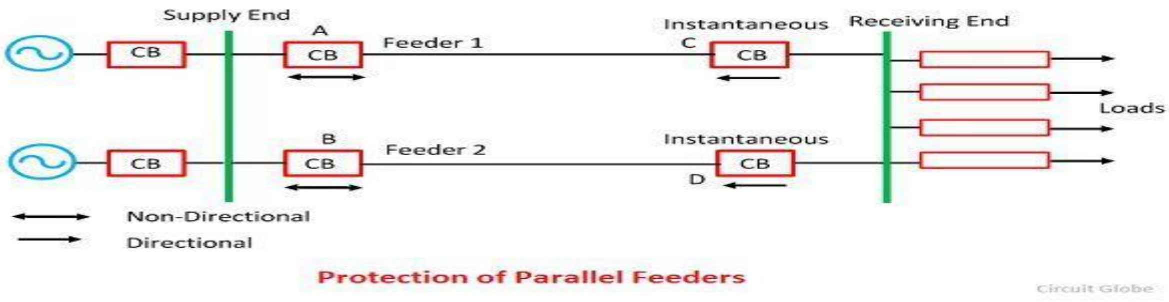


Figure 20-parallel feeder protection

Protection of Ring Main : The ring main is a method of connecting many power plants by taking a different path. When the interconnection is used, the main ring system allows for flexible power direction changes. The system's basic diagram is depicted in the image below, where G represents the generating station and A, B, C, and D represent the substations. Because there is just one direction of power flow at the generating station, time lag overload relays are not necessary. At the end of the substation, a time-grade overload relay is installed, and it will only trip if overload flows away from the substation it is meant to safeguard.

The relay is established with decreasing time lags on the farther side of each station as you go around the ring in the direction of GABCD. At the generating station, the time taken is 2 seconds at stations A, B, and C, as well as 1.5 seconds, 1.0 second, 0.5 second, and instantaneous. The relay would be set up similarly on the outgoing sides when moving around the ring in the other way. [21]

The power F is injected into the fault by two pathways, ABF and DCF, if the fault happens at point F. The relay that must be in operation is the one between substations B and C and fault point F. The relay on that portion will therefore activate if there is a failure in that segment, whereas the healthy section will not. [13]

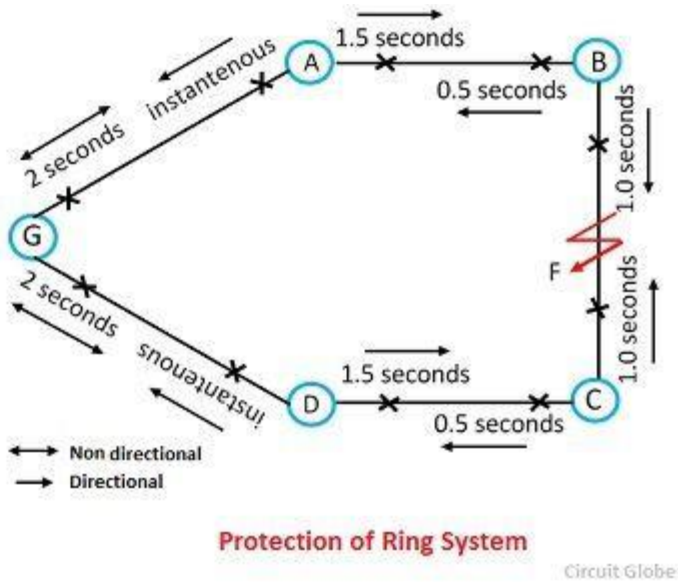


Figure 21-ring feeder protection coordination

1.11Conclusion

This chapter provides a comprehensive exploration of the theoretical foundations for designing protection schemes that cover a wide range of electrical equipment and scenarios. The main objective is to protect individual components from faults, failures, and abnormal operating conditions. The chapter emphasizes the importance of selectivity and relay coordination in achieving this goal. Selectivity ensures that only the affected portion of the system is disconnected, minimizing overall system impact and enabling quick fault location and restoration. By understanding these theoretical principles, engineers can develop robust protection schemes that ensure reliable and efficient operation of electrical systems.

Chapter two : Generality on distribution system

Distribution system

2.1inroduction

In this chapter I will talk about electrical network focusing more on private one and it's component how we can distrusted power to loads and how to protect it in case of fault occurs after that we will get into the concept of selectivity how to apply into any networks.

2.2Definition:

The component of an electric system that is responsible for providing electric energy to a final user comes after the transmission system.

Electricity is delivered from the transmission system to individual consumers at the electric power distribution stage, which is the last in the process. Distribution lines are the system of lines that transport electricity from distribution substations to customer dwellings. The consumer then uses the dispersed electricity.

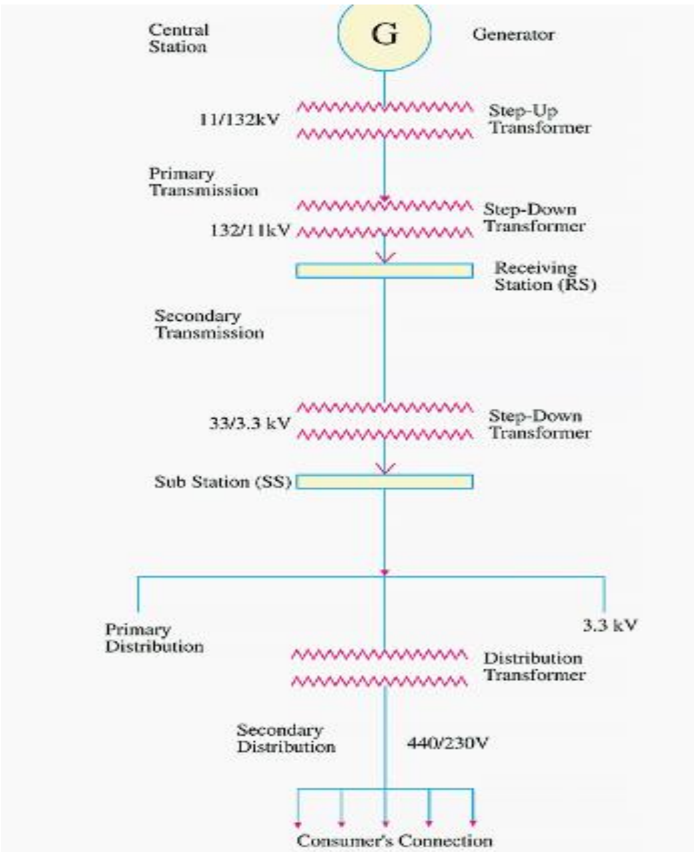


Figure 22 distrubtion system topology

2.3Components of Distribution System :

the distribution system components are:

2.3.1Substation

2.3.1.1Difintion:

The electrical substation is the part of a power system in which the voltage is transformed from high to low or low to high for transmission, distribution, transformation and switching.

Figure 23 MV/LV substation

2.3.1.2Componenns of substation:

substation has a lots of component, I mentioned the main ones only which are:

1-Switchgear:

Definition :is a collective word for switching and interrupting equipment. Switchgear equipment has two distinct purposes:

Switchgear equipment makes it possible for common switching activities to take place under normal circumstances.

- To reduce damage when there are abnormalities, switchgear equipment immediately disconnects faulty equipment from the rest of the power system. Switchgear equipment serves a protective purpose in these circumstances.

Electric conductors (contacts) are pulled apart by every switchgear to work. An arc develops between the contacts when electricity is applied to the device and the contacts are driven apart. The length of the arc increases as the contacts expand. The arc must be put out with a dielectric substance, such as air, oil, or sulfur hexafluoride (SF6), in order to stop the flow of current. [14]

Figure 24 -medium voltage switchgear

equipment of switchgear: Switchgear essentially consists of :

1-Power-conducting components : Switches, circuit breakers, fuses, lightning arrestors, insulators, and other parts of a system that conduct power are examples. These switchgear parts are necessary to stop and restart the system's electric current flow. When necessary, they turn a circuit on or off.

2-Control-system components : To identify the malfunctioning system components, the control system components of HV switchgear are crucial. Along with the rest of the system, the control-system components monitor, detect, and protect the power conducting parts of the system. Relays, current or potential transformers, control panels, and other components make up the switchgear.

3-Bushings : When a conductor of a high-voltage current level passes through a metal sheet placed within an earthing substance, bushing insulators are the switchgear component employed. When required, they have the capability to safeguard the system.

Note:We will talk about this components in details in another section.

Classification: fundamentally SW is classified according to :

Depending on the Voltage Level

1-Low voltage switchgear: Power electronic circuits that deal with voltage levels up to 1KV require low voltage switchgear. Air circuit breakers, oil circuit breakers, earth leakage circuit breakers, miniature circuit breakers, molded case circuit breakers, switch fuse units, HRC fuses, and small circuit breakers are some of the most often used low voltage devices needed to protect the low voltage systems. etc. [15]

2-Low medium switchgear: Medium voltage electrical systems are those that operate up to 36 kV. Medium voltage switchgear is used by the systems operating at this specific voltage level. Equipment like minimum oil circuit breakers and bulk oil circuit breakers are examples of medium voltage switchgear. A particular non-toxic, inert, and insulating gas, like as SF6, may be employed by medium voltage switchgear in place of oil, vacuum, or another interruption medium. The medium voltage switchgear can be divided into air, vacuum, and gas-insulated switchgear depending on the type of interruption medium utilized. Similar to this, there are many varieties of medium voltage switchgear based on casing and installation, including indoor type metal-enclosed, outdoor type metal-enclosed, and outdoor type medium voltage switchgear without metal casing., etc. [15]

3-High medium switchgear: Electrical systems running at voltages more than 36 kV need high voltage switchgear. The main piece of equipment utilized in the construction of high voltage switchgear is the high voltage circuit breaker. The interruption medium for high voltage switchgear is typically SF6 gas, vacuum, etc. Due to their propensity to generate substantial arcing while switching, high-level voltage systems and devices must be carefully designed. These devices need to be extremely trustworthy. It is important to note that high voltage switchgear tripping and switching operations are: [15]

Depending on the Voltage to be Handled

Outdoor type Switchgear : Switchgear of the outdoor type is utilized for voltages more than 66 kV. This is due to the equipment needed by the system, such as transformers, switches, circuit breakers, etc., needing a sizeable surface area and a broad electrical clearance between the conductors at such high magnitude voltages. Such a device cannot be installed indoors at all economically.. [15]

Indoor type Switchgear Indoor type switchgear is preferred for voltages under 66kV. Indoor type switchgear is often made of a metal-clad type of construction. All of the system's components are gathered in this location and housed in an earthed metal box. As a result of its greater compactness and affordability, this sort of system can be readily put indoors.. [15]

Functions of switchgear:

switchgear has several functions:

- The prime function of switchgear is similar to that of a switch. It is mainly used to carry, make, and break the flow of current between the source and the load.

- Switchgear is used in a variety of power electronics applications and is crucial because it shields the linked devices from high magnitude current, also referred to as surge current. The

device becomes destroyed if the switchgear is missing. As a result, the system that contains the damaged device experiences service intrusion.
Transformers, generators, and other electrical circuits and devices are generally protected from short circuits by switchgear.
- Devices connected to the load side are isolated from the primary power source via switchgear.
- It works by preventing damage to the transmission lines, extending the life of the cables, and reducing the frequency of maintenance.
-It is utilized to increase the system's availability. Here is
- One of the main functions of switchgear is to detect the overload conditions and trip off immediately in case of an excessive flow of power to the load.
- A switchgear aids in switching currents that are both inductive and capacitive.
Switchgear stops the flow of current during a short circuit, preventing property damage and accidents. [16]

2-Capacitors:

Definition: is equipment used for compensation reactive power in network, in most cases it is aimed at saving during operation of distribution networks and at the same time at improving voltage quality.

Type of connection: In substation is either connected in

1-delta connection: give more reactive power according to equation $Q = \frac{V^2}{Xc}$ but cause problem when we have unbalanced load

2-star connection: commonly used because it does not any problem in case of unbalanced load

3-Reactors: Reactors are coils that are primarily used to protect other devices, such as power transformers, from reactive currents produced during transmission fault conditions. Inductive materials make up the majority of the reactor. Reactors are utilized when needed, but their primary purpose is to restrict reactive currents that could harm the power transformer during transmission or distribution in the substation.

Depending on how they are used, the reactors perform a variety of different tasks within the electrical power system. Such types of operations require the reactor to be used, such as the elimination of harmonics, reactive currents, and fault rectification [4]. The various reactor types used in the electrical power system include:

-Shunt reactor

-Series reactor

-Damping reactor

-Tuning reactor

-Arc suspension reactor

4-UPS

definition: Uninterruptable power supply, or UPS, is a device that provides backup power when utility power fails, either long enough for critical equipment to shut down gracefully so that no data is lost, or long enough to keep required loads operational until a generator comes online. It also conditions incoming power so that often-occurring sags and surges don't harm sensitive electronic equipment.

Types of UPS: UPS can be classified into three types which is :

Single-conversion systems : These supply IT equipment with incoming utility AC power during typical operations. The UPS uses its inverter to draw electricity from the battery if the AC input supply exceeds predetermined limitations, and it also disconnects the AC input supply to prevent backfeed from the inverter to the utility. Until the AC input recovers to normal tolerances or the battery runs out of power, whichever occurs first, the UPS functions on battery power. The two single-conversion designs that are most widely used are standby and line-interactive:

-IT equipment can use grid power when connected to a standby UPS while waiting for an issue to be detected before switching to battery power. Transformers or other components are used in some standby UPS configurations to provide some limited power conditioning.

-Line-interactive UPSs regulate input utility voltage up or down as necessary before allowing it to pass through to protected equipment. However, like standby UPSs, they use their battery to guard against frequency abnormalities.

Double-conversion systems : These gadgets double the power conversion, as their name implies. An output inverter receives AC power from an input rectifier, which first converts it to DC. The electricity is then converted back to AC by the output inverter before being used by IT devices. By totally separating essential loads from raw utility power during this double conversion process, IT equipment is guaranteed to only receive safe, dependable electricity.

A double-conversion UPS continuously splits power in half during typical use. However, if the AC input supply exceeds predetermined thresholds, the input rectifier turns off and the output inverter starts pulling power from the battery. Until either the battery runs out of power or the AC input returns to normal tolerances, whichever comes first, the UPS uses battery power. The static switch bypass circuit is promptly turned on to support the output loads in the event of a severe inverter overload or failure of the rectifier or inverter.

Multi-mode systems : These offer significant gains in efficiency and reliability while combining aspects of single- and double-conversion technologies.

Multi-mode UPSs are made to dynamically strike the perfect balance between protection and efficiency. When things are normal, they work at their highest capacity. But when issues arise, they automatically give up some effectiveness in order to provide the highest levels of security. As a result, data centers can save tens of thousands of dollars annually on energy without sacrificing the performance or reliability of the facility.

5-Motor control center

Definition: is an assembly of one or multiple enclosed sections that have a common power bus that primarily contains motor control units.

MCCs are provided with Class I or Class II wiring. With any of the classes, the user can specify the physical arrangement of the units within the motor control center (subject to design parameters).

Figure 25- low voltage switchgear

functions of Motor Control Center : **MCCs** are used as a link between generation equipment and end consumers such as engines, air conditioning equipment, etc.

The MCCs offer the advantage of integrating within the same cabinet the motor starter systems of different areas of a plant as well as the distribution system of the same.When using this equipment costs are reduced since the power lines reach a single place (the MCC). From MCC the power and control cables go to the final loads.

Starters : Starters are the simplest control devices that can be used to start motors and to protect them against overloads. There are several types of starters which are:

-Direct-On-Line starter.
-Rotor Resistance starter.
-Stator Resistance starter.
-Auto Transformer starter.
-Star Delta starter
-soft starter
-Variable frequency drive starter

MCC wiring Classification : The following are various NEMA classifications and their description. Wiring of MCC conforms to two **NEMA** classes (1, and 2) and three types (A, B, C).

-Class 1 : Bus bar systems, protection equipment, overload relays, and contactors are all organized for ease of use. However, the manufacturer doesn't offer any wiring or interlocking between the devices. Only compartment drawings, not wiring between the center's sections, are provided by the manufacturer. For small applications with a constrained number of motors, Class 1 type MCCs are advised.

-Class 2 : Required to providing by the manufacturer, with interlocking and their control wiring completed between compartments of the center.

With Type A: No terminal blocks (TBs) are provided.

With Type B: All connections within individual compartments are made to the terminal blocks.

With Type C: All connections are made to the master terminal block located in the horizontal wiring through at the top bottom of the center. [17]

2.3.1.3Classification of substation: discuss substations based on insulation:

1-Gas-insulated Substation: A high voltage substation with sealed principal structures is referred to as a gas insulated substation. It belongs to the class of switchgear that is removable. As the insulating medium, it is made up of dielectric gases like SF6 or sulfur hexafluoride gas. Electric bus bars, electric isolators or disconnectors, circuit breakers, voltage converters, earth switches, surge arresters, and lightning arrestors are some of the parts.

2-Air-insulated Substation: The main circuit of an air-insulated substation is one that is isolated from the ground using insulators like porcelain. The most typical kind of substation is the air-insulated substation. When the area is large, this sort of substation performs best for low voltage and is very effective. Additionally, the erection takes less time to complete.

2.3.2Feeders: A feeder is a conductor which connects the distribution sub-station to the area where power is to be distributed. The current in a feeder remains the same throughout its length because no tapings are taken from it. The main consideration in the design of a feeder being its current carrying capacity.

1.3.3Distributor :A distributor is a conductor from which tapings are taken for supply to the consumers. Due to the taping is done at various places in a distributor, the current being not same throughout its length. The main design consideration of a distributor is the voltage drop across its length because the statutory limit of voltage variations is ± 5 % of rated voltage at the consumer’s terminals.

2.3.4Distribution Transformers :

Definition : In the first and final stages of the grid, distribution transformers are a crucial component. They are used in conventional electrical networks to transform high voltage delivered into medium voltage or medium voltage into low voltage that can be used in infrastructure, industry, and homes. They are now also in charge of supplying electricity to the grid due to the growth of decentralized generated electricity.These transformers are often offered in a variety of sizes, efficiency, and insulating oil types. These transformers come in a range of sizes and efficiency levels. The user's needs and budget have a major role in the transformer's selection. Distribution transformer connections come in four different varieties: star-star, delta-star, star-delta, delta-star, and zigzag/delta zigzag.

Figure 25-26MVA distribution transformer

Types of Distribution Transformer : Based on the application or requirement, these transformers are categorized into different types:

- **Single Phase:** These transformers are specially used for networks wherever a three-phase supply is not required. Usually, these are used for repairing overhead distribution loads in residential. These are also applicable in industrial lighting, light commercial loads & power applications.

-**Three Phase :** This kind of transformer is used to hold electrical energy from the main distribution circuit to a minor distribution circuit. This type of transformer transmits the current to a secondary distribution circuit and also reduces the voltage of the primary distribution circuit. These transformers reduce the voltage supply for the primary circuit based on the consumer requirement.

This voltage is constantly fluctuating and may be different for users in light industries, residential, and commercial applications. Depending on the national standards in use, these transformers operate at various voltage and frequency levels. These transformers come in single-phase and three-phase versions. Residential uses employ single-phase, while underground primary circuits use 3-phase with a pad.

- Pad-Mounted : This particular transformer has a locked steel cabinet placed on a concrete pad. When there isn't enough room for a gated enclosure, this sort of transformer is built. This transformer is used with overhead electrical wires that distribute electricity to reduce the primary voltage needed to give power to the customers. A large structure or numerous residences can be served by a single transformer of this kind. This transformer has fixed switches and fuses and has a power rating of 75 kVA to 5000 kVA.

Transformer can also classified into two type

-dry transformer

-oil immersed transformer

Type of cooling system: Oil and air are the primary cooling materials used in a transformer.

Dry-type transformers, are normally cooled by air. The following two transformer cooling methods are adopted in dry-type transformers.

Air Natural (AN) cooling – Cooled by surrounding air. Heat transfer by natural air convection.

Air Force (AF) cooling – Forced air circulation using fans and blowers.

Oil-type transformers are cooled using oil-air cooling or oil-water cooling method. There is a wider range of cooling methods for oil-type transformers.

(Mineral) Oil Natural Air Natural (ONAN) :The core and coils are cooled by surrounding in oil. Heat transfer of oil by natural air convection.

(Non-Mineral) Oil Natural Air Natural (KNAN) :The core and coils are cooled by surrounding in synthetic oil. Heat transfer of oil by natural air convection.

Oil Natural Air Forced (ONAF) :Cooled by surrounding in oil. Forced air circulation using pumps, fans and blowers.

Oil Forced Air Forced (OFAF) : Forced oil and air circulation using fans and blowers.

Oil Natural Water Forced (ONWF) :Cooled by surrounding in oil. Forced water circulation using heat exchanges.

Oil Forced Water Forced (OFWF) :Forced oil and water circulation using oil-to-water heat exchanges [18]

Transformer parts: facilitate the delivery of electrical energy with minimal power loss. The basic parts of a transformer are the core, primary and secondary windings. In addition to these components, there are many other components such as insulation, transformer oil, cooling arrangements, protective relays, enclosures, etc., available in larger transformers.

1-Core: The windings are supported by the transformer's core. Its soft iron construction lowers hysteresis and eddy current losses and gives flux current a low-reluctance channel. The width of the transformer core is inversely correlated with the iron loss and directly correlated with the copper loss.

2- Winding: The winding consists of many turns of copper coils bundled together, each bundle being joined together to form a complete winding. The coils can be based on an input-output supply or on a voltage range. Power supply-based windings are classified as primary and secondary, that is, the coil to which the input and output voltages are applied, respectively. On the other hand, coils based on voltage range can be classified into high voltage coils and low voltage coils.

3-Insulating materials**:** Insulating materials like paper and cardboard are used to separate the primary and secondary coils from the transformer core. These coils are made of copper due of its superior conductivity and ductility. The amount of copper required is reduced by the high conductivity and minimal loss. Along with decreasing the weight of the copper and windings, the great ductility of the conductor makes it simple to bend it into small coils around the core.

4-Transformer oil: Transformer oil insulates as well as cools the core assembly and windings. The core and windings of the transformer shall be completely immersed in an oil usually containing hydrocarbon mineral oil.

5- Conservator: The conservator is an airtight metal cylindrical drum mounted above the transformer to store transformer oil. It is vented at the top and is only half filled with oil to allow expansion and contraction during temperature changes. However, the transformer's main tank is connected to the storage unit, which is completely filled with oil through a pipe.

6-Breather: he breather is a cylindrical container filled with silica gel, which is used to keep the air entering the vessel from becoming damp. This is because insulating oil reacts with moisture which can affect the insulation and cause internal failures, so it is important to keep the air free of moisture. As the air passes through the silica gel in a breathing tube, the moisture components are absorbed by the silica crystals.

7-Tap changer-transformer parts: A tap changer is used to balance voltage variations in the transformer. There are two types of tap changers - on load and off load. In a loaded tap changer, tapping can be changed without isolating the transformer from the supply, while at no load the transformer needs to be disconnected from the supply.

8-Cooling tube: As the name suggests, the cooling tube is used to cool the transformer oil. The circulation of oil in the transformer can be natural or forced. In the case of natural circulation, when the oil temperature rises, the hot oil naturally moves upward and the cold oil moves downward, while in the case of forced circulation, a permanent pump is used.

9-Buchholz Relay: Placed on the connecting pipe that runs from the main storage tank to the storage tank, the Buchholz Relay senses faults in the transformer. It operates on the gases emitted by the breakdown of transformer oil during internal faults. So this device is used to sense and in turn protect the transformer from internal faults.

10- Explosion vent: The boiling hot oil from the transformer is drained out in case of internal fault through the vent of the generator to avoid explosion of the transformer. This is generally placed above the level of the conservatory tank.

2.4Type of connections in Distribution System :

The distribution system is classified into three types according to the method of connection:

-Radial System : Each location in a radial system receives power from the substation via a different feeder. Additionally, this feeder only supplies electricity in one direction to a distributor. The radial system's design is straightforward and easy to integrate in the system.

When compared to other systems, this system has a lower startup cost. [19]

But the reliability of this system is very low. If one feeder is out of step condition, the entire system will stop. This type of system is only used for a short-distance distribution system.

The consumer far from the feeder may suffer poor voltage regulation and voltage fluctuation with a variation of load. Due to this advantage, this type of system is only used to supply the load which is near to the feeder.

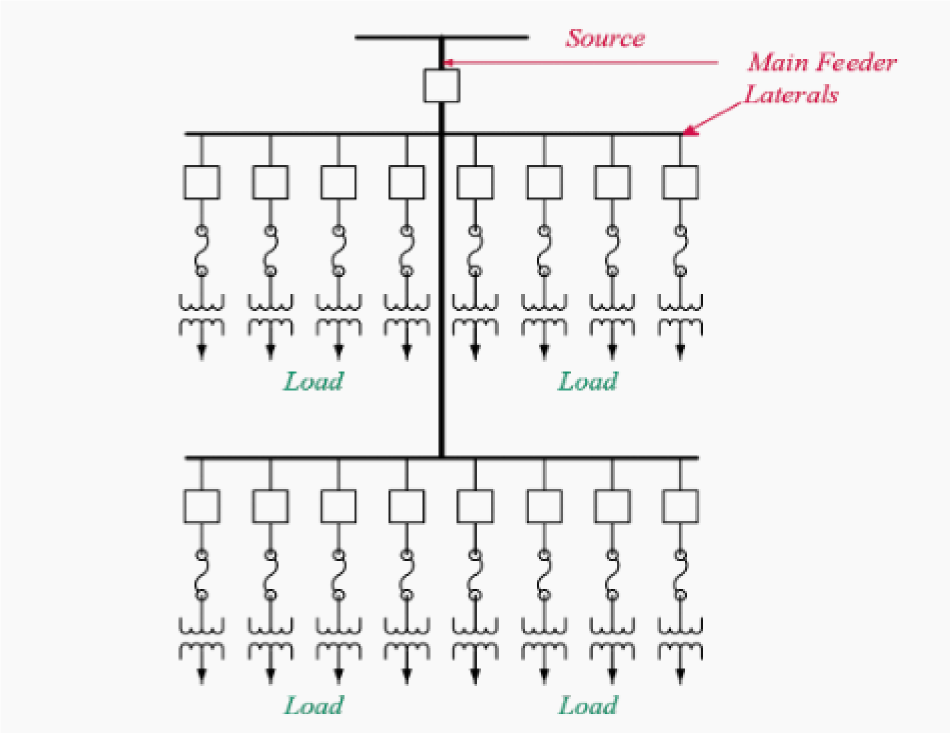


Figure 26-radial distribution system topology

-Ring Main System: In the ring main system, the distribution transformer is connected in a loop and supplied by a substation from one end. It means each distribution transformer has two different ways to connect with the substation

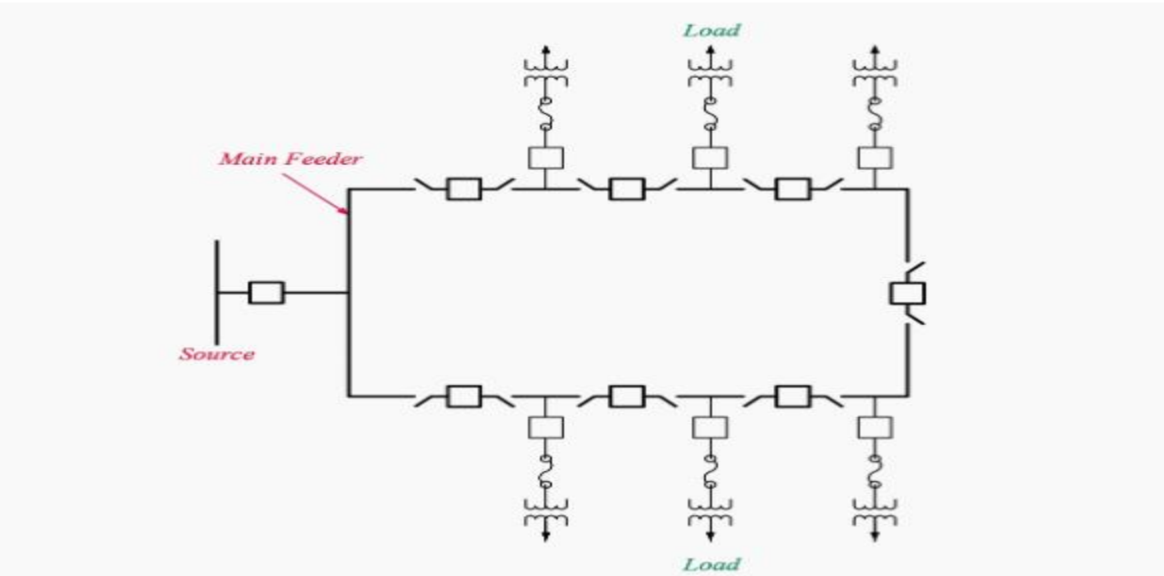


Figure 27-ring main distribution system topology

This configuration is comparable to two feeds that are connected in parallel. Assume a fault develops between points B and C. The region between B and C will isolate from the system in this scenario. Power is supplied via substations in two different methods.It increases the system's dependability. At the consumer's end, there is also reduced voltage fluctuation. Less current flows through each ring component. Therefore, compared to a radial system, less conductor material is needed. [19]

Interconnected Distribution System : In an interconnected distribution system, a loop is supplied by more than one substation at different points. This system is also known as a grid distribution system

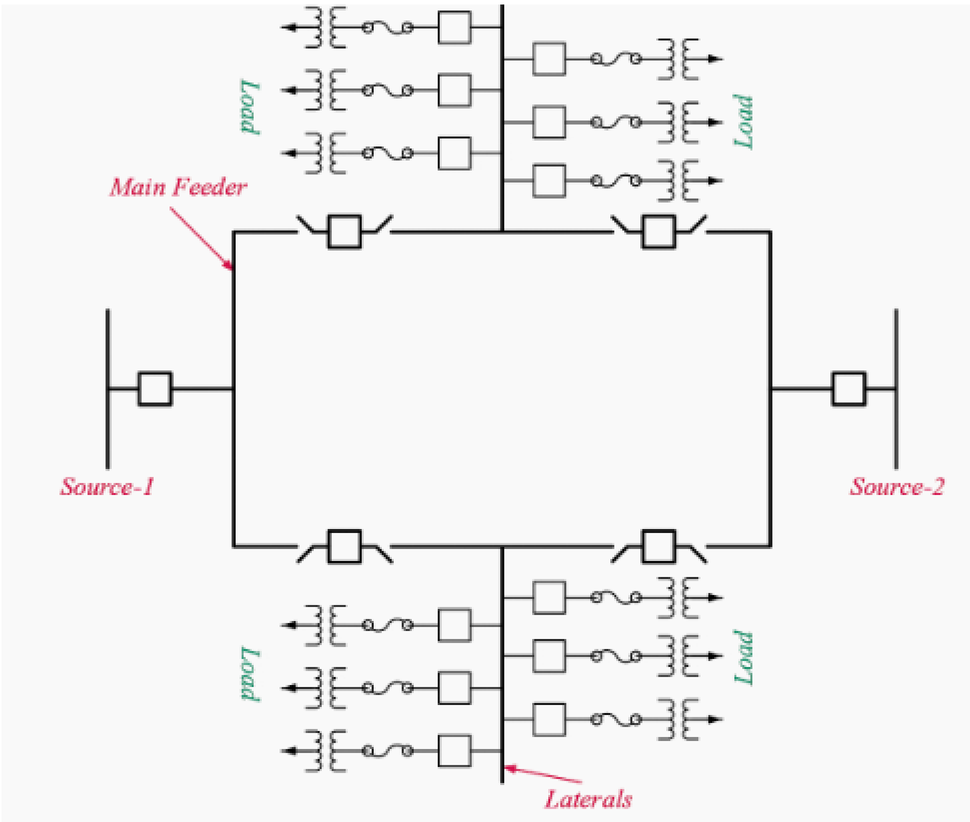


Figure 28-interconnected distribution system topology

The loop ABCDEFGHA is fed by two substations at positions A and E, as seen in the following diagram. Comparing the system to the ring main and radial system, this sort of layout boosts system reliability.

As more substations are needed in a system, the design of the connected system is particularly challenging, and the system's initial cost is likewise significant. However, this method has the benefit of having better power quality and being more effective. This system lowers the capability for reserve power.. [19]

2.5conclusion

This introductory chapter provides an overview of the distribution system's structure and introduces the key elements that will be discussed in upcoming chapters. Understanding the terminology and concepts presented in this chapter is vital for comprehending the content of the subsequent chapters. It establishes the necessary foundation for delving deeper into the subject matter.

Chapter three : Presenting SCMI factory network & philosophy of protection scheme

SCMI distribution system

3.1Introduction

This chapter provides an overview of the SCMI factory distribution network, including its overall structure, zones, and the progression from high voltage to low voltage. The chapter also discusses the methodology and design procedures for implementing protection schemes in each voltage level. It is important to note that all the information and schemes presented in this chapter are derived from the SCMI factory.

3.2High voltage substation

SCMI factory has two transmission line one of them is main and used to feed the factory and other is backup in case that first one had fallen down. The power which curry on by the lines is coming Arabaa power station.

Transmission line characteristics are :

-has length of 22km

-has height of 20m

-it operate with 63kV

-type of high voltage alternative current HVAC

-cross section of the cable is 331mm^{2}AAAC

At The end Transmission line there is substation. Consisting of instrument transformer CT and VT which divided into transformer used for measurement and others used for protection.

It must be mention the differences between instrument transformer used for measurement and one used for protection first has better accuracy but enter the saturation zone after 1.25 times of nominal secondary current and it connected with control room where DCS and PLC are there while protection instrument transformer has less accuracy and wider saturation zone because it enter it after 20 times of nominal current and it connected to protective relays through special communication channels.

After CT and VT there is high voltage circuit breaker HVCB this circuit breaker can operate up to 72kV and used SF6 gas as extinction on series with disconnector .

There are component except what mention above like switch earth, lightning arrestor ,insulator which exist in each section and special transformer which used to create neutral.

The power line go through CB to couple with 63KV bus bar ,feeding two 63/5.5kV transformer one with full power of 37MVA and second with full power of 26MVA they have same characteristics like vector group(DYN11)same voltage(63/5.5) ,tap changer(5%)

frequency but there is coupler in 5.5kV bus bar in secondary side which is on open state so that the two transformer are not in parallel and each on feeding own section that due two reasons:

-absence of synchronoscope in case of voltage fluctuation in one or two of sides ,that will cause of circulating current inside the transformers.

-danger that if two transformers are loaded with over 50% of total nominal power in case that one of them did go out of service the others will be loaded over 100% of full capacity which will lead to overheat or ever damage to the transformer.

Beside that we find ring main unit RMU which feed an other consumer out of factory, following figure represent the schematics of HV system of factory.

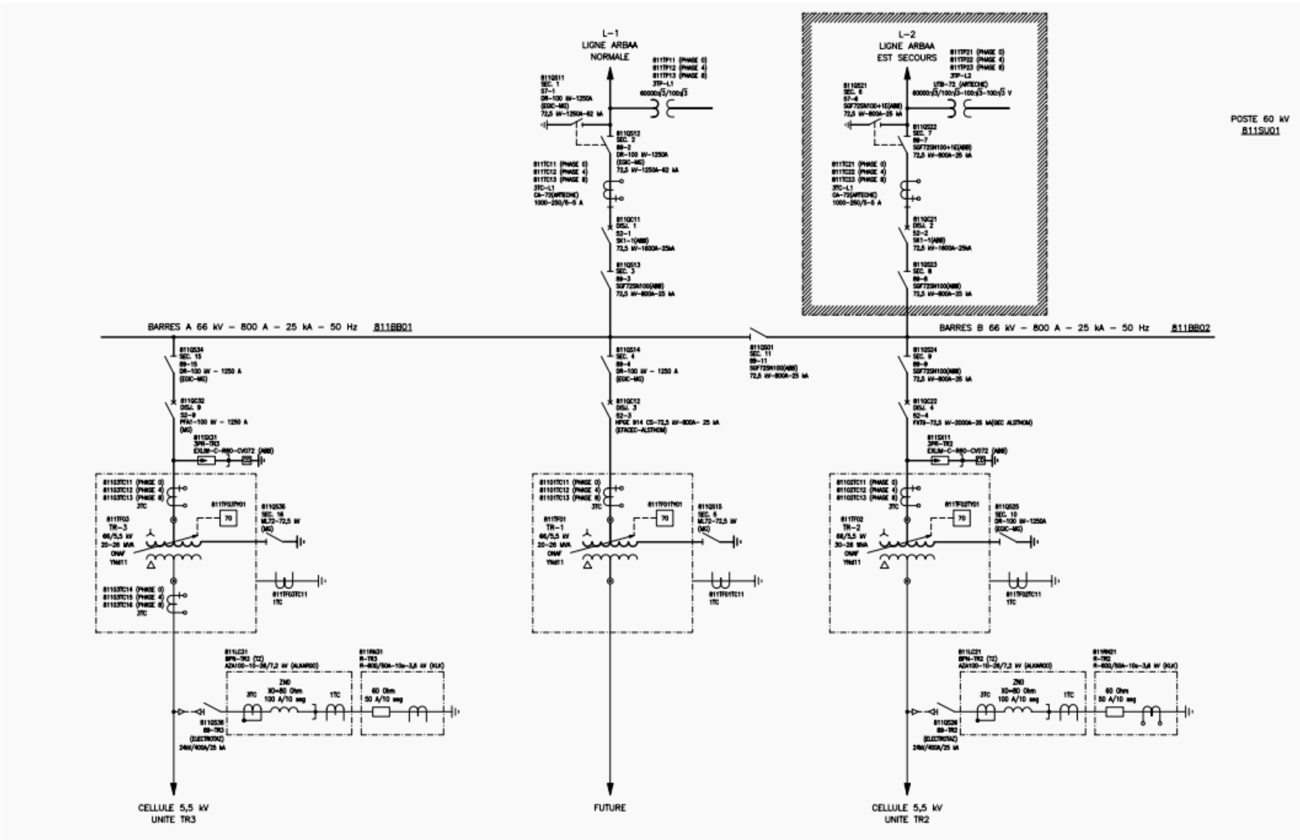


Figure 29-60Kv substation of SCMI factory

The transmission lines are safeguarded by the REL 615 relay manufactured by ABB, which incorporates two active protection functions. The primary and highest priority is assigned to distance protection (function 21), while the secondary priority is allocated to overcurrent protection (function 50/51).

The RET615 relay provides protection for the two transformers, offering differential protection (function 87T) for faults occurring within the transformer zone. Additionally, it includes overcurrent protection for the transformers as a secondary measure if the differential protection (87T) fails to operate.

If a fault occurs outside the transformer zone, the overcurrent protection is activated as follows:

-If the fault is on the primary side, the RET615 relay will open the primary circuit breaker.

-If the fault is on the secondary side, the REF615 relay will open both the primary and secondary circuit breakers.

Furthermore, the RET615 relay features an additional protection function for the primary side, which is ground fault protection (functions 50N/51N). This protection mechanism is designed to detect and respond to ground faults in the transformer's primary circuit.

In summary, the RET615 relay provides differential protection, overcurrent protection, and ground fault protection for the two transformers, ensuring reliable and comprehensive protection coverage, while REF615 protect bus bar and incoming 5.5KV from short circuit and undervoltage and overvoltage protection

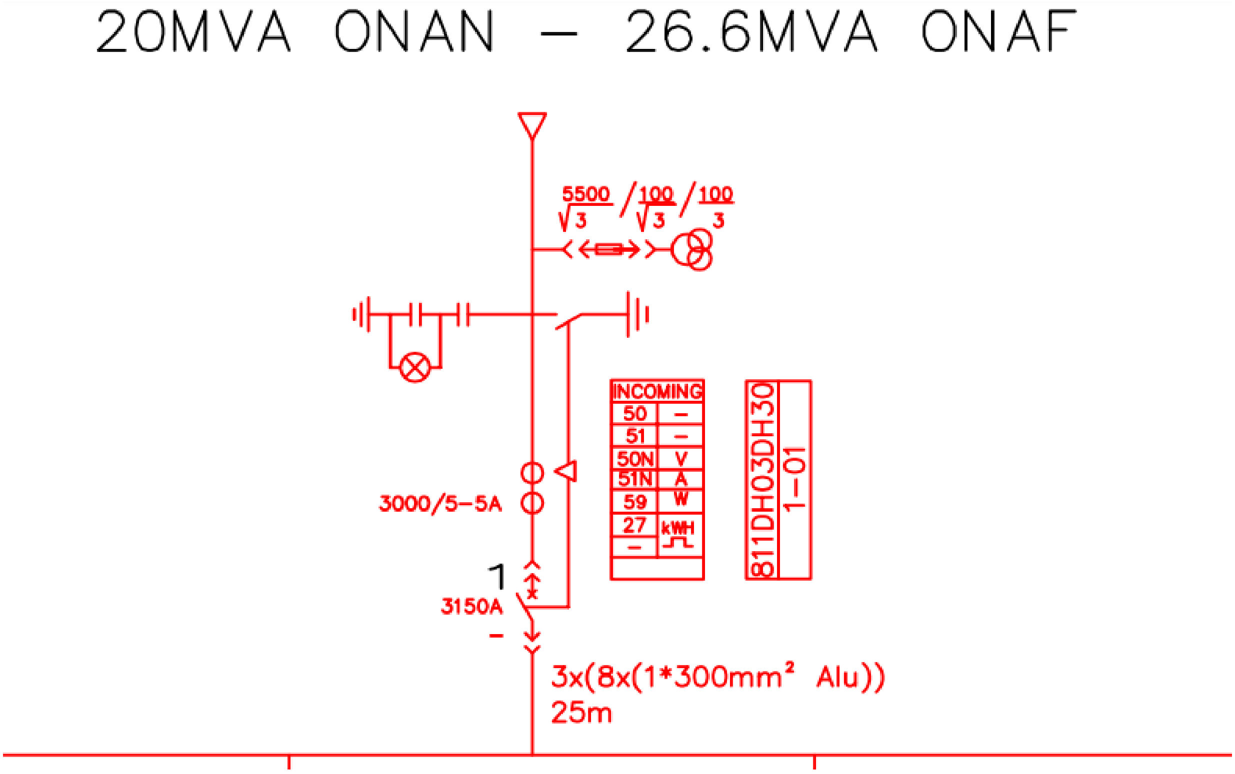


Figure 30-protection scheme of secondary side of 60/5.5Kv transformer

3.3Medium/Low voltage substation

The 5.5 kV busbar is linked to the incoming medium voltage switchgear manufactured by Schneider Electric. The outgoing connections from the busbar serve various purposes, including supplying power to individual zones, multiple zones, or compensation panels used for power factor correction.

Phase-to-ground faults, specifically faults occurring in the phases (50N/51N), are detected in the system. Additionally, there is an additional protective function known as negative sequence/unbalanced protection (function 46). This function serves to detect and respond to imbalances or negative sequence currents in the system. In the switchgear that supplies power to capacitor banks, an extra protective function for overvoltage protection is present, and time delay overcurrent protection for phase faults (51) and ground faults (51N) is not implemented. Instead, instantaneous protection (50/50N) is utilized for these faults. The switchgear is protected by the SEPAM S40 protective relay from Schneider Electric, which is a multifunction relay providing active overcurrent protection (51/50) as the primary protective measure for faults.

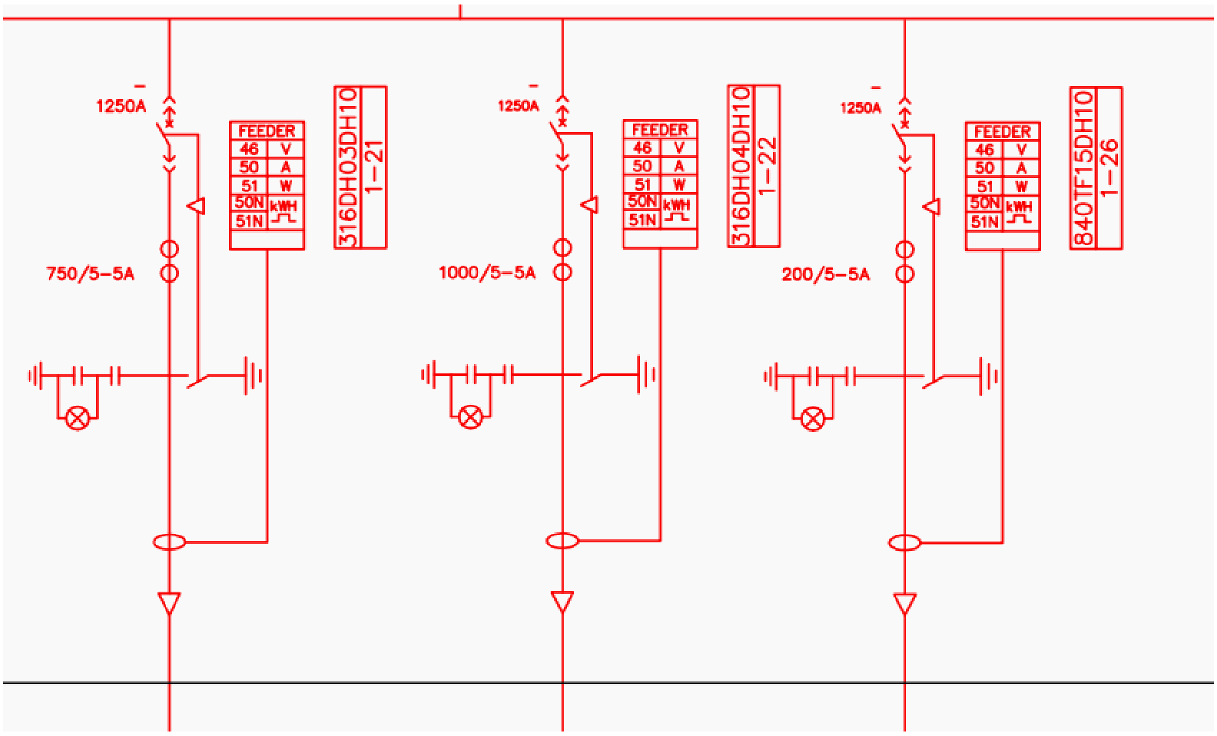


Figure 31- protection scheme of medium voltage feeder

There are two capacitor banks connected in a delta configuration with a total capacity of 400 kVA. These capacitor banks are linked to the 5.5 kV bus bar, forming part of the electrical distribution system. The delta connection ensures a balanced distribution of reactive power and helps improve the power factor of the system by compensating for any lagging reactive power. The capacitor banks play a crucial role in maintaining a more efficient and stable electrical system by reducing losses and improving voltage regulation.

In the SCMI factory, there are five main production zones that are presented as follows:

1.-Quarry Area: This area is dedicated to the extraction of raw materials, such as stones or minerals, needed for the production process.

2.-Flood Area: The flood area is involved in the preparation and treatment of materials before they proceed to the next stages of production.

3.-Cooking Area: In the cooking area, the raw materials are processed and transformed into the desired products through specific heating or cooking processes.

4-.Cement Area: This area focuses on the production and handling of cement, which is a vital component in various construction and manufacturing processes.

5.-Shipping Area: The shipping area is responsible for the packaging, storage, and transportation of the finished products to their respective destinations.

Additionally, some of these main areas may consist of subareas, which are specific sections within each zone that serve distinct purposes or carry out specialized tasks related to the overall production process.

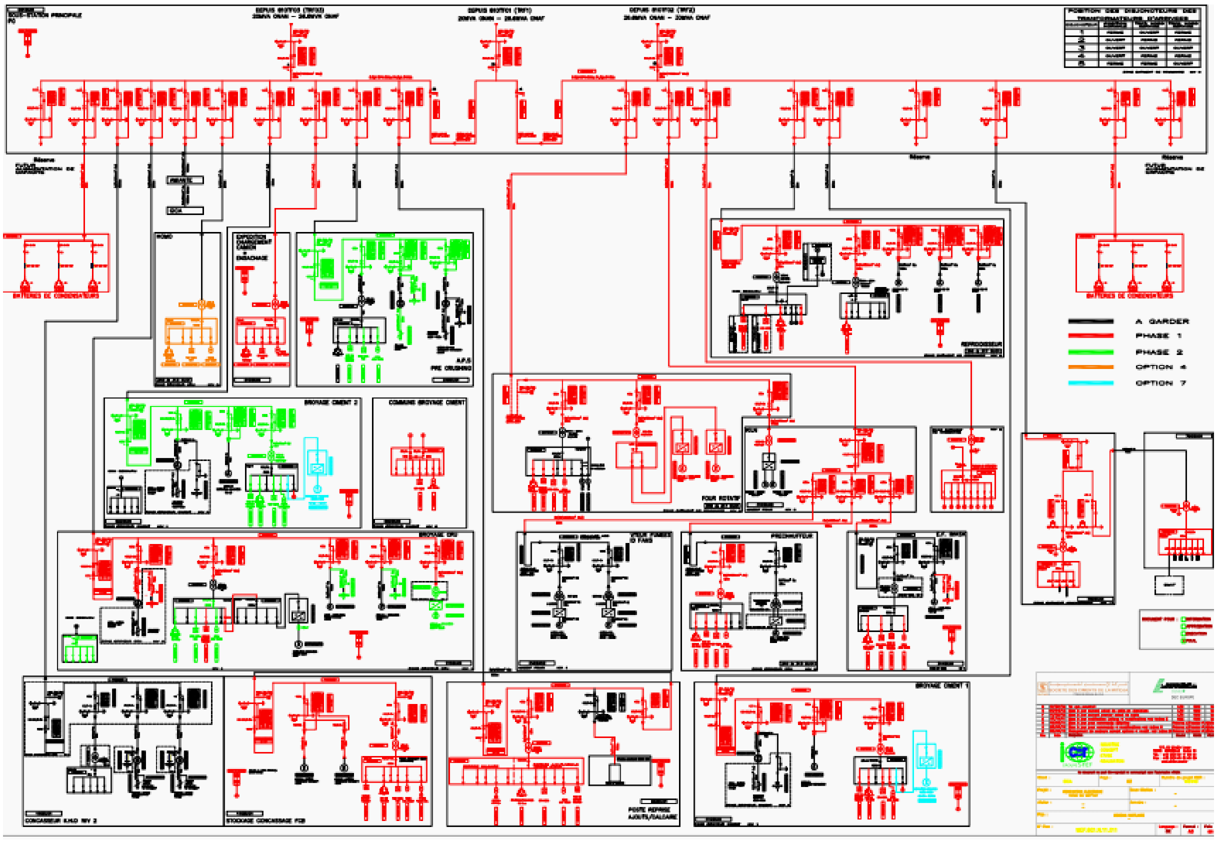


Figure 32-single diagram of SCMI factory

In ETAP (Electrical Transient Analyzer Program), when designing a protection scheme that addresses selectivity issues, it is important to focus on specific zones or areas of the electrical system. Selectivity refers to the ability of the protection devices to isolate only the faulty section of the system while leaving the rest of the system operational. This ensures that disruptions are minimized and power supply is maintained to unaffected areas.

For example, let's consider a protection scheme involving cooking equipment and a subarea called APS (Assumed Power Supply) Pre Crushing. The objective is to design a protection scheme that allows the detection and isolation of faults in these specific zones while maintaining selectivity.

To achieve this, you would typically analyze the electrical system, considering factors such as fault currents, protective device characteristics, and coordination requirements. The following steps can be followed:

Define the protection zones: Identify the specific areas or zones within the electrical system that require protection, such as the cooking equipment zone and the APS Pre Crushing subarea.

Determine fault characteristics: Analyze the fault currents and other fault parameters within each zone. This information helps in selecting appropriate protective devices and settings.

Select protective devices: Choose protective devices such as circuit breakers, relays, fuses, or other protective elements suitable for each zone. Consider the characteristics of these devices, including their time-current curves, trip settings, and coordination capabilities.

Coordinate protective devices: Ensure that the protective devices in each zone are coordinated properly. Coordination involves setting the trip times and current thresholds of the protective devices to create a time-current grading scheme. This allows the device nearest to the fault to operate first, while minimizing unnecessary tripping of upstream devices.

Conduct simulation and analysis: Utilize ETAP or similar software to simulate fault scenarios and verify the selectivity and coordination of the protection scheme. This step helps identify any selectivity problems and allows adjustments to be made to settings or device selection if required.

Iterate and optimize: Fine-tune the protection scheme based on the simulation results and analysis. Make adjustments to settings, device ratings, or coordination parameters as needed to achieve the desired level of selectivity and fault isolation.

By following these steps and utilizing ETAP or other similar software, you can design a protection scheme that addresses selectivity problems and ensures reliable and selective operation in specific zones like cooking equipment and subareas such as APS Pre Crushing.

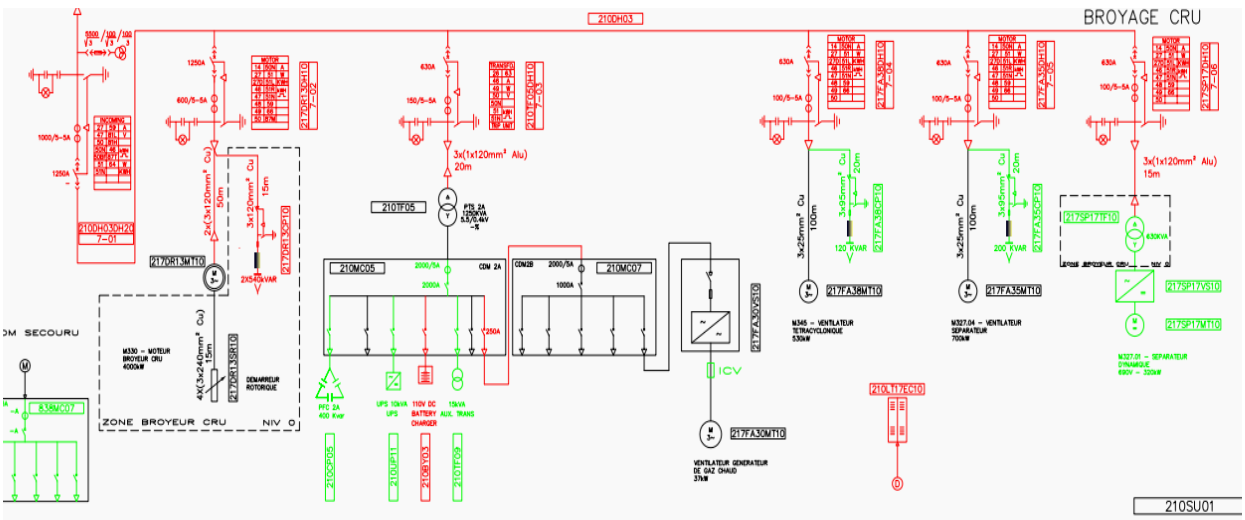


Figure 33-“cru” zone single diagram

Switchgear that feeds medium voltage motors can be protected by SEPAM S40, which provides various functions for motor protection. One of the primary functions is the overcurrent protection (50/51) that activates in the case of phase faults. Additionally, there are specific overcurrent protection functions for ground faults, such as 50G/51G or 50N/51N, depending on the CT's (Current Transformer) connection.

In addition to overcurrent protection, SEPAM S40 also offers other protections like under and overvoltage (27/59) to safeguard the motor against voltage abnormalities. However, these additional protections are often disabled unless there is a specific requirement or concern.

For larger motors exceeding 1000kW, an extra protection feature called motor differential protection (87M) is commonly employed. Motor differential protection (87M) is a sensitive protection scheme that detects internal faults within the motor windings by comparing the currents entering and leaving the motor. It helps prevent damage to the motor due to internal faults and ensures the motor's safe operation.

Furthermore, the SEPAM S40 may include other advanced protection functions like negative sequence/unbalanced protection (46) and negative sequence overvoltage (47)..etc. These functions provide enhanced protection against unbalanced conditions and negative sequence voltages, which can occur due to system faults or abnormalities.It is important to note that the specific configuration and functionalities of protection devices can vary based on the application, motor type, and the requirements of the electrical system. Consulting the product documentation and working with qualified professionals is essential to ensure the appropriate

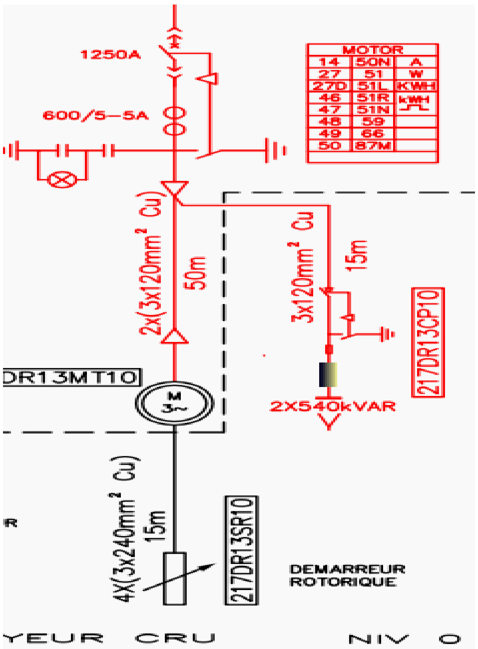


Figure 34-4Mw motor protection scheme

Switchgear that supplies medium voltage/low voltage transformers are safeguarded by the SEPAM S40 relay, which incorporates various features to ensure protection. These features include the ability to detect overcurrent faults in the phases (50/51 function) and ground faults (50N/51N function). Additionally, the SEPAM S40 relay can offer supplementary protections tailored to specific application requirements.

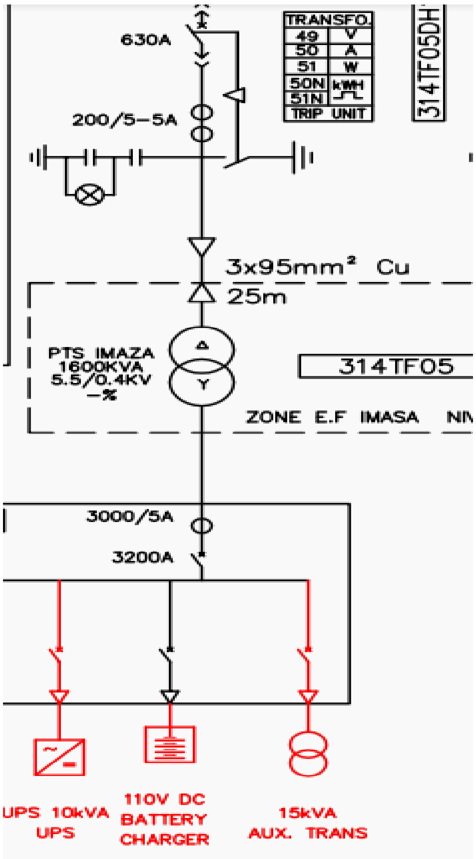


Figure 35-protection scheme of 5.5/0.4Kv transformer

In a low voltage system, which typically comprises various loads such as Motor Control Centers (MCCs), lighting, and resistive loads, the protection is typically provided by a combination of three devices: Miniature Circuit Breakers (MCBs), thermal relays, and fuses. These devices work together to ensure the safety and proper functioning of the system.

Miniature Circuit Breakers (MCBs): MCBs are commonly used in low voltage systems to protect against overcurrents and short circuits. They are designed to trip and interrupt the current flow when the current exceeds a certain threshold. MCBs are adjustable and provide convenient manual operation for circuit isolation.

Thermal Relays: Thermal relays, also known as overload relays, are designed to protect the system against excessive current over an extended period. They monitor the current flowing through the circuit and, if it exceeds a predetermined level for a specified time, they trip and disconnect the circuit. Thermal relays provide protection against sustained overloads that could damage the equipment.

Fuses: Fuses are another common protection device in low voltage systems. They consist of a metal wire or strip that melts when exposed to excessive current. When a fault occurs, the excessive current causes the fuse element to melt, opening the circuit and protecting the connected equipment. Fuses are generally one-time use devices and need to be replaced after they operate.

The combination of MCBs, thermal relays, and fuses allows for comprehensive protection in low voltage systems. MCBs offer quick and adjustable protection against short circuits, while thermal relays protect against sustained overloads, and fuses provide an additional layer of fault protection. The specific choice and arrangement of these devices depend on the load characteristics, system requirements, and safety standards applicable to the installation.

3.4Importance Damage curve

The damage curve, also known as a time-current characteristic curve or trip curve, plays a crucial role in setting protective relays in electrical power systems. It helps ensure that the relays are properly coordinated and provide effective protection against faults and overloads. Here are some key reasons why the damage curve is important in protective relay setting [20]:

-**Selective Coordination**: Selective coordination is the ability to selectively isolate faults in a power system, ensuring that only the closest protective device to the fault operates while minimizing the impact on the rest of the system. The damage curve allows engineers to set the time-current characteristics of protective relays at different locations within the system, ensuring proper coordination. By analyzing the damage curves of relays and their respective settings, engineers can determine the appropriate time delays and current thresholds to achieve selective coordination.

Fault Detection and Clearance: The damage curve helps in setting the relay's trip characteristics for fault detection and clearance. By analyzing the curve, engineers can determine the appropriate settings to ensure that the relay operates within a specific time frame when a fault occurs. The curve provides valuable information about the relay's response to fault currents of different magnitudes, helping to detect and clear faults efficiently.

Overload Protection: In addition to fault protection, protective relays also play a crucial role in protecting the system against overloads. The damage curve helps in setting the relay's time-current characteristics to ensure effective overload protection. By analyzing the curve, engineers can determine the appropriate time delays and current thresholds to prevent sustained overloads that could damage the equipment or lead to system instability.

Equipment Protection: Setting the protective relay based on the damage curve helps in protecting critical equipment within the power system. By ensuring that the relay operates within the specified time frame, faults and overloads can be cleared promptly, preventing excessive damage to transformers, motors, generators, and other components. This helps in reducing downtime, minimizing repair costs, and extending the equipment's operational lifespan.

Safety: The damage curve also contributes to ensuring the safety of personnel working in and around the power system. By setting the protective relay with appropriate trip characteristics, it helps in quickly isolating faults, minimizing the risk of electrical hazards, and enhancing overall system safety.

In summary, the damage curve is vital in protective relay setting as it enables selective coordination, facilitates fault detection and clearance, provides overload protection, safeguards critical equipment, and enhances system safety. It allows engineers to determine the optimal relay settings to achieve reliable and efficient protection for electrical power systems.

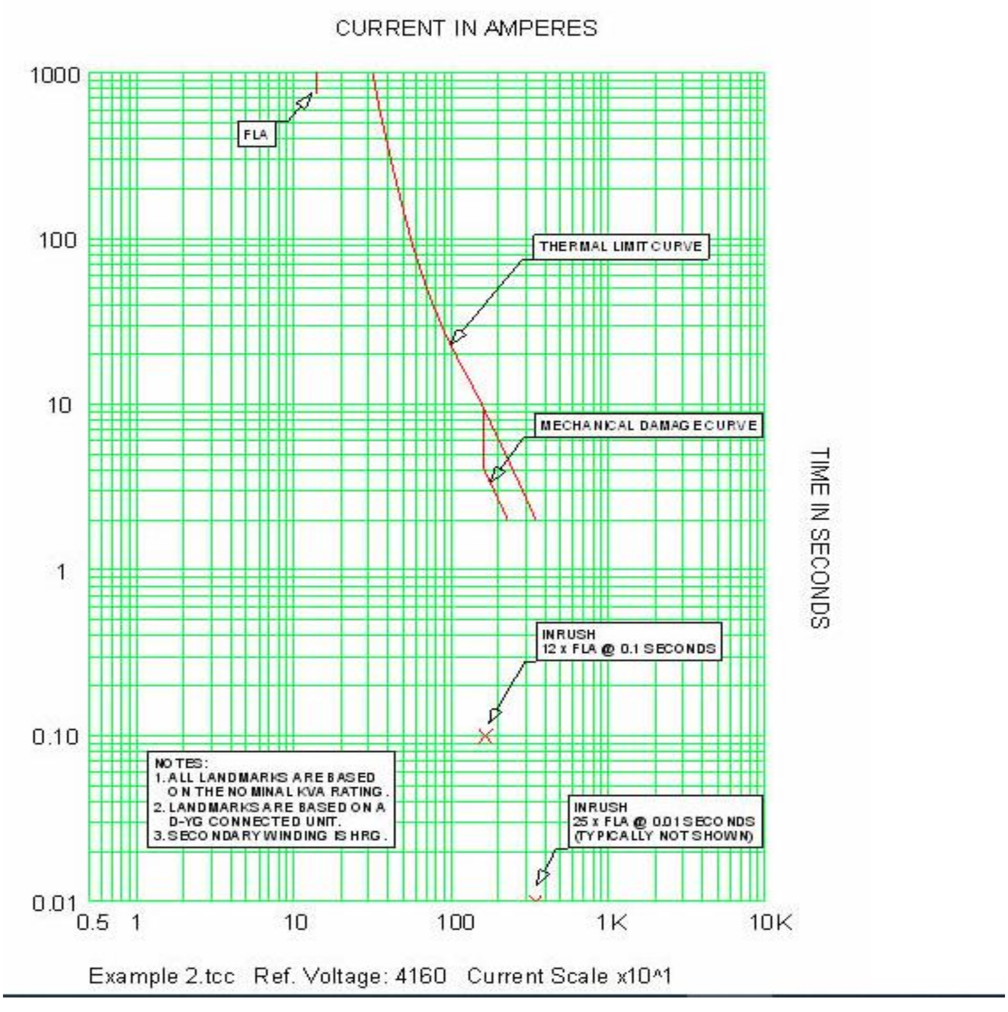


Figure 36-damage curve of transformer

3.5Overcurrent relay setting

The process of setting overcurrent relays involves several steps to ensure effective and coordinated protection. Here is a general outline of the steps involved in overcurrent relay setting:

3.5.1CT selection:

CT selection for a power system primarily depends on two key factors: the maximum load current and the CT class. [21]

1-**Maximum Load Current:** The CT should be selected to accurately measure the maximum load current in the system. This involves considering the expected normal operating current levels of the power system. The maximum load current helps determine the appropriate current rating of the CT. The CT's primary current rating should be higher than the maximum load current to ensure accurate measurement and avoid saturation of the CT core.

2-**CT Class:** The CT class refers to the accuracy class of the CT and specifies the allowable error in current measurement. CT classes are defined by standards such as IEEE C57.13 and IEC 60044. The selection of the CT class depends on the specific application requirements. Common CT classes include Class 0.1, Class 0.2, Class 0.5, Class 1.0, and Class 3.0, among others. The accuracy class determines the maximum deviation allowed between the CT's measured current and the actual current flowing through the primary circuit. Higher accuracy classes are typically used for more critical applications, such as protective relaying, revenue metering, or power quality monitoring.

While maximum load current and CT class are important factors, other considerations may also come into play when selecting CTs, including:

-**Saturation Characteristics**: CTs should be selected to operate within their linear range to avoid distortion and inaccuracies. Consider the expected fault currents and potential transient currents to ensure that the selected CT can handle such conditions without saturation.

That can calculated by compare between V_S and V_K where:

$$V_S = If*(R_{CT} + R_L + R_r)$$

$$V_K = \frac{\text{rated VA}}{\text{In}} * ALF + In * Rct * ALF$$

It must be that :$V_K > V_S$ in order to say that CT is suitable for realy

-**Burden**: Consider the burden requirements of the connected devices (e.g., protective relays, meters) that the CT will supply current to. Ensure that the CT can deliver the necessary secondary current while meeting the burden and accuracy requirements of the connected devices.

3.5.2Pickup value:

The pickup value for an overcurrent relay is indeed dependent on various factors such as the type of loads, sources, and feeders being protected. Here are some common considerations for determining the pickup value:

Motor Loads: For motor loads, it is generally recommended to set the pickup value of the overcurrent relay between 125% to 150% of the maximum load current. This range provides an appropriate margin for motor starting currents and transient overloads. [21]

Sources and Feeders: When protecting sources such as transformers or power cables, the pickup value can be determined using the following guideline:

Minimum pickup value: 1.25 times the full load current of the equipment being protected. [22]

Maximum pickup value: 2/3 of the minimum short circuit current available at the relay location. This ensures proper coordination with downstream protective devices and avoids nuisance tripping. [22]

ETAP can assist in identifying both the minimum and maximum pickup values for overcurrent relays.

3.5.3TDS selection

The selection of the Time Dial Setting (TDS) for overcurrent relays should take into consideration a coordination study, which involves setting a time gap between relays to ensure proper coordination. This time gap is known as the relay time grading margin and depends on four factors [22]:

-t_{CB}=operating time for circuit breaker =40:100ms

-t_{Reset}=Reset time for relay=40:70ms

-t_{Inacc}=the sum of inaccuracy in time measurement=50:70ms

-t_{margin}=safety magin=30:100ms

Considering these factors, practical experience has shown that a suitable time gap between relays is often around 400 ms. This allows for adequate coordination and ensures that the downstream relay operates within its time margin after the upstream relay has cleared the fault.

Once the coordination time interval is determined, select the appropriate TDS multiplier for each relay involved in the coordination. The TDS multiplier is typically chosen to achieve the desired coordination time interval. [22]

3.5.4Advantages of inverse curve over definite time curve

Inverse curve relays offer several advantages over definite time curve relays in protective relay applications. Here are some of the advantages of using inverse curve relays:

-Selectivity and Coordination: Inverse curve relays allow for better selectivity and coordination in protective systems. The inverse characteristic provides a time delay that decreases as the fault current increases. This allows relays closer to the fault to operate faster, ensuring that only the nearest relay trips while other downstream relays remain unaffected. Selectivity and coordination are crucial in preventing unnecessary tripping of healthy sections of the system and minimizing power interruptions.

-**Flexibility and Adaptability**: Inverse curve relays offer greater flexibility in adjusting the time delay based on the magnitude of the fault current. The inverse characteristic allows for customization of the relay settings to match the specific requirements of the system. This flexibility is particularly useful when dealing with different types of loads, fault levels, and system configurations.

-Improved Sensitivity: Inverse curve relays are more sensitive to low-level fault currents compared to definite time curve relays. The inverse characteristic allows for faster response to smaller fault currents, enabling earlier detection and quicker isolation of faults. This improved sensitivity enhances the overall reliability and performance of the protective system.

-Fault Discrimination: Inverse curve relays can discriminate between different types of faults more effectively. The varying time delay with fault current magnitude allows the relay to distinguish between low-level faults, such as transient or temporary faults, and high-level faults, such as sustained faults. This discrimination capability helps in minimizing unnecessary tripping during transient fault conditions, thereby improving system reliability.

-Industry Standards: Inverse curve relays are widely accepted and recommended by industry standards such as ANSI/IEEE or IEC. These standards have established curve shapes and settings for different types of inverse curves (e.g., standard inverse, very inverse, extremely inverse). Adhering to these standards ensures compatibility, interoperability, and consistency in protective relay applications across different systems and manufacturers.

3.4.5Instantaneous overcurrent relay

Instantaneous overcurrent relays are ideal for detecting severe high-current faults because they trip instantly without any time delay when the fault current exceeds the set value. However, coordinating the timing between different relays, especially when there are successive lines of different lengths, can be challenging. When determining the settings for an instantaneous overcurrent relay, several factors should be considered:

-Coordination with Consecutive Lines: If the relay is used to protect consecutive lines, the pickup value should be set higher than 125% to 150% of the symmetrical fault current value at the next substation. This ensures that the closest relay to the fault operates first while allowing coordination with downstream relays. [22]

-Last Relay in the System: The final relay in the system, which does not coordinate with any other relays, should be set to trip at half of the short circuit current value. This setting enables prompt detection of faults at the end of the line without unnecessary tripping for lower-level faults.

-Setting Adjustment Steps: When adjusting the settings of instantaneous overcurrent relays, it is advisable to start from the furthest point from the power source and gradually work towards the source. This approach facilitates proper coordination and sequential operation of the relays along the power distribution system.

Calculating the settings for instantaneous overcurrent relays requires a comprehensive understanding of the system, fault currents, and protective relay settings. Conducting coordination studies, including fault analysis and load flow calculations, is crucial for achieving the desired coordination and selectivity in the protective system. Adhering to industry standards and best practices is essential for effective relay coordination, ensuring reliable fault detection, and efficient fault isolation

here actual excel sheet of real configuration of protective relay

Calculation of IDMT Over Current Relay Settings:		
Name of Feeder		
Load Current: (IL)	384	Amp
Min Fault Current (Line-Line):	11000	Amp
Max Fault Current (Line-Line):	22000	Amp
Relay Type		
Relay Code		
Relay No		
CT Primary Current	600	Amp
CT Secondary Current	1	Amp
Relay Error (%)	**7.5%**	
CT Error (%)	**10.0%**	
Over shoot	**0.05**	Sec
C.B Interrupting Time	**0.17**	Sec
Safety	**0.33**	Sec
Total Grading Time	**0.58**	Sec
Expected Operating Time of Relay	**0.271**	Sec
Over Current Relay Setting		
Low Over Current Setting: (I>)		
Over Load Current :	125%	X IL
Over Load Current :(In)	480	Amp
Required Over Current Relay Plug Setting	0.8	**0.8 A X In**
Actual Plug Setting of Over Current Relay	0.80	**0.8 A X In**
Time Dial Setting of Over Current Relay (TMS)	0.125	Sec
Curve Selection for Relay	Normal Inverse (NI)	
Pick Up Setting of Over Current Relay (P	**0.8**	**Amp**
Plug Setting Multiplier (PSM):	**22.92**	
Operation Time of Relay	2.17	Sec
Actual Operating Time of Relay : (tI>)	**0.271**	**Sec**
Total Grading Time	0.58	Sec
Operating Time of Previous Up steam Relay	0.85	Sec
High Over Current Setting: (I>>)		
Actual Plug Setting of Relay	2.50	**2.5 A X In**
Time Dial Setting of Over Load Relay (TMS)	0.100	Sec
Curve Selection for Relay	Normal Inverse (NI)	
Pick UP Setting of Over Load Relay (PM:	**2.5**	**Amp**
Plug Setting Multiplier (PSM):	**7.33**	
Time of Operation of Relay	3.44	Sec
Actual Operating Time of Relay : (tI>>)	**0.34**	**Sec**
Total Grading Time	0.58	Sec
Operating Time of Previous Up steam Relay	**0.92**	Sec

Calculation of IDMT Earth Fault Relay Settings:		
Name of Feeder		
Load Current: (IL)	384	Amp
Min Fault Current (Line-Ground):	11000	Amp
Max Fault Current (Line-Ground):	22000	Amp
Relay Type		
Relay Code		
Relay No		
CT Primary Current	600	Amp
CT Secondary Current	1	Amp
Relay Error (%)	**7.5%**	
CT Error (%)	**10.0%**	
Over shoot	**0.05**	Sec
C.B Interrupting Time	**0.17**	Sec
Safety	**0.33**	Sec
Total Grading Time	**0.58**	Sec
Expected Operating Time of Relay	**0.176**	Sec
Earth Fault Relay Setting		
Low Earth Fault Setting: (Ie>)		
Earth Fault Current :	20%	X In
Earth Fault Current	96	Amp
Required Earth Fault Relay Plug Setting	0.2	**0.2 A X In**
Actual Plug Setting of Earth Fault Relay	0.16	**0.2 A X In**
Time Dial Setting of Earth Fault Relay (TMS)	0.125	Sec
Curve Selection for Relay	Normal Inverse (NI)	
Pick Up Setting of Earth Fault Relay (PM	**0.16**	**Amp**
Plug Setting Multiplier (PSM):	114.58	
Operation Time of Relay	1.41	Sec
Actual Operating Time of Relay : (te>)	**0.18**	**Sec**
Total Grading Time	0.58	Sec
Operating Time of Previous Up steam Relay	0.76	Sec
High Earth Fault Setting: (Ie>>)		
Actual Plug Setting of Relay	2.50	**2.5 A X In**
Time Dial Setting of Over Load Relay (TMS)	0.100	Sec
Curve Selection for Relay	Normal Inverse (NI)	
Pick UP Setting of Earth Fault Relay (PM	**2.5**	**Amp**
Plug Setting Multiplier (PSM):	**7.33**	
Time of Operation of Relay	3.44	Sec
Actual Operating Time of Relay : (te>>)	**0.34**	**Sec**
Total Grading Time	0.58	Sec
Operating Time of Previous Up steam Relay	0.92	Sec

Figure 37-excel sheet of overcurrent / earth fault relay

3.5Undervoltage /Overvoltage relay setting

Undervoltage and overvoltage relay settings typically include a margin and a time delay to ensure reliable and stable operation. Here's a breakdown of these settings:

Undervoltage Setting Margin: The undervoltage setting margin is a percentage above or below the nominal voltage level at which the relay is designed to operate. This margin provides a buffer to prevent unnecessary tripping or alarming for minor voltage variations or transient conditions. The specific margin value depends on the application and system requirements. Typically, the undervoltage setting margin can range from 5% to 10% above or below the nominal voltage.

Overvoltage Setting Margin: Similar to undervoltage, the overvoltage setting margin is a percentage above the nominal voltage level. It serves as a buffer to prevent false tripping due to minor voltage surges or transient conditions. The overvoltage setting margin also varies based on the application and system requirements. Typically, it can range from 5% to 10% above the nominal voltage. [22]

The time delay settings for undervoltage relays vary depending on the specific application, equipment being protected, and the desired response time. The purpose of the time delay is to allow for temporary voltage fluctuations or dips without tripping the relay, while still providing adequate protection against sustained low voltage conditions. Here are some typical time delay settings for undervoltage relays:

Instantaneous: Some undervoltage relays may have an instantaneous trip feature, which means they will trip immediately when the monitored voltage falls below the set threshold. This setting is typically used for critical equipment or applications where any voltage drop is considered unacceptable.

Short Time Delay: For less critical loads or systems, a short time delay is often applied to allow for momentary voltage dips or fluctuations. Common short time delay settings range from 0.1 to 1 second. [22]

Long Time Delay: In certain cases, a longer time delay may be used to avoid unnecessary tripping for temporary low voltage conditions. This setting allows for sustained low voltage conditions, such as during a brownout or voltage stabilization period. Common long time delay settings range from 1 to 10 seconds or more. [22]

In Chapter 4 of our ETAP simulation for protection schemes, we will provide a brief overview of additional protections, including differential protection.

Finally we talk about section which can not implemented in ETAP but it exist in industry which is relay communication and control circuit of circuit breaker

3.6Motor contribution

Motor contribution refers to the current produced by one or more motors when a short circuit occurs. Although this value is relatively small, it plays a crucial role in determining the maximum available short circuit current and establishing the short circuit rating of electrical equipment. Whether the motor is large or small, and regardless of its voltage rating, it is evident that motor contribution is present during a fault situation.

In the event of a short circuit, the system voltage experiences a decay, resulting in the absence of a stable voltage supply. At this point, the rotor's rotating magnetic field strives to compensate for the reduced voltage by acting as a power source. As a result, the motor starts supplying additional current to the faulty electrical system. This phenomenon is commonly referred to as "motor contribution." [23]

The current magnitude is determined by the impedance of the motor. Initially, there is an asymmetrical current comprising both AC and DC components. As the rotor flux starts to decrease due to the absence of a stable voltage supply, the AC component of the current decays. Similarly, without a stable voltage supply, the transient DC component also diminishes over time.

Initially, the current provided by the motor has a frequency different from the system frequency due to motor slip. The rate of decay is influenced by the inertia of the motor and the load. It is important to note that this frequency difference does not impact the calculation of the short circuit.

The AC component of the motor's current is determined by the motor impedance, which consists of a resistive component (Rm) and a reactive component (Xm). The resistive component is significantly smaller than the reactive component. Hence, when calculating motor contribution, the inductive component (Xm) is considered to provide a conservative value. [23]

Induction motor contribution typically lasts from one to four cycles from time equal zero during a short circuit condition. Some may this interval very small but it may cause unnecessary tripping and increase the short circuit above maximum short circuit current.

When detailed motor data is unavailable, approximations can serve as a valuable tool. In the case of large motors or groups of large motors, the lock rotor current, which is typically 5 to 7 times the full load current, can be used as a substitute for the actual motor impedance. This approach ensures a highly conservative value for calculations. [23]
For small motors or groups of small motors, it is recommended to use a value of 0.20 to 0.28 per unit instead of relying on actual motor impedance data. This approximation provides a practical estimate for the motor contribution in such cases. [23]

To mitigate or avoid motor contribution during a short circuit condition, there are a few possible solutions:

-Variable Speed Drives (VSD): Using a VSD or VFD (Variable Frequency Drive) for motor control can help reduce motor contribution during a short circuit. VSDs have built-in protection features that can detect fault conditions and quickly disconnect the motor from the system. This helps minimize the contribution of the motor to the short circuit current. [24]

-Reactors: Installing reactors in the motor circuit can limit the magnitude of motor contribution during a short circuit. Reactors introduce impedance into the motor circuit, which reduces the fault current and limits the contribution of the motor to the overall short circuit current. [25]

-Current Limiters: Current limiters, such as fuses or circuit breakers with adjustable current limiting features, can be employed to restrict the amount of current that the motor can contribute during a short circuit. These devices are designed to limit the fault current to a specific level, preventing excessive motor contribution [25]

3.7relays communication and control circuit of CB

Communication between relays and the control circuit of a circuit breaker is essential for coordinated and efficient protection of the electrical system. It enables relays to send signals to the circuit breaker, instructing it to open or close based on the detected fault or abnormal condition. Here are the key aspects of communication between relays and the control circuit of a circuit breaker: [26]

Trip Signals: When a relay detects a fault, it sends a trip signal to the control circuit of the circuit breaker. This signal instructs the circuit breaker to open and disconnect the faulty section of the electrical system.

-Communication Protocols: Communication between relays and the circuit breaker control circuit is typically established using standardized communication protocols, such as IEC 61850, Modbus, or DNP3. These protocols define the format and rules for data exchange and ensure compatibility and interoperability between devices from different manufacturers.

Communication Medium: The communication medium used for relay-circuit breaker communication can vary. It can be wired communication using Ethernet cables or serial communication, or it can be wireless communication using technologies like radio frequency (RF) or Wi-Fi.

-Protection Coordination: Communication between relays and the circuit breaker control circuit allows for coordinated protection schemes. Through proper communication and coordination, relays can exchange information, coordinate trip signals, and ensure selective tripping of circuit breakers to isolate faults while minimizing disruption to the rest of the system.

Status Feedback: In addition to trip signals, relays can receive status feedback from the circuit breaker control circuit. This feedback includes information about the circuit breaker's position (open or closed), status (tripped or reset), and any alarms or faults detected by the circuit breaker.

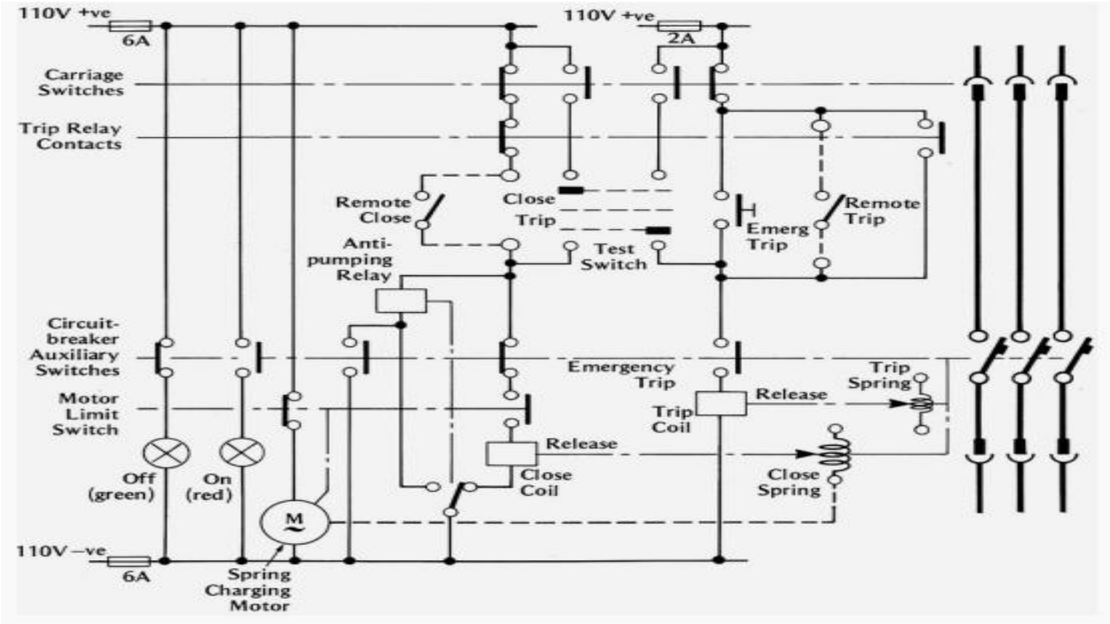


Figure 38-control circuit of MV CB

3.8Conclusion

This chapter presents an in-depth analysis of the distribution system in the SCMI factory. It explores various protection schemes, relays, and the underlying philosophy employed within the factory. Furthermore, the chapter outlines the methodology and procedures involved in designing an effective protection scheme for the system.

Chapter four :

implementing the protection scheme in ETAP software

Design protection scheme

4.1Introduction

This chapter introduces the ETAP software, its tools, and libraries. The focus is on replicating the SCMI factory schematic and transferring data for transformers, motors, cables, busbars, and other loads. The chapter also covers the inclusion of protection functions for each element, as well as the configuration of protective relays for HV/MV and MV/LV substations. Furthermore, a step-by-step procedure is provided to guide the process of setting up the protective relays.

4.2Consideration

When designing a protection scheme for a factory, several considerations should be taken into account. These include:

-Comprehensive transfer: The majority of the factory should be transferred into the protection scheme. However, there might be some elements, particularly in the low voltage zones and motor control centers (MCCs), that have been neglected. This is because certain MV/LV transformers may not be connected to any loads.

-Relay selection: The selection of relays is based on the existing relays present in the factory. The goal is to maintain consistency and compatibility with the existing setup.

-Lack of data: In some cases, there may be a lack of data for certain elements. In such situations, load flow analysis is necessary to approximate the required information, especially for LV cables and loads. However, it's important to note that due to this approximation, the results obtained may not be 100% accurate.

It is essential to exercise caution and consider these factors during the design process to ensure the protection scheme is as reliable and effective as possible.

4.3Presentation of the ETAP software

ETAP (Electrical Transient Analysis Program) is the most comprehensive analysis platform for the design, simulation, operation, and automation of industrial power production, distribution, and energy systems. ETAP is developed within an established quality assurance program and is globally recognized as a high-impact software. It is fully localized in four languages, with output reports translated into six languages. As a fully integrated enterprise solution, ETAP extends to a real-time intelligent energy management system for monitoring, controlling, automating, simulating, and optimizing power systems.

ETAP is a full-spectrum engineering software company specializing in the analysis, simulation, monitoring, control, optimization, and automation of electrical power systems. The ETAP software offers the most comprehensive suite of integrated power system enterprise solutions

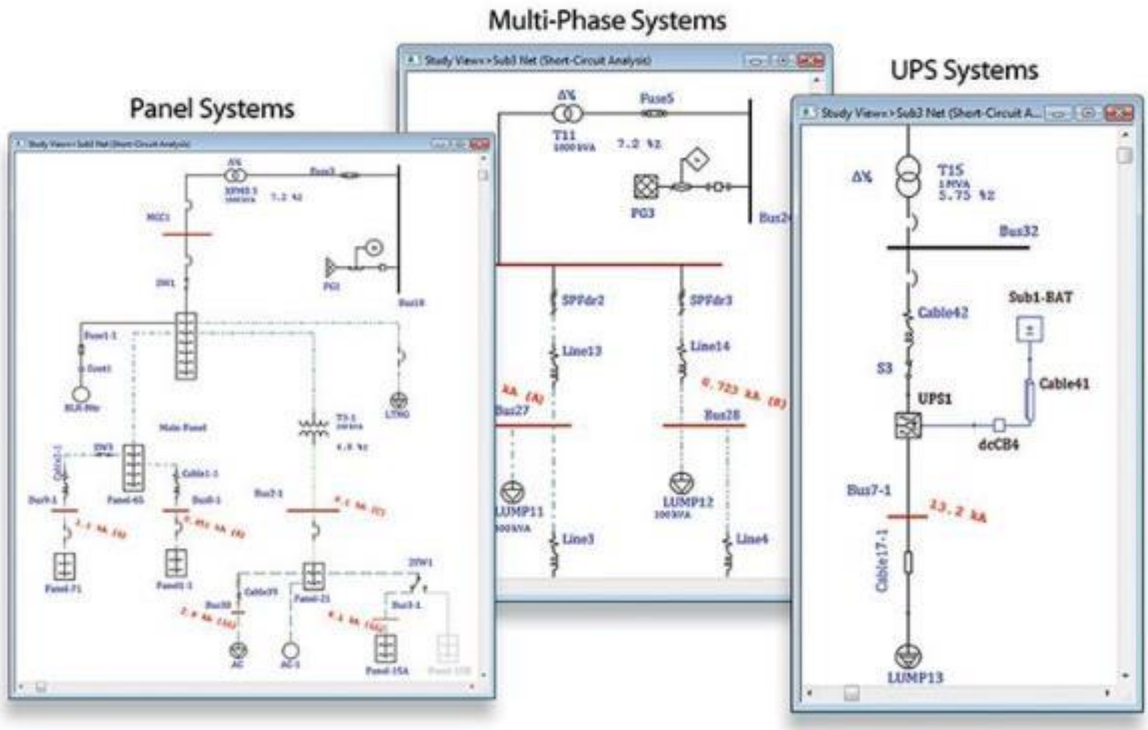


Figure 39-edit mode

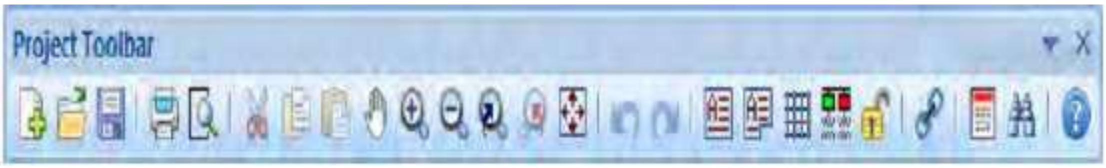
Menu bar

The menu bar consists of a comprehensive list of menu options. Each option activates a dropdown list of commands, such as File Operations, Printing, Database Conversions, Data Exchange, OLE Objects, Project Standards, Project Settings and Options, Libraries, Default Values, Annotation Fonts, Base, and Revision.

Project toolbar

The Project toolbar consists of buttons that provide shortcuts to commonly used functions. These functions include creating projects, opening projects, saving projects, printing, print preview, cut, copy, paste, pan zoom, undo, redo, text box, grid view, continuity check, themes, obtaining a model, adding to the OLV model, hyperlink, power calculator, search, and help.

To access the Power Grid feature, simply click on the Power Grid button in the toolbar. As you hover over the OLV (One-Line View), the cursor will transform into a Power Grid icon. Click anywhere on the OLV to place a utility on your single-line diagram.



Modify toolbars

The Modify toolbars are active when you are in Edit mode. You can click or double-click to select, drag and drop AC, DC, and instrument elements onto single-line diagrams. Additionally, you can perform the following functions:

- View and print customizable output reports (Text and Crystal Reports)
- Modify display options
- Access Schedule Report Manager
- Add new ground grid systems
- Add composite networks and composite motors

The data contained within an element of the OLV can be accessed by opening its editor. Double-click on Cable1 to open the cable editor. You can click on any tab within the editor to open its respective page. The data can be entered manually into the fields with a white background only."

Note: "OLV" and "Cable1" are kept as acronyms/identifiers since they represent specific elements in the software.

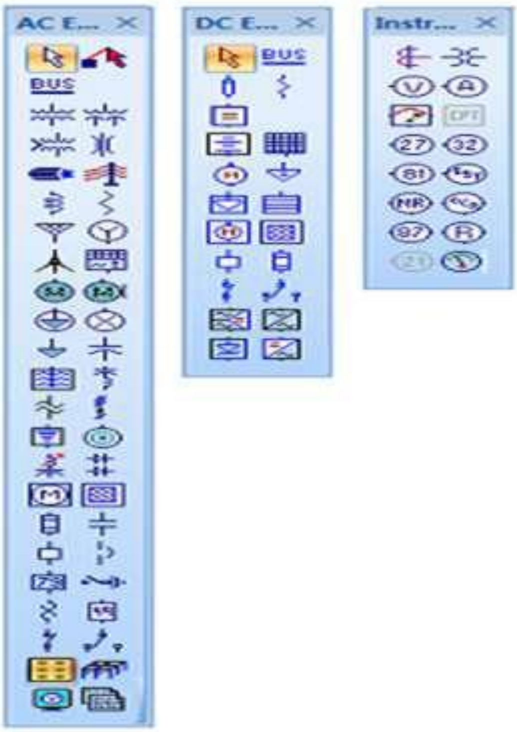


Figure 40-modify tools bar

Study mode

study modes are designed to simulate and analyze various operating conditions and scenarios to assess the performance, reliability, and safety of the power system.

Some common study modes in ETAP include:

Load Flow Analysis: This mode calculates the steady-state voltage, current, and power flow throughout the power system under normal operating conditions.

-**Short Circuit Analysis**: This mode simulates fault conditions and calculates the fault currents that occur during a short circuit event. It helps determine the ratings and settings of protective devices.

-**Transient Stability Analysis**: This mode assesses the dynamic behavior of the power system under transient conditions, such as during faults or disturbances, to ensure system stability and prevent cascading failures.

Harmonic Analysis: This mode examines the presence and impact of harmonic distortion in the power system, helping to identify harmonic sources, evaluate equipment compatibility, and mitigate potential issues.

Motor Starting Analysis: This mode evaluates the starting behavior of electric motors, considering factors such as voltage drop, motor acceleration, and impact on the power system during motor startup.

Relay Coordination Analysis: This mode focuses on coordinating the settings of protective relays throughout the power system to ensure selective and reliable fault detection and clearance.

beside that we found starZ and Arc flash

Figure 41-study tools bar

4.4Replicating the data

In this section, we describe the methodological process of transferring data for the different elements present in the factory (such as transformers, cables, motors, etc.) from manufacturer documents and data sheets to the ETAP software. We provide a step-by-step guide on how to accurately enter the data for each specific element within the ETAP platform.

Transmission line/cables

We enter Transmission line from modify tools we choose transmission line symbol from info choice we enter the length and connection which is three phase

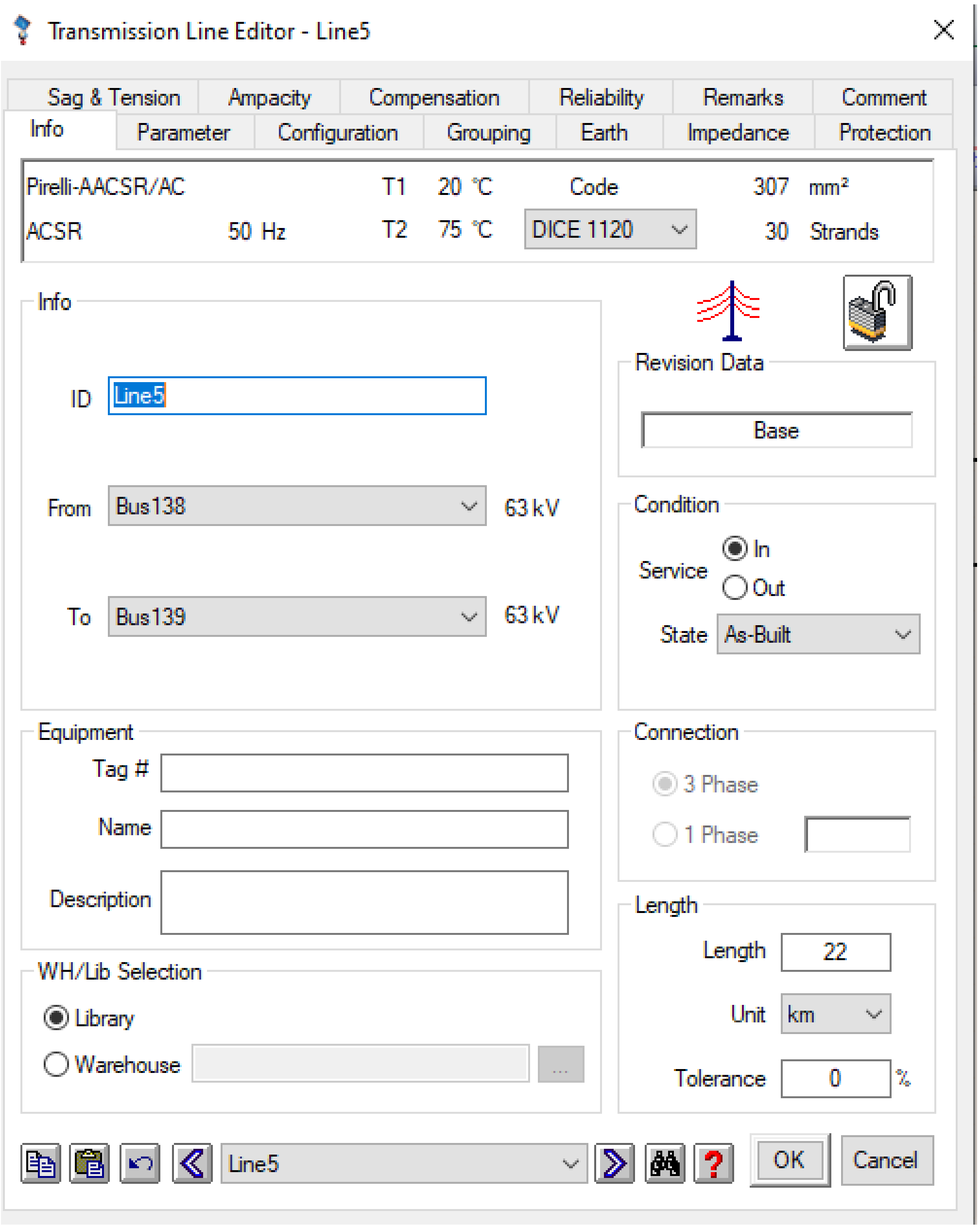


Figure 42-transmission line info section

After that we go to parameters we enter to library to chose the cable characteristics(sizing, number of cores , frequency ..)

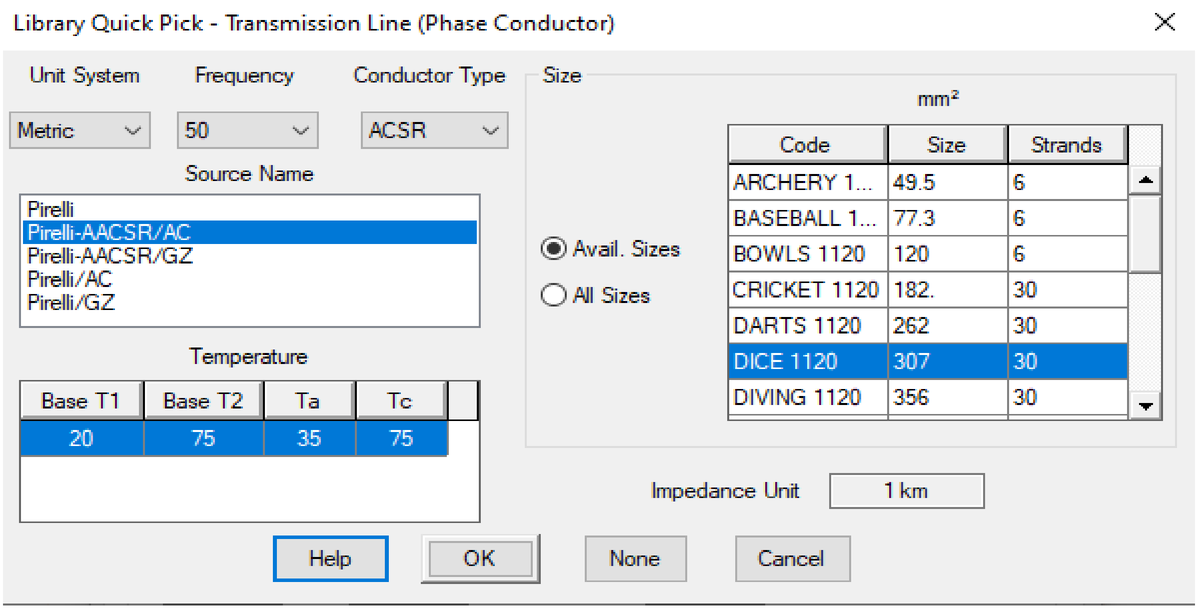


Figure 43-library of transmission line

Beside that it must add extra information like height ,GMD ,GMR is there lighting arrestor or not space between phase, weather condition …etc. or that so model can operate as real one in different condition could calculate right impendences which is importance in short circuit evaluation and approximate damage curve .

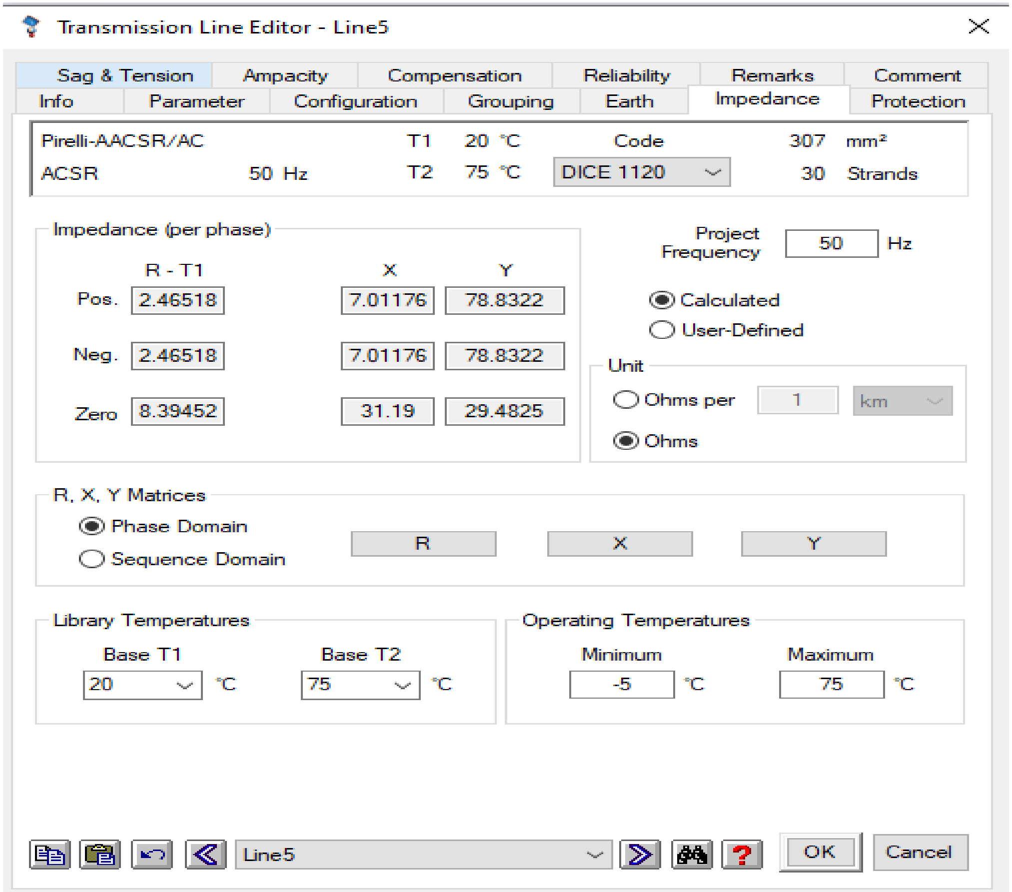


Figure 44-impedance section

Same apply on cable except cable does not have GMD and GMR

Power grid

Entering power grid modify tools from info and rating we choose operating voltage magnitude and angle , type of connection, operating power and operating mode

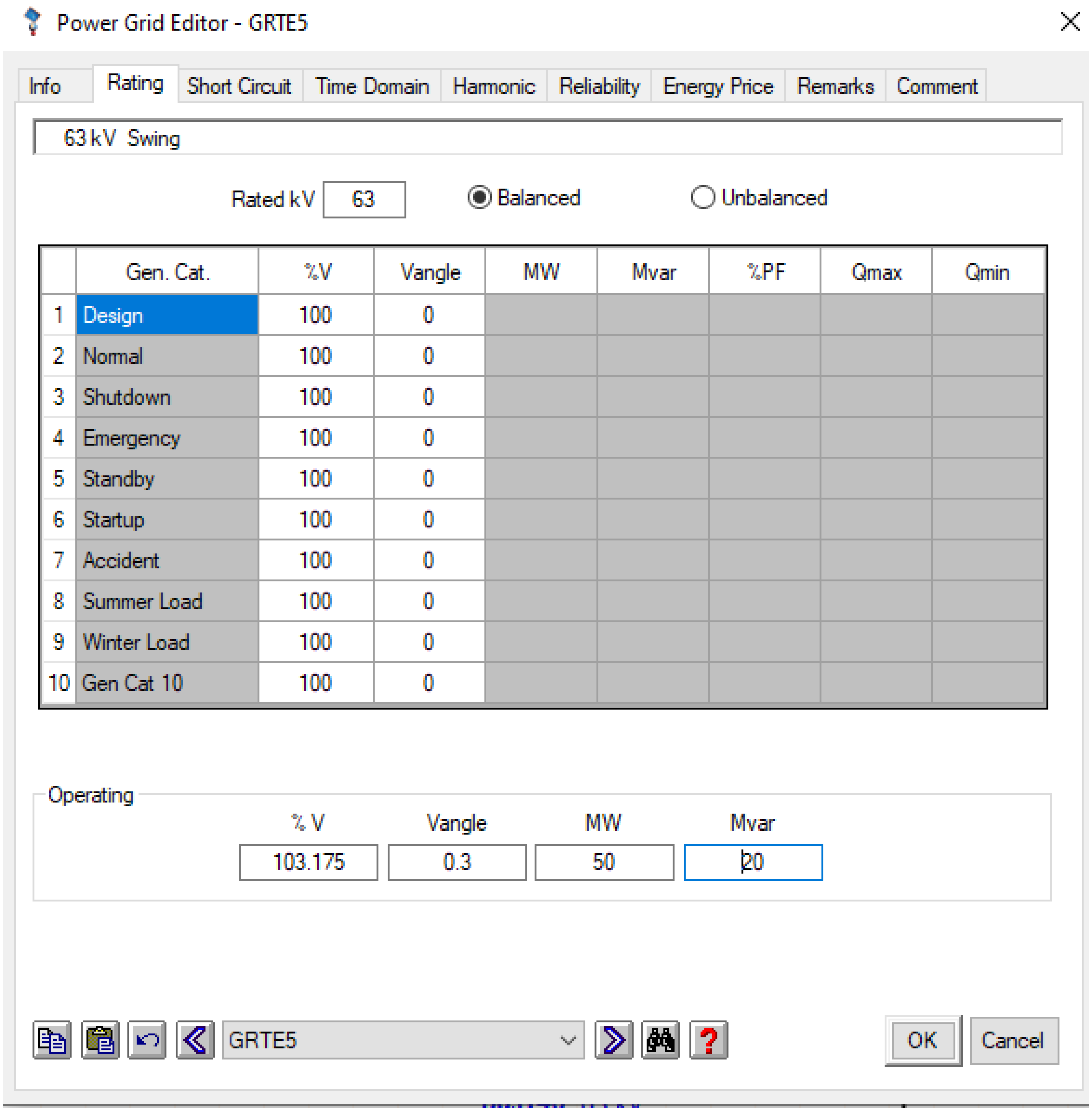


Figure 45-power grid rating section

Concerning faults study we choose to short circuit to enter the parameters of short circuit rating and impedance

All this parameters has been provided by GRTE of Arabaa.

Busbar

Entering power grid modify tools from info and rating we enter the nominal operating voltage, continuous current ,load diversity factor and limit voltage beside that we can add parameters like peak short circuit current and physical dimension of busbar

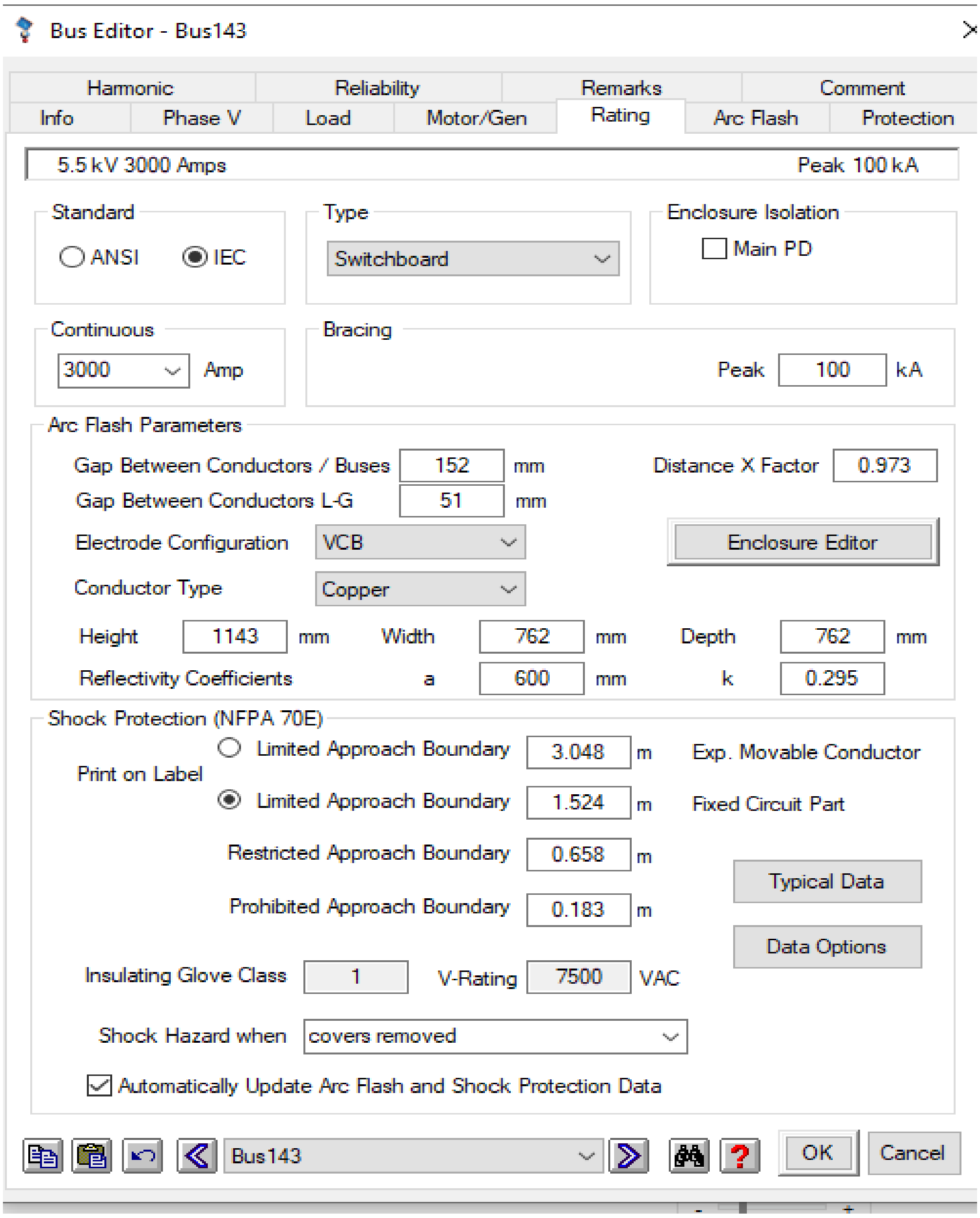


Figure 46-rating section of busbar

Transformer

Transformer consider most important element in distribution system that why data which been entering must be accurate such as rated MVA operating voltage for both primary and secondary side and vector group.

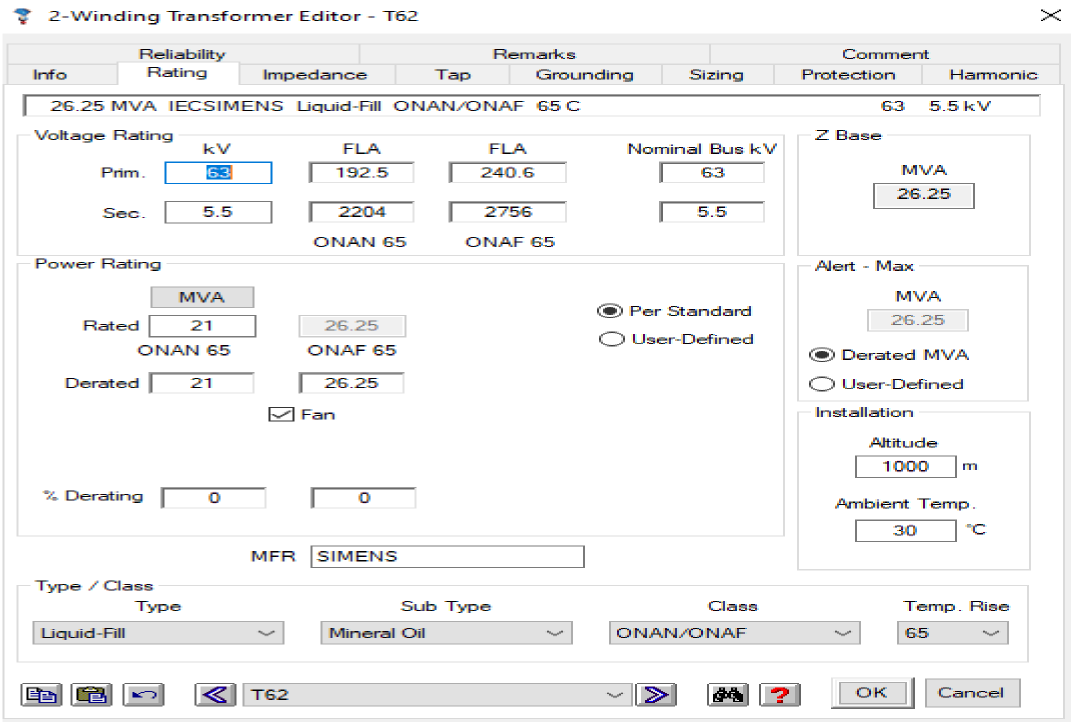


Figure 47-transformer rating section

In addition, when performing the short circuit calculation, it is essential to input the Z% value to accurately determine the maximum symmetrical short circuit. This information enables the system to generate the appropriate damage curve and account for magnetized inrush current. By including these factors in the analysis, we can obtain more precise results and effectively assess the impact of short circuit events on the electrical components and overall system performance.

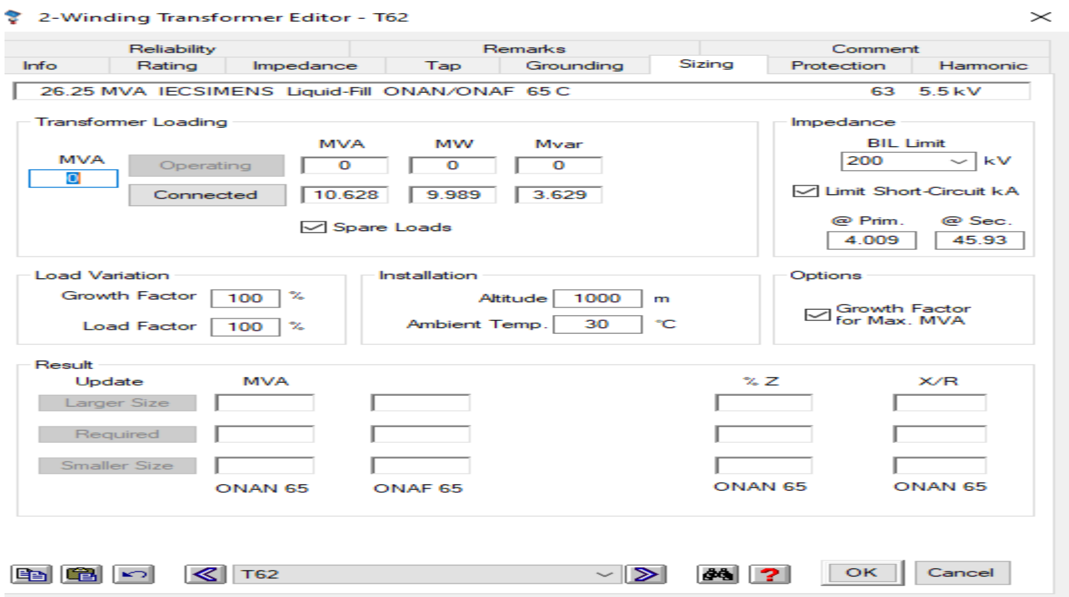


Figure 48-transformer sizing

Motor

Next, let's shift our focus towards the utilization of 90% of the loads in the industrial setting which are motors.it enter basics data like power rating, power factor operating voltage and demand factor.

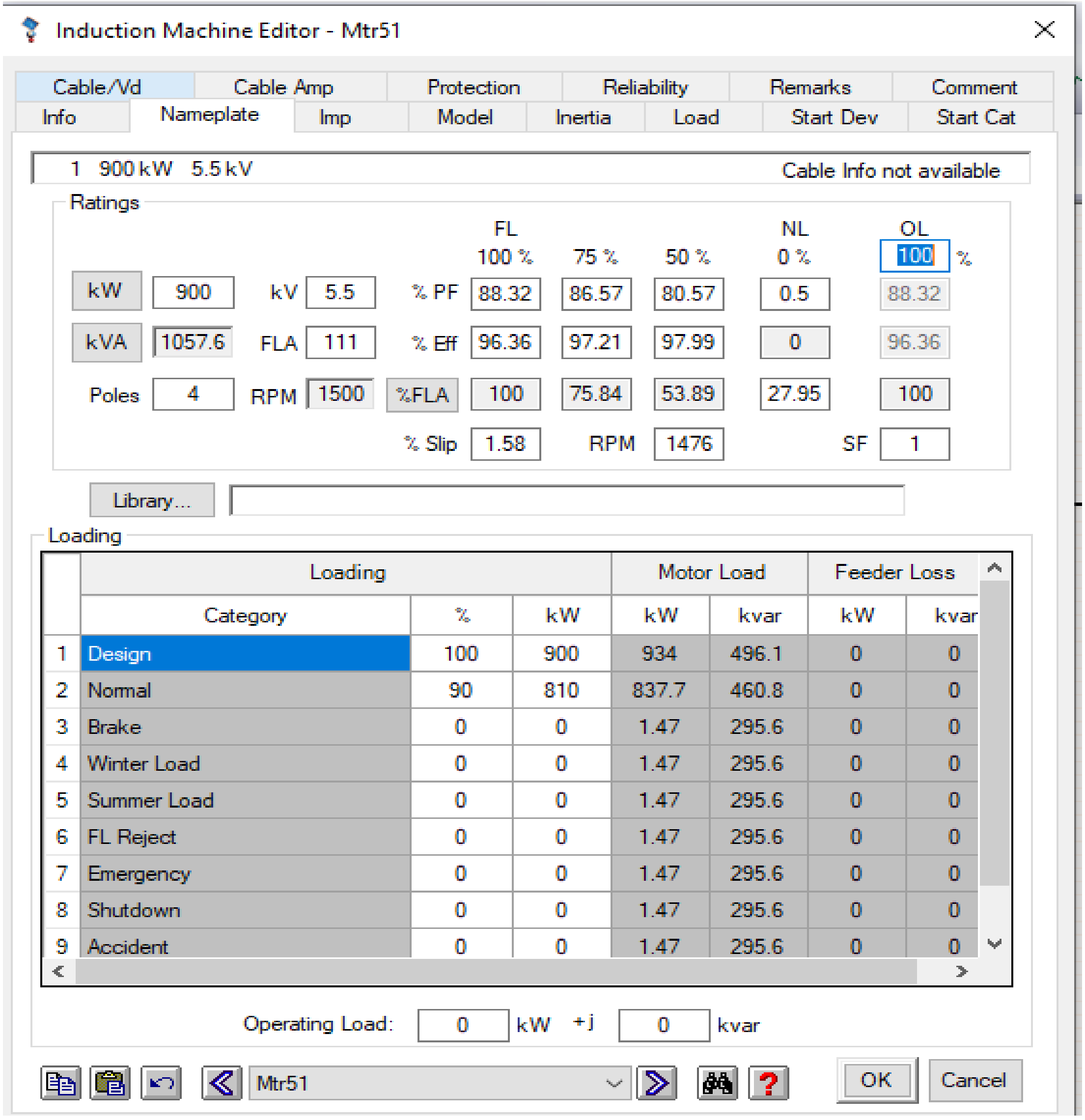


Figure 49-induction motor section

Beside that we have to not overlook the impedances type of motors starter since it defined the motor conurbation in short circuit .

Single-line diagrams

Single-line diagrams serve as primary reference plans for substations and require special attention. These references should be the first drawings prepared. Switching and functional relay information can appear on the same single-line diagram if the presentation is not too detailed or complicated. It is recommended to prepare single-line diagrams using the 'Typical Substation' procedure.

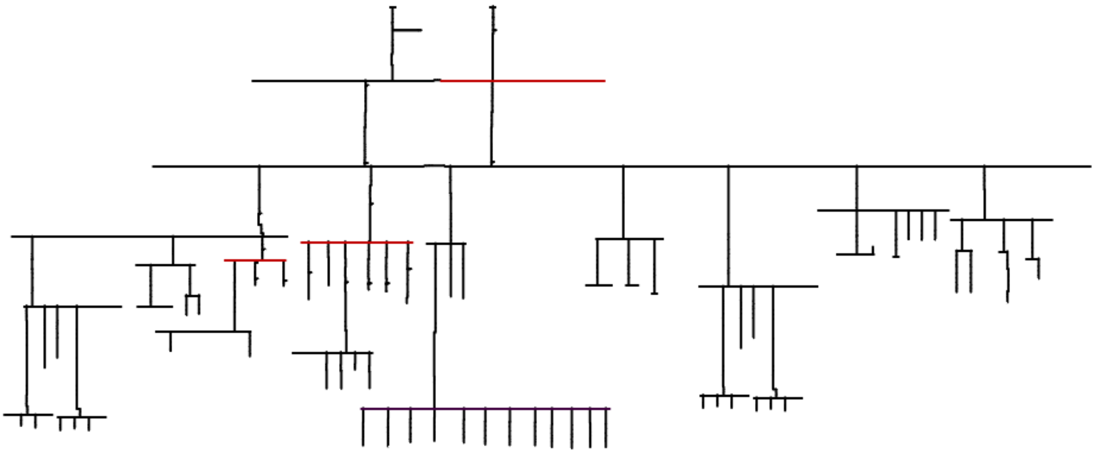


Figure 50-single diagram of SCMI

Power flow

Flow analysis provides valuable insights into our network, including power consumption, power factor, operational voltage, , voltage drop an power loss. It also assesses the condition of each electrical component, indicating whether they are overloaded, normally loaded, underloaded, or damaged.

Additionally, flow analysis determines the maximum load current, which aids in selecting the appropriate current transformer (CT) ratio and pickup value for relays. This information is crucial for ensuring accurate and reliable protection of the electrical system.

In summary, flow analysis serves as a comprehensive tool that not only reveals important network parameters but also assists in making informed decisions regarding equipment selection and protective relay settings.

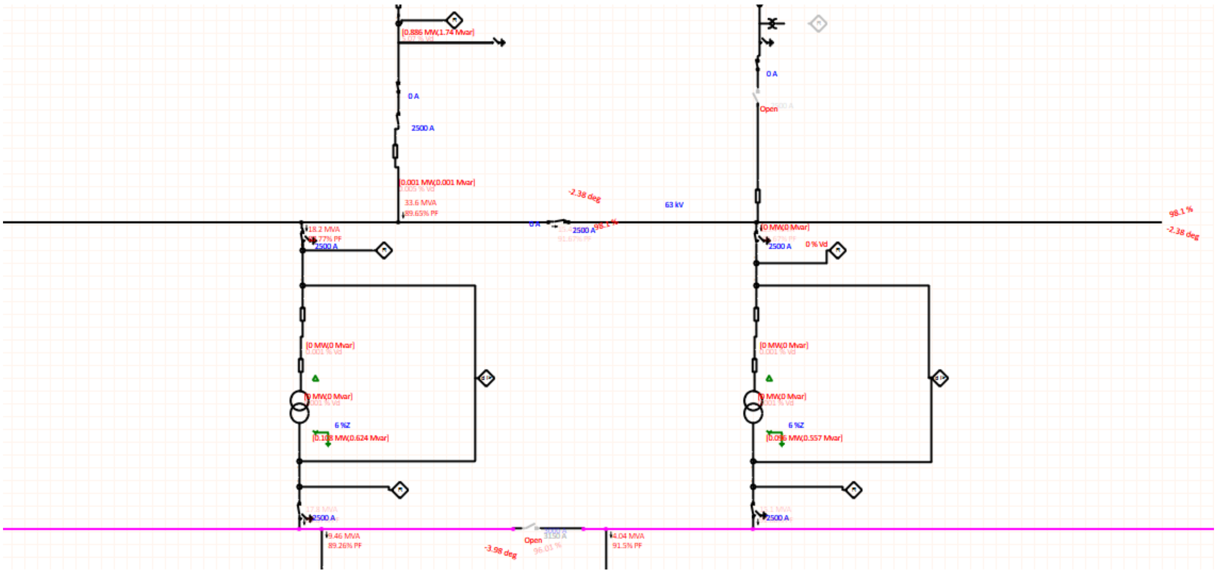


Figure 51-load flow analysis

4.5Short Circuit analysis

To grasp the significance of conducting a short circuit analysis, we will simulate a three-phase fault at the 63Kv busbar level, setting the simulation time to 0.1 seconds.

Project:	**ETAP**	Page:	1
Location:	19.0.1C	Date:	31-05-2023
Contract:		SN:	
Engineer:	Study Case: SC	Revision:	Base
Filename: cheboub project		Config.:	Normal

Short-Circuit Summary Report

3-Phase Fault Currents

Bus		Short Circuit Current (kA, rms)		
ID	kV	Subtransient	Transient	Steady State
63kv busbar	63.000	3.634	3.634	2.501

Figure 52-short circuit summary

Contribution		% Voltage at From Bus						Current at From Bus (kA)						Sequence Current (kA)		
From Bus	To Bus	Va		Vb		Vc		Ia		Ib		Ic				
ID	ID	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	I1	I2	I0
63kv busbar	Total	108.22	0.0	54.11	180.0	54.11	180.0	0.000	0.0	3.070	-163.9	3.070	16.1	1.772	1.772	0.000
Bus157	63kv busbar	108.22	0.0	54.11	180.0	54.11	180.0	0.016	103.3	0.549	-161.1	0.548	17.3	0.309	0.324	0.000
Bus159	63kv busbar	108.22	0.0	54.13	-180.0	54.09	179.9	0.038	-71.5	2.058	-163.8	2.057	17.2	1.207	1.169	0.000
Bus139	Bus140	108.22	0.0	54.11	180.0	54.11	180.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000	0.000
Bus363	Bus140	108.22	0.0	54.11	180.0	54.11	180.0	0.023	112.2	0.464	-167.3	0.468	9.9	0.258	0.280	0.000
Bus302	Bus157	108.22	0.0	54.12	180.0	54.11	180.0	0.016	103.3	0.549	-161.1	0.548	17.3	0.309	0.324	0.000
Bus160	Bus159	109.03	-0.1	73.30	-144.2	65.61	139.1	0.038	-71.5	2.058	-163.8	2.057	17.2	1.207	1.169	0.000
Bus364	Bus363	108.22	0.0	54.12	180.0	54.11	180.0	0.023	112.2	0.464	-167.3	0.468	9.9	0.258	0.280	0.000

Figure 53-short circuit report

The following curve in question displays the waveform of the fault current. We observe an asymmetry in the waveform due to the angle alpha of the sinusoidal voltage. This causes a temporary transient state in the network. It can be said that there is a certain speed of the current over time, in other words, the current propagates very quickly over time.

Translation and rephrasing: "The depicted curve shows the fault current's waveform. We notice an asymmetry in the waveform, attributed to the phase angle of the sinusoidal voltage. This leads to a temporary transient state within the network. It can even be described as a rapid progression of the current over time, indicating its swift propagation

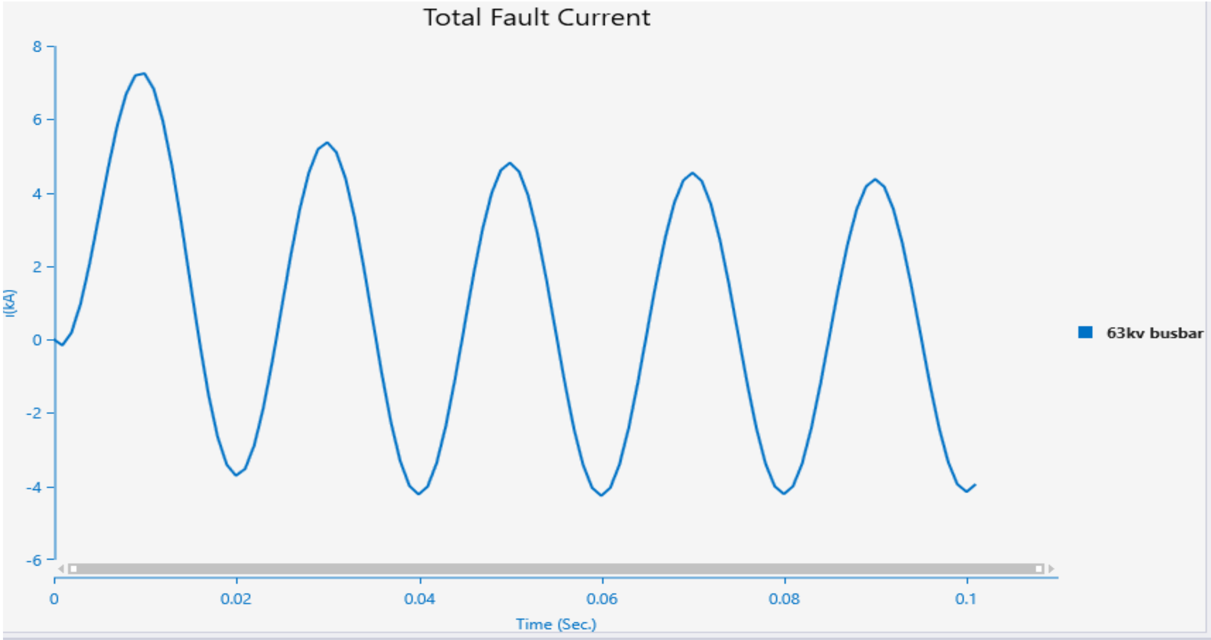


Figure 54-Short circuit characteristics

4.6Protection scheme

Next, we will delve into the most significant part, which entails the practical implementation of a protection scheme using the ETAP software. Our first step involves visualizing the scheme for each component (e.g., transmission lines, transformers, motors, feeders) within different substations. It is crucial to highlight that we have carefully considered the parameters for overcurrent protection relays, fuses, or MCBs based on the results of a thorough conducting selectivity study. Moving on to the second part, we will explain the step-by-step procedure for conducting the selectivity study, utilizing various techniques.

4.6.1Transmission line protection

The MiCOM P446 protection relay is responsible for ensuring the protection of the transmission lines. We will enable the following protection functions on it: 50/51, 50G/51G, and 46 for overcurrent protection, and 27/59 for under/over voltage protection. These functions are specifically designed to detect and mitigate the majority of faults that may occur in the transmission lines.

After performing a load flow analysis, we determined that the total load current is 312A. Based on this information, we will select a current transformer (CT) ratio of 400:5. To ensure accurate protection, we will choose a CT class with a tolerance of 5%. To prevent saturation, we will select a burden that is 20 times the expected load current. Considering the presence of low current detection protection functions such as 51G and 46, which impose significant burden, we will opt for a CT with a high burden rating, such as 30VA or a value close to it. Same goes for VT selection.

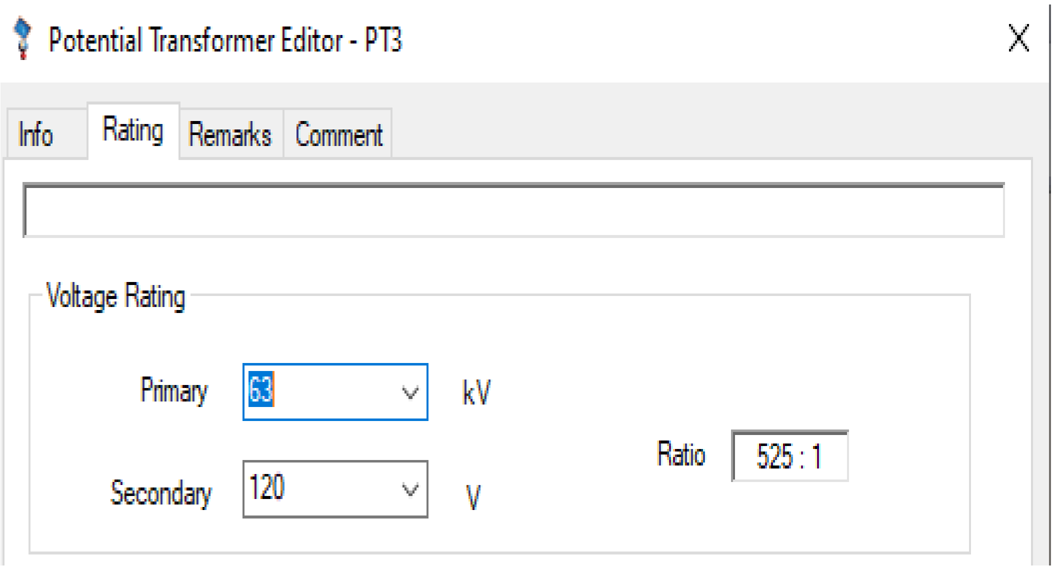


Figure 55-potential transformer parameters

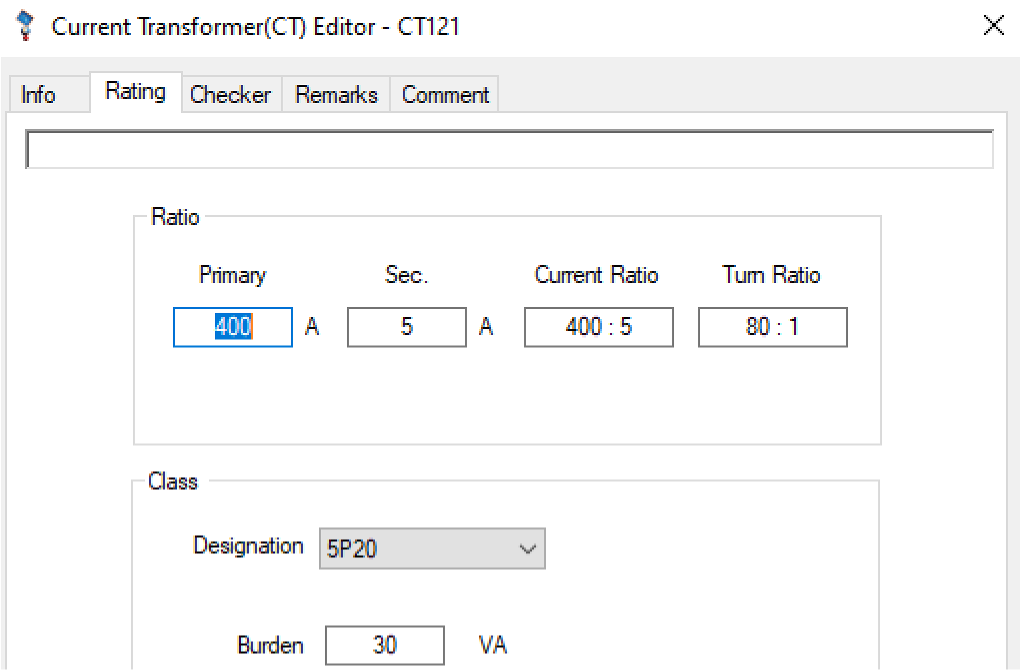


Figure 56-current transformer parameters

For phase overcurrent protection 51/50 the relay 83 setting will be:

-pickup value=312*1.25=390

-type of curve: for long distance we choose inverse curve

-time dial:1 choosing according to selectivity study

-for instantaneous value we choose 15 times and delay 20ms

For earth fault protection the setting will be :

-pickup value=around 20% of phase current

-type of curve: inverse curve

-time dial:1.2 choosing according to selectivity study

-for instantaneous value we choose approximately 80% of phase current pickup delay 0.02s

-pickup value=312*1.25=390

-type of curve: for long distance we choose inverse curve

-time dial:1 choosing according to selectivity study

-for instantaneous value we choose 15 times and delay 20ms

Some faults, particularly imbalanced faults, cannot be detected by conventional overcurrent (OC) and earth fault (EF) protections. To address this limitation, an additional protective measure known as relay 46 is employed. This specific relay is designed to detect negative currents and is utilized to enhance fault detection capabilities in such scenarios. The settings for relay 46 will need to be configured as follows:

-pickup value=5-10% of phase current

-type of curve: definite time

-time dial:1 choosing according to selectivity study

Before enter the setting to relay 83 we define the input and the output of the relay

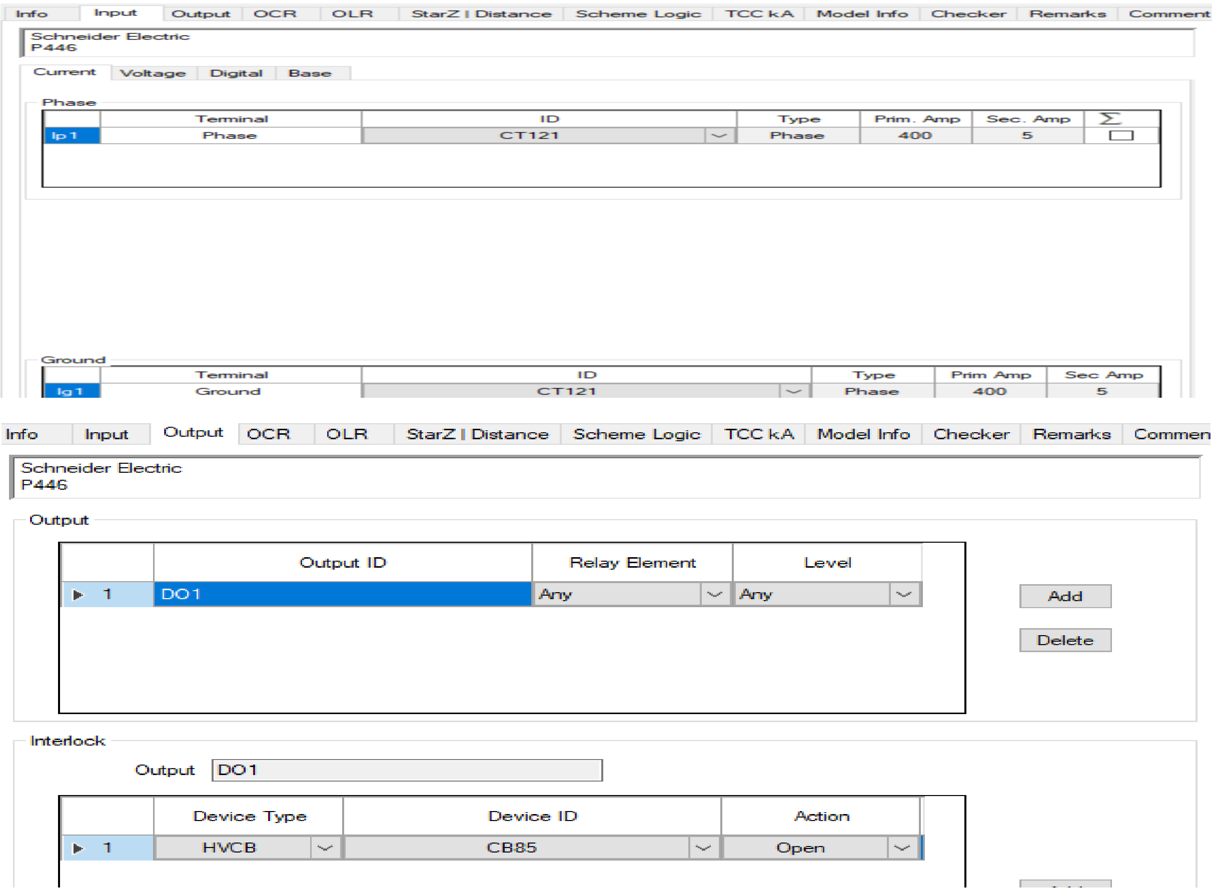


Figure 57-MiCOM P446 input/output devices

The MiCOM setting for above protections functions are :

-Phase overcurrent protection

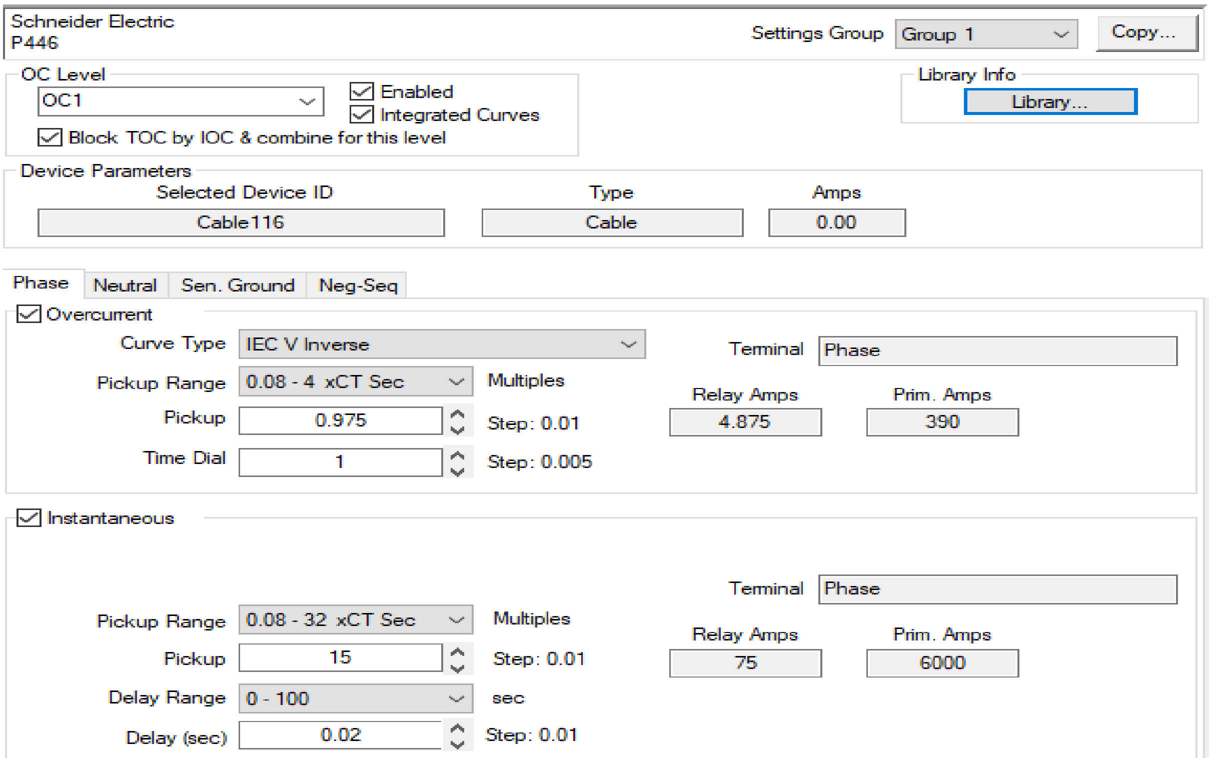


Figure 58-MiCOM P446 phase overcurrent setting

-ground overcurrent protection

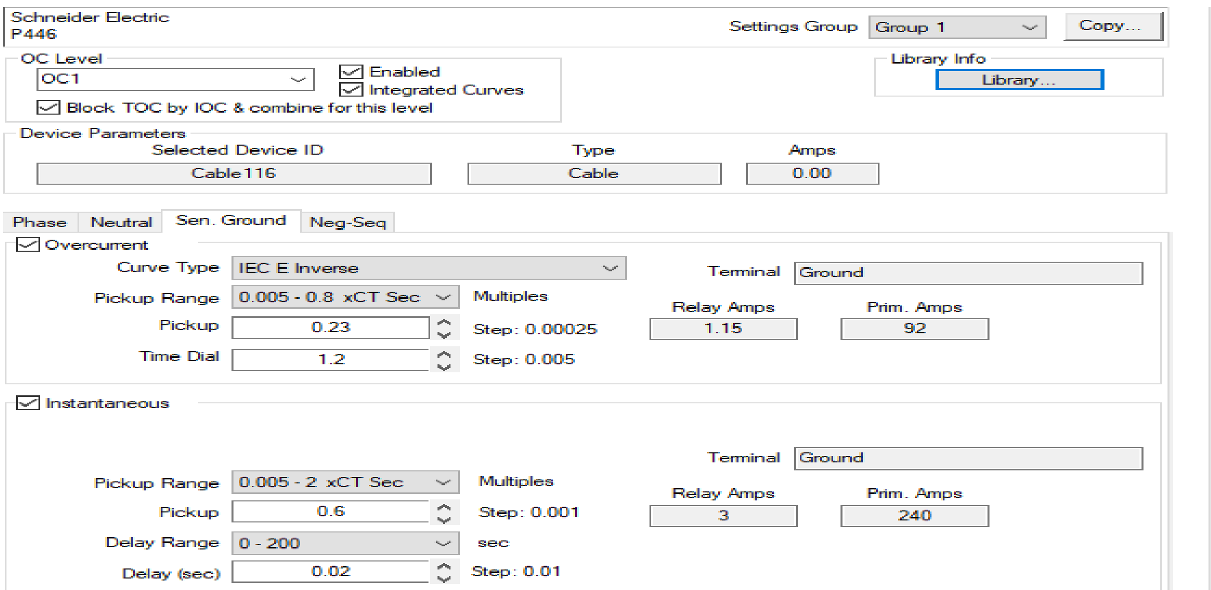


Figure 59-MiCOM P446 ground overcurrent setting

-negative sequence protection

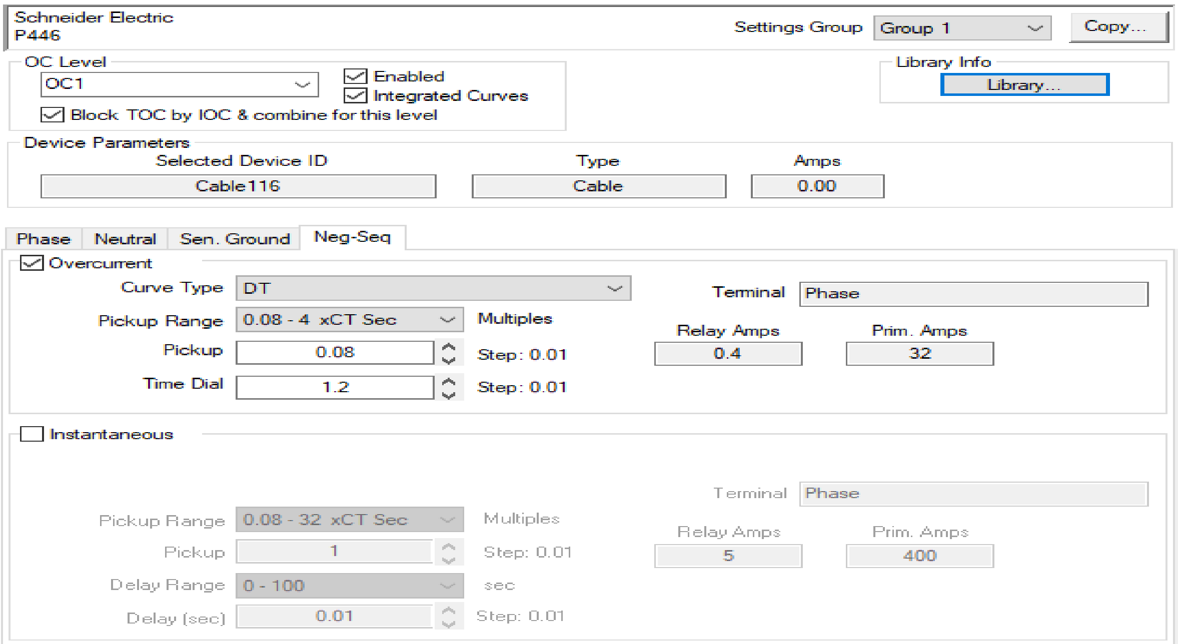


Figure 60-MiCOM P446 negative sequence overcurrent setting

In order to ensure proper protection of the transmission line, it is crucial to set the relay settings in a way that the relay operates within the damage curve of the line. This means that the relay should be able to trip the circuit breaker (CB) before the line itself sustains any damage.

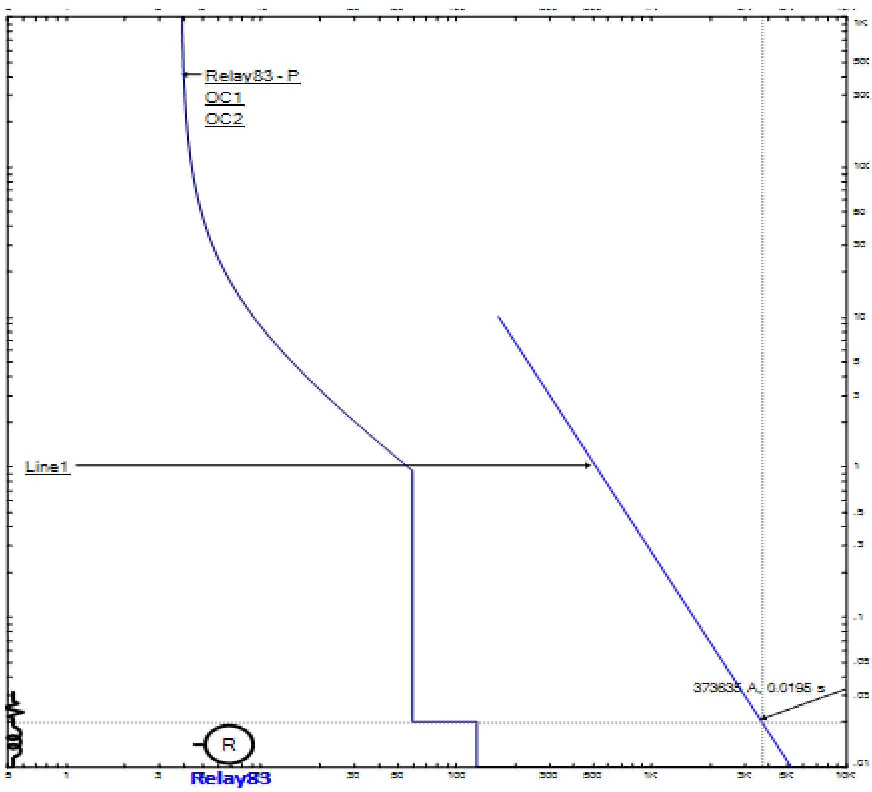


Figure 61-relay curve versus damage curve of TL

It is important to highlight that a second stage was incorporated into the relay curve to ensure that it remains below the damage curve, particularly after a current level of 373,635A. However, since this current level is considered impossible to reach, it can be safely omitted from the relay settings. This approach helps maintain the relay's operation within a safe range, avoiding the risk of false tripping or unnecessary system interruption.

To provide protection against under/overvoltage conditions, the following settings are applied: The undervoltage threshold is set to 90%, while the overvoltage threshold is set to 110%. A time delay of 10 seconds is incorporated to ensure stability and avoid false triggering.

Under/overvoltage setting relay:

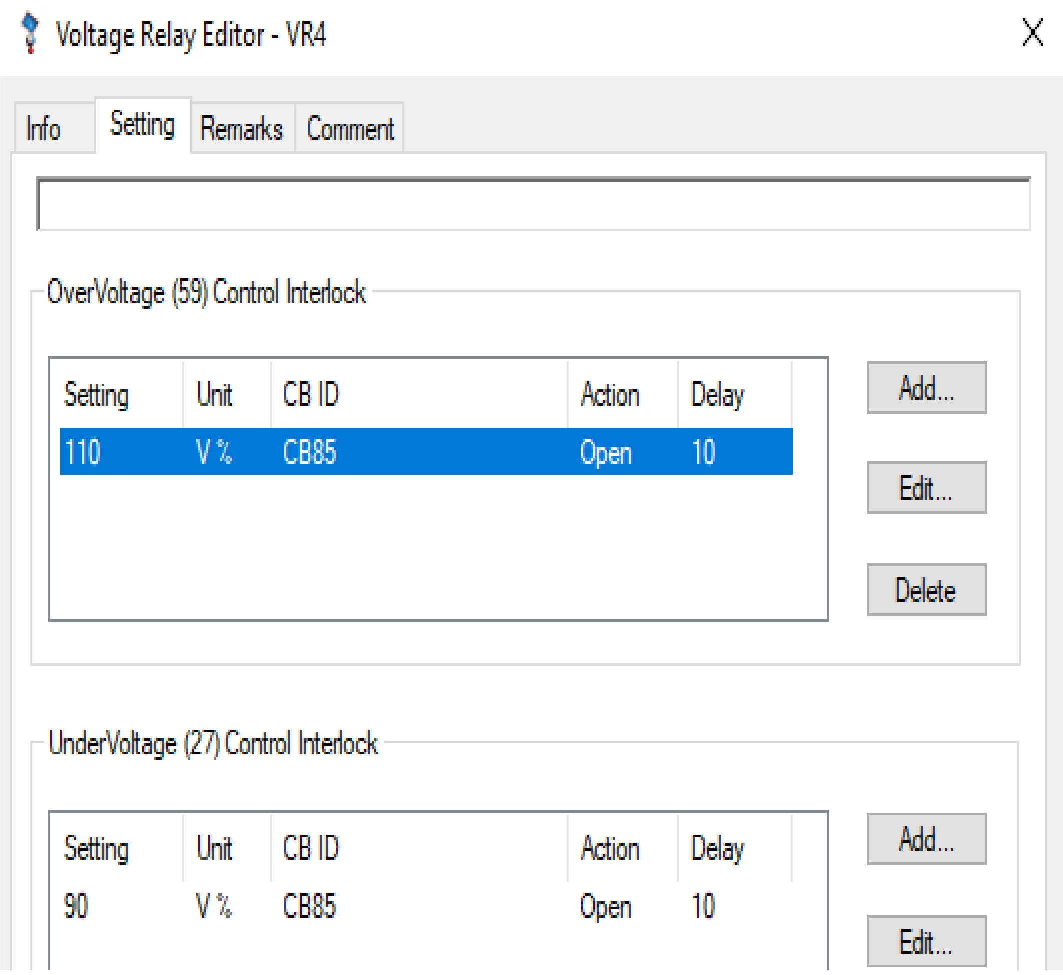


Figure 62-under/overvoltage relay setting

So the overall protection scheme will be :

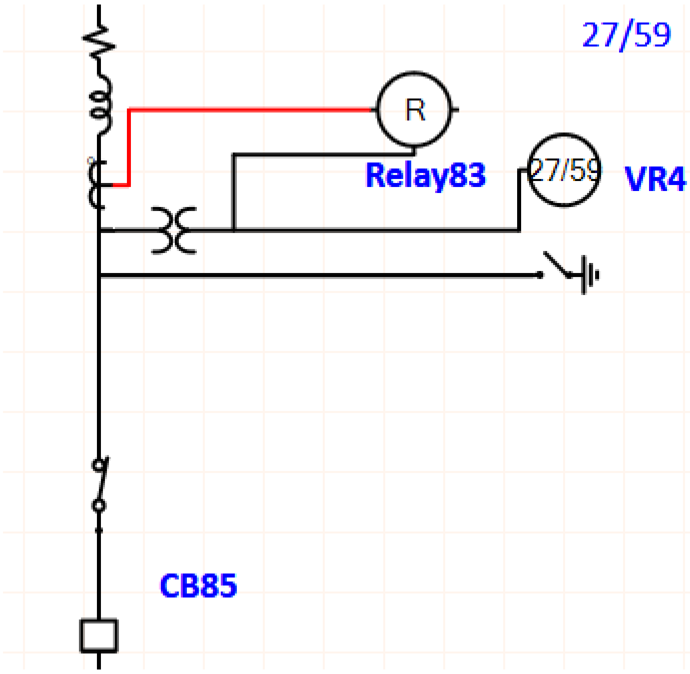


Figure 63-protection scheme of TL

4.6.2Transformer protection

63/5.5Kv transformer protection

The delta-connected primary side of the transformer is safeguarded by the RET615 protective relay. The following functions have been enabled for this relay: 50/51, 46, 87T, and under/overcurrent protection 27/59. On the secondary side, the REF615 relay is employed, which offers phase overcurrent protection 50/51, earth fault protection 50N/51N, and directional protection 67.

The transformer protection scheme follows a specific philosophy to address faults occurring on either the primary or secondary side.

-Differential Protection Philosophy: If a fault occurs within the differential protection zone (which encompasses both primary and secondary sides), the primary response is provided by the 87T relay. It initiates by opening both the primary and secondary circuit breakers (CB). If the fault is not cleared by the 87T relay, backup protection is implemented using overcurrent protection based on the type of fault detected.

-Faults Outside the Differential Protection Zone: a. Unbalanced Faults on the Primary Side: In case of unbalanced faults occurring on the primary side, the 46 relay responds first and opens the primary CB. The primary 51 relay acts as the first backup, followed by the secondary 51 relay, both of which open the secondary CB.

- Earth Faults on the Secondary Side: For earth faults occurring on the secondary side, the secondary protections respond first. Once the fault is detected, the secondary protection relays initiate, opening the secondary CB. The same backup protection sequence of primary 51 and secondary 51 relays is followed.

-LLL (Line-to-Line-to-Line) Faults: In the case of LLL faults, the 50 instantaneous overcurrent protection relay responds first, sending a blocking signal to the 51 relay. In certain scenarios, both the secondary and primary instantaneous overcurrent protection relays may activate simultaneously, irrespective of the fault's location.

-Directional Protection: The directional protection serves the purpose of preventing the parallel transformer from being affected or going out of service in the event of a fault in the transformer being protected.

Following a load flow analysis, the results indicate that the maximum load current on the primary side of the transformer is 144A, while on the secondary side it is 1953A. Considering these values, the current transformer (CT) current ratio has been set to 200 for the primary side and 2000 for the secondary side. Additionally, the CTs are specified with a class rating of 5P20.

It is necessary to configure the relays in a manner that ensures the curve remains below the damage curve. Additionally, the setting for instantaneous overcurrent should be above the inrush current, which is typically around 8 times the primary rated current

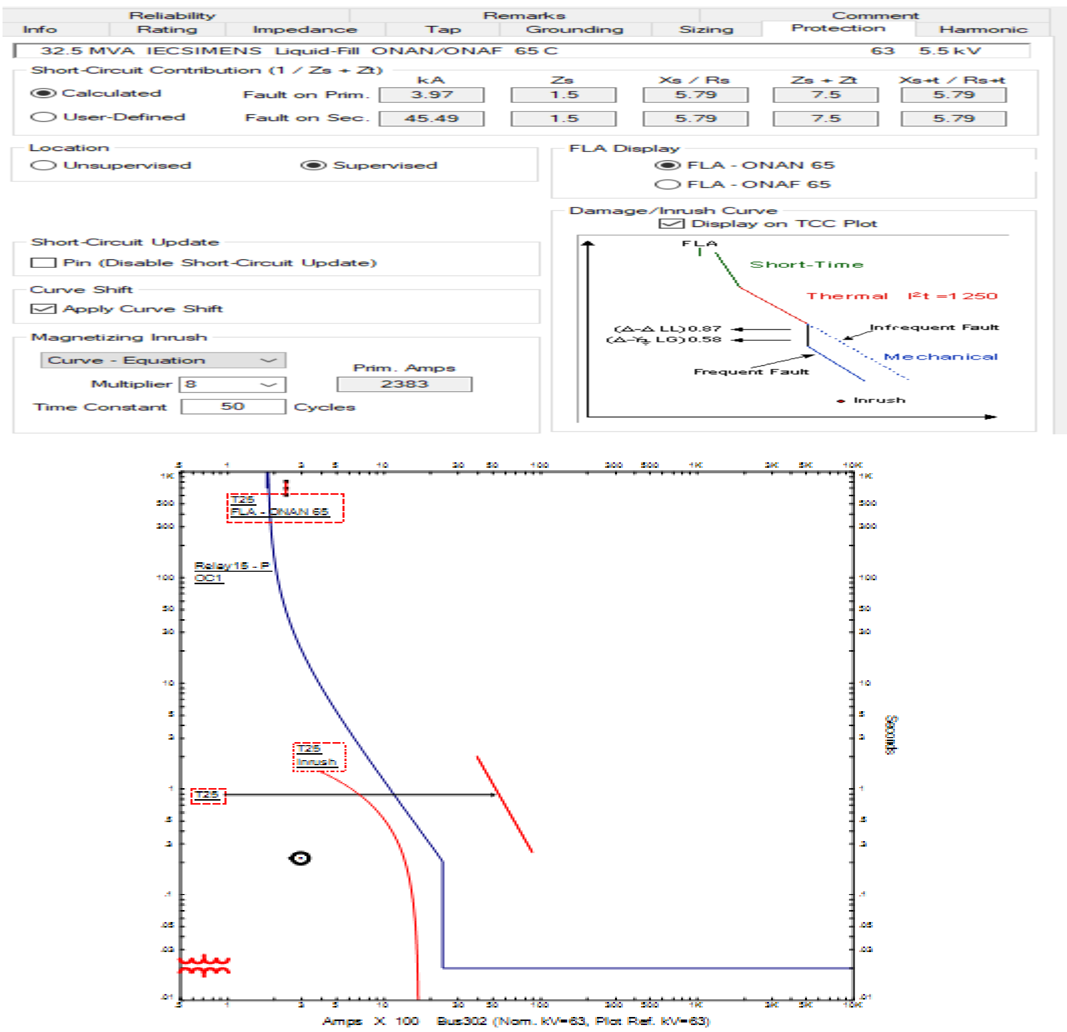


Figure 64-relay protection of 63/5.5Kv transformer

So the setting of RET615 are

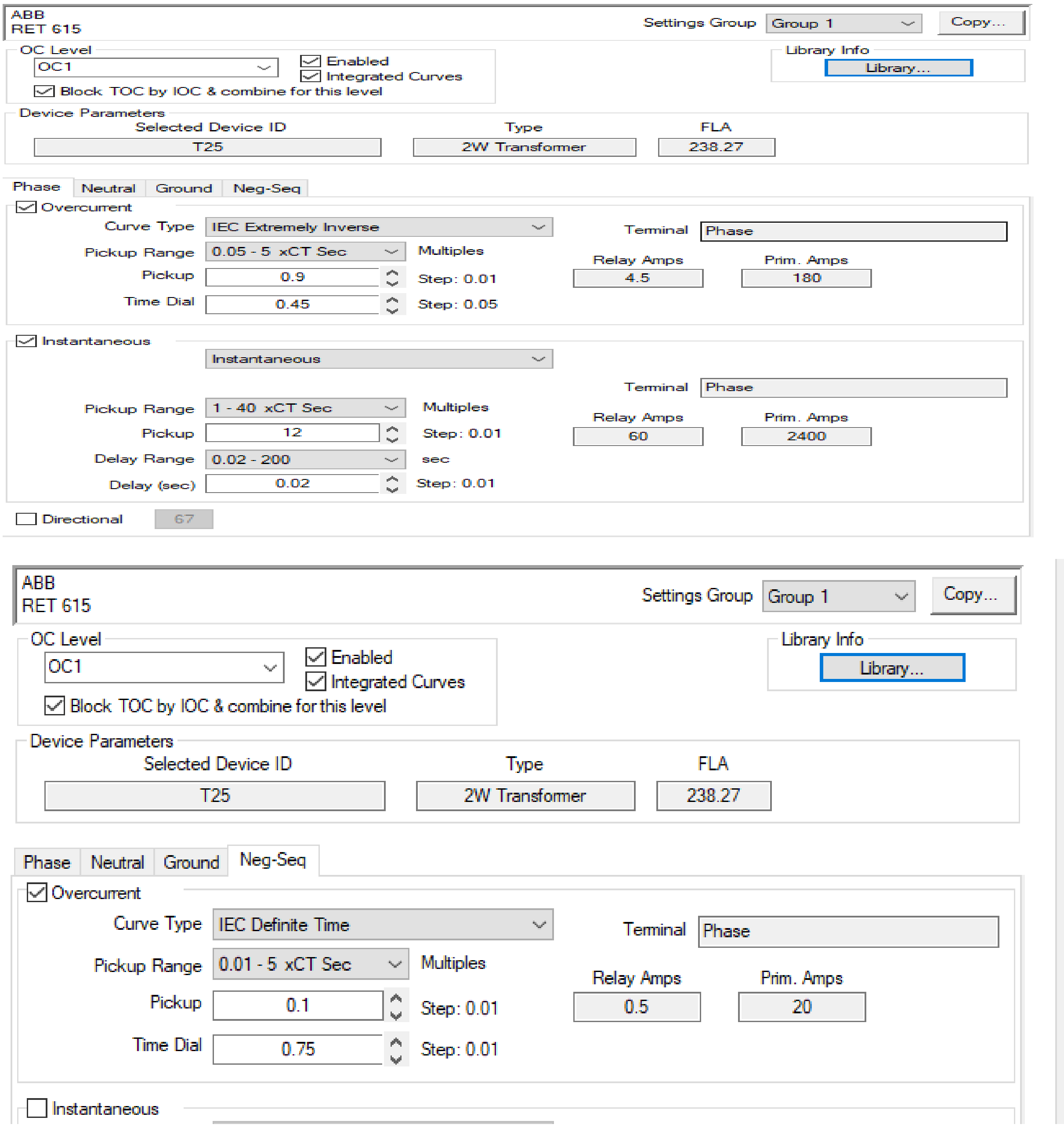


Figure 65-RET615 overcurrent setting

The setting for REF615 are

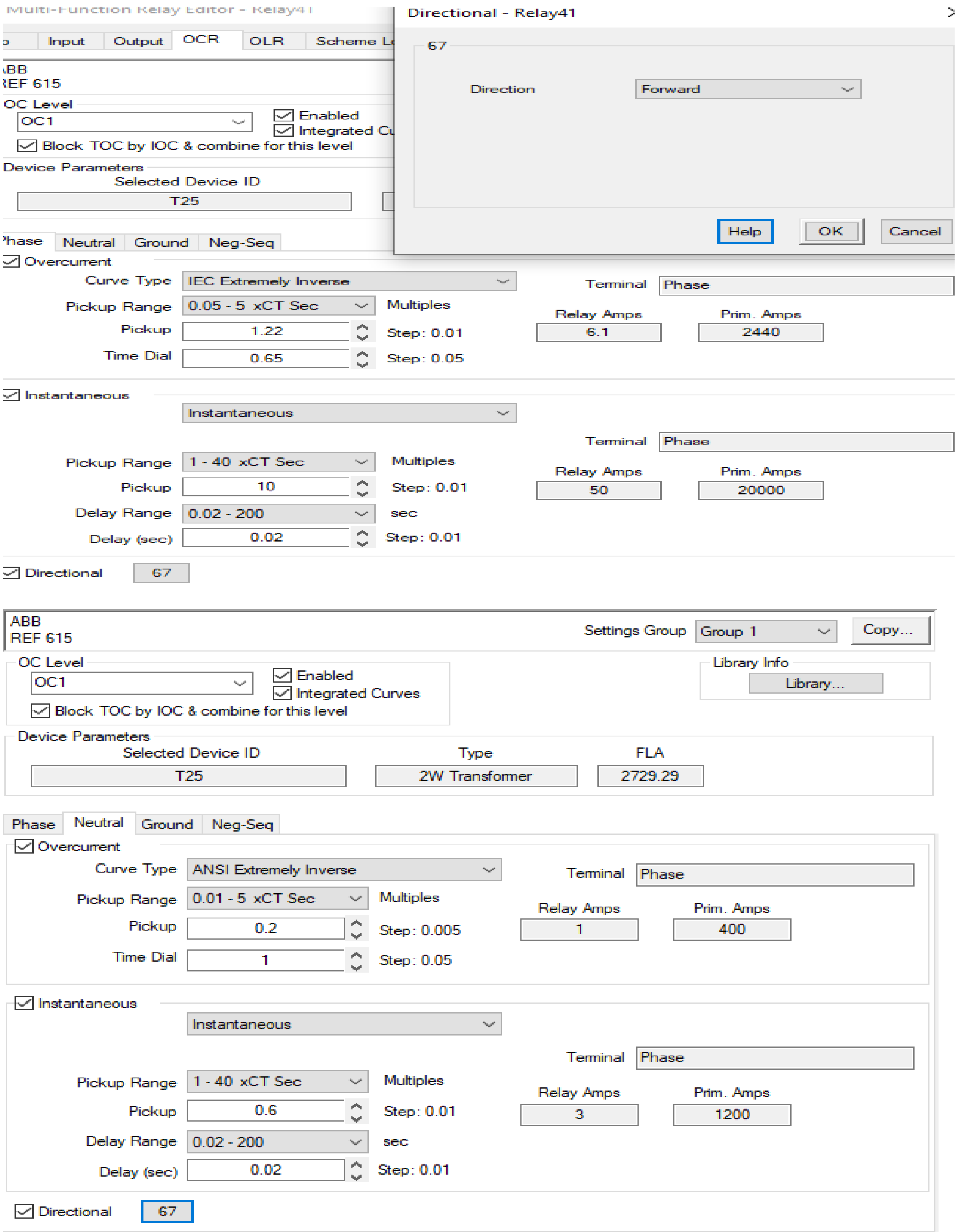


Figure 66-RET615 overcurrent setting

For under/overvoltage relay parameters will be the same as the one in transmission line

So the overall protection scheme will be:

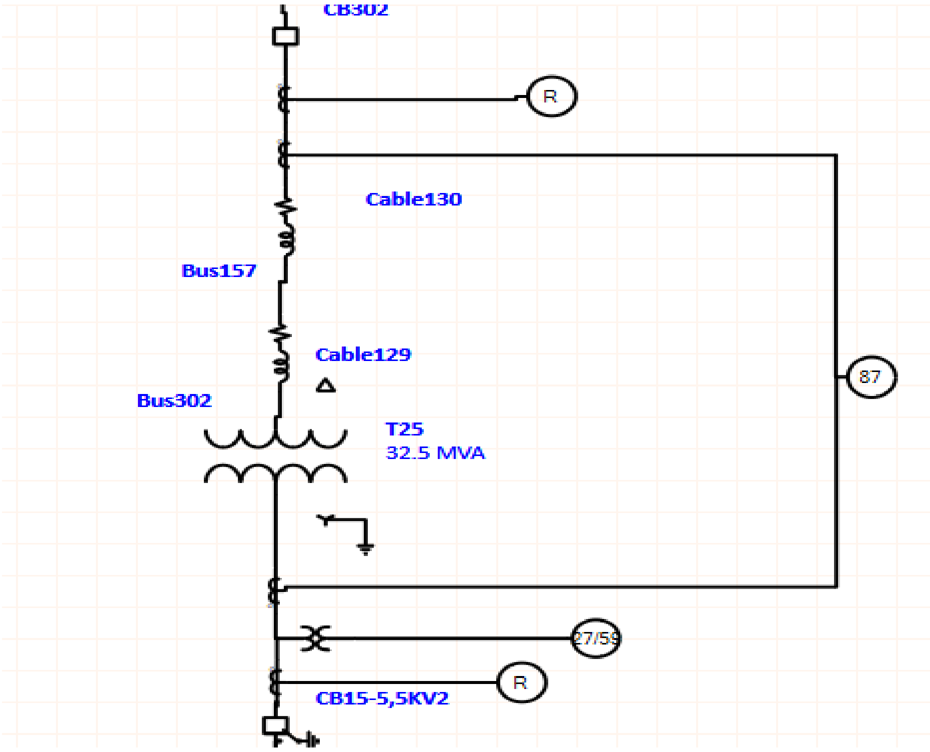


Figure 67-transformer protection scheme

5.5/0.4Kv transformer protection

the primary side of the transformer is protected by the SEPAM S40 protective relay, which is configured to enable functions such as 50/51 for phase overcurrent protection and 50N/51N for earth fault protection. On the low voltage side, protection is provided by the Micrologic MCB.

When selecting and sizing the MCB for the low voltage side, the following factors should be considered:

-Rated Current: The rated current of the MCB should be chosen based on the maximum load current determined through load flow analysis. This ensures that the MCB can handle the expected current without tripping during normal operating conditions.

-Rated Short Circuit Capacity (Peak kA): The MCB should have a rated short circuit capacity that can handle the peak fault current expected in the system. This is important to ensure that the MCB can safely interrupt the fault current without damage.

-Rated Short Circuit Ultimate Breaking Capacity (Icu): This parameter represents the maximum short circuit current that the MCB can safely interrupt without causing harm or excessive wear to the device.

-Rated Short Circuit Service Breaking Capacity (Ics): The rated short circuit service breaking capacity indicates the maximum short circuit current that the MCB can repeatedly handle without damage or significant performance degradation.

-Rated Voltage: The MCB should have a rated voltage compatible with the system voltage on the low voltage side of the transformer.

By carefully considering these factors and selecting an MCB that meets the specified requirements, you can ensure effective protection and safe operation on the low voltage side of the transformer.

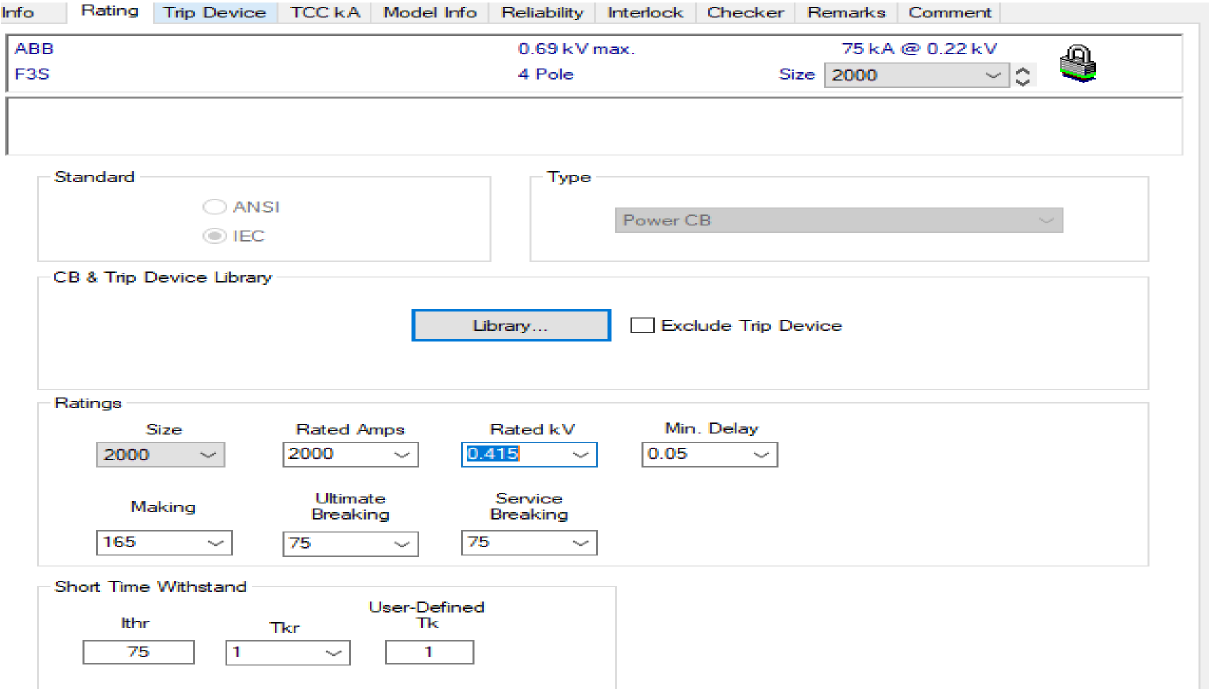


Figure 68-sizing of low voltage CB

Note: HV/MV circuit breaker are also sized in same method.

Note2:we have another transformer like 5.5/3.3kV this special transformer has another protection philosophy

4.6.3Feeder protection

SEPAM S40 protective relays are employed to safeguard various feeders. These relays are equipped with 50/50 and 50N/51N functions to ensure comprehensive protection for both the cable and incoming busbar. To achieve this, the relay settings must be carefully adjusted to ensure that the relay curve remains below the damage curves of the cable and arc energy/damge point of busbar. By setting the relay curve in this manner, optimal protection can be provided for the feeders, effectively mitigating the risk of damage to the cable and busbar components as demonstrate it in following figure

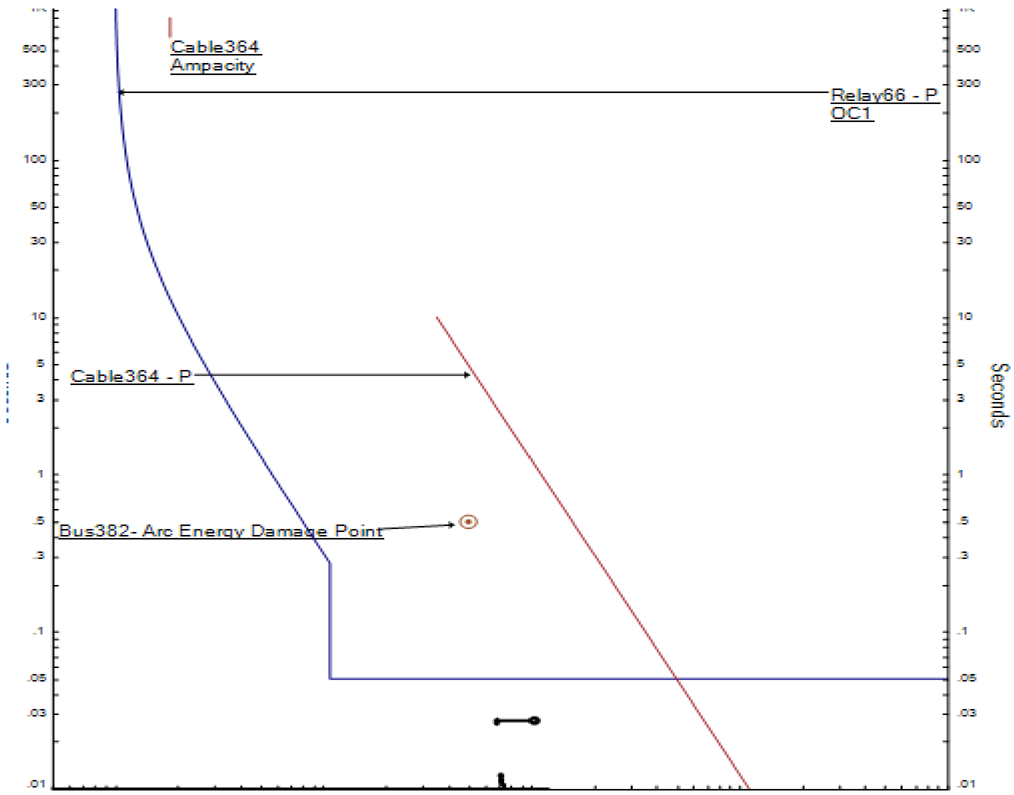


Figure 69-relay protection of 5.5Kv busbar

4.6.4Motor protection

Medium voltage motor protection

The protection of medium-voltage (MV) motors is facilitated by the implementation of SEPAM S40 protective relays. These relays incorporate essential functions such as 50/51 for phase overcurrent protection and 50N/51N for earth fault protection. In this particular application, the SEPAM S40 relays are employed to ensure the safety and reliability of both the MV motor and the associated cable that supplies power to it. This integrated protection scheme effectively safeguards the motor and the cable against potential faults and abnormal operating conditions, enhancing the overall performance and longevity of the MV motor system.Beside motor is protected from voltage fluctuation by 27/59.

When setting we have to consider that relay should the one which response first since it consider downstream load so we expected TDS to be smaller as possible .

Here the SEPAM S40 setting

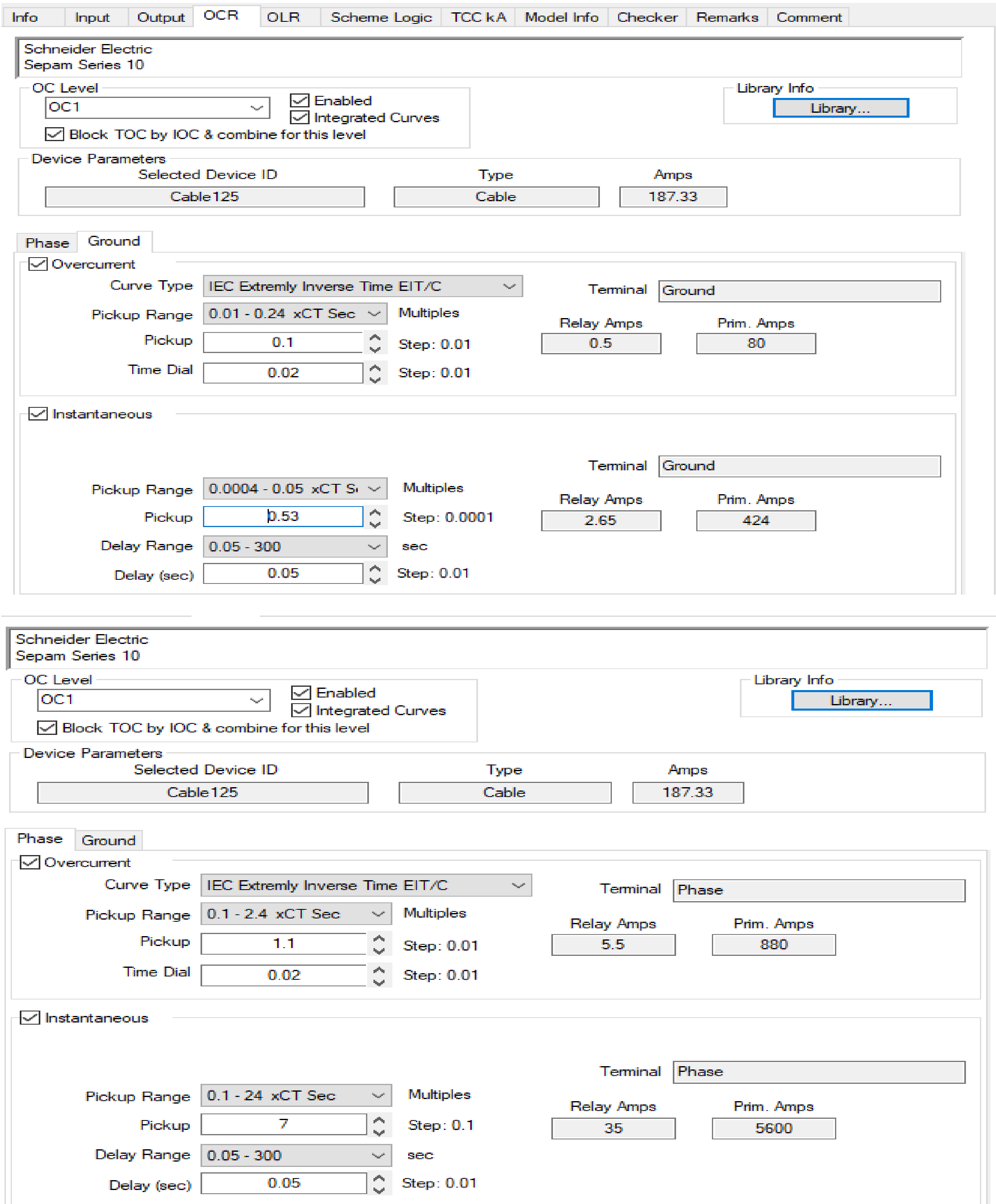


Figure 70-SEPAM S10 overcurrent setting

The relay curve is intentionally set to be higher than the inrush current curve, particularly for motors connected to the line, while still remaining below the damage curve.

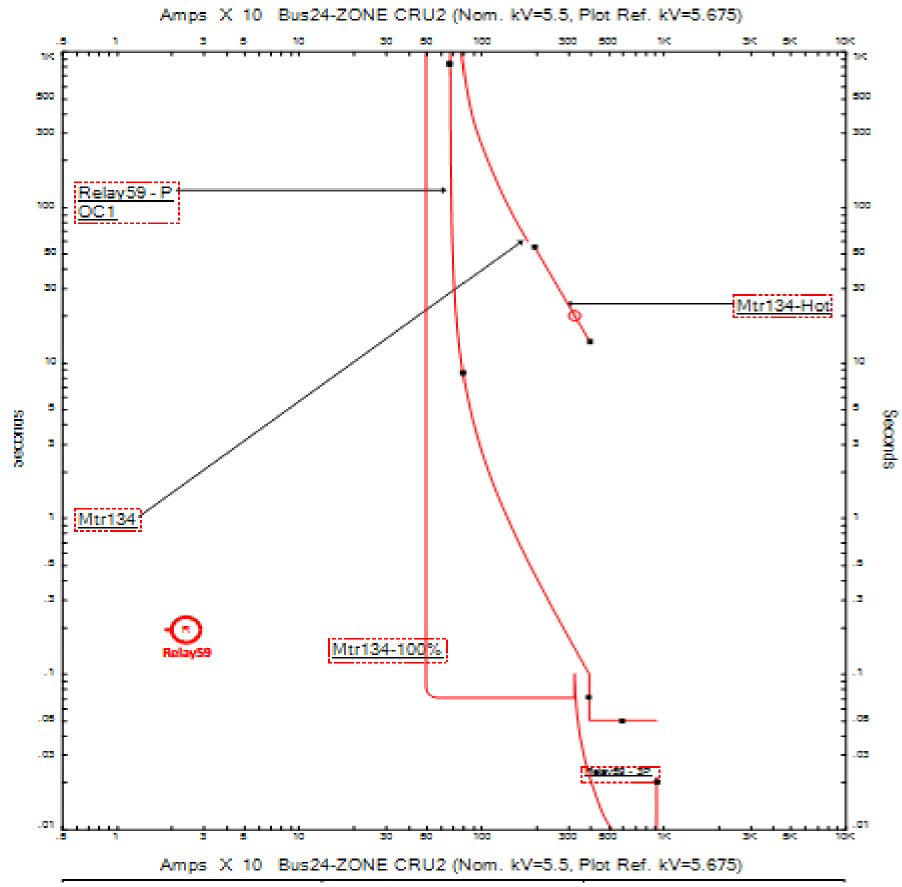


Figure 71-relay protection of 5.5kV induction motor

So the overall protection scheme will be:

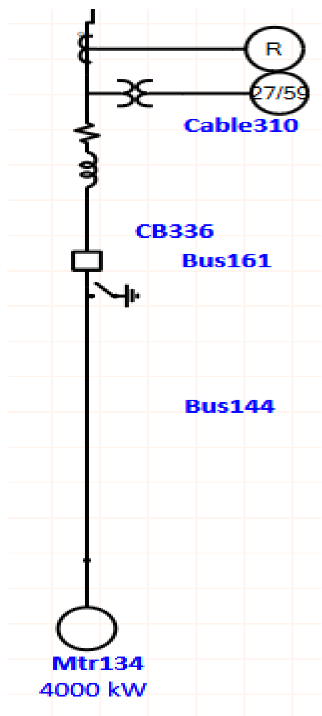


Figure 72-protection scheme of MV motor

Low voltage motor protection

The low voltage motor is safeguarded by an overload relay, which serves to protect against excessive loads and overloads. Additionally, fuses and miniature circuit breakers (MCBs) are employed to provide protection against overcurrent conditions. It is important to note that these protective devices are carefully selected and configured to ensure that they operate within the safe operating range, remaining under the damage curve while effectively handling inrush currents. This comprehensive protection scheme helps to maintain the motor's longevity and prevent any potential damage due to excessive currents or overloads.

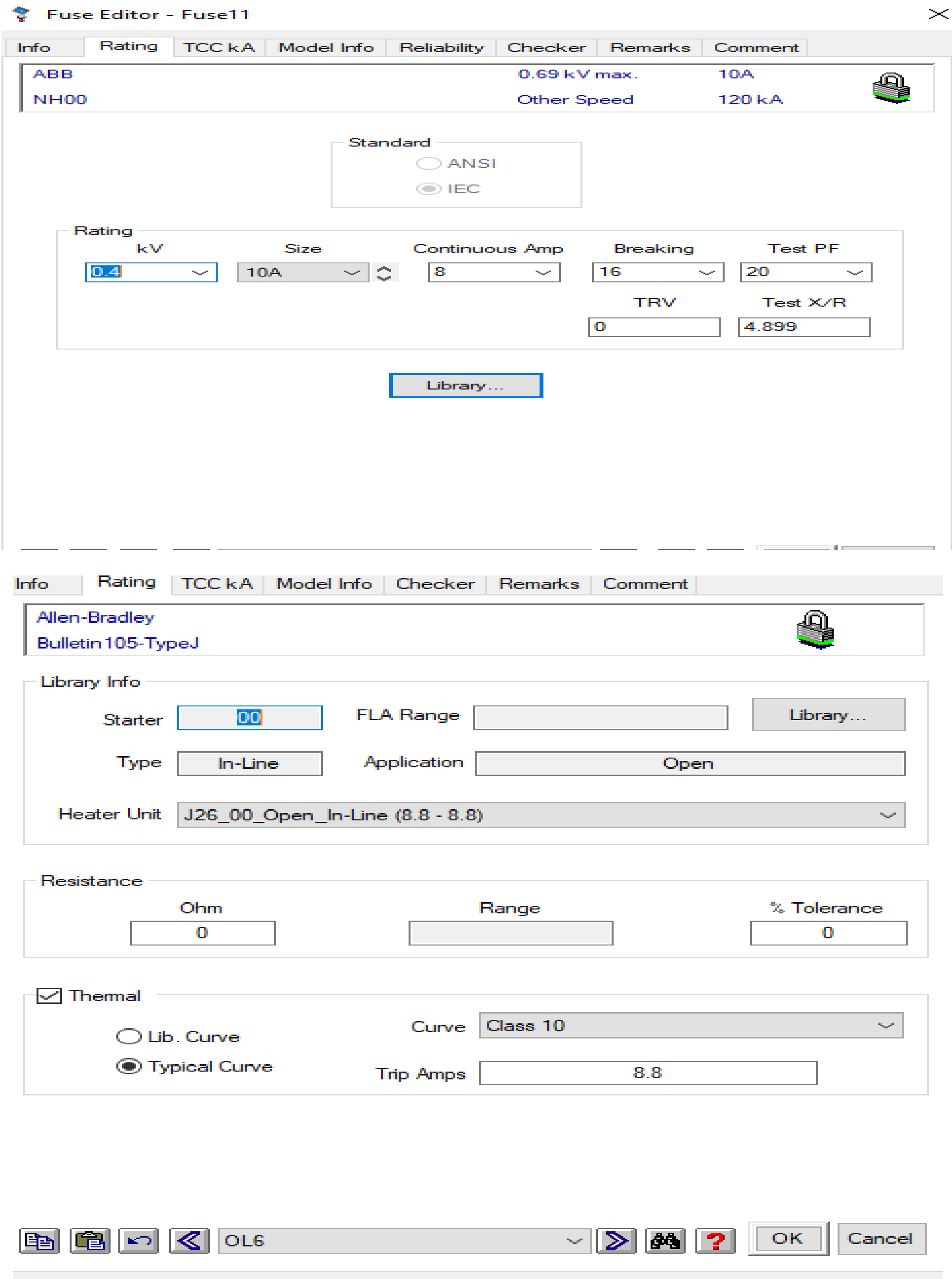


Figure 73-fuse-thermal relay selection for LV motor

4.65Selectivity

4.6.1Low/medium voltage selectivity

The selectivity primarily focuses on achieving coordination between the fuse and MCB within the Motor Control Center (MCC), as well as between both of them and the MCB responsible for protecting the low voltage (LV) busbar. This selectivity is determined using protection and coordination tools, specifically by analyzing the curve section view.

It is important to note that the curves of the MCB, fuse, and relay differ from each other. These variations in curves must be taken into account when establishing the selectivity and coordination between the protective devices. By carefully analyzing the curve section view and considering the distinct characteristics of each protective device, an optimized selectivity scheme can be developed to ensure proper discrimination and efficient protection of the LV system.

The following figure display how the selectivity LV-LV are done form downstream to upstream

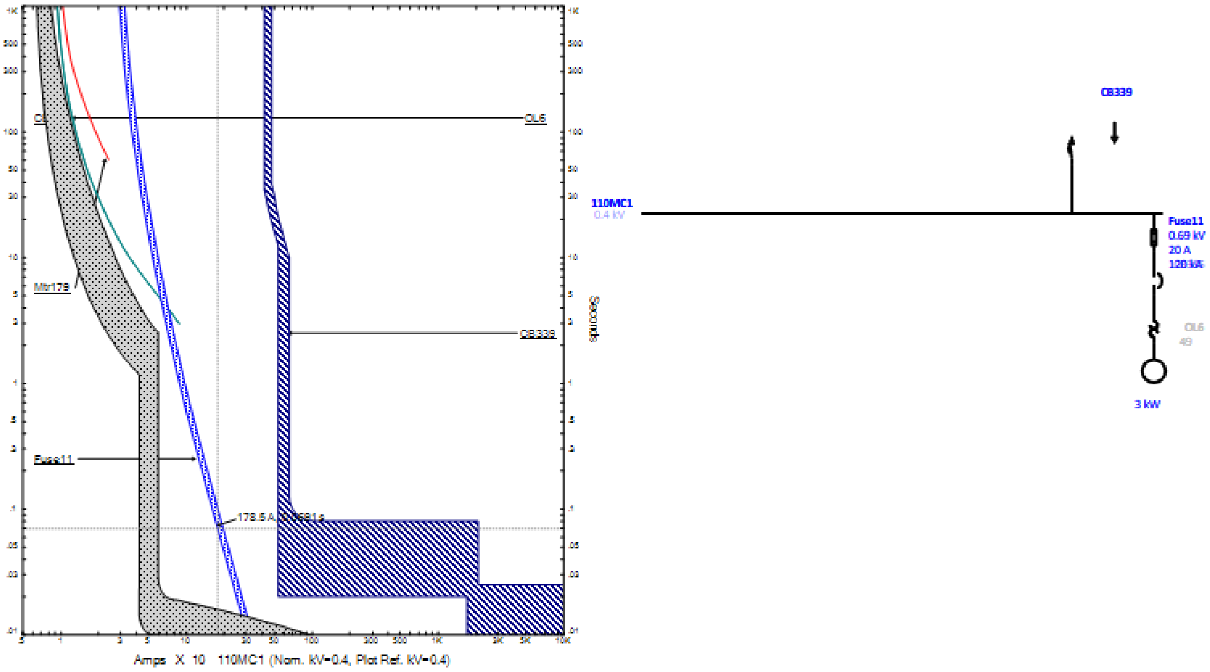


Figure 74-Low/low voltage selectivity

In the selectivity approach employed, the first level of response is given to the Motor Control Center (MCC) MCB. If the fault is not cleared by the MCC MCB, the next level of response is provided by the motor fuse downstream. If the fault still persists, the MCB protecting the LV busbar upstream is activated. This selectivity method primarily focuses on achieving current discrimination and is known as time-current selectivity.

Following the selectivity between the motor protection devices and LV busbar protection devices, the next step involves establishing selectivity between the MCB on the secondary side and the relay on the primary side of the transformer. In this case, if a fault occurs on the low voltage side of the busbar, the primary objective is for the MCB to respond first. The MCB acts as the initial line of defense, promptly detecting and isolating the fault.

However, if the fault is beyond the capabilities of the MCB to handle, the relay on the primary side of the transformer serves as a backup protection measure. The relay is designed to activate in such instances, providing additional protection and ensuring the fault is promptly cleared to prevent further damage or complications.

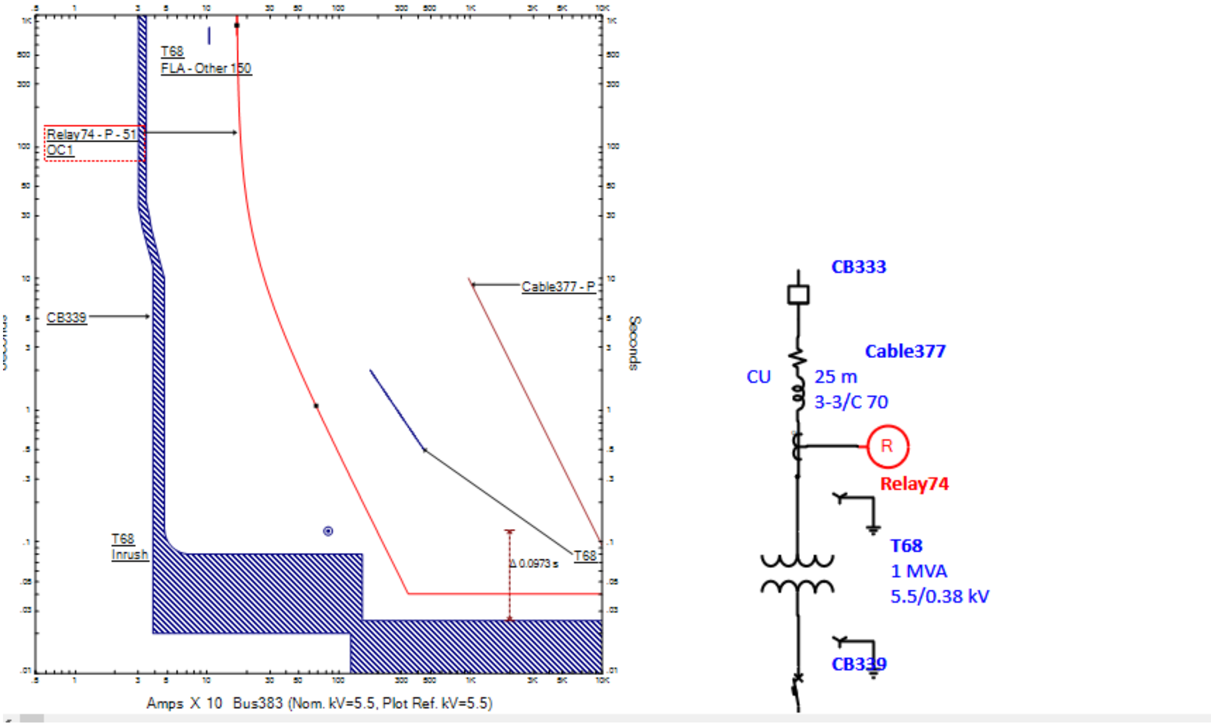


Figure 75-meduim/low voltage selectivity

We notice that time gap in not the same and it getting smaller by the current in this type of devices we can not keep CTI fixed.

Selectivity does not overlook the matter that both curve should be below damage curve in this case of cable and transformer.

4.6.2 Medium/medium voltage selectivity

The coordination between protective relays is accomplished using a time-current technique, typically employing an Inverse Definite Minimum Time (IDMT) curve. This curve combines an inverse curve and an instantaneous curve to determine the operating time of the relays.

According to this coordination principle, the relay located closest to the fault should respond first, providing primary protection. The relays located further upstream serve as backup protection, with each relay responding consecutively based on their distance from the fault.

By coordinating the relays in this manner, the system ensures that faults are cleared efficiently and rapidly, minimizing potential damage and maintaining the reliability of the power distribution network.

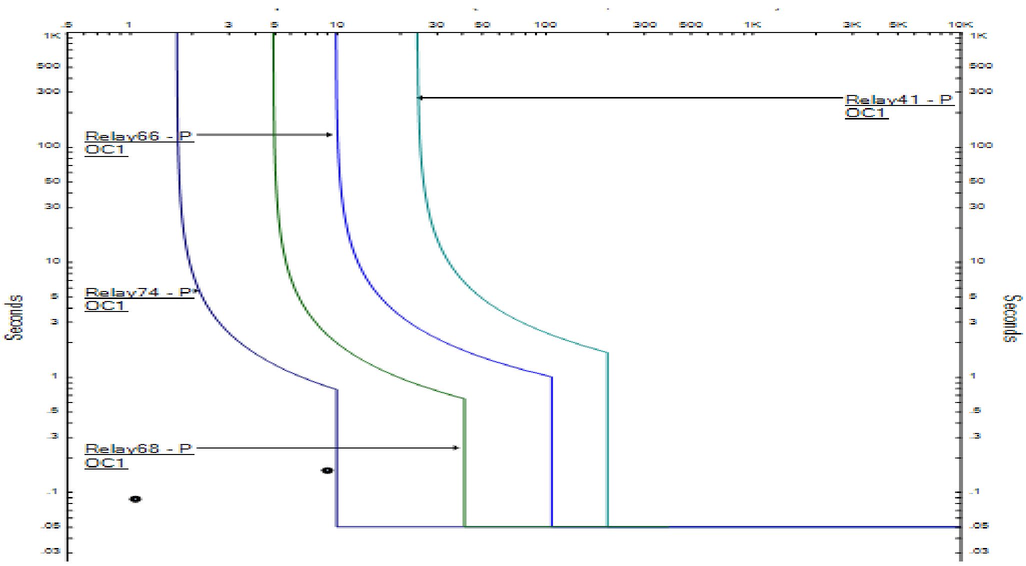
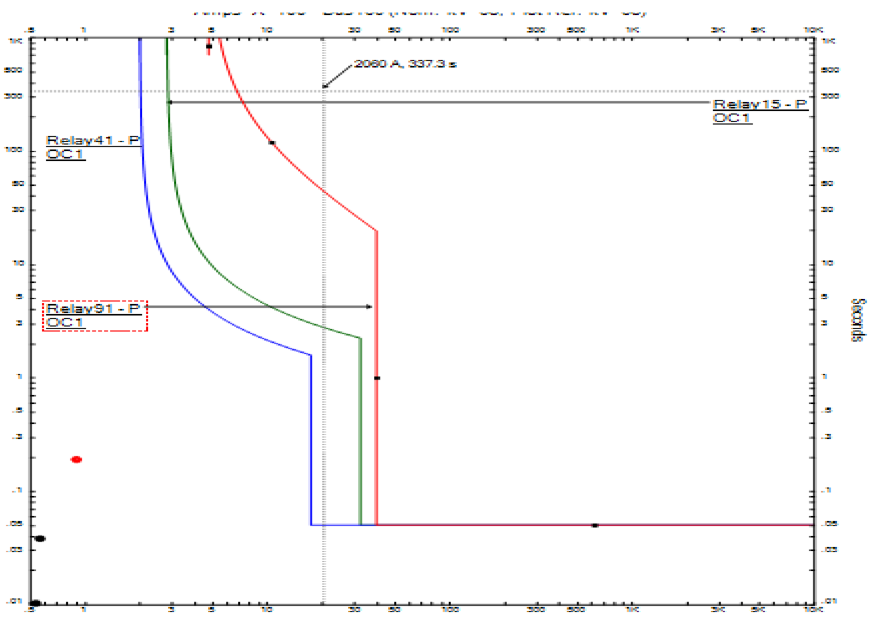


Figure 76-medium/medium voltage selectivity

4.6.3Medium/high voltage selectivity

In this particular level of coordination, the secondary side relay is designed to be the first to respond in the event of a fault. It provides the initial protection for the system. If the fault is not cleared by the secondary side relay, the primary side relay comes into action as the next line of defense. It serves as a backup protection measure to ensure that the fault is isolated and cleared. Lastly, the relay responsible for protecting the transmission line is the last in line to respond to the fault. This sequential coordination of relays ensures an efficient and reliable response to faults, prioritizing the protection of the system components and minimizing potential disruptions.



The coordination approach is not limited to just phase overcurrent relays, but it also extends to earth fault relays, which are specifically designed to provide high sensitivity for detecting earth faults. The coordination of these relays ensures effective detection and response to earth faults in the system as shown in figure

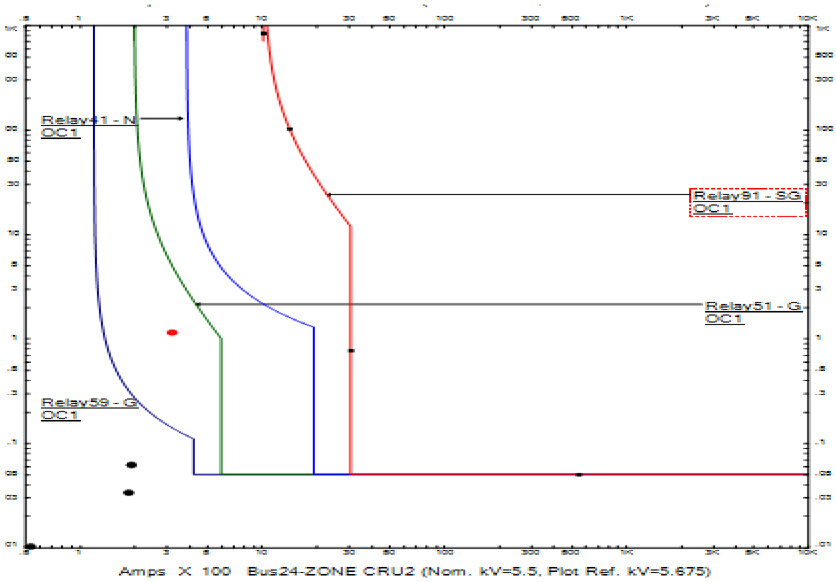


Figure 77-earth fault selectivity

Not only that but we can do a relay coordination using definite time relays in order to apply time selectivity method and it must combined with current selectivity method it easier to perform since we can ensure a constant CTI among all relay, however in some cases it can inapplicable as we seen in chapter5.

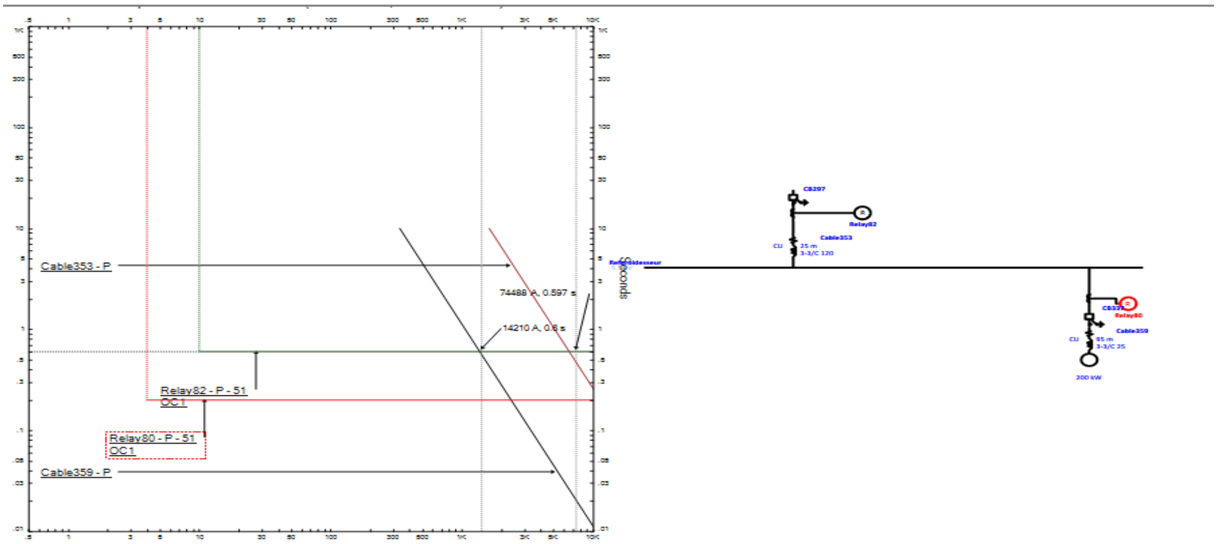


Figure 78-time selectivity

Another drawback is intersection of relay with damage curve it can be tolerated if intersection point is beyond maximum symmetrical fault current

As it said before it should combined with current selectivity method depending on current magnitude

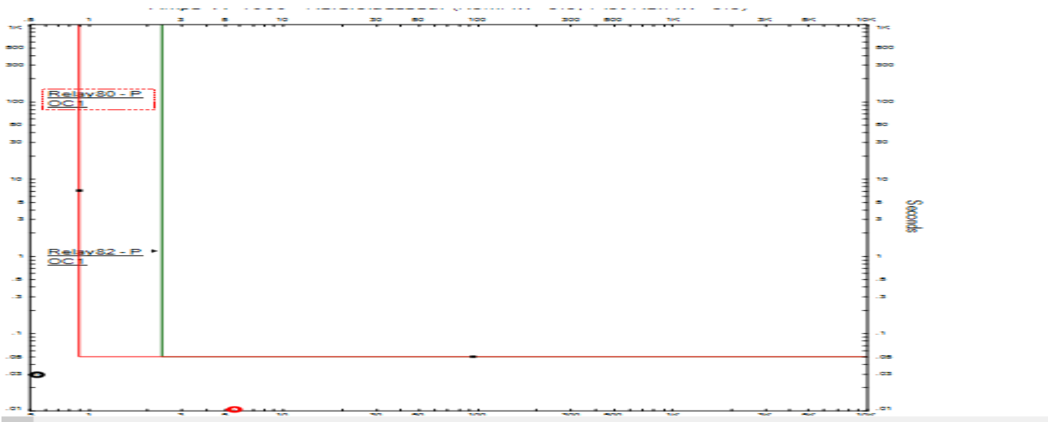


Figure 79-current selectivity

We can check the validity of relay coordination using star auto evaluation which gives information about coordination in certain zone

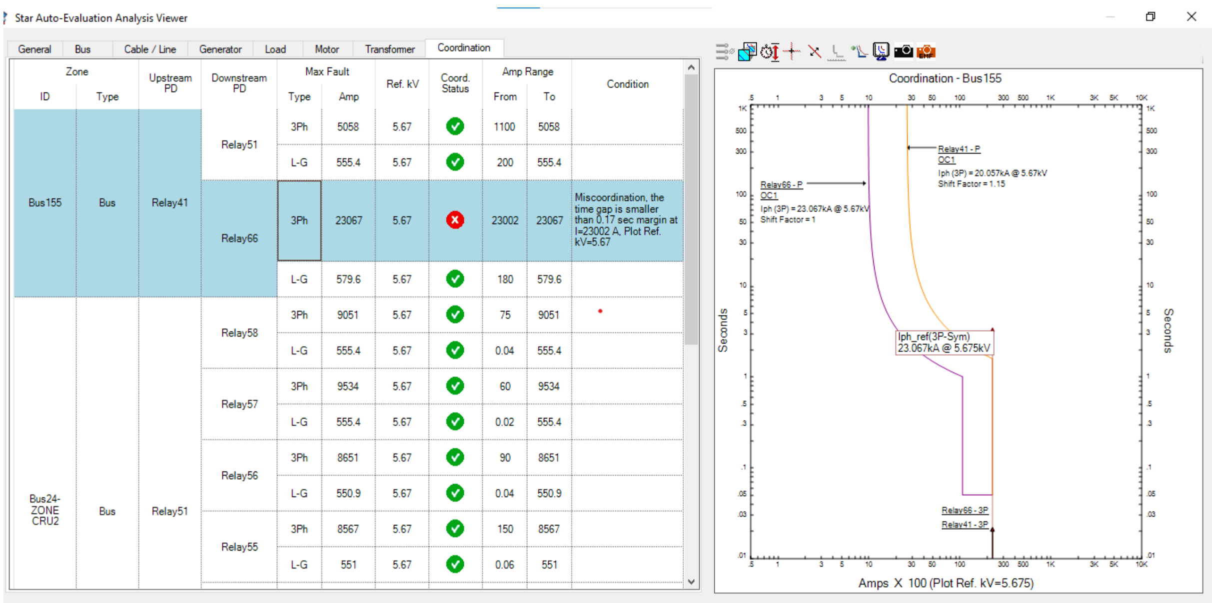


Figure 80-Star Auto Evaluation

4.7Conclusion

This chapter primarily centers around the process of entering SCMI factory data into ETAP software and subsequently implementing a comprehensive protection scheme. The chapter covers various aspects, including CT selection, relay setting, and circuit breaker sizing. Additionally, the chapter emphasizes the implementation of selectivity using the Time Current Characteristic (TCC) curve. By utilizing ETAP software and following the outlined procedures, engineers can design an effective protection scheme that ensures selectivity and coordination among protective devices in the SCMI factory.

Chapter five : Results & discussion

Results&discussion

5.1Introduction

In this chapter we will talk about the results of the protection scheme so we will try to simulate different types of faults and see how our system respond correspond to the case then discuss the possible problems give as suggestion solution for it.

5.2Protection results

For protection results we will see the results of our protection scheme in each electrical equipment relative to faults type with interpretation for the results

It been create a three phase symmetrical faults in transmission line :

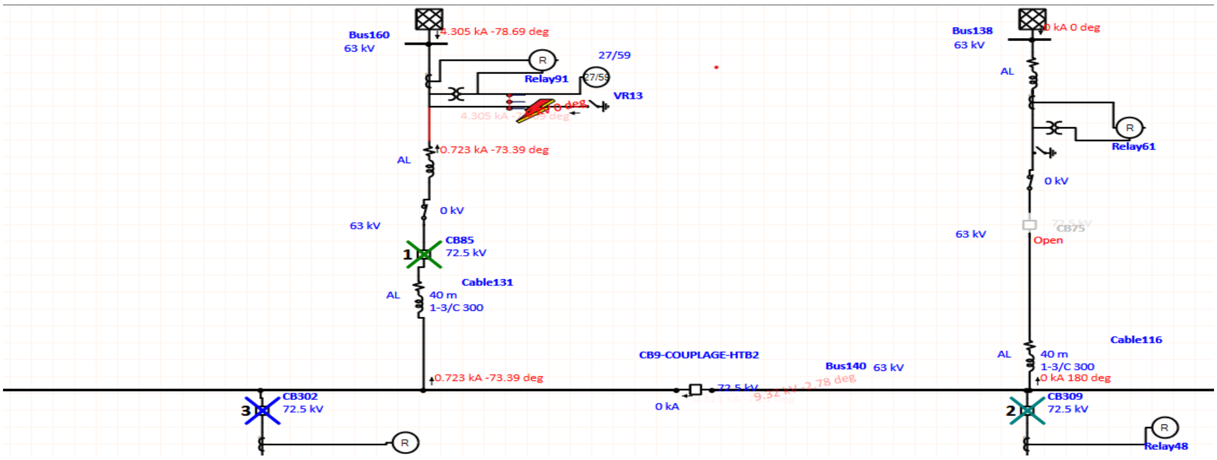


Figure 81-apply three phase fault on TL

The sequence events will :

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between Line1 & GS34. Adjacent bus: Bus160

Data Rev.: Base Config: Normal Date: 05-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
50.0	Relay91	4.305	50.0		Phase - OC1 - 50
100	CB85		50.0		Tripped by Relay91 Phase - OC1 - 50
7164	Relay48	0.311	7164		Phase - OC1 - 51
7214	CB309		50.0		Tripped by Relay48 Phase - OC1 - 51
7650	Relay15	0.414	7650		Phase - OC1 - 51
7700	CB302		50.0		Tripped by Relay15 Phase - OC1 - 51
10000	VR9		10000		Undervoltage - 27
10000	VR13		10000		Undervoltage - 27
10000	VR14		10000		Undervoltage - 27
10050	CB15-5,5KV2		50.0		Tripped by VR9 Undervoltage - 27
10050	CB85		50.0		Tripped by VR13 Undervoltage - 27
10050	CB336		50.0		Tripped by VR14 Undervoltage - 27

Figure 82-sequence of operation of faulted TL

The initial response to an instantaneous phase overcurrent is triggered by relay 91, with a response time of 50ms. This is followed by an additional 50ms of operating time for the circuit breaker (CB), resulting in a total clearing time of 100ms. The operation of the instantaneous overcurrent relay (51) is blocked by the faster response of the instantaneous phase overcurrent relay (91).

As a backup protection measure, relay 48 is responsible for protecting the primary side of transformer 1 and operates after a delay of 7.650ms. Additionally, relay 15 operates after the same delay of 7.650ms.

The relays 41 and 49, which are responsible for protecting the secondary transformers, have been restrained from tripping, despite the current flowing on both sides being above the pick value. This is due to the presence of directional protection relay 67.

The distance between the relay and the fault location plays a significant role in determining the magnitude of the fault current detected by the relay. A greater distance results in a larger impedance, leading to a smaller fault current detected by the relay.

It is important to note that phase faults can result in a voltage drop, which explains the response from undervoltage relays.

It been encountered a problem with earth faults where relays 41 and 49 do not respond to the faults because they are not equipped with earth fault protection functionality, as indicated.

Sequence-of-Operation Events - Output Report: Untitled

Line-to-Ground (Asymmetrical) fault on connector between Line1 & GS34. Adjacent bus: Bus160

Data Rev.: Base Config: Normal Date: 05-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
50.0	Relay91	3.557	50.0		Sensitive Ground - OC1 - 50
100	CB85		50.0		Tripped by Relay91 Sensitive Ground - OC1 - 50
10000	VR9		10000		Overvoltage - 59
10000	VR9		10000		Undervoltage - 27
10000	VR13		10000		Undervoltage - 27
10000	VR14		10000		Overvoltage - 59
10050	CB15-5,5KV2		50.0		Tripped by VR9 Overvoltage - 59
10050	CB15-5,5KV2		50.0		Tripped by VR9 Undervoltage - 27
10050	CB85		50.0		Tripped by VR13 Undervoltage - 27
10050	CB336		50.0		Tripped by VR14 Overvoltage - 59
25263	Relay91	3.216	25263		Phase - OC1 - 51
25313	CB85		50.0		Tripped by Relay91 Phase - OC1 - 51

Figure 83-sequence of operation of phase to ground fault of TL

The absence of earth fault protection in relays 41 and 49 does not pose a problem, as overcurrent protection is typically considered a secondary measure following distance protection (relay 21).

Now, let's discuss the protection of the 63/5.5kV transformer. In the event of faults occurring within the differential zone, the protection is determined by CT expansion. The initial response comes from the 87 protection, followed by other protective functions.

We will disable under/overvoltage for sake of seeing all relays events.

Applying three phase symmetrical faults in primary side of transformer inside differential protection zone

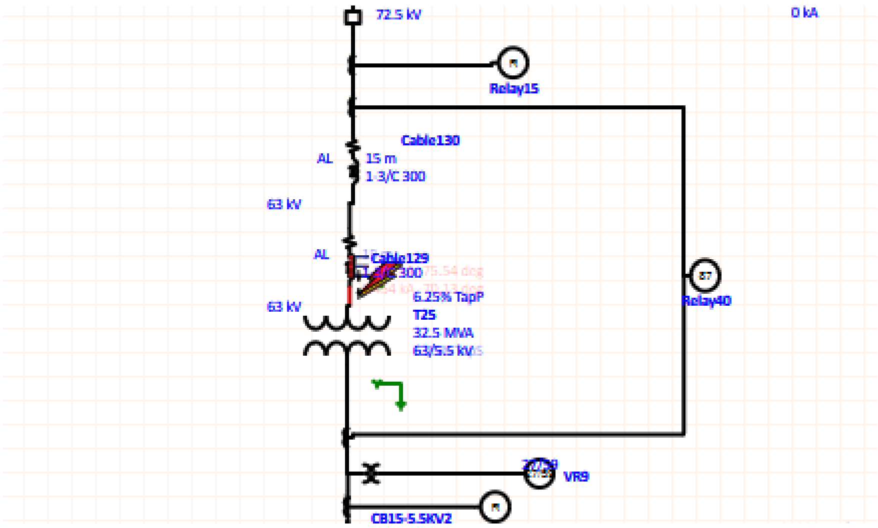


Figure 84-fault inside protection zone of transformer

The results will be

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between Bus302 & Cable129. Adjacent bus: Bus302

Data Rev.: Base Config: Normal Date: 05-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
20.0	Relay40		20.0		Phase - 87
50.0	Relay15	2.756	50.0		Phase - OC1 - 50
70.0	CB15-5,5KV2		50.0		Tripped by Relay40 Phase - 87
70.0	CB302		50.0		Tripped by Relay40 Phase - 87
100	CB302		50.0		Tripped by Relay15 Phase - OC1 - 50
4259	Relay41	5.197	4259		Phase - OC1 - 51
4309	CB15-5,5KV2		50.0		Tripped by Relay41 Phase - OC1 - 51
4956	Relay48	0.36	4956		Phase - OC1 - 51
5006	CB309		50.0		Tripped by Relay48 Phase - OC1 - 51
36065	Relay91	2.397	36065		Phase - OC1 - 51
36115	CB85		50.0		Tripped by Relay91 Phase - OC1 - 51

Figure 85-sequence of operation of fault inside protection zone of transformer

If the same faults applied out of protection zone 87 relay will not respond as this case

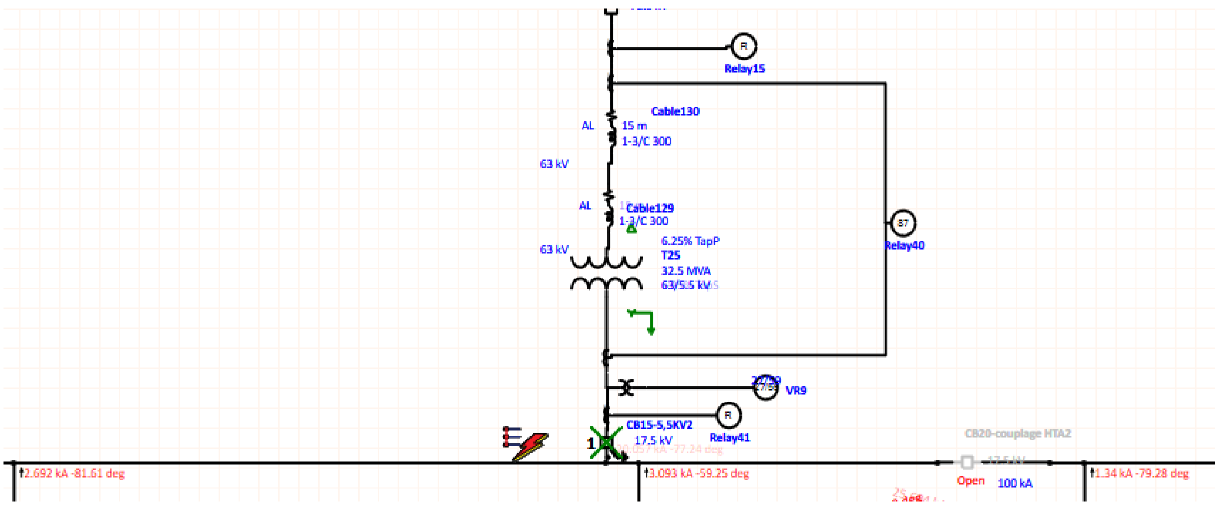


Figure 86-fault outside protection zone of transformer

The sequence of events will be

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on bus: Bus155

Data Rev.: Base Config: Normal Date: 05-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
50.0	Relay41	20.057	50.0		Phase - OC1 - 50 - Forward
100	CB15-5,5KV2		50.0		Tripped by Relay41 Phase - OC1 - 50 - Forward
2525	Relay15	1.751	2525		Phase - OC1 - 51
2575	CB302		50.0		Tripped by Relay15 Phase - OC1 - 51
19066	Relay48	0.229	19066		Phase - OC1 - 51
19116	CB309		50.0		Tripped by Relay48 Phase - OC1 - 51
66281	Relay91	1.523	66281		Phase - OC1 - 51
66331	CB85		50.0		Tripped by Relay91 Phase - OC1 - 51

Figure 87-sequence of operation Figure5.4 fault inside protection zone of transformer

Referring that relay 41 are designated mainly to protect main 5.5kV bus bar.

it can exhibit the effectiveness of negative sequence protection in imbalanced faults by applying the line to line faults to primary side of power transformer the first which detect the faults will be 46 protection as shown :

Sequence-of-Operation Events - Output Report: Untitled

Line-to-Line (Asymmetrical) fault on connector between CB302 & CT54. Adjacent bus: 63kv busbar

Data Rev.: Base Config: Normal Date: 07-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
750	Relay15	0.23	750		Negative Sequence - OC1 - 51
800	CB302		50.0		Tripped by Relay15 Negative Sequence - OC1 - 51
874	Relay91	1.172	874		Negative Sequence - OC1 - 51
924	CB85		50.0		Tripped by Relay91 Negative Sequence - OC1 - 51
1038	Relay68	1.816	1038		Phase - OC1 - 51
1088	CB328		50.0		Tripped by Relay68 Phase - OC1 - 51
2459	Relay66	2.655	2459		Phase - OC1 - 51
2509	CB266		50.0		Tripped by Relay66 Phase - OC1 - 51
2958	Relay74	0.272	2958		Phase - OC1 - 51
3008	CB333		50.0		Tripped by Relay74 Phase - OC1 - 51
3257	Relay48	0.18	3257		Negative Sequence - OC1 - 51
3307	CB309		50.0		Tripped by Relay48 Negative Sequence - OC1 - 51
7310	Relay48	0.309	7310		Phase - OC1 - 51
7360	CB309		50.0		Tripped by Relay48 Phase - OC1 - 51
7451	Relay15	0.401	7451		Phase - OC1 - 51

Figure 88-sequence of operation of line to line fault

So rather than clearing the faults within 7451ms using phase overcurrent we clear it only in 750ms using negative sequence protection since it is very sensitive to unbalanced faults

5.3Selectivity results

To obtain selectivity results, simulations have been conducted and tested to validate the selectivity under various conditions. During these tests, we specifically focused on identifying any problems that could arise during faults, as they have the potential to cause significant issues. By analyzing and displaying the problems encountered during fault scenarios, we aimed to ensure the effectiveness and reliability of the selectivity scheme.

Starting with LV we create faults at it to see the sequence of operation we applied three phase faults on 3kW/380V motor in crusher zone

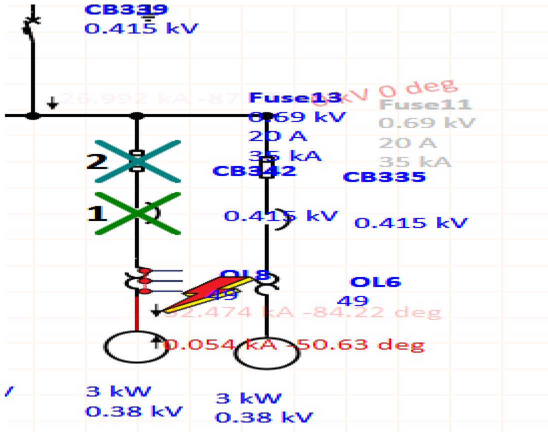
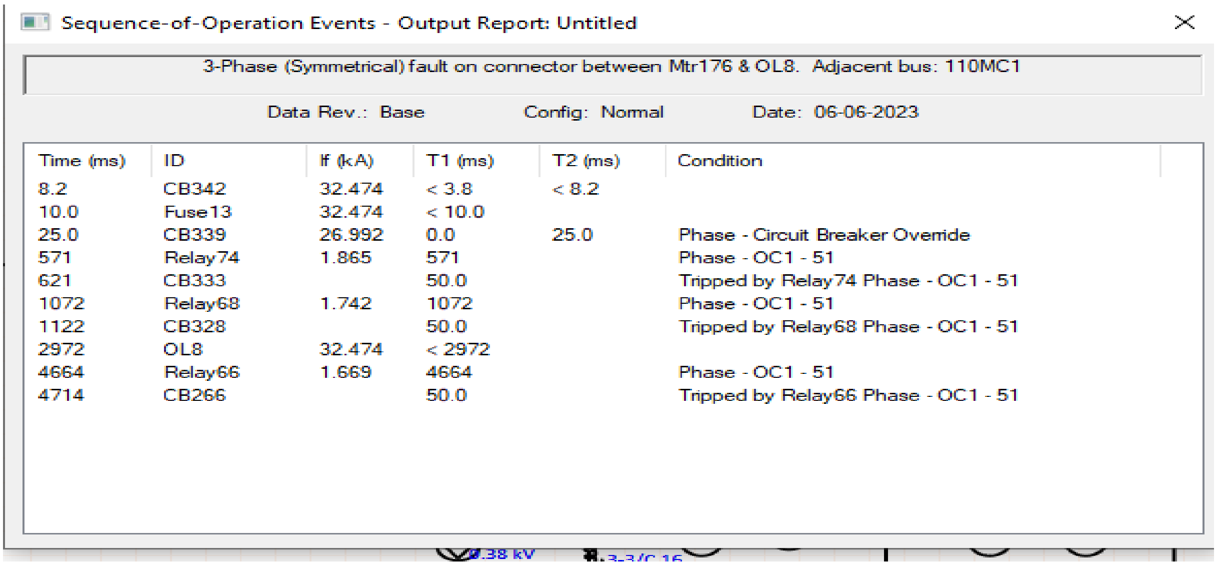


Figure 89-three phase fault in LV motor

The event sequence operation of faults will be:



Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between Mtr176 & OL8. Adjacent bus: 110MC1

Data Rev.: Base   Config: Normal   Date: 06-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
8.2	CB342	32.474	< 3.8	< 8.2	
10.0	Fuse13	32.474	< 10.0		
25.0	CB339	26.992	0.0	25.0	Phase - Circuit Breaker Override
571	Relay74	1.865	571		Phase - OC1 - 51
621	CB333		50.0		Tripped by Relay74 Phase - OC1 - 51
1072	Relay68	1.742	1072		Phase - OC1 - 51
1122	CB328		50.0		Tripped by Relay68 Phase - OC1 - 51
2972	OL8	32.474	< 2972		
4664	Relay66	1.669	4664		Phase - OC1 - 51
4714	CB266		50.0		Tripped by Relay66 Phase - OC1 - 51

Figure 90-sequence of operation of three phase fault in LV motor

It observed that both the circuit breaker (CB) and fuse protecting the motor took action almost simultaneously. This can be attributed to the magnitude of the fault, which was significant. Subsequently, a short time later, we noticed that the CB protecting the low voltage (LV) busbar tripped. The reason behind the small time margin between the three devices is the substantial fault current. In cases where the fault current is much smaller, we would expect to observe differences in the time of action between these devices.

Regarding the LV devices, we observed that relay 74, responsible for protecting the primary side of the 5.5/0.4kV system, sends a trip signal to CB333 (located in the primary side) in the event of a problem. If CB333 fails to trip, relay 68, designed to protect the concasseur zone feeder, takes action. Similarly, if relay 68 fails to respond, relay 66, responsible for protecting the multi-zone feeder, comes into play.

In this scenario, the faults occur in areas with insignificant power loads, resulting in a lower fault current that may not be sufficient to trigger the upper-level distribution system relays (relay 41, relay 15, relay 91). However, the faults can still activate these relays, as observed in the case of large motors.

the overload relay responds relatively slowly, but it is specifically designed to protect against overload faults, including phase-to-ground faults.

Sequence-of-Operation Events - Output Report: Untitled

Line-to-Ground (Asymmetrical) fault on connector between Mtr176 & OL8. Adjacent bus: 110MC1

Data Rev.: Base Config: Normal Date: 06-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
6499	OL8	0.048	6499		
8683	CB342	0.048	1818	8683	
32672	Fuse13	0.048	18293	32672	

Figure 91-sequence of operation of phase to ground fault in LV motor

Staying with concasseur zone I went to give a spot to an issue that concern current selectivity (instantaneous overcurrent) when it come to relays coordination in case there are two short and consecutive lines because the difference between the fault current on both lines is not significant so the relay can not distinguish .is this fault on my line or on the other line.

To clarify the situation, let's consider the application of a three-phase fault on the primary side of the 5.5/0.4kV transformer. There is a zone in which this transformer exists, with each busbar connected by a short conductor length of approximately 25 to 30 meters.

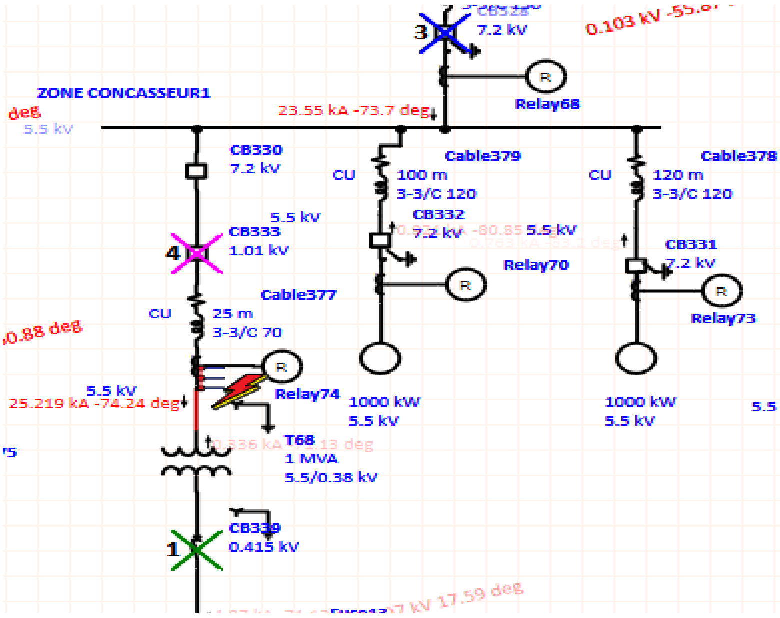


Figure 92-three phase fault in 5.5/0.4Kv transformer

The sequence of event operation will be

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between Bus383 & T68. Adjacent bus: Bus383

Data Rev.: Base Config: Normal Date: 06-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
50.0	Relay66	22.576	50.0		Phase - OC1 - 50
50.0	Relay68	23.55	50.0		Phase - OC1 - 50
50.0	Relay74	25.219	50.0		Phase - OC1 - 50
80.0	CB339	4.87	20.0	80.0	Phase
100	CB266		50.0		Tripped by Relay66 Phase - OC1 - 50
100	CB328		50.0		Tripped by Relay68 Phase - OC1 - 50
100	CB333		50.0		Tripped by Relay74 Phase - OC1 - 50
2549	Relay15	1.717	2549		Phase - OC1 - 51
2599	CB302		50.0		Tripped by Relay15 Phase - OC1 - 51
7161	OL8	0.045	7161		
10327	CB342	0.045	2021	10327	
20600	Relay48	0.224	20600		Phase - OC1 - 51
20650	CB309		50.0		Tripped by Relay48 Phase - OC1 - 51
51460	Fuse13	0.045	27797	51460	

Figure 93-sequence of operation three phase fault in 5.5/0.4Kv transformer

Disregarding the tripping of CB339 and other LV circuit breakers due to the effects of motor contributions, we observe that relay66, relay68, and relay74 have activated the 50 protection function. This activation is a result of the large fault current present, with relay74 being the closest relay to the fault and the one expected to intervene in such a scenario.

That why it is not advisable to use instantaneous overcurrent even in the protection of the power transformer for the same previous reason. The difficulty of coordination between transformer protection and feeder protection or set the value of short circuit above maximum value in case faults happen in nearest feeder.

So it more suitable in this case to use time-current curve (IDMT) instead of time curve without instantaneous overcurrent with using extremely inverse for simulating the 50 protection in large current fault the result for same fault will be :

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between Bus383 & T68. Adjacent bus: Bus383

Data Rev.: Base Config: Normal Date: 09-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
40.1	Relay74	22.383	40.1		Phase - OC1 - 51
80.0	CB339	4.87	20.0	80.0	Phase
90.1	CB333		50.0		Tripped by Relay74 Phase - OC1 - 51
320	Relay68	20.713	320		Phase - OC1 - 51
370	CB328		50.0		Tripped by Relay68 Phase - OC1 - 51
549	Relay66	19.734	549		Phase - OC1 - 51
599	CB266		50.0		Tripped by Relay66 Phase - OC1 - 51
2484	Relay15	1.723	2484		Phase - OC1 - 51
2534	CB302		50.0		Tripped by Relay15 Phase - OC1 - 51
7161	OL8	0.045	7161		
10000	VR9		10000		Undervoltage - 27
10000	VR14		10000		Undervoltage - 27
10050	CB15-5,5KV2		50.0		Tripped by VR9 Undervoltage - 27
10050	CB336		50.0		Tripped by VR14 Undervoltage - 27
10327	CB342	0.045	2021	10327	

Figure 94-sequence of operation three phase fault in 5.5/0.4Kv transformer

Ignoring other tripping due to motor contribution it seen that there selectivity and time gap between each upstream and downsteam is around 250ms

That why for small factories where the conductor length is short it preferable to use IDMT curve instead of definite time curve even that coordination in first method is harder then second one.

We can use another effective solution yet difficult one which is differential line protection which will apply the term of zone protection. But it required skillful protection engineers to apply it

Now let talk about selectivity in MV motor we same procedure as LV motor. First by applying phase to ground fault in 4MW MV motor.

We apply phase to ground fault to it

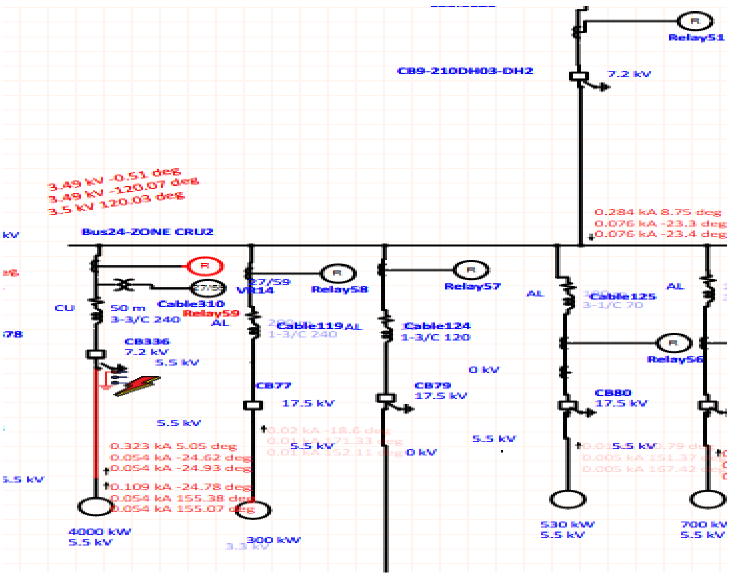


Figure 95-phase to ground fault in MV motor

The sequence event will be :

Sequence-of-Operation Events - Output Report: Untitled

Line-to-Ground (Asymmetrical) fault on connector between Bus393 & GS16. Adjacent bus: Bus393

Data Rev.: Base Config: Normal Date: 07-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
98.7	Relay59	0.421	98.7		Ground - OC1 - 51
149	CB336		50.0		Tripped by Relay59 Ground - OC1 - 51
2328	Relay51	0.421	2328		Ground - OC1 - 51
2378	CB9-210DH...		50.0		Tripped by Relay51 Ground - OC1 - 51
9777	Relay41	0.421	9777		Neutral - OC1 - 51
9827	CB15-5.5KV2		50.0		Tripped by Relay41 Neutral - OC1 - 51
10000	VR9		10000		Overvoltage - 59
10000	VR14		10000		Overvoltage - 59
10050	CB15-5.5KV2		50.0		Tripped by VR9 Overvoltage - 59
10050	CB336		50.0		Tripped by VR14 Overvoltage - 59

Figure 96-sequence of operation of phase to ground fault in MV motor

During a phase-to-ground fault, an overvoltage condition can occur due to a phenomenon known as Transient Recovery Voltage (TRV). When a fault is detected in an electrical system, protective devices like circuit breakers are activated to isolate the faulty section. As part of this process, the fault current flow is swiftly interrupted. However, this interruption of current can give rise to a temporary overvoltage called TRV. TRV emerges as a result of the sudden release of energy stored in the system's inductance and capacitance components. It is characterized by high voltages that surpass the normal operating levels. It is important to address TRV during phase-to-ground fault scenarios to prevent potential damage to the system. Protective measures such as surge arresters and voltage limiters are commonly employed to mitigate the effects of transient recovery voltage.

There are another effect which can triggered the overcurrent protection faults in case of current fault like system imbalanced can lead to increased voltages on the remaining healthy phases.

Now applying three phase faults on the same motor the results will be:

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between CB336 & Cable310. Adjacent bus: Bus393

Data Rev.: Base   Config: Normal   Date: 07-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
50.0	Relay59	6.445	50.0		Phase - OC1 - 50(TOC blocked by IOC)
100	CB336		50.0		Tripped by Relay59 Phase - OC1 - 50(TOC block...
1812	Relay51	5.041	1812		Phase - OC1 - 51
1862	CB9-210DH...		50.0		Tripped by Relay51 Phase - OC1 - 51
5393	Relay41	4.383	5393		Phase - OC1 - 51 - Forward
5443	CB15-5,5KV2		50.0		Tripped by Relay41 Phase - OC1 - 51 - Forward
7943	Relay15	0.383	7943		Phase - OC1 - 51
7993	CB302		50.0		Tripped by Relay15 Phase - OC1 - 51
8119	CB339	1.063	5529	8119	Phase
10000	VR14		10000		Undervoltage - 27
10050	CB336		50.0		Tripped by VR14 Undervoltage - 27
38925	CB94	1.968	7105	38925	
618819	OL8	0.01	618819		

Figure 97-sequence of operation of three phase fault in MV motor

Now we do protection scheme for the rest parallel motors and it will be appear an issue the effect it clear which is motor contribution.

5.4Motor contribution

We have previously discussed the impact of motor contribution during a fault, which includes consequences such as the amplification of fault current magnitude and voltage dip. Additionally, the potential issues of miscoordination and undesired tripping were also highlighted. Now, let's delve into the specific case we are about to discuss, focusing on these aspects.After setting relays in parallel busbar let create three phase fault in 4000Kw the results will be:

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between Bus393 & GS16. Adjacent bus: Bus393

Data Rev.: Base   Config: Normal   Date: 07-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
50.0	Relay59	6.522	50.0		Phase - OC1 - 50(TOC blocked by IOC)
56.4	Relay58	0.79	56.4		Phase - OC1 - 51
100	CB336		50.0		Tripped by Relay59 Phase - OC1 - 50(TOC block...
106	CB77		50.0		Tripped by Relay58 Phase - OC1 - 51
106	Relay57	0.22	106		Phase - OC1 - 51
113	Relay56	0.325	113		Phase - OC1 - 51
132	Relay55	0.428	132		Phase - OC1 - 51
156	CB79		50.0		Tripped by Relay57 Phase - OC1 - 51
163	CB80		50.0		Tripped by Relay56 Phase - OC1 - 51
202	CB81		70.0		Tripped by Relay55 Phase - OC1 - 51
1812	Relay51	5.041	1812		Phase - OC1 - 51
1862	CB9-210DH...		50.0		Tripped by Relay51 Phase - OC1 - 51
5393	Relay41	4.383	5393		Phase - OC1 - 51 - Forward
5443	CB15-5.5KV2		50.0		Tripped by Relay41 Phase - OC1 - 51 - Forward
7943	Relay15	0.383	7943		Phase - OC1 - 51

Figure 98-sequence of operation before adding current limiter

During our observation, we noticed that in addition to the tripping of the relay (designated as 59) responsible for protecting the 4MW motor, the relays safeguarding the parallel motors on the same busbar also trip, albeit with a slight delay. The relay (designated as 58), which is closest to the fault, trips almost simultaneously with relay 59. This indicates that each motor contributes differently to the fault current, ranging from 0.22kA to 0.79kA. The specific contribution depends on factors such as the locked rotor current, reactance percentage, and transient time of each motor.The analysis of the short circuit in the feeding busbar confirms that larger motors have a higher current contribution and generally exhibit longer transient times compared to smaller motors.

Short-Circuit Summary Report

3-Phase Fault Currents

Bus		Device		Device Capacity (kA)				Short-Circuit Current (kA)					
				Making									
ID	kV	ID	Type	Peak	Ib sym	Ib asym	Idc	I"k	ip	Ib sym	Ib asym	Idc	Ik
Bus24-ZONE CRU2	5.500	Bus24-ZONE CRU2	Bus					9.813	20.082				4.825

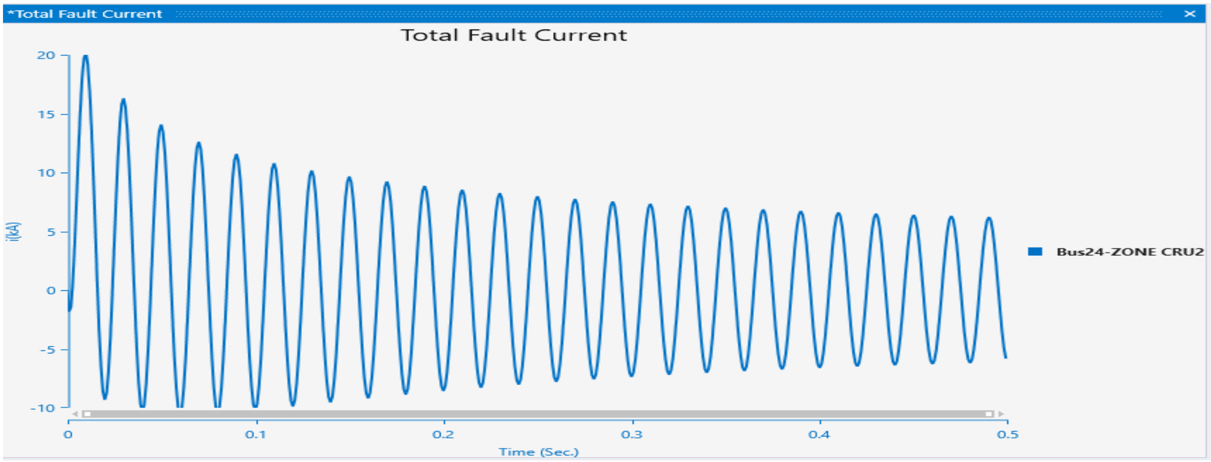


Figure 99-short circuit analysis with the effect of motor contribution

The motor contribution is influenced by several parameters, including the rotor locked current, transient time, and reactance impedance. These parameters play a crucial role in controlling the behavior and characteristics of the motor.

As the motor size increases, the magnitude of both the transient current and the contributed current also grows larger.

To address this issue, a proposed solution involves implementing a series reactance in the motor circuit. The principle behind this proposal is to increase the total reactance of the motor, which effectively limits the magnitude of the contributed current. By introducing additional reactance in the circuit, the impedance is increased, thereby reducing the flow of current and mitigating the impact of the larger motor size. This solution helps maintain the stability and proper functioning of the electrical system by managing the current levels associated with larger motors.

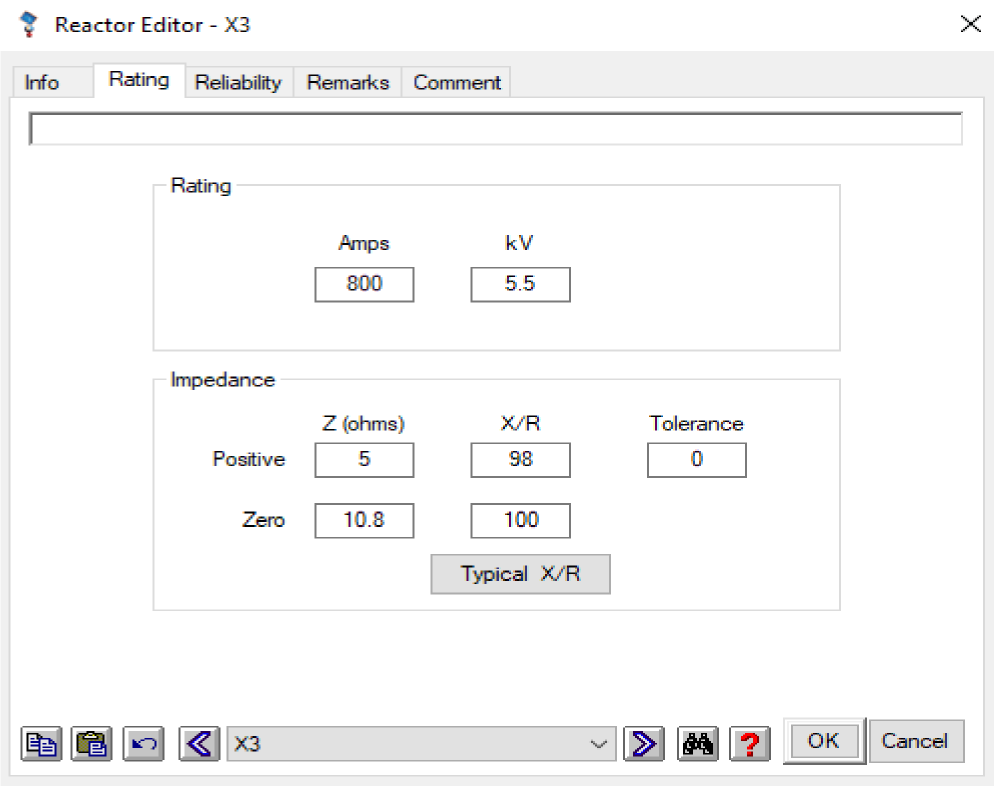


Figure 100-series reactor parameters

And the results will be :

Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on bus: Bus382

Data Rev.: Base Config: Normal Date: 09-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
50.0	Relay59	5.831	50.0		Phase - OC1 - 50
100	CB336		50.0		Tripped by Relay59 Phase - OC1 - 50
106	Relay57	0.22	106		Phase - OC1 - 51
156	CB79		50.0		Tripped by Relay57 Phase - OC1 - 51
165	Relay56	0.209	165		Phase - OC1 - 51
215	CB80		50.0		Tripped by Relay56 Phase - OC1 - 51
279	Relay55	0.247	279		Phase - OC1 - 51
349	CB81		70.0		Tripped by Relay55 Phase - OC1 - 51
471	Relay58	0.324	471		Phase - OC1 - 51
521	CB77		50.0		Tripped by Relay58 Phase - OC1 - 51
1811	Relay51	5.043	1811		Phase - OC1 - 51
1861	CB9-210DH...		50.0		Tripped by Relay51 Phase - OC1 - 51
5393	Relay41	4.383	5393		Phase - OC1 - 51 - Forward
5443	CB15-5.5KV2		50.0		Tripped by Relay41 Phase - OC1 - 51 - Forward
7943	Relay15	0.383	7943		Phase - OC1 - 51

Figure 101-sequence of operation after adding series reactor

It been noticed that the motor contribution for each parallel motor has been reduced beside that we find that the total current from6.522kA to 5.831kA .

And cause an attenuation in transient and subtrasient phases according to circuit analysis results :

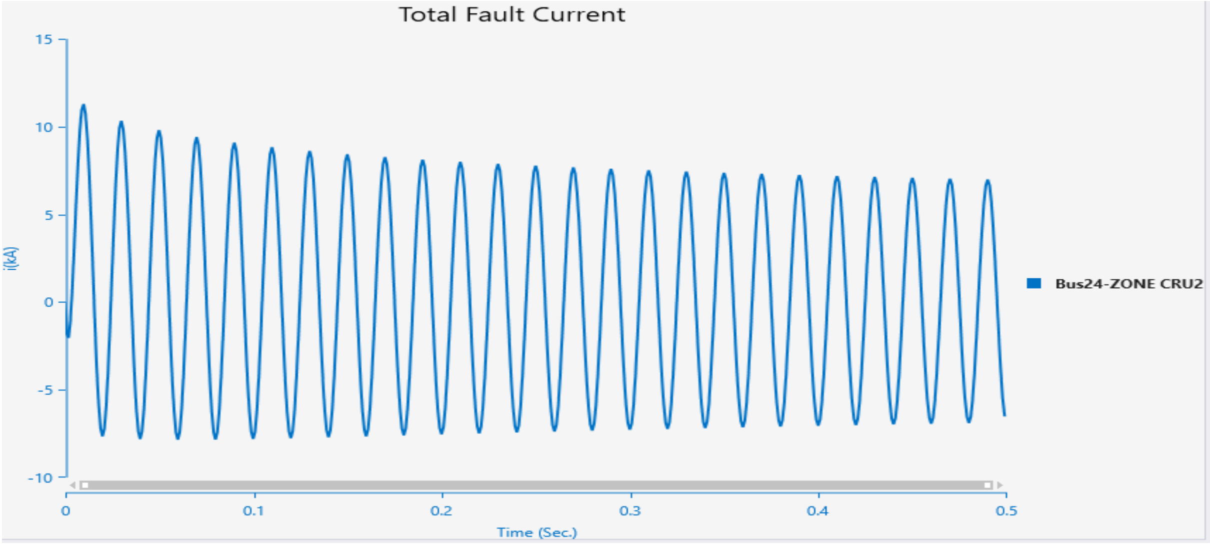


Figure5.18short circuit analysis after adding series reactor

Trying another solution more effective yet more expensive which using a variable frequency drive(VFD) by

-Current Limiting: VFDs have the capability to set maximum current limits for the motor. In the event of a short circuit, the VFD will regulate the motor current to stay within the predefined limits, effectively limiting the amount of contributed current.

-Fast Fault Detection: VFDs are equipped with advanced fault detection mechanisms. They can detect short circuit conditions rapidly and activate protective measures without delay. By quickly interrupting the power supply to the motor, the VFD prevents excessive current contribution.

-Active Current Control: VFDs utilize active current control techniques to manage and regulate the motor current. This enables them to respond swiftly to changes in system conditions, such as a short circuit, and adjust the motor current accordingly, minimizing the contributed current.

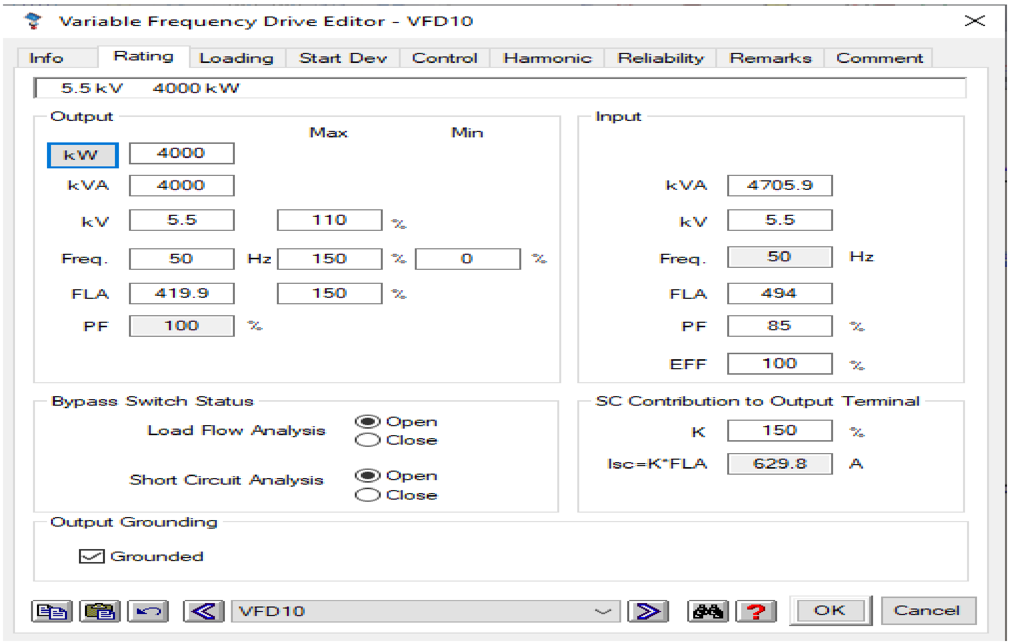
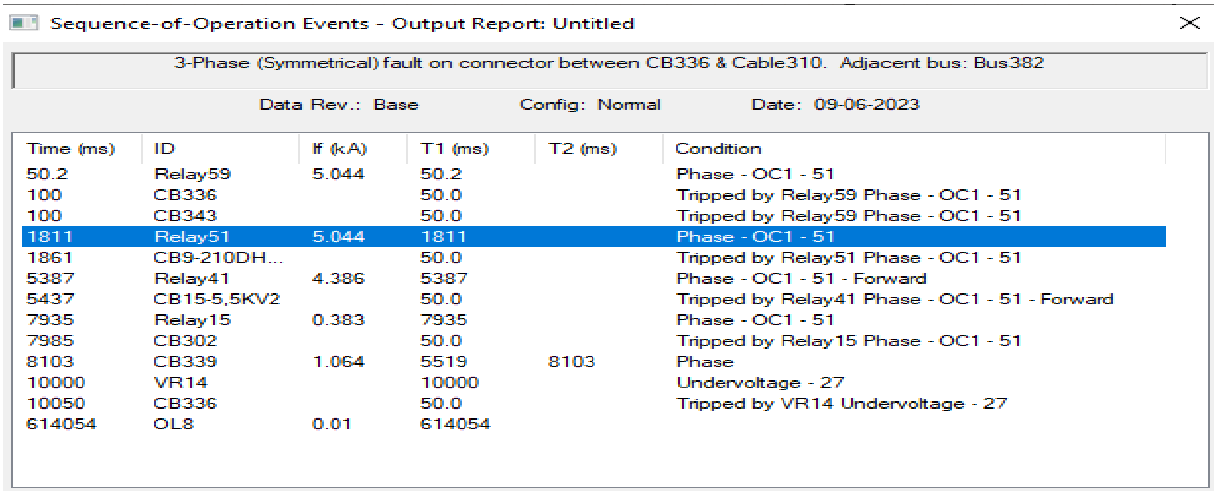


Figure 102-VFD parameters

One of draw back of this solution beside high cost is the that VFD has it own short circuit contribution.

The results of adding the VFD in each motor will :


Sequence-of-Operation Events - Output Report: Untitled

3-Phase (Symmetrical) fault on connector between CB336 & Cable310. Adjacent bus: Bus382

Data Rev.: Base Config: Normal Date: 09-06-2023

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
50.2	Relay59	5.044	50.2		Phase - OC1 - 51
100	CB336		50.0		Tripped by Relay59 Phase - OC1 - 51
100	CB343		50.0		Tripped by Relay59 Phase - OC1 - 51
1811	Relay51	5.044	1811		Phase - OC1 - 51
1861	CB9-210DH...		50.0		Tripped by Relay51 Phase - OC1 - 51
5387	Relay41	4.386	5387		Phase - OC1 - 51 - Forward
5437	CB15-5,5KV2		50.0		Tripped by Relay41 Phase - OC1 - 51 - Forward
7935	Relay15	0.383	7935		Phase - OC1 - 51
7985	CB302		50.0		Tripped by Relay15 Phase - OC1 - 51
8103	CB339	1.064	5519	8103	Phase
10000	VR14		10000		Undervoltage - 27
10050	CB336		50.0		Tripped by VR14 Undervoltage - 27
614054	OL8	0.01	614054		

Figure 103-sequence of operation after VFD

It not clear hear but contribution of each motor has decreased to zero so no undesirable trapping and total fault has deduced to current coming from incoming bus bar from 6522A to 5044A.

In addition to the absence of transient or subtransient phases, during a short circuit, only the steady-state fault current will be present. This means that the fault current will reach a stable level without any significant oscillations or transients. The steady-state fault current is typically the maximum current that flows through the system during the fault condition. By considering and analyzing only the steady-state fault current, engineers can accurately assess and design the protection and coordination of protective devices to effectively handle the fault and ensure the safety of the electrical system.

According to the short circuit analysis

Short-Circuit Summary Report

3-Phase Fault Currents

Bus		Device		Device Capacity (kA)				Short-Circuit Current (kA)					
				Making									
ID	kV	ID	Type	Peak	Ib sym	Ib asym	Idc	I"k	ip	Ib sym	Ib asym	Idc	Ik
Bus24-ZONE CRU2	5.500	Bus24-ZONE CRU2	Bus					5.057	7.504				4.825

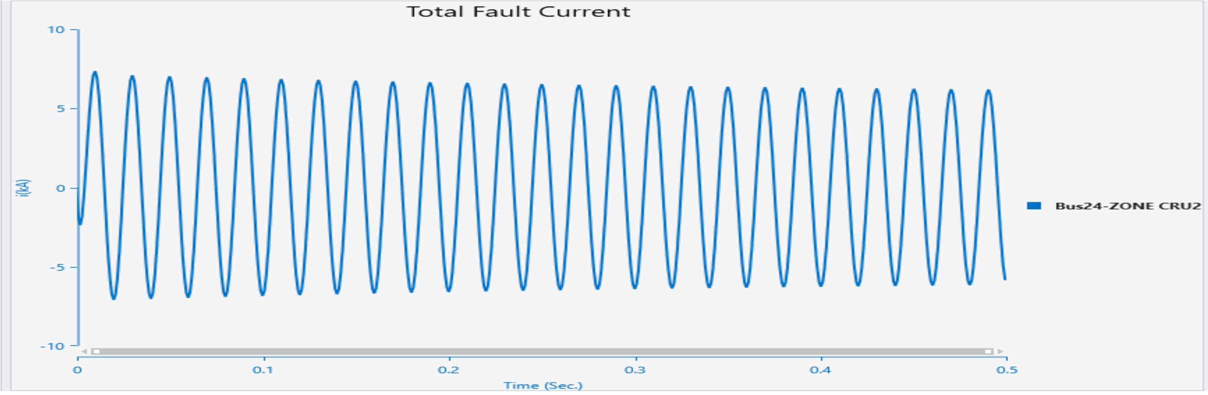


Figure 104-short circuit analysis after adding VFD

Ultimately, a combination of two solutions can be employed to address the motor contribution issue. For small low-voltage (LV) motors located away from capacitor banks, a series reactor can be utilized. The series reactor increases the total reactance of the motor circuit, limiting the contributed current and mitigating the impact of larger motors.

On the other hand, for large medium-voltage (MV) motors, Variable Frequency Drives (VFDs) can be implemented. VFDs offer precise control over motor operation and provide features like current limiting and fast fault detection. These capabilities allow VFDs to effectively reduce the motor's contribution to short-circuit currents.

By employing series reactors for LV motors and VFDs for MV motors, the combined solution addresses the motor contribution issue across different voltage levels. This approach ensures efficient and optimized protection while managing the impact of motor currents during short-circuit conditions.

5.4Conclusion

In this chapter, the results of the protection scheme are presented through the application of various faults and scenarios. The analysis includes an examination of potential problems that may arise during these situations. Furthermore, the rationale behind choosing the Inverse Definite Minimum Time (IDMT) curve over the definite time curve is discussed. The chapter also proposes a potential solution to address the motor contribution during short circuits. By evaluating these results and offering solutions, this chapter provides valuable insights into the effectiveness and optimization of the implemented protection scheme.

General conclusion

In conclusion, this master report has presented a comprehensive analysis and evaluation of the implemented protection scheme for power systems. Through the application of various faults and scenarios, the thesis has provided a detailed examination of the system's response and the effectiveness of the protection measures.

By investigating potential problems that may arise during fault conditions, the thesis has identified vulnerabilities and highlighted the critical importance of robust protection strategies. The findings underscore the significance of implementing reliable and efficient protection schemes to safeguard the power system and prevent potential damage or disruptions.

The discussion on the choice of the Inverse Definite Minimum Time (IDMT) curve over the definite time curve has demonstrated a deep understanding of protection scheme design. The rationale behind this decision, considering factors such as speed and accuracy, reveals the meticulous consideration given to optimizing the protection scheme's performance.

Furthermore, the report has addressed a specific challenge in protection scheme implementation—the motor contribution during short circuits. By proposing a potential solution, the research has shown a commitment to overcoming practical obstacles and enhancing the overall effectiveness of the protection scheme.

The evaluation of results and the provision of practical solutions in this thesis offer valuable insights for power system engineers, researchers, and practitioners. The analysis conducted throughout the thesis contributes to the body of knowledge in power system protection and serves as a foundation for further advancements in this critical field.

Overall, this master report has not only provided a comprehensive understanding of the implemented protection scheme's performance but also demonstrated the potential for optimization and enhancement. The research findings underscore the importance of continuous improvement in power system protection, ensuring the reliability, security, and stability of electrical grids. By contributing to the field's knowledge and offering practical solutions, this thesis contributes to the broader goal of advancing power system protection practices and technologies.

For further work, enhancing the protection scheme with more advanced and sophisticated features can be a valuable direction. Some potential areas of improvement to consider include incorporating Restricted Earth Fault (REF) Protection (64) to enhance sensitivity and ground fault detection. Additionally, implementing Circuit Breaker Failure Protection ensures prompt fault clearance and minimizes system downtime in case of breaker failures.

Considering the implementation of differential protection for motors and busbars can enhance the reliability and selectivity of the overall protection system. Relay pilot systems can be explored for improved protection coordination by enabling communication and data exchange between relays in different locations.

Furthermore, adding protection for phase fluctuation, such as monitoring voltage or frequency variations, can help prevent equipment damage and maintain system stability. Conducting thorough studies, simulations, and feasibility assessments while adhering to industry standards and guidelines are essential for incorporating these advanced protection features.

By integrating these advancements, the protection scheme can become more sensitive, faster, and better coordinated, ultimately enhancing the overall reliability, security, and performance of the power system.

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