Optimal Coordination of Protective Devices for Power Distribution System using Teaching Learning Based Optimization

(Case Study: Dilla Power Distribution System)

A Thesis Submitted to the Department of Electrical and Computer Engineering of Hawassa University Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Power System and Energy Engineering

BY

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the school of graduate studies (SGS) through the Department Graduate Committee (DGC) of Electrical and computer Engineering.

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Declaration

I the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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This thesis has been submitted for examination with my approval as a university advisers.

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Abstract

A protective device coordination study can maximize power system selectivity, avoid mal-operation of the relay and remove unnecessary power loss in the power system protection. In Dilla power distribution system, various problems arise in the primary and secondary protection systems. These are overloading, overlapping and short circuit problems. In this case, the overcurrent relay cannot sense such fault which causes protective devices to miss coordination and sympathetic tripping. To reduce such problems, proper setting and selection of protective devices have to be done on the existing distribution system. This thesis presents optimal coordination of protective devices for Dilla power distribution system through minimizing the total operating time of relays in the primary and secondary protection systems. To minimize the total operating time of the relay, existing and optimized system results have been compared. Before optimization, the total operating time of the relay in the primary and secondary protection system has been determined using Electrical Transient Analyser Program (ETAP). Then after optimization, the total operating time of the relay in the primary and secondary protection system has been determined using Teach Learning Based Optimization (TLBO) algorithm and Particle Swarm Optimization (PSO) algorithm. Thus, the total operating time of the relay in the primary and secondary protection systems have been minimized by 89% and 89.3% respectively using TLBO. Similarly, the total operating time of the relay in the primary and secondary protection system has been minimized by 87.7% and 87.39% respectively using PSO. It is seen that the performance of both algorithms are suitable, but TLBO gives better results of minimizing the total operating time of the relay in primary and secondary protection system.

Keywords: *Setting, Selection, Protective Devices Coordination, Over Current Relay, Teach Learning Based Optimization algorithm.*

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List of Abbreviations

CB	Circuit Breaker
CT	Current Transformers
CTI	Coordination Time Interval
DLG	Double Line to Ground
DOCR	Directional Overcurrent Relay
ETAP	Electrical Transient Analyzer Program
EFO	Electromagnetic Field Optimization
EEU	Ethiopian Electrical Utility
EC	Ethiopian Calendar
ETB	Ethiopian Birr
FC	Fault Current
FLA	Full load ampere
GA	Genetic Algorithm
GFR	Ground Fault Relay
GSA	Gravitational Search Algorithm
HSA	Harmony Search Algorhim
HRCF	High Rupture Capacity Fuse
IDMT	Inverse Definite Minimum Time Relay
IP	Pickup current
IFR	Fault Current Relay
KA	Kilo Ampere
KV	Kilo Volt
KWH	Kilo Watt Hour
LL	Line to Line
LPP	Linear Programming Problem
MVA	Mega Volt Ampere
MW	Mega Watt
OCPD	Over Current Protective Device

OCR	Over Current Relay
OTCB	Operating Time Circuit Breaker
PSM	Plug Setting Multiplier
PSO	Particle Swarm Optimization
R	Relay
SC	Short Circuit
SLG	Single Line to Ground
SF6	Sulphur hexafluoride
TDS	Time Dial Setting
TMS	Time Multiple Setting
TOTR	Total Operating Time of Relay
TLBO	Teaching Learning Based Optimization
V	Volt
VT	Voltage Transformers
Z	Impedance

Chapter 1
Introduction

1.1 Back Ground

A power system is not only capable to meet the present load but also has the flexibility to meet the future demands on a continuous basis. To ensure the maximum return on the large investment in the equipment which goes to make up the power system and to keep the users satisfied with reliable service the whole system must be kept in operation continuously without major breakdowns. This can be achieved in two ways:

The first way is to implement a system adopting components, which should not fail and requires the least or nil maintenance to maintain the continuity of service. By common sense, implementing such a system is neither economical nor feasible, except for small systems. The second option is to foresee any possible effects or failures that may cause long-term shutdown of a system .The main idea is to keep the protection equipment in the power protection system is to limit the disturbance throughout such a failure to restricted space and uninterrupted power supplies balance in the power distribution system.

Hence, proper use of the overcurrent protective device such as circuit breaker, fuse and over current relay is necessary for an electrical power protection system the following way. The primary way is to minimize the duration of a fault and minimize the number of consumers affected by the fault. The second way is the power distribution system to protect the system from unnecessary service interruptions, disconnect faulted lines from transformers and other apparatus [1].

A protective device coordination study is to determine the setting and select a rating of overcurrent protective devices from the load upstream to the power supply. It maximizes power system selectivity, as well as helping to avoid mal operation of the relay and remove un necessary power loss in the power protection system.

When two or more series protective devices coordinated in the power protection system during this time the nearest fault point will operate first. The other upstream devices must be coordinated to operate in sequence to provide backup protection, if any device fails to respond. To meet this requirement, protective devices were rated or set to operate on minimum overcurrent, in minimum time and selective with other devices fulfilling; maximum protection to equipment, production, reduce downtime outages and supply of reliable power can be achieved.

In any power protection system, proper coordination of protective device such that overcurrent relays isolate the faulted portion of the system to healthy portion of the system and minimize damage of protection equipment. In case of failure of primary relays, back up relays operate after sufficient time discrimination. The over current relay should be able to discriminate fault normal and abnormal conditions [2].

One of the critical and important elements in the family of power system is the overcurrent protection. This protection helps to protect in case of over current flowing through the branches or the feeders due to overload or short circuit. Overcurrent protection is essential in order to minimize disturbances caused by any failure in the system and to ensure continuous power delivery. Overcurrent relay is the best overcurrent protective device in the power protection system, provides instruction to disconnect faulty parts to healthy parts of the system. This action leads to the remaining system fed with power and protects the system from any injury or fault. The overcurrent relays initiate the corrective mechanism to determine the operation time of the relay. Thus, the overcurrent relays must have high reliability and accuracy to detect any fault currents in the power protection system and determine the operation time.

An active role of the overcurrent relay setting procedure has great significance. To trip off the respective device, it is necessary to set correct values of time setting multiplier. In this case, the adjustment is not accurate so, maximum fault happens in the protection system and damage of protective devices. The proper settings of overcurrent relays are essential for reliable operation of electrical power systems, during both normal and abnormal operating conditions.

For an overcurrent relay, time dial setting determines the actual operating time of the relay whereas plug setting determines the required amount of current values to be pick up. If the value of the plug setting multiplier is less than one, it signifies that normal current is flowing in the circuit and there is no tripping of the devices. As the value of plug setting multiplier is greater than one, it signifies now that larger value of current is flowing which is normally the fault current. The more value of plug setting multiplier signifies that the multiples of larger current flowing in the feeders or the branch.

Hence, the overcurrent relays should be operated as quickly as possible with a minimum interrupting time. Further, the backup protection should wait for the primary protection system to delivering the trip command to its associated protective devices [3].

1.2 Statement of the Problem

The protective devices coordination in Dilla power distribution system was not properly set due to that the power system protection system operation was weak; in that case, various problems arise like, overload, short circuit, overlapping and under reaching problems causes mal-functioning in the whole primary and secondary protection system. In such settings of over current relay, in the protection system can't sense faults properly and which caused protective devices overheating, miss coordination, sympathetic tripping, service outage, as well as extensive equipment damage and disturb the whole existing distribution system.

The optimal setting and selection of protective devices coordination in power distribution system using teach learning-based optimization algorithm can effectively minimize the total operating time of the relay in the primary and secondary protection system for reliable and good power quality.

1.3 Objectives of the Thesis

1.3.1 General Objective

The main objective of this thesis is the optimal coordination of protective devices for the Dilla power distribution system using a teaching learning-based optimization algorithm.

1.3.2 Specific Objective

- To study present fault analysis and protective devices for the Dilla distribution system.
- To apply the appropriate setting of overcurrent relay and selection rating of protective devices
- To examine the coordination of protective devices especially, in terms of load flow and fault analysis using ETAP software.
- To determine minimizing the total operating time of the relay, considering the given constraint.

1.4 Significance of the Thesis

This thesis presents optimal coordination of protective devices is essential to minimize unnecessary time outages and isolate a fault or overload anywhere for the Dilla power distribution system.

1.5 Scope of the Thesis

This paper has mainly limited the selection of protective devices coordination and the total operating time of relay compares before and after optimization for the Dilla power distribution system.

This thesis work mainly includes:

- The selection of protective devices has based on parameters such as fault MVA, full load current, equipment the same feeders, and equipment parallel feeders.
- Before optimization, to determine the total operating time of relay in the primary and secondary protection system using ETAP software.
- After optimization, to determine the total operating time of relay in the primary and secondary protection system using teaching learning-based optimization algorithm and particular swarm optimization algorithm.
- The selection of protective devices coordination for the Dilla power distribution system improvement total power loss and cost.

1.6 Methodology

The following activities performed in this thesis:

Literature review: same journals, articles, and papers on the power distribution system, fault analysis, power protection systems, coordination of protective devices and other related works have been review.

Assessment: This thesis goes starting with problem identification and reading helpful literature. Problem identification is the first stage of solving public problems. For the particular problem in the power distribution system that is an interruption, miss coordination, the study goes through a literature survey on properly coordination of protection devices to mitigating this problems.

Data Collection and Analysis: The 2012 E.C peak load and interruption data has been collected from the Dilla power distribution system. The feeder line, line length in kilometers, conductor type, voltage level, current transformer ratio, number of a circuit breaker, and ratings of transformers has been collected from the existing system and the districts. The collect data has been used to analysis coordination problem of existing distribution system.

System Modeling: it is used to properly setting overcurrent relay and selecting rating of protective device in the dilla power distribution system.

- The first, system has been modeled and simulated using the latest electrical software, ETAP 12.6.0.
- The second, to apply the appropriate setting and selection of rating protective devices based on the dilla distrubstion system data.
- The third, load flow analysis, fault analysis and evaluation of coordination protective device in the primary and secondary protection system using ETAP soft ware.
- The fourth, writing program of optimization algorithm using math lab version 2016.
- Finally, evaluation of coordination protective device in the primary and secondary protection system using TLBO and PSO algorithm.

1.7 Thesis Outline

This thesis organized into five chapters:

Chapter one: presents the overview of the protective device coordination, statement problem, the objective of the thesis, scope, and significance of the thesis, methodology part discussed data collection analysis, and system modeling.

Chapter Two: presents faults occurrences in the power distribution system, different types of faults, basic requirements of protective device in the power protection system, some selected review part of coordination protective devices using different types of algorithm and summary of literature review it is describes the research gap of the thesis.

Chapter Three: presents modeling of protective device coordination in the Dilla power distribution system using Electrical Transient Analysis Program software. Based on data calculate fault current at each feeder and depend on the fault current select rating of protective device in the dill power distribution system. Finally, it describes problem formulation and possible solution of coordination protective device based on teaching learning based optimization algorithm and particle swarm optimization algorithm in the primary and secondary protection system.

Chapter Four: reports and discusses the results obtained from the test of the protective devices due to the simulation using ETAP software. It describes load flow analysis, fault analysis, evaluation coordination in the primary and secondary protection system. It discusses to evaluate operating time of relay compare results with before optimization and after optimization. Then after optimization improvement of the total operating time of relay by teaching learning-based optimization algorithm and particle swarm optimization algorithm. Finally, with selection of protective device coordination for the power distribution system improvement total power loss and cost.

Chapter Five: presents conclusion, recommendation and for future study protective device coordination.

Chapter 2

Literature Review

2.1 Faults Occurrences

The nature of a fault just defined as any abnormal condition, which causes decreases the insulation strength between phase conductors, earth, and any earthed screens adjacent to the conductors. The fault usually occurs due to the breakdown of the insulator between live conductors. This breakdown may be caused by any one or more of numerous factors, for example, mechanical damage, overheating, voltage surges caused by lightning, ionization of air, and misuse of equipment. In practice a reduction is not regarded as a fault until is it is detectable that is until it results either in an excess current or in a reduction of the impedance between conductors and earth to a value below that of the lowest load impedance normal to the circuit. Thus a higher degree of pollution on an insulator string, though it decreases the insulation strength, and affected phase does not become a fault up to a flashover produces excess current or other visible abnormality. The fault current releases a huge amount of thermal energy, not cleared rapidly may cause fire hazards, extensive damage to equipment, and risk to human life [4].

The types of fault causes are similar, but the proportions are different in different boundary those are:

Grounding System

This system can be divided into two parts those are an effectively grounded system (including solidly grounded and low resistance grounded system) and a non-effectively grounded system (including ungrounded, high resistance grounded, and resonant grounded).

Conductor Type

The fault origin in overhead line, this fault is protected by overhead conductor and underground cable in the power distribution system. The overhead line and the underground cable are the most commonly used in power distribution systems.

Geographical Environment

The fault causes in natural and forestry are different, but tree-caused and animal-caused fault in forestry areas would be more.

Weather Season

The summer of a lighting fault is maximum in this case to break down protective equipment in the power distrubstion system.

The most cause of fault in the power distribution system are:

Lightning

Many electrical faults occur on overhead power transmission lines are caused by lightning.

Pollution

Pollution is usually deposited dust or cement powder in industrial areas and silt deposited by wind borne sea spray in coastline areas. It causes a flashover rope to decrease extra current or other visible abnormality example, abnormal current flow in the power distribution system.

Fires

The incidence of fire under transmission lines is responsible for an excessive number of line outages in many countries. An extra problem rising from burning is the pollution of the insulators due to the gathering of particles of dust on their surfaces. In this case, the line insulation requirements should be determined in such a way that the outages under fire could be reduced to a minimum. Additional causes of faults on the above lines are trees, birds, aircraft, ice, snow loading, broken insulators, open circuit conductors ,and nonstandard loading [5].

2.2 Types of Faults

They are two kinds of faults those are: symmetrical and unbalanced (asymmetrical)

Symmetrical faults involve all three phases are grounded and simple fault currents the systems terribly. The unbalanced fault is consists line to line fault, line to ground fault, and the double line to ground fault. Most times occur faults in the power distribution system are Single Line to Ground faults (SLG). This type of fault occurs when one conductor touches to ground or contacts the neutral wire and the falling of trees on the overhead line. The line to Line fault exists as the second most occurring fault in the power network. It is the outcome of the two conductor’s contacts to each other’s. The third type of fault is Double Line to a Ground fault (DLG), this types of fault is occurs the two conductors touch to ground and the tree falling on two transmission lines. The fourth type of fault is symmetrical fault, this fault is occur three lines touch to ground and three lines are contact to each other’s in the power distribution system.

For the above description of faults shows that all faults are not equally occur in the power distribution system. Most time happens faults in the power distribution system are single lines to ground fault. The symmetrical or balanced faults that happen in the power network are rare time [6]. Fault is an undesired and sudden condition that not only affect the protection equipment but also risk to personal. Before damaging any protection equipment in the power distribution system is mandatory to block the high flow of current. Types of faults are described the below of figure 2.1.

Represents of (A) is line to ground fault

Represents of (B) is line to line fault

Represents of (C) is line to line to ground

Represents of (D) Three phase fault

Represents of (E) Three phase to earth fault

Represents of (ZR) is Transmission line impedance three

Represents of (ZS) is Transmission line impedance two

Represents of (ZT) is Transmission line impedance one

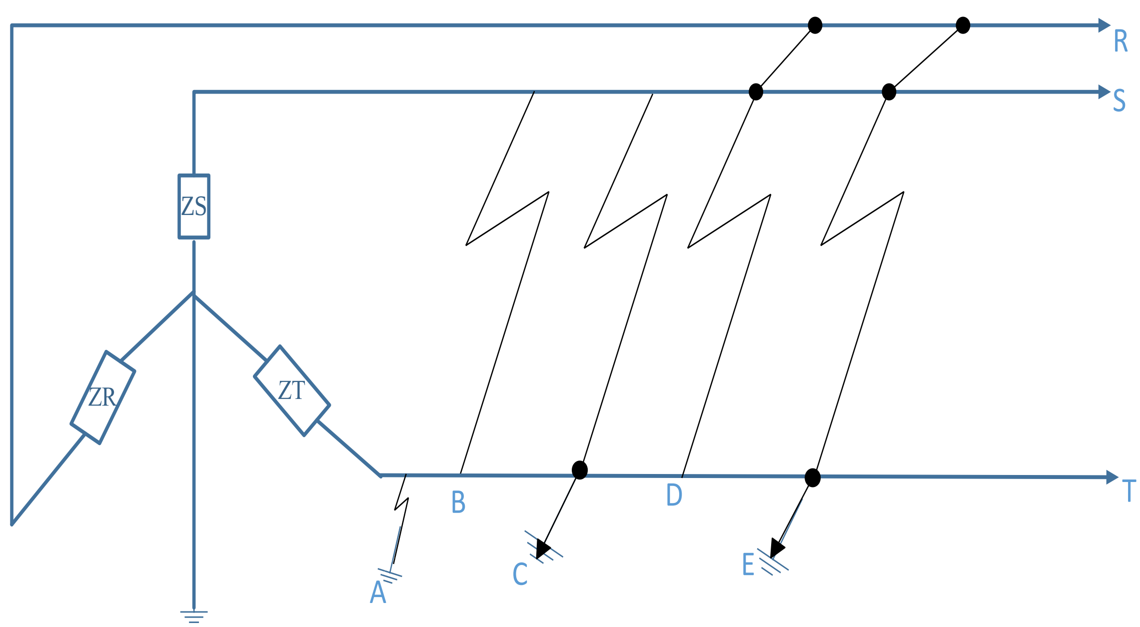

Figure 2 .1: Types of faults on a three phase system [1].

The fault statistics with reference to type of fault in the power distribution system defined below in the table.

Table 2.1: Fault statistics with reference to type of fault [1].

Fault	Description	Percentage occurrence	Severity
Single line to ground	Due to the breakdown of insulation between one of the phases and ground.	85%	Least
line to line	Due to the breakdown of insulation between either of the two phases.	8%	
Two line to ground	Due to the breakdown of insulation between two phases and ground	5%	
All three line to ground	Due to the breakdown of insulation between all three phases and ground.	2%	Most

2.3 Power System Protection

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

Protection System: a complete arrangement of protection equipment and other devices required to achieve a specified function based on a protection principle

Protection Equipment: a collection of protection devices such as (relays, fuses, Current Transformers and Circuit Breakers.

Protection Scheme: a collection of protection equipment providing a defined function and including all equipment required to make the scheme [6].

The purpose of the power protection system are:

i. To keep and minimize damage of electrical equipment.
ii. To isolate the fault portion system to healthy portion of the system.

iii. Provided reliable power supply distributed to the consumers.
iv. Securing from the risk sits for the electricity to persons [7].

The function of a protective device for power protection system is minimize damage to the system and its components to limit the duration of service interruption, whenever apparatus failure, human error, and lighting stork occur on any portion of the system. The overcurrent relay is a sensor fault that sends the signal to the circuit breaker is the trip fault. The electrical power engineer in the power protection system, one of the power problems is solved differentiating faulted and health parts from of the power distribution system. This problem is solved significantly by the power system to protect humans or any components from assist injury. Power protection systems detect and isolate the faulty party automatically. Some abnormal conditions are happening in the power protection system that cannot connect one system to the anthers system [6, 7].

2.4 Protection Device

When the selection of overcurrent protection devices in the protection system deepened up on fault current. Protection for the electric system is an art as well as science and should be modeled with the following objectives in mind

- Prevent or minimize damage to equipment.
- Minimize the effect of the disturbance on the uninterrupted portion of the system both in its extent and duration.
- Minimize interruption of power.
- Minimize the effect on the utility system.
- Prevent injury to personnel.

The separation of short circuits needs the application of protective apparatus which will sense an abnormal current flow and eliminate the affected portion from the system. The sensing and interrupting device may be separately interconnected only through external control wiring, they may be the same device and isolated devices mechanically coupled to function as a single device. The equipment used for the protection system is a relay, fuse, and circuit breaker. The following part is clarified each overcurrent protective device in detail [8].

2.4.1 Relay

The purpose of the protective relay is to the quick elimination fault from a part of the power protection system. When it begins to operate in an abnormal manner that might cause damage or otherwise interfere with the effective operation in the rest of the system. Over current relay is one of the major overcurrent protective devices. In distribution feeders, they play a more significant role and there may be simply protection provided. The power protection system primary protective devices fail, then a backup of the protective device is the clear fault. In any power system, protective devices are coordinated in such a way that protects the adjacent equipment [9].

Over Current Relays (OCR) are normally applied in the power protection system can prevent overcurrent, short circuit, and phase failures. An overcurrent protective device was created to diminish damage to the transformer, electrical device, and support to operate the power distribution system [10].

According to [11] power protection system in high voltage transmission uses more overcurrent relay and ground fault relay as limited backup protection. Over current relay is works when the current exceeds the predetermined setting. The ground fault is disturbances in transmission lines because the transmission line is air insulation, so it is very susceptible to soil disturbance. To detect any current flowing from the power system to the ground is called the residual current. Ground fault relay is a working relay based on the amount of residual current flowing from the system.

According to [12] the significant appearances of an overcurrent relay are selectivity, reliability, and discrimination. For any kind of fault occur in the protection system to be either symmetrical or unsymmetrical fault during this time the overcurrent relay has to operate efficiently and provide correct discrimination. Moreover, these relays must operate after a certain time delay and act as backup protection for other relays.

The directional overcurrent relays modeled to sense the actual operating situations on an electrical circuit and trip circuit breakers when a fault is detected. The phase relationship of voltage and current is used to limit the direction of a fault. The relay first discriminates the fault is sited in front or behind the relay. If the fault is placed behind the relay is no operation will take place. When the fault happens in front of the relay during this time comparison of fault level and position of current will take place to decide whether to operate or not [13].

2.4.2 Fuse

Fuse is the best common and broadly used protective device in the power protection system. Rewire able type of fuse, as the name indicates the fuse is replaced or rewired once it fails. The fusible wire used to be limited as the best tube to avoid the splashing of volatile metal. Fuse is the short length of wire select to melt and isolate in case of excessive current. The fuse is linked phase to the supply. It is always linked in series with circuit apparatuses that need to be protected. After the current is drawn with the circuit and components that need to be protected. When the flow of current exceeds rate of current during this time the fuse wires are melt and break. Disconnect supply from the circuit is to protect the components from any damage [14].

The general purpose of the fuses is no time delay and to protect the fuse panel but, the heavy fuses are more time delay. High Rupture Capacity Fuse (HRCF) is normally modeled high current carried component to be replaced by a new one. A high rupture capacity fuse cannot be rewired if a closed one has the following characters that are low resistivity, low melting point, and low conductivity. The most significant of high rupture capacity fuse have in the power system used are required maintenance, operate at high speed interrupting rate, three phase operation, provide better coordination with downstream devices and good performance. Some disadvantages of high rupture capacity fuses are maximum cost, difficulty maintains the required substation battery, and relaying transformer [15].

2.4.3 Circuit Breaker

The operating principle of circuit breaker abnormally and normally condition in the power protection system are: the normal operating condition is closed, and the faulty condition is open. The purpose of the circuit breaker is fault occurs in the power protection system during this time trip a fault and control protective relay.

The significant characteristics of the main breaker in the power protection system are interrupting and clearing fault currents.

The circuit breaker tripping, total clearing, and break time is defined as follows:

Opening time: The time among immediate application of tripping power, to the immediate separation of the main circuit breaker.

Arcing time: The time among the immediate separation of the main circuit breaker, to the immediate arc extinction of short circuit current.

DC stationary battery it supplies the energy needed to manage the protective devices, high voltage components and allows electrical faults to be safely isolated.

Relay (S1) are used to control contacts of an electrical circuit due to a change of parameters or conditions in the same circuit or any other associated circuit. Contactors, on the other hand, are used to interrupt or establish connections in an electrical circuit repeatedly under different conditions.

Circuit Breaker (S2) is an automatically operated electrical switch to protect an electrical circuit from damage due to overload or short circuit.

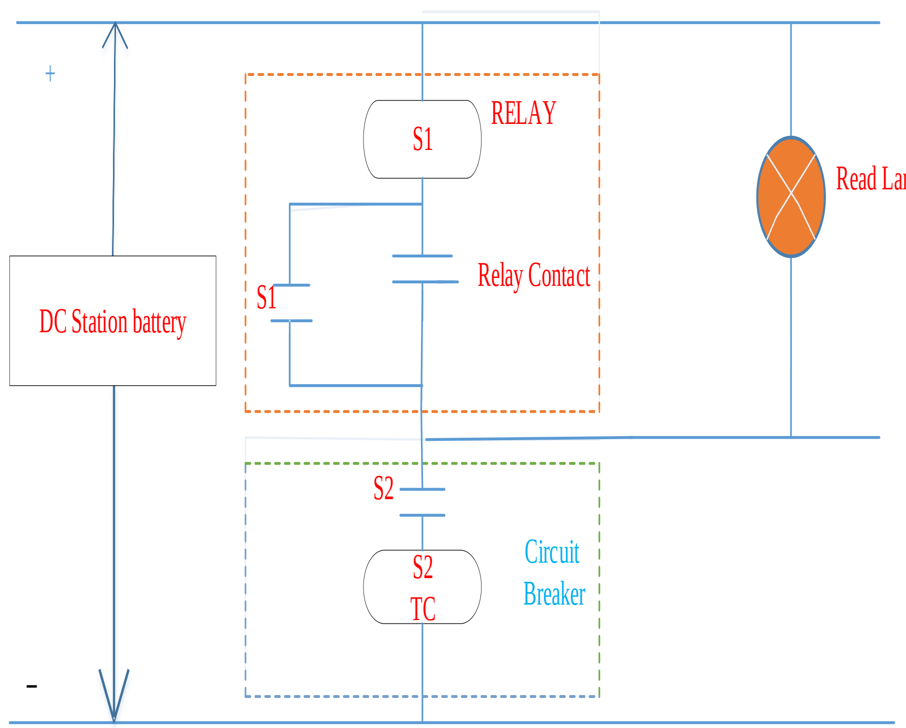

Figure 2.2: Simplified circuit diagram trip circuit of a circuit breaker [4].

The types of the circuit breaker are defined as follows:

Arc Control Device

This breaker consists of fixed and moving parts but the arc occurs times separation needs to be controlled.

Oil Circuit Breaker

In recent, installation oil circuit breakers are becoming out of date are being replaced by vacuum and SF6 breakers.

Advantages of oil circuit breaker

- The Capacity of cool oil to flow into the protection equipment during this period the flow of current is zero.
- The Cooling surface existing by oil.
- Absorption of energy by breakdown of oil.
- The action of oil as an insulator lending to a more compressed design of switchgear.

Disadvantages of oil circuit breaker

- Inflammability (exactly if there is any air nearby hydrogen).
- Maintenance (changing and purifying).
- In the primary stages, the use of the high volume of oil circuit breakers was more common in this kind.

SF6 Circuit Breaker

Sulfur hexafluoride (SF6) is an inert insulating gas, which is becoming increasingly popular in modern switchgear designs both as an insulating and as well as an arc quenching medium.

Vacuum Circuit Breaker

Vacuum and Contactors Circuit breaker is designed depending upon fault current during this time interrupting capacity greater than the full load current.

2.4.4 Voltage Transformer

They are two methods of voltage transformers used for protection apparatus.

i. Electromagnetic method
ii. Capacitor method

The accuracy of the voltage transformer is capable to supply the secondary voltages. Voltage transformers for cover are needed to take care of fairly sensible accuracy over an outsize vary of voltage from 0 to 173% of standard construction of voltage transformers. Electromagnetic voltage transformers are also connected lay to rest line or between line and ground. However, capacitor voltage transformers will be a connected line to the ground. Voltage transformers with the first connected line to the ground and secondary voltage earthed at the terminal. A voltage transformer is a device that produces different types of voltage. The secondary voltage transformer is proportional to the primary voltage transformer. In distinction to the current transformer, voltage transformer has primary and secondary windings of many turns with high resistance current flow. As a result of this high electrical resistance, current flow is extremely low and voltage with very little or no distortion in representing primary voltage [1].

2.4.5 Current Transformer

The wound primary is working for the smaller currents, will first be applied on low fault level installations because of thermal limitations as structural necessities because of high magnetic forces. For currents larger than one hundred amperes, the bar primary way is working. If the secondary coil is equally distributed around the complete iron core, its outflow reactance is rejected. The current transformer is an electrical device that produces an alternating current to measured current and protecting the overcurrent in the power protection system. The primary coil current transformer has few turns compared to the secondary coil transformer. The secondary coil of the current transformer has a higher amount of turn's decreases the flow of current. The secondary coil of the current transformer has models 1A to 5A, for observing current flows through the system does not overload any protection components.

2.5 Protection Device Quality

A protective device is to detect the fault and isolate faulty parties from healthy parties. For any individual specific application, several ways to try and do this purpose, with fluctuating degrees of effectiveness.

The power protection system is divided into two protection zones, the control system is often adequately protected with the least part of the system during fault conditions.

2.6 Basic Supplies of Protection Device

Protection equipment has three main functions and duties:

- Defense complete system to continuity of the source.
- Minimize injury and repair price wherever it senses fault.

- Ensure the safety of personnel.

These necessities are essential, firstly for early detection and sense faults, secondly for quick removal of faulty apparatus from the service. The above expressions are the protection qualities duties [2].

Basic supplies of a protective device in a power protection system should have the following quality:

Unit Protection (Selectivity)

The protection relays are to operate isolating the fault portion system to a healthy portion system and minimizing damage to the power protection system. This requires the coordination of a protective relay in the power protection system those are, time grading, current grading, and unit protection approaches are commonly used to required coordination of relays. In the time grading technique, the protection relay is near to the fault operate first. For this purpose, definite time relays are used the independent level of fault current [16].

The main Advantages of unit protection device are:

- Only the faulted device or part of the system is disconnected, with minimum interruption to the power distribution system.
- Unit protection operates automatically, limiting damages to apparatus and danger to human life. A quick operation is possible because the presence or absence of a fault may be an exact clear cut case.
- Unit protection is stable, actually reliable provided the communication path is undamaged and actual sensitive.

The main Disadvantages of unit protection device are:

- It is expensive.
- It depends on communication between the relays connected at either termination.
- It is often maintenance concentrated to keep the communication medium completely dependent on the appliance and surroundings.
- The discrimination qualities of non-unit protection do not complete because the relay can usually operate whenever it gets a fault, despite wherever the fault is founded.

Speed

Relays are possible to operate as fast as likely to keep the dependability of supply by getting clear of each fault before it spreads to healthy systems.

Reliability

The strategy of protection must balance two key requirements. These are dependability and security. Dependability is defined as making sure the protection system operates when it would. Security is defined as making sure the protection system does not operate when it would not. However, dependability and security are opposite goals of the protection engineer must attack balance between them. Any protection system can be defined as correct relay operation anywhere sense fault occurs send command to the protective device and isolate faulty part from the healthy party. From these explanations, any relay operation is well defined according to correctness and appropriateness.

Stability

Without any disturbance, the operating a protective device in the power protection system. In this case, the normal operation of a protective device, and not transient problems occur in the power protection system. Most stability issues arise from an incorrect application of relays and a lack of maintenance.

Sensitivity

The term sensitivity refers to the magnitude of fault current occurs in the power protection system. The protection relay is supposed to be sensitive once the first operative current is low [17].

2.7 Primary and Backup Protection

Achieving higher reliability, fast action improvements, and operating flexibility of the protection schemes separate elements of a power protection system. In addition to primary protections are provided with backup and auxiliary protections. Initial the line of defense is the core of protection which ensures fast action and selective clearing of faults within the margin of the circuit section or the component it protects. The main protection is providing a rule primary protection leading to the backup protection, when the primary protection fails to operate.

Failure of the main Protection may be due to the next reasons:

- D.C source to the tripping circuit fails
- The current or voltage source to the relay fails
- The tripping device of the circuit breaker fails
- The circuit breaker fails to operate

Main protective relay fails backup protection provided either on the similar circuit breakers will be opened by the main protection or may dissimilar circuit breakers. Habitually, more than the faulty unit is isolated when the backup of the protection operates. The backup of protection is providing where primary protection of the nearby circuit fails to back up the given circuit. For explanation, backup protection can have an inferior sensitivity factor, be operative over a restricted backup zone and for only part of the protected circuit [18].

2.8 Coordination Study

The coordination study overcurrent relays wanted to the next one:

- The single line drawing of the system with rating and type of protection system is identifying.
- The impedance of power system apparatuses like cables, transmission lines, transformers, and rotating machines.
- The low and high short circuit currents are estimated to flow through each of the protection components.
- The maximum load current is work for each of the protection devices and beginning currents of different types of motors, the thermal withstand transformer.

2.9 Protective Device Coordination

The power protection system is properly modeled suddenly a short circuit occurs on the protection system protective device to operate open the circuit and prevent the continuous flow of electrical energy to the faulted area. The protective device closest to the short circuit operates first to clear the fault, provide the circuit breaker should open first to isolate the fault, and rather than the main breaker in the panel would interrupt service to all circuit branches.

If a circuit breaker fails to operate after a given time then the main breaker would operate to open or trip the circuit, thus providing backup protection.

When the protective device operates time sequence operation is called proper coordination. The protection coordination study is to define the trip settings of each protective device in the power protection system with the least interruptions happen, the system is isolates fault parts from healthy parts [19].

2.10 Selective Coordination

According to [20] the power protection systems overcurrent and earth fault relay are very important to detect the fault and provide a correct sequence of fault clearing. By setting principle overcurrent relay is based on the full load current in the power protection system. Selective coordination is the setting and to select rating of protective device in the power protection system. The select rating of protective device in the power protection system depend on the fault current during this time removing undesired power loss. Power protection system is modeled, if the overcurrent protect device settings are above the load operating levels and below the electrical apparatus injury curves.

The circuit's protection and coordination should meet the following characteristics. That is quickly isolated the affected portion of a power system to keep the normal service as much as possible, diminish the damages, diminished the magnitude of the fault current, and diminish the duration of the apparatus outages.

To obtain proper circuit protection coordination the electrical engineer wants to perform the following studies, load flow analysis, short circuit analysis, selection rating of the protective device depending upon fault current, and evaluation coordination.

According to [21] several power analysis programs can be used to model the power distribution system and evaluate its behavior on faults at different locations.

Current Selectivity

The current selectivity procedure is based on the failure current approach to the supply. It is used in low voltage systems anywhere. The impedance of the conductors is very high between the points where selectivity is needed. For this selectivity for satisfied the protection upstream of the fault current must be set lower than the protection downstream fault current. The protective device that interrupting the rating is above the fault currents.

Relay Coordination Concept

According to [22] the protective relay as primary or backup is significant in the power protection system. A protective relay is applied to protect the system component to the protection system. The primary relay and backup relay fault at the remote location helping as a backup relay. Providing both functions simultaneously to helping each other's primary relay its zone of protection and backup relay remote zone of protection. Besides, the protective relay must be time coordinated so that the primary relay always operates faster than the backup relay.

2.11 Principles of Time and Current Grading

They are several possible approaches to consider the correct relay coordination using time, overcurrent, and a combination of both.

2.11.1 Discrimination by Time

In this approach, a suitable time setting is given to each of the relays controlling circuit breakers in the power system that the breaker nearest to the fault opens first. Each protection unit includes a time delay of the overcurrent relay in which the operation of the current sensitive component. The relay time setting must be sufficient for upstream relays operating to send a signal to the circuit breaker at the fault location that has tripped and cleared the fault.

2.12 Standard IDMT Overcurrent Relay

The current time tripping features of Inverse and Definite Minimum Time (IDMT) relays may want to be varied according to the tripping time required and the features of other protection devices used in the system. This purpose defines standard characteristics that follow: Standard Inverse, Very Inverse, Extremely Inverse, and Definite Time [1, 18].

2.12.1 High Instantaneous Over current Relay

High rapid components used the source impedance is lower than protected circuit impedance. Then, the source of impedance is less than the protect circuit impedance is decreases tripping time at fault levels possible. It also improves the overall system grading for the discriminating curves after the high set instantaneous devices to be lower. One of the advantages of the high set fast devices is to reduce the operating time of the circuit protection by the covered area under the discriminating curves. A feeder fault origins the source side relay to trip not only the customers but the faulted feeder disturbed with an outage all the customers. That is assisted by the other feeders from the same source side relay, and the breaker also experiences an outage. It is essential to discrimination must be assisted during fault conditions. This can be achieved in the following ways checking only the current level for the current grading and checking time delay operation for the time grading [23].

2.13 Optimization Technique

2.13.1 Particle Swarm Optimization

The paper in [24] presents a particle swarm optimization method to find minimum Time Dial Setting (TDS) for coordination of overcurrent relay. Then this method is compared with the linear programming method. The algorithm has been implemented in the math lab for radial and parallel feeder systems. The time of operation for the relay coordination is established using both techniques. The result obtained in both cases particle swarm optimization is better than the linear programming technique.

According to [25] digital relay fractional value of time dial setting moreover kept and improves the system performance of operational time. This paper defines an effective variant of particle swarm optimization algorithm based on time varying acceleration coefficients for optimal coordination of directional overcurrent relays since the integration of series compensation. Simulation results are compared to other approaches to support the efficiency of the advised variant particle swarm optimization algorithm in solving the optimal coordination of directional overcurrent relay in the presence of series compensation.

The paper in [26] Particle Swarm Optimization (PSO) for overcurrent relay coordination problems. Particle swarm optimization is optional to solve miscoordinations problems and reduce the operation time of the relays. These algorithms have been tested effectively on eight bus test systems. The simulation outcomes have shown that the particle swarm optimization algorithm is to minimize the total operation time of relays and to solve the miscoordinations problem in the power protection system. The efficiency of this technique is compared with those obtained using a genetic algorithm.

The result obtained in both cases particle swarm optimization is better than genetic algorithm.

According to [27] Power system protection is modeling to continuously monitor the system to ensure maximum continuity of supply without damaging the system equipment. Since developments in power systems change their structure of the power system protection becomes vital. If any abnormality or fault occurs in this system there must be such devices that can identify a fault and to isolate the faulty section from the remaining healthy section. This very much essential function is carried out for protective relays. Relay coordination is to select the appropriate relay settings such that their essential protective function is met under the requirements of sensitivity, selectivity, reliability, and speed in this effort focus is to find out optimal time dial setting for the relays connected at all configuration using particle swarm optimization algorithms.

2.13.2 Genetic Algorithm

The paper in [28] Genetic Algorithm approaches coordination of Over Current Relays (OCR) is obtained through careful time grading. Due to the extension of electric systems, the essential for an efficient coordinated protective system is critical. To resolve the problem of the coordination of overcurrent relays using Genetic Algorithm (GA) method is applied. Two different time settings calculation strategies were applied one technique is based on the sum of both far and near the end time calculation and the other technique is based on the addition of the remote time setting only. For both strategies, the pickup currents were the same critter to differentiate between both strategies is the time setting values. The results show that for vital loads in which currents can never be allowed to be attained for a long time, the modeling of the time dial setting based on far end time calculations provides better performance. The resolve of the overcurrent relay coordination is to find an optimal relay setting to reduce the Time Dial Setting (TDS) and calculate the pickup current. The setting of the relay is essential for the coordination study to satisfy the primary and secondary protection system. According to [29] presents an application of Genetic Algorithm approaches for optimal coordination of overcurrent relays to a six bus ring system. This power protection systems are infrequently exposed to excessive currents caused due to short circuits and ground faults. When the current exceeds threshold level during this time the overcurrent relay is operated. In this paper, genetic algorithms compare with others optimization techniques are used to reduce time multiplier setting values of relays implemented on a radial network. This is achieving suitable overcurrent relay coordination.

The paper in [30] scheduled for the mathematical formulation of directional overcurrent relay coordination in connected networks. The fuzzy based genetic algorithm is used to optimize for coordination of overcurrent relay. The defined fuzzy rules are update the weighting factors of the simulation. The miscoordinations problem of overcurrent relays is resolved while reducing the operating time of the relays. This method is applied in three different networks and the simulation outcomes have been compared with previous studies. To coordinate directional overcurrent relays with both discrete and Continuous Time Setting Multipliers (TSM) Presenting the new term in the performance of the proposed method has not been affected the size of the networks.

2.13.3 Teaching Learning Based Optimization

According to [31] presents teaching learning based optimization algorithm is used to coordination of overcurrent relays. The short circuit conditions can happen unexpectedly in any part of the power system at any time due to various physical problems. Such conditions cause a large amount of fault current flow over power protection system. The incidence of the fault is isolated rapidly by a set of the protective devices. One of the most important protective component in the power protection system is over current relays. In this article, a new algorithm is presented to solve the optimization problem of coordination overcurrent relay by using a teaching learning -based optimization algorithm. The present work solved the optimal relay coordination problem for three bus and eight bus test systems using a teaching learning based optimization algorithm to get the minimum possible operating times while maintaining coordination among all relays in the power protection system.

The paper in [32] presents the application of the Teaching Learning Based Optimization (TLBO) algorithm for the optimal coordination of directional overcurrent relays in a looped power system. Coordination of directional overcurrent relays is tested three, four, and six bus systems. The main function is improved to optimize the operating time of primary protection system and secondary protection system. The outcomes are compared with the optimized values of time dial setting and plug setting values are succeeded from enhanced differential evolution algorithm. This algorithm is gives an optimal coordination margin between 0.3 and 0.8 second during this time no miscoordinations between the primary protection system and backup protection system. The outcomes are also proved using Digsilient power factory simulation software.

2.13.4 Modified Electromagnetic Field Optimization

The study in [33] focused on the optimal coordination of directional overcurrent relays by using a modified electromagnetic field optimization algorithm.

Firstly to solved optimally coordination of directional overcurrent relays and the next improved modified electromagnetic field optimization algorithm minimizing time outage of directional overcurrent relays. Mainly focused on this paper to develop a modified electromagnetic field optimization algorithm compared to the traditional electromagnetic field optimization algorithm. The behavior of the electromagnetic field optimization algorithm is electromagnetic particles with attraction and repulsion force among this particle lead to the global minimum. The purpose of this paper is used to test, three bus, eight buses, nine buses, and fifteen bus systems. Finally, obtained the result is minimizing time outage of directional overcurrent relays.

2.13.5 Harmony Search Algorithm

According to [34] this paper mainly focused coordination of directional overcurrent relays using Harmony Search Algorithm (HSA). The optimal coordination of directional overcurrent relays are depend on the Plug Setting Multiplier (PSM) and Time Multiplier Setting (TMS). To diminish the operating time of relays considering the boundary constraints. The large connected power systems problem with resolved directional overcurrent relay is to achieve correct relay coordination with satisfying all coordination constraints. To solve relay coordination problems are used to test different parameter those are linear programming problems, nonlinear programming problems, and mixed integer nonlinear programming problems. The main contribution of this paper is minimizing total operating time of the relay considering primary and backup protection system. Directional overcurrent relay setting is depending on various boundary constraint.

According to [35] this paper is enhanced coordination protection technique is suggested. Nuisance tripping is removed by integrating the extra selectivity constraints in the conventional overcurrent relay coordination. This paper is solved minimize the operating time gap between primary and secondary protection systems. The differential search algorithm is solved for optimization of greatly non-linear overcurrent relay coordination problem. The result is shows overcurrent relay coordination technique is against sympathetic and nuisance tripping. The operating time difference between primary relays at the near end and the far end is also minimized within an acceptable time margin.

2.13.6 Gravitational Search Algorithm

The paper in [36] presents the Gravitational Search Algorithm (GSA) technique for coordination of overcurrent relays currently, various programming optimization techniques are normally used to find optimal relay settings of overcurrent relays. The purpose of this paper is to find an optimal relay setting to reduce the total operating time of the relay and at the same time to avoid the maloperation of the relay. This optimization technique is used in this paper in order to find the optimal time multiplier setting and Plug setting of six relays so that their total operating time can be minimized. The simulated fault current retrieved is subsequently processed in the math lab. Additional it is minimized by maintaining the range of time multiplier setting of each relay as 0.08 to 1sec and the coordination time interval is 0.3sec.

2.13.7 Linear Programming Based Optimization

The study in [37] Linear Programming Problem (LPP) approach is used for the optimization of the heavy fault currents flow in the event of a fault at the loads connected in the distribution system. To protect these loads, circuit breakers and relays are required at suitable places with proper coordination among them. This paper focuses on finding the optimum relay setting requisite minimum time disturb in the power supply to avoid miss coordination problem in operation of relays and also examining outcome on Time Multiplier Settings (TMS) of DOCR a system with interconnected overhead lines and underground cables.

2.13.8 Fuzzy Logic

According to [38] this paper an adaptive protection system focused on fuzzy logic the adjustment of the overcurrent relay’s setting time, current voltage based inverse time units in

Brazil power distribution system. The over current relay coordination problem is solved in this power distribution system using fuzzy logic design.

The system is designed and analyzed as an alternative electromagnetic transients program. For good performance, the overcurrent protective device automatically detects a fault and increased the sensitivity of the relay.

2.14 Summary of Optimization technique

Most of the approaches presented above are the optimization of a single objective (mono objective) function such as minimizing the total duration of operating time relay. Although, some papers have proposed the multi objective optimization for coordination problems of power distribution system but not a selection of the protective device. The multi criteria for load flow analysis, fault analysis and coordination evaluation are not included. Therefore, in this thesis, the multi objective to allocate for evaluating coordination of overcurrent protective devices and simultaneously proposes the objective functions for minimizing total operating time of overcurrent relays in the Dilla power distribution system. After primary protection system and secondary protection system to minimizing total operating time of overcurrent relay using a teaching learning -based optimization algorithm.

Chapter 3

Modeling and Problem Formulation of Protective Devices Coordination

3.1 Flow Chart of Coordination Protective Devices

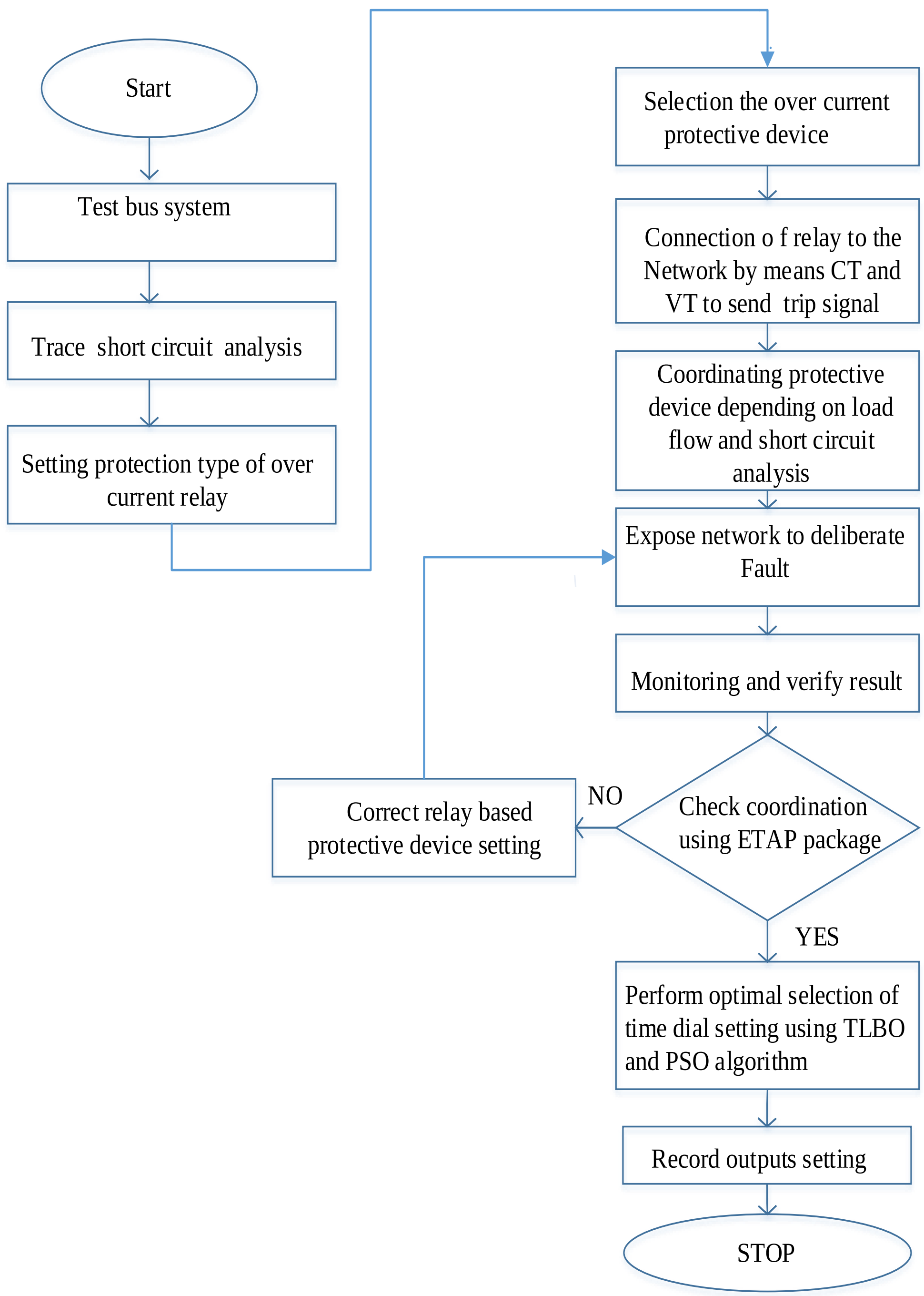

Figure 3.1: Flow chart of coordination protective devices.

3.2 Protective Devices Coordination Procedures

The following procedure must be involves coordination study:

i. Primary issues of short circuit analysis
ii. Setting and Selection of over current protective devices
iii. Protective device Coordination time intervals

3.2.1 Primary Issues of Short Circuit Analysis

Especially calculated maximum and minimum value of fault current each protective device in power protection system. Short circuit analysis in power distribution system coordination of protection devices the next step.

- Differentiating operating protective device and stability limits using network diagram by available information.
- Calculating minimum and maximum values of fault currents for each type of unsymmetrical fault through each protective device points.
- Calculating fault current in the power distribution system through each protective device point.

A short circuit analysis to keep people and apparatus are protected from injury in the protection system using suitable interrupting ratings of protective devices such that circuit breakers and fuses [39].

3.2.2 Setting and Selection of over current Protective Devices

The properly setting over current relay and selection rating of protective device in the power protection system isolate faulty part from healthy party. The maximum short circuit current flow in the power protection system at this time upper protective device send to command primary protection system, in this case fail primary protection system to operate secondary protection system. The connection principle traces the curves for all protective devices on a composite graph to select ratings or settings that will protect over current and overlapping in the power protection system.

Setting of Overcurrent Relay

The relay will operate if the current passing through the operating coil are higher than the threshold current. The threshold current are the set current below which the relays must not operate and above which they should operate. Basically overcurrent relay is a type of protective relay which operates when the load current exceeds a preset value. The setting of over current relay is depending in this paper the Inverse Definite Minimum Time relay (IDMT).

Selection of Fuse Rating

A time delay fuse will prevent the fuse from blowing if it is set to the normal running current. This fuse to protect very low with standpoint apparatus such as semiconductors, motors and transformers in the power distrubstion system. It is prevent blowing them on motor startups you may have to put in a fuse rated for the starting current rather than the running current. The generally, Selection fuse rating in the power protection system interrupting rating greater than fault current. Standard of the Fuse Ampere Rating =125 % Full load Amperes.

Selection of Circuit Breaker Rating

Fuse ratings are allowed to be lower than circuit breaker ratings because of the variances in operating characteristics for the overload region. The main breaker installed in the circuit primary and secondary of the transformer to have a kilo ampere interrupting rating greater than fault current. Standard of the Circuit Breaker Ratings is equal to 150 % Full Load Amperes.

3.2. 3 Protective Device Coordination Time Interval

Coordination time intervals should maintain curves of several protective devices to confirm the correct sequential operation of time. These intervals are needed as relays have over travel and curve tolerances. When fuses have damage characteristics, and circuit breakers operate at certain speeds. Usually, these operation intervals are called margins.

When fault occurs on a system both primary and backup relay sense, but primary relay is first to issue the trip signal because it’s operating time is less in comparison to that of the backup relay. That means there is certain amount of delay in operating time of primary and backup relay known as Coordination Time Interval (CTI).The coordination time interval between the backup and the primary relay depends on various parameters such as operating time of primary relay, operating time of circuit breaker associated with the primary relay, overshoot time of backup relay, and signal travelling time [2,36].

3.3 Modeling of Dilla Distribution System by ETAP software

3.3.1 Overview of Electrical Transient Analysis Program

The Electrical Transient Analysis Program (ETAP) is a completely graphical enterprise package that operates on different Microsoft windows operating systems. It is the most comprehensive analysis tool for the model and enhancement of power systems available. Using its standard of line simulation modules, ETAP can utilize real time operating data for advanced monitoring, real time simulation, energy management systems and high speed intelligent load shedding. It can be combining the electrical, logical, mechanical and physical attributes of system materials in the similar database. It is one of the most integrated database for electrical systems, allowing engineers to have multiple presentations of a system for different analysis or model purposes. This software uses to analyze most electrical analysis, for example reliability, short circuit, load flow, arc flash, protection coordination and others. For this thesis, ETAP 12.6.0 is used for model and simulation coordination of protective device for dilla power distribution system. The parameters used in modeling, load flow analysis, fault analysis and evaluation of coordination protective devices are those shown on this page.

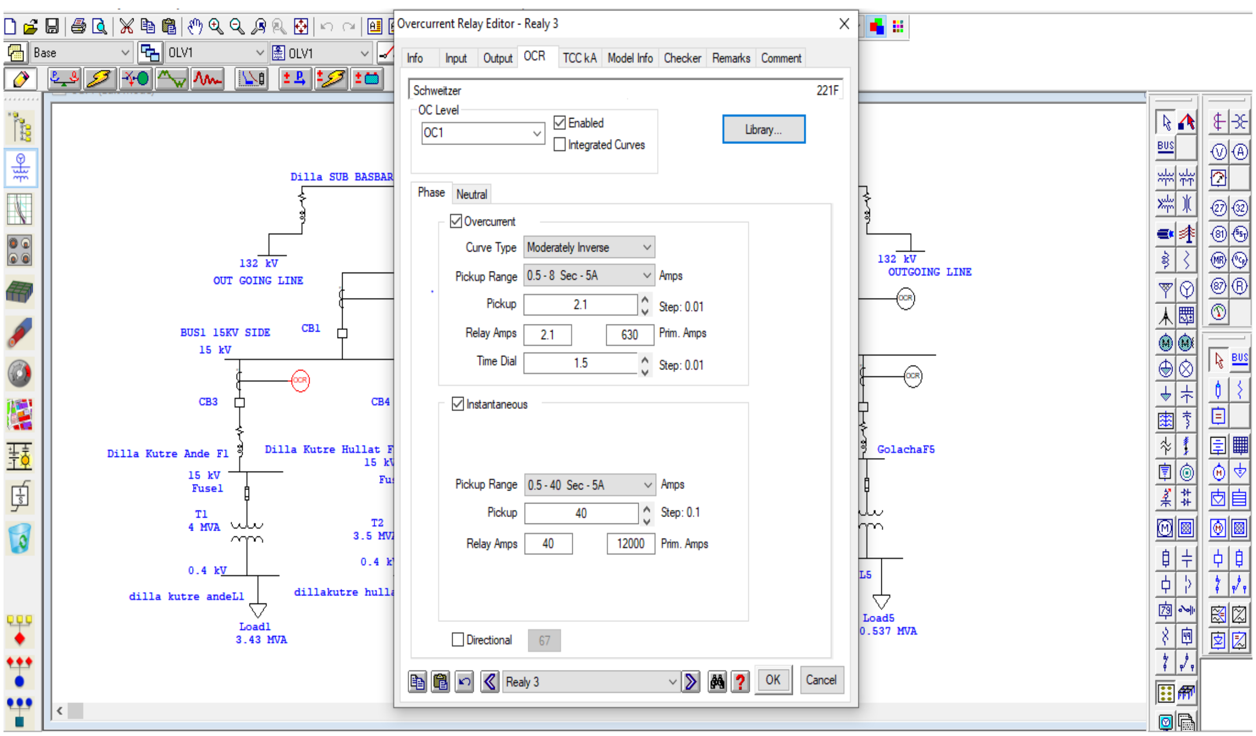

Figure 3.2: Fault editor view with the coordination protective device page open.

3.3.2 Overview of Dilla Distribution System

General Information about Dilla Distribution System is formed two outgoing line carries for 132KV and incoming line carries 132 KV from Warra substation. The Dilla distribution system is five radial feeders. The three radial feeders are found 15 KV sides those are represented by local name Feeder number one (Dilla Kutre Ande), Feeder number two (Dilla Kutre hullat), Feeder number three (Yirga chafe) and 33 KV sides are two radial feeders those are represented by local name feeder number four (Solomo), and Feeder number five (Gollcha).

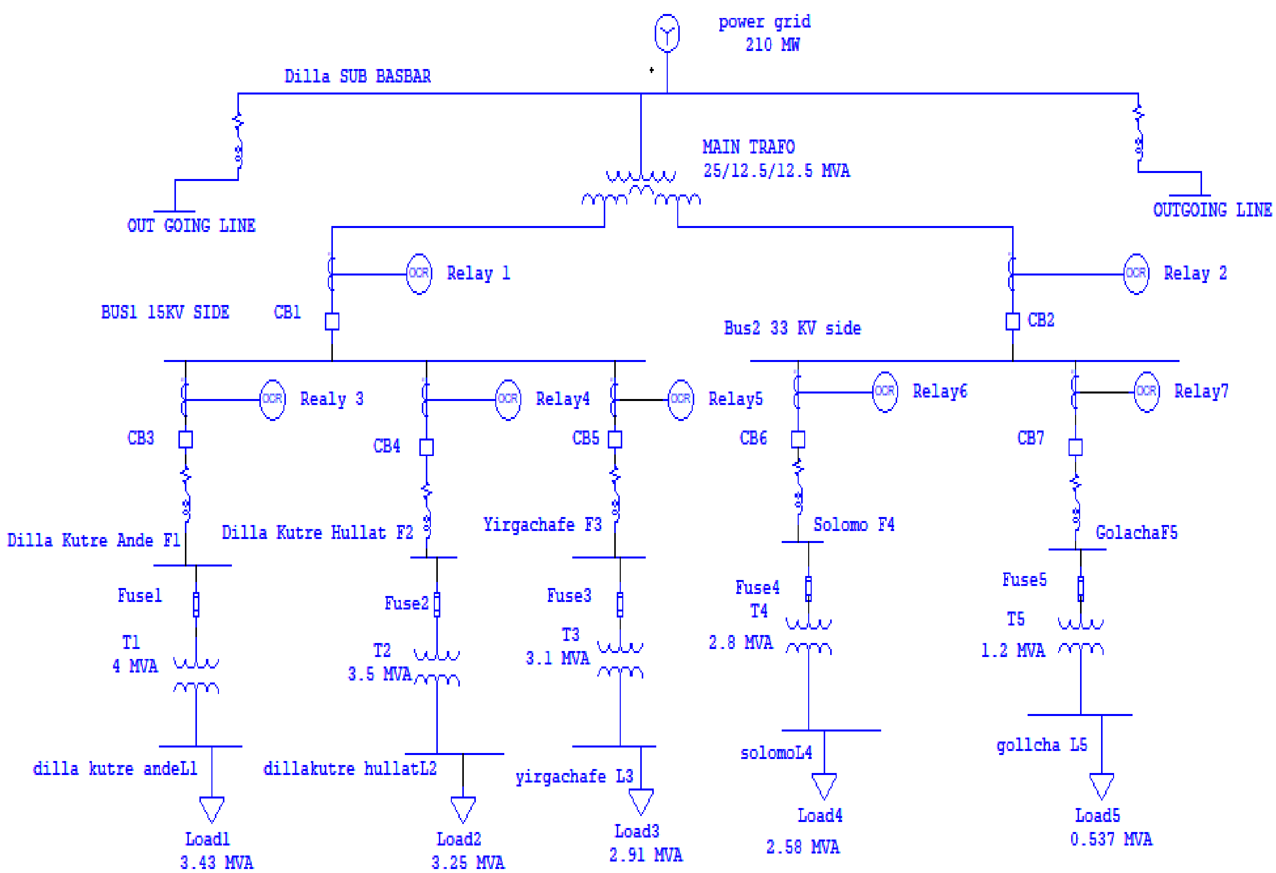

Figure 3.3: Overview of Dilla power distribution system.

In Dilla distribution system, the primary data necessary for this thesis are.

- Length of the feeder
- Rating of each transformer
- Impedance value

- Current transformer ratio
- Conductor type
- Peak load
- Duration of interruptions
- Circuit Breaker and Fuse specification

Table 3.1: Peak load MW dilla distribution system.

Peak load MW dilla distribution system 2012 data												
MONTHS	SEP	OCT	NOV	DES	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG
Feeder 1 Peak Load MW	2.5	2.3	2.3	2.9	2.9	3.26	3.3	3	2.5	3.10	3.4	5.95
Feeder 2 Peak Load MW	2.5	2.6	2.6	3.3	3.3	3.5	4.08	4.2	4.04	3.7	0.8	5.06
Feeder 3 Peak Load MW	3.13	2.91	2.91	2.5	2.5	3	3.13	3.13	2.44	2.5	1.2	2.06
Feeder 4 Peak Load MW	2.18	3.28	3.28	1.09	1.09	1.33	1.3	1.4	1.4	1.2	2.36	4.8
Feeder 5 Peak Load MW	1.09	1.09	1.09	0	0	0	0	0	0	0	1.1	1.5

$$\text{Total Load in MW of Feeder} = \frac{\text{The Sum of each Feeder Load}}{\text{Tweleve Months}} \tag{3.1}$$

The power demand at dilla distribution system active power and apparent power by considering a power factor of 0.91.

Table 3.2: Peak load data calculated for 2012 E.C.

Feeder name	Feeder1	Feeder2	Feeder3	Feeder4	Feeder5
Peak load MW	3.1175	3.965	2.65	2.35	0.489
Peak load MVA	3.43	3.25	2.91	2.58	0.537

3.4 Mathematical Modeling of Selection Protective Devices

The following are mathematical express ions to determine relevant parameters for protection device coordination [40].

Fault MVA=$\frac{\text{Base MVA}}{\text{Zp.u}}$ (3.2)

Fault Current: IF =$\frac{\text{FAULT MVA}}{\sqrt{3}*\text{KV}}$ (A) (3.3)

Load Current: IFL=$\frac{\text{KVA}}{\sqrt{3}*\text{KV}}$ (3.4)

Equipment the same feeder= $\text{MVA}_{\text{SCresultant}}$ =INV ($\frac{1}{\text{MVA}_{\text{SC1}}}$+$\frac{1}{\text{MVA}_{\text{SC2}}}$) (3.5)

Equipment parallel feeder = $\text{MVA}_{\text{SCresultant}}+\text{MVA}_{\text{SCload}}$ (3.6)

Total summation of short ckt= short ckt1 + short ckt2+ short ckt3 (3.7)

The purpose of determining fault current on the primary and secondary of a transformer have the selected rating overcurrent protective devices that can interrupt available fault current. The main breaker installed in the circuit primary and secondary of the transformer to have a kilo ampere interrupting rating greater than the Fault current.

Circuit breaker rating=1.5* Fault Current.

Fuse rating =1.25*Fault Current.

3.4.1 Short Circuit Calculation at 15KV Side

At Feeder 1: Transformer1 (MVA) = 4MVA Z=0.0475

By using eqn(3.2) $\text{T1MVA}_{\text{SC1}}$= $\frac{\text{Base MVA1}}{\text{Zp.u}} = \frac{4}{0.0475}$= 50MVA

The impedance of transmission line found on the appendix.A2

$\text{Z1MVA}_{\text{SC1}}$=$\frac{\text{KV}*\text{KV}}{\text{Z}}$=$\frac{15\text{KV}*15\text{KV}}{0.867}$ =259.5MVA

If the equipment found on the same feeder

By using eqn (3.5) $\text{MVA}_{\text{SCresultant1}}$ = INV ($\frac{1}{\text{Z1MVA}_{\text{SC}}}$+$\frac{1}{\text{T1MVA}_{\text{SC}}}$) = INV ($\frac{1}{259.5}$+$\frac{1}{50}$)= 63.29MVA

Their for load is connected parallel voltage level=0.4KV

By using eqn (3.4)Fault $\text{MVA}_{\text{SCload2}}$ =$\frac{\text{load1MVA}*\text{ KVA}}{\sqrt{3}*0.4\text{KV}} = \frac{3.43\text{KVA}*10^3}{\sqrt{3}*0.4\text{KV}}$=4949A

$\text{FaultMVA}_{\text{SCresultant}}$ =$\frac{\text{MVAsc resultant1}*\text{KVA}}{\sqrt{3}*\text{l5 KV}}$ =$\frac{63.29\text{KVA}*10^3}{\sqrt{3}*15\text{KV}}$ =2436A

By using eqn (3.6) Fault Current=$\text{FaultMVA}_{\text{SCresultant1}}$+$\text{FaultMVA}_{\text{SCload2}}$ =7385A

At Feeder 2: Transformer 2(MVA) =3.5MVA Z=0.06

By using eqn (3.2) $T2MVA_{SC2}= \frac{\text{Base MVA2}}{\text{Zp.u}} = \frac{3.5}{0.06} = 58.4MVA$

$z2MVA_{SC2}=\frac{KV*KV}{Z} = \frac{15KV*15KV}{0.867} =259.5MVA$

If the equipment found on the same feeder

By using eqn(3.5) $MVA_{SCresultant2}$ = INV $(\frac{1}{Z2MVA_{SC}}+\frac{1}{T2MVA_{SC}}) = (\frac{1}{259.5}+\frac{1}{58.4})=47.85MVA$

Their for load is connected parallel voltage level=0.4kv

By using eqn (3.4) $FaultMVA_{SCload1} = \frac{load2MVA*KVA}{\sqrt{3}*KV} \frac{= 3.25KVA*10^3}{\sqrt{3}*0.4KV} = 4689.75A$

$FaultMVA_{SCresultant2} = \frac{\text{MVAsc resultant } 2*KVA}{\sqrt{3}*15KV} = \frac{47.85KVA*10^3}{\sqrt{3}*15KV} = 1841.9A$

Fault Current=$FaultMVA_{SCresultant2}+FaultMVA_{SCload2}$ = 6531.7 A

At Feeder 3: Transformer (MVA) = 3.1MVA Z=0.08

By using eqn (3.2) $T3MVA_{SC3} = \frac{\text{Base MVA3}}{\text{Zp.u}} =\frac{3.1}{0.08} =38.75$

$Z3MVA_{SC3}=\frac{KV*KV}{Z}=\frac{15KV*15KV}{0.867} =259.5$

If the equipment found on the same feeder

By using eqn (3.5)$MVA_{SCresultant3}$ =INV $(\frac{1}{Z3MVA_{SC}}+\frac{1}{T3MVA_{SC}}) = (\frac{1}{259.5}+\frac{1}{38.75})=33.72MVA$

Their for load is connected parallel voltage level=0.4kv

By using eqn (3.4) Fault $MVA_{SCload3} = \frac{load2*KVA}{\sqrt{3}*0.4\ KV} = \frac{2.91KVA*10^3}{\sqrt{3}*0.4KV}=4301A$

Fault $MVA_{SCresultant3} = \frac{MVASCresultant3*KVA}{\sqrt{3}*15\ KV} = \frac{33.72KVA*10^3}{\sqrt{3}*15KV} =1298A$

By using eqn (3.6) Fault Current=Fault $MVA_{SCresultant3}+FaultMVA_{SCload3}$ =5599A

3.4.2 Short Circuit Calculation at 33 KV Side

At feeder 4: Transformer (MVA) = 2.8MVA Z=0.0475

By using eqn (3.2) $T4MVA_{SC4}= \frac{\text{Base MVA4}}{\text{Zp.u}} = \frac{2.8}{0.0475} = 58.947$

The impedance of transmission line found on the appendix.A2

$z4MVA_{Sc4}=\frac{KV*KV}{Z}=\frac{33*33}{0.867} =1256$

If the equipment is found on the same feeder

By using eqn (3.5) $MVA_{SCresultant}$ = INV ($\frac{1}{Z4MVA_{SC}}$+$\frac{1}{T4MVA_{SC}}$) = ($\frac{1}{1256}$+$\frac{1}{58.947}$)=56.94MVA

Their for load is connected parallel voltage level=0.4kv

By using eqn (3.4) $FaultMVA_{SCload4}$ $=\frac{Load\ 4*KVA}{\sqrt{3}*0.4KV}$ $=\frac{2.58KVA*10^3}{\sqrt{3}*0.4KV}$ =3724A

$FaultMVA_{SCresultant}$ $=\frac{MVAsc\ resultan4t*KVA}{\sqrt{3}*33\ KV}$ $=\frac{56.94KVA*10^3}{\sqrt{3}*33KV}$ =989A

By using eqn (3.6) Fault Current=$FaultMVA_{SCresultant4}$+$FaultMVA_{SCload4}$ = 4713A

At Feeder 5: Transformer (MVA) = 1.2MVA Z=0.035

By using eqn (3.2) $T5MVA_{SC5}$= $\frac{Base\ MVA5}{Zp.u} = \frac{1.2\ MVA}{0.035}$=34.285

$Z5MVA_{SC}$=$\frac{KV*KV}{Z}$=$\frac{33*33}{0.867}$ =1256

If the equipment on the same feeder,

By using eqn (3.5) $MVA_{SCresultant5}$ = INV ($\frac{1}{Z5MVA_{SC}}$+$\frac{1}{T5MVA_{SC}}$) = ($\frac{1}{1256}$+$\frac{1}{34.285}$)=33.37MVA

Their for load is connected parallel voltage level=0.4kv

By using eqn (3.4) $MVA_{SCload5}$ $=\frac{load5*KVA}{\sqrt{3}*0.4\ KV}$=$\frac{0.537KVA*10^3}{\sqrt{3}*0.4KV}$ =775A

$MVA_{SCresultant5}$ $=\frac{MVAsc\ resultant5*KVA}{\sqrt{3}*33\ KV}$=$\frac{33.37KVA*10^3}{\sqrt{3}*33KV}$= 584A

By using eqn (3.6) Fault Current=$MVA_{SCresultant5}$+$MVA_{SCload5}$ =1359 A

Table 3.3: Summary of fault analysis and selection rating of protective device.

Number of feeders 15kv and 33kv side	Fault Current(Ampere)	selection rating of protective device	
		Circuit breaker rating (Ampere)	Fuse rating (Ampere)
Feeder 1	7385	11077	9231
Feeder 2	6531	9797	8164
Feeder 3	5599	8398	6998
Feeder 4	4713	7069	5891
Feeder 5	1359	2036	1699

Total summation of short ckt at 15 kV bus bars =short ckt feeder 1 + short ckt feeder 2 + short ckt feeder3. = 7385 +6531+5599=19515A.

Total summation of short ckt at 33 kV bus bars = short ckt at feeder4 + short ckt at feeder 5= 4713+1359=6072A.

3.5 Problem Formulation of Coordination Protective Devices

The objective function of this problem is minimizing the total operating time of relay in the primary protection system and secondary protections system using a teaching learning-based optimization algorithm and particle swarm optimization algorithm [24,28].

$$\text{Min FX}=\sum_{i=1}^{m} \text{Wi}.\, t_{ijk} \tag{3.8}$$

Where

Min FX= minimizing the total operating time of the relay

m = Number of relays

t_{ijk} = Operating time of primary protection system and secondary protection system relay R_{ij} for fault at k

Wi = weight assigned for the operating time of the relay R_{ij}

Wi=1

Short circuit occur in the power protection system therefor for relay operation line considered in the network should be weight assigned for the operating time of the relay is one. This paper will conduct the simulation by using the over current relay with Inverse Definite Minimum Time (IDMT) or standard inverse function.

$$t_i= \frac{0.14 * TMS_i}{\left({}^{ICi}/_{PSMi*CTi}\right)^{0.02}-1} \tag{3.9}$$

Where TMSi and PSMi are the TMS (Time multiplier setting) and PSM (Plug setting multiplier) of relay R_i , $IC_i$is the fault current passing through the operating coil of relay R_i and CTi is secondary current transformer rated.

3.5.1 Possible Solution of Coordination Protective Devices

To be able to minimize the total operating time of the relays four constraint positions are considered. This constraints subjected to the possible solution of coordination protective device must be outlined as follows.

a) Operating Time of Primary and Backup Relay

The fault current is detected in both primary and backup relays at the same time, as the coordination process is to check each fault in the protection zone. To be able to minimize the malfunction of the relay and power interruption if the primary relay failed to operate secondary relay should only trip. The backup relay would have a minimum level of operational time.

The operating time of the secondary relay must be dependent on the primary relay. The primary relay sends commands to the primary circuit breaker to overshoot the operating time. The coordination of protective devices in the primary and secondary protection system consider timing is an essential factor. The total operating time of the relay is the sum of the protective device operating time considering the coordination time interval (CTI).In this paper CTI is regarded as 0.1 seconds. R_j is the primary relay and R_i is backup relay both for fault at k. The coordination constraint one would be formulated as below equation [41].

$$t_{jk} - t_{ik} \geq \Delta t \tag{3.10}$$

t_{ik} = Operating time of the primary relayR_j for fault at k

t_{jk}= Operating time of the backup relayR_i for the same fault at k

Δt = CTI

b) Boundary Constraints on Operating Time of Relay

As much as minimum time is very much desired for a relay to operate but they are some limitation within the system that needs to be considered while coordinating over current relay. The operating time of over current relay with limit is bounded minimum and maximum value to desired operation. The operation time of the relay can be mathematically represented as following, equation.

$$t_{imin} \leq t_{ik} \leq t_{imax} \tag{3.11}$$

Where

i = relay number at fault location.

t_{imin} = minimum operating time of relay.

t_{imax}= maximum operating time of relay.

c) Boundary constraints on TMS

The boundary on the Time Multiplier Setting (TMS), which affects the operation timing of the relay needs to be set as follows.

$$TMS\ i\ min \leq TMSi \leq TMSimax \tag{3.12}$$

TMS_{imin} = minimum value of relay R_i

TMS_{imax}= maximum value of relay R_i

WhereTMS_{imin} and $TMS_{imax}$are the minimum and maximum value of TMS of relay R_i which are provided by relay maker.

d) Boundary Constraints on PSM

Another critical setting criterion of the relay setting is Plug Setting Multiplier (PSM). The boundaries on the PSM are as follows.

$$PSM_{i\,min} \le PSM_i \le PSM_{i\,max} \tag{3.13}$$

Where

PSM i min = minimum PSM value for R_i

PSM i max = maximum PSM value for R_i

Where PSMi min and PSMi max are the minimum and maximum values of PSM of relayR_i.

The over current relay to operate normal condition or small amount of overload condition the minimum pickup current setting must be equal to or more than one point two five times of the maximum load current. Similarly, maximum pickup setting should be less than or equal to zero point six seven times of the minimum fault current [28,31,41].

3.5.2 Teaching Learning Based Optimization

Teaching Learning Based Optimization (TLBO) is population based optimization algorithms for the interaction between teachers and students in the class. The teaching learning-based optimization algorithm is the teaching and learning process that encouraged algorithms based on the teacher output of learners in the class. Teaching Learning Based Optimization algorithm is a teaching and a learning process but, a teacher is the consequence of learners in the class.

The algorithm defines two basic methods of the learning:

i. The teacher (known as teacher phase)
ii. The interaction with the other learners (known as learner phase).

Initialization to be able to define population X, there is a random method concerned in the first step. The boundaries within the search method must be involved with in a matrix of N×D.N is the number of students in the class which is similar to population size. On the other ways, D the number of the courses being offered and G is the iteration process.

The initial random of the i and j rank of the matrix is being calculated in the below equation.

$$x^{1}_{(ij)}=x^{min}_{j}+rand\times (x^{max}_{j}-x^{min}_{j}) \tag{3.14}$$

Where: rand = a variable between 0 and 1 to show random uniform distribution within that range.

x^{min}_{j}=minimum value of j^{th}parameter.

x^{max}_{j}= maximum value of j^{th}parameter.

j= 1, 2, 3 … D , i= 1, 2, 3… N and g= 1, 2, 3… G

The student parameter with would be ith parameter at iteration G is formulated in the below equation.

$$x^{g}_{(i)}=[x^{g}_{(i,1),}x^{g}_{(i,2)\ K}\ ,\ x^{g}_{(i,j),K}\ ,x^{g}_{(i,D)}] \tag{3.15}$$

The TLBO is classified into two parts Teacher phase and Learner phase action of both phases is clarified below

Teacher Part

In the teacher's part, there is a vector called M^{g}which is the mean value of the students in the class for each topic that would be calculated at iteration G. the below equation represents M^{g}it is a more effective way represented as equation.

$$M^{g}=[m^{g}_{1,}\quad m^{g}_{2,}\quad ,K,\quad m^{g}_{j}\quad ,K, m^{g}_{D}] \tag{3.16}$$

For each iteration the teacher selected best minimum objective this algorithm carries on with replacing the students mean values that approach the teachers' values. To be able to get an improved student course, the algorithm forms a differential vector of the existing mean values, which all have weights that are randomly calculated. The vector gets additional to the current population of students. The below equation represents the new student vector.

$$x^{g}_{(new)}=x^{g}_{(i)}+rand\times (X^{g}_{Teacher}\ -\ T_{F}\ M^{g}) \tag{3.17}$$

Where: r_2 = a random number between 0 and 1.

$T_{F(teacher\ factor)}$ = A value that is either 1 or 2 that randomly with change in each iteration.

T_F = round [1+r_2] (To select T_F randomly with the same probability between 1 and 2)

Note that, T_F is not considered a parameter that teaching learning based optimization uses. It is a randomly selected value and will not require it as an input.

Learner Part

As it was described before student technically will learn from each other rather than their teacher. Each student interacts with the other student and in this method will learn more. The students are randomly interacting with the other students and start the knowledge transfer. It is the second part of the algorithm where learners rise their knowledge by interacting between themselves. The learner interacts randomly with other learners for rise his or her knowledge.

The learner learns new things if the other learner has more knowledge than him or her .The below equation mathematically represents the student learning interaction, calculation of $x^{g}_{new(i)}$.

$$x^{g}_{new(i)}=\begin{bmatrix} x^{g}_{i} + rand \times x^{g}_{i} - x^{g}_{r} & \text{if } (x^{g}_{i} < x^{g}_{r}) \\ x^{g}_{i} + rand \times x^{g}_{r} - x^{g}_{i} & \text{atherwise} \end{bmatrix} \tag{3.18}$$

Where: If $i \neq r$ then

$x^{g}_{(i)}$= student

$x^{g}_{(r)}$= another student.

Steps for the TLBO

The following steps are explanations to the TLBO algorithm.

Step 1: Initialize the population size or total of learners in the class (N) total of generations (G) total of design variables or subjects (courses) offered which coincides with the amount of units to place in the distribution system (D) and limits of design .The purpose of optimization problem as: Minimize f(X), where f (X) is the objective function X is a vector for design variables such that $L_l \leq x \leq. U_l$

Step 2: Randomly selected population giving to the number of students in the class (N) and number of subjects presented (D).

Step 3: calculate the mean of each subject presented in the category.

Step 4: supposed on grade of students from maximum to minimum range.

Step 5: modification score of every subject for every the individual student.

Step 6: Every learner modification score of every subject through the mutual interaction with the further learners. Every learner interacts subjectively with anther learners and thus facilitates information sharing [31].

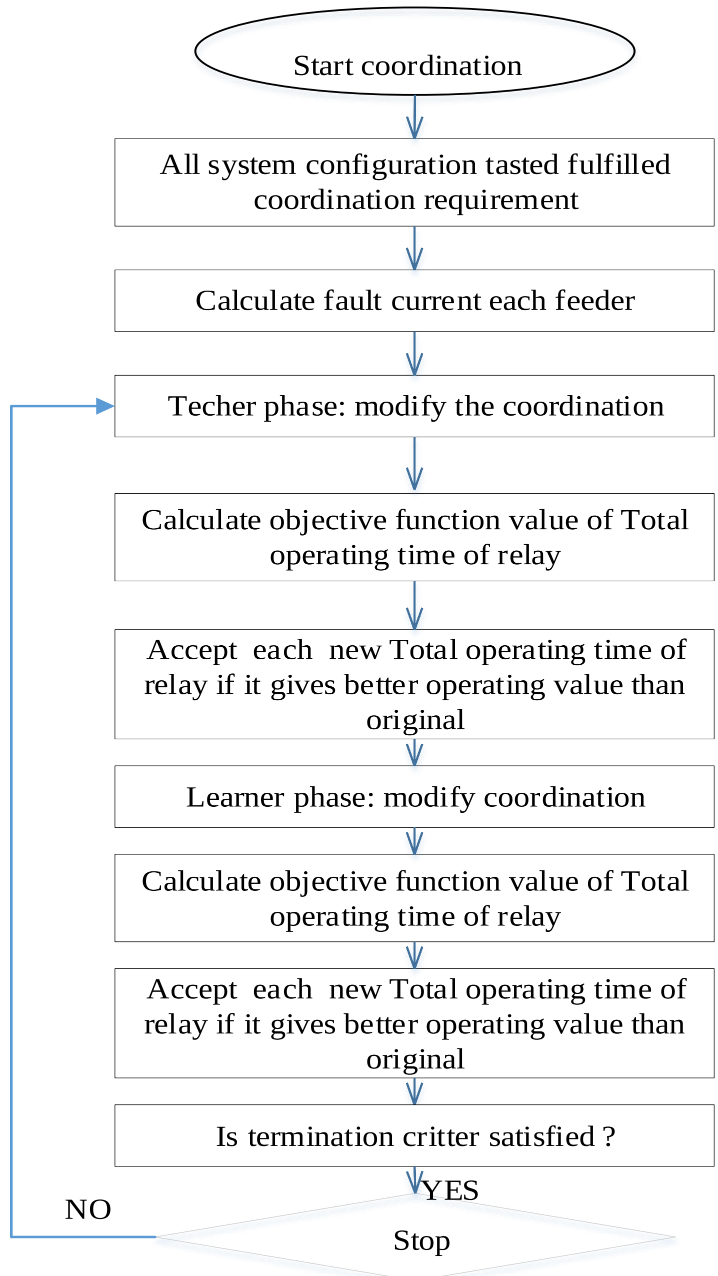

Figure 3.4: Flowchart of teaching learning based optimization algorithm.

3.5.3 Particle Swarm Optimization

PSO is a population based optimization method which is moved by the sociological behavior associated with bird flocking and fish schooling. The main feature of PSO is that no gradient information derived from objective function. The main idea of the PSO algorithm is to maintain a population of particles which is referred as swarm in which each particle represents a potential solution to the objective function. Each particle in swarm can remember its current position which can be certain by evolution of objective function, velocity and best stay position during its flying tour in the problem search space which is its Personal best solution (Pbest). The personal best solution represents highest fitness value for the particle in minimization task higher fitness means the position having a smaller function value. The best position among all personal best solution is known as global best position. At each iteration the velocity of each particle is changed with current velocity and distance from p best and g best [42].

Steps of PSO

Step 1: Initialize the population of the particles (parameters of the controller) such that they are equidistant from each other and covering the total search space.

Step 2: Activate the controller on the platform to each position and compute its fitness value.

Step 3: Location of the $\mathrm{i^{th}}$ particle in the swarm is known as its Particle Best and the current best position Pbest of each particle is determined by the following formula:

$$\mathrm{v_i^{k+1}} = \mathrm{v_i^k} + \mathrm{c_1} * \mathrm{rand}\,() * \frac{\mathrm{Pbest_i} - \mathrm{S_i^k}}{\Delta \mathrm{t}} + \mathrm{C_2} * \mathrm{rand}\,() * \frac{\mathrm{gbest_i} - \mathrm{S_i^k}}{\Delta \mathrm{t}} \quad (3.19)$$

$\mathrm{v_i^k}$ is $\mathrm{i^{th}}$ velocity component at iteration k, rand () is random number between 0 and 1, $\mathrm{S_i^k}$ current position in the ith dimension, $\mathrm{C_1}, \mathrm{C_2}$ is acceleration coefficients, $\mathrm{Pbest_i}$ is personal best position in the ith dimension, $\mathrm{gbest_i}$ is global best position in the ith dimension and $\Delta\mathrm{t}$ is time.

Step 4. The particle with the better fitness value (here minimum) within the swarm is known as the Global Best. Each time, judge against the fitness value of particle *i* with the Global Best as it try to move towards the Global Best. If the function value of the individual particle exceeds the, Global Best replace the Global Best with that function value.

Step 5: Attempting to increase the rate of convergence to global optimum, the inertia weight is scaling factor update the velocity of position.

$$v_i^{k+1} = w v_i^k + c_1 * \mathrm{rand}\,() * \frac{Pbest_i - S_i^k}{\Delta t} + C_2 * \mathrm{rand}\,() * \frac{gbest_i - S_i^k}{\Delta t} \quad (3.20)$$

Where w is the inertia weight

Step 6: After that each particle is free to update its position by its current velocity to explore the problem search space to get better results as follows. s_i^{k+1}=s_i^k+$v_i^{k+1} * \Delta t$ (3.21)

Step 7: If the termination condition is satisfied, the operation is stopped, otherwise, transfer to Fitness particle [24, 42].

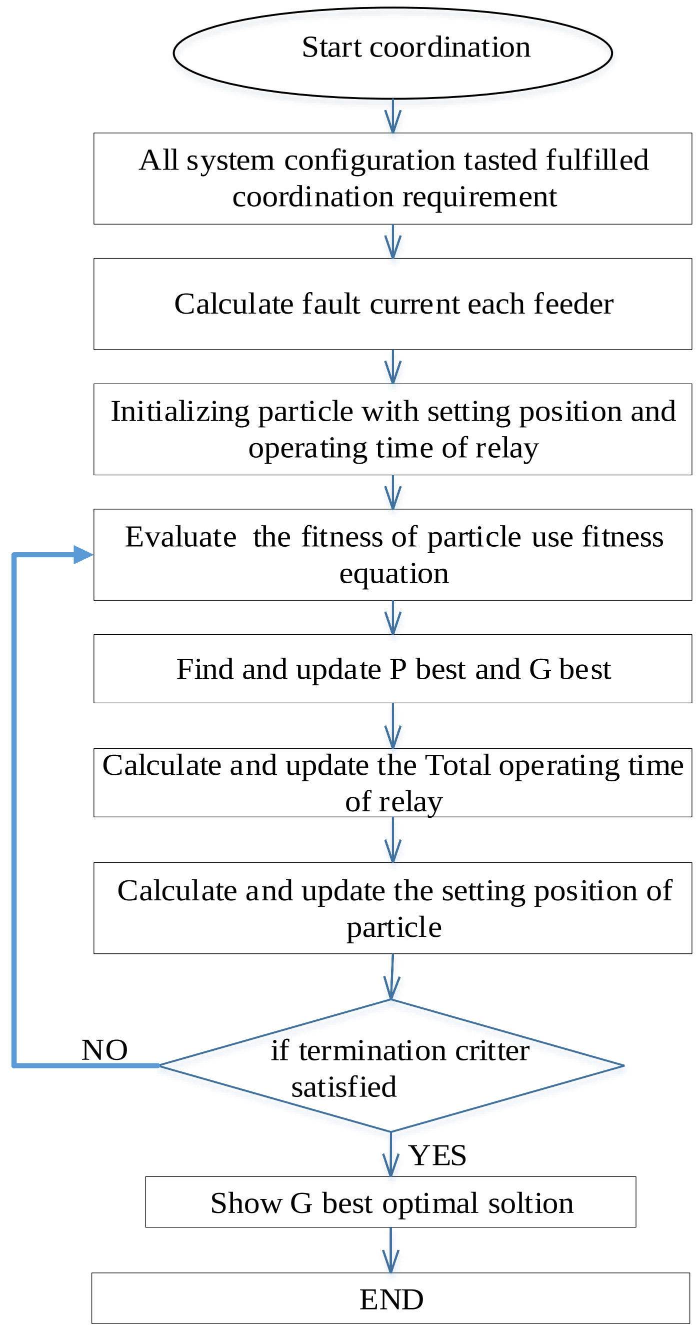

Figure 3.5: Flow chart of particle swarm optimization algorithm.

Chapter 4
Result and Discussion

4.1 Load Flow Analysis

Load flow analysis is simply evaluation of real and reactive power loss in the power protection system using ETAP software. It is analysis power protection system to perform during normal and emergency operating conditions providing information. The arrangement of relays, circuit breakers, fuses and current transformers are used in this system to achieve desired coordination.

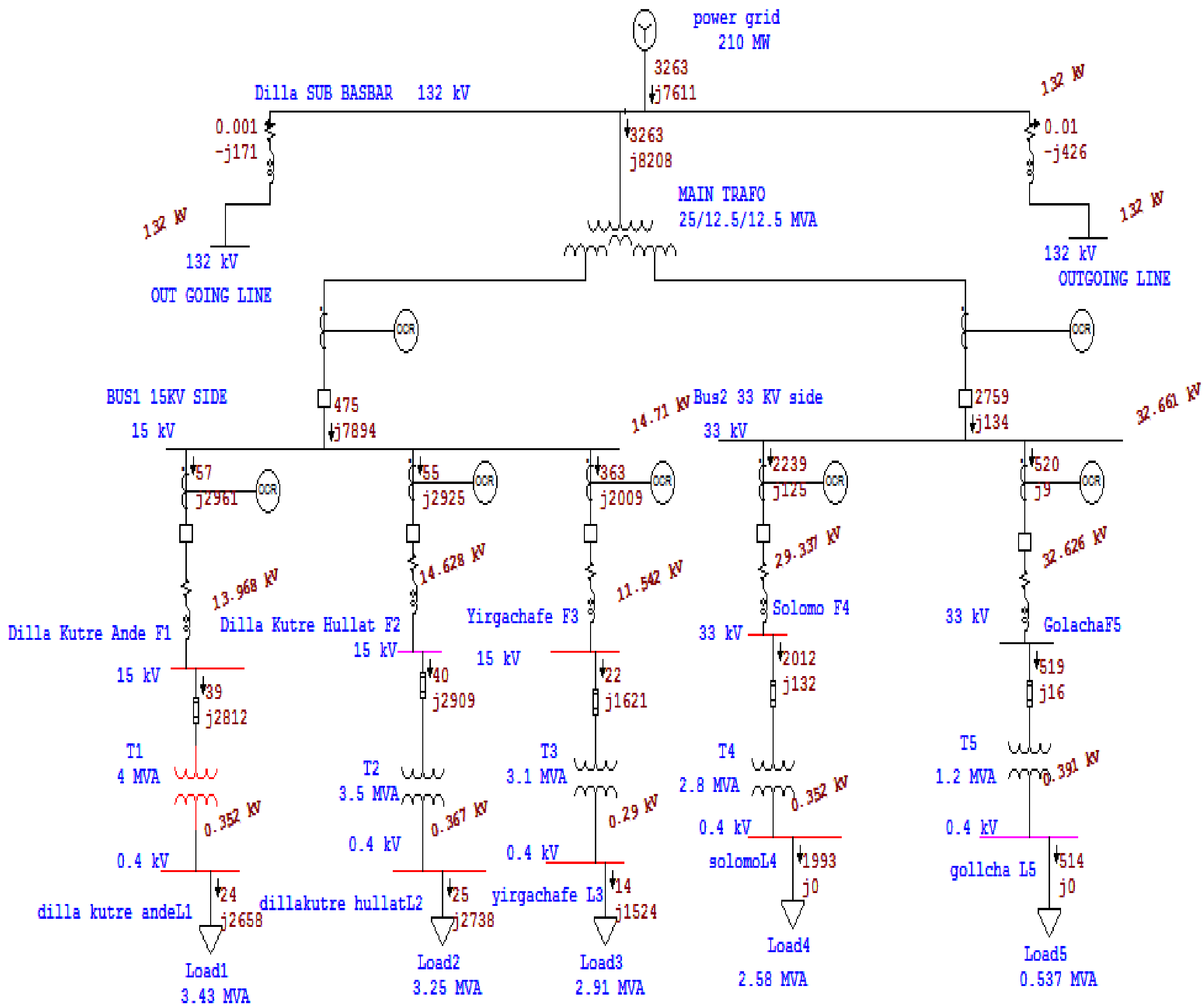

Figure 4.1: Load flow analysis.

When above figure indicates load flow it Report for15 KV side feeder one transformer is over loaded and feeder three is least operating value than by other feeders.

4.2 Fault Analysis

The goal of the short circuit studies is to find the maximum fault current which appears only whenever there is a fault in the circuit. Short Circuit of bus 15 KV side and 33 KV side analyses during unsymmetrical fault.

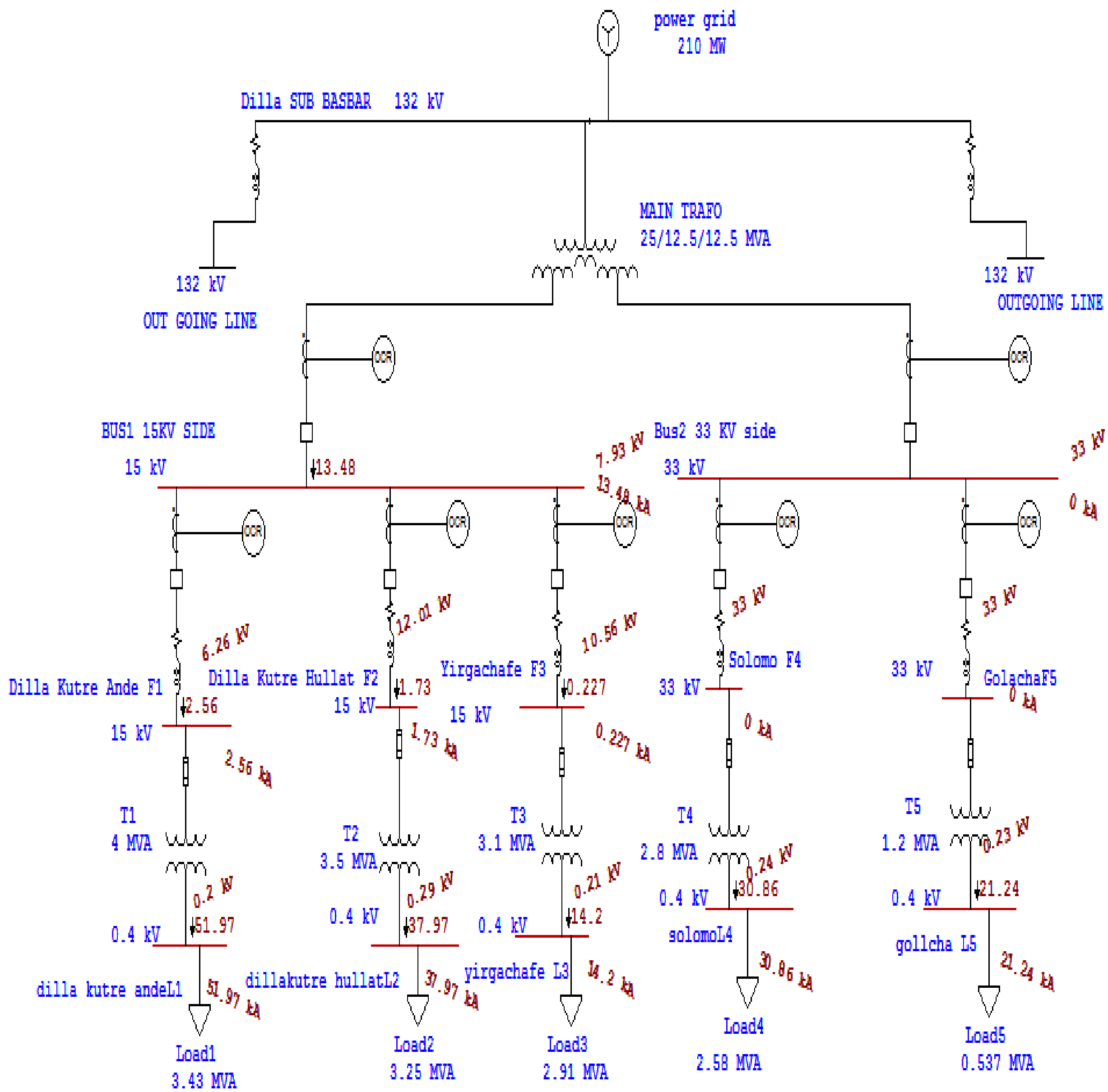

Figure 4.2: Short circuit analysis.

Table 4.1: Short circuit analysis line to ground and line to line fault.

Short-Circuit Summary Report

1/2 Cycle - LG, & LL Fault Currents

Prefault Voltage = 100 % of the Bus Nominal Voltage

Bus		Line-to-Ground Fault			Line-to-Line Fault		
ID	KV	Real	Imag	Mag	Real	Imag	Mag
BUS1 15KV SIDE	15.00	2.299	-13.287	13.484	10.302	1.494	10.410
Bus2 33 KV side	33.00	0.000	0.000	0.000	4.147	0.718	4.209
Dilla Kutre Ande F1	15.00	1.159	-2.279	2.557	1.986	0.424	2.030
Dilla kutre andeL1	0.40	7.219	-51.463	51.967	37.182	5.658	37.610
Dilla Kutre Hullat F2	15.00	0.288	-1.708	1.733	1.180	0.124	1.186
Dillakutre hullatL2	0.40	3.631	-37.796	37.970	26.258	2.568	26.384
GollchaF5	33.00	0.000	0.000	0.000	1.243	0.494	1.338
Gollcha L5	0.40	6.687	-20.161	21.241	16.526	5.537	17.429
Solomo F4	33.00	0.000	0.000	0.000	0.192	0.335	0.386
SolomoL4	0.40	17.360	-25.516	30.861	16.325	13.606	21.252
Yirgachafe F3	15.00	0.123	-0.190	0.227	0.209	0.169	0.268
Yirgachafe L3	0.40	7.537	-12.041	14.205	7.254	4.899	8.753

The short circuit summary report indicates faults for the 15KV side, and 33 KV side is most time happens line to ground fault. The result of a fault for the 15 KV sideshows, Dilla Kutre ande L1 is 51.97, Dilla Kutre hullat L2 is 37.97, and Yirgachafe L3 is 14.205. Then compare the results of line to ground fault, for the three feeders indicates a short circuit summary report Dilla Kutre ande Load one side is maximum fault happen. After the result of a fault for 33 KV side shows Solomo Load four is 30.861, and Gollcha Load five is 21.241. Then compare the two feeders of line to ground fault, solomo Load four is the maximum fault that happens. Finally, the line to line fault happens for 15 of the KV and 33 KV sides short circuit summary reports show, respectively maximum fault at Dilla Kutre ande and Solomo feeder side.

4.3 Coordination Evaluation

Anywhere in the protection system fault appears, relay sense sends the signal to a circuit breaker. The protective device isolates, the place where the fault occurs primary protection devices fail the backup devices must eliminate the danger

4.3.1 Fault at Dilla Kutre Ande primary protection

When a fault happens for the 15 KV side, Dilla Kutre Ande during this time fuse does not control fault. After the upper stream of relay three senses fault sends a trip signal to the circuit breaker three, next relay four senses fault sends a trip signal to the circuit breaker four, then relay five senses fault sends a trip signal to circuit breaker five, and those relays are the primary protection it shows below figure 4.3.

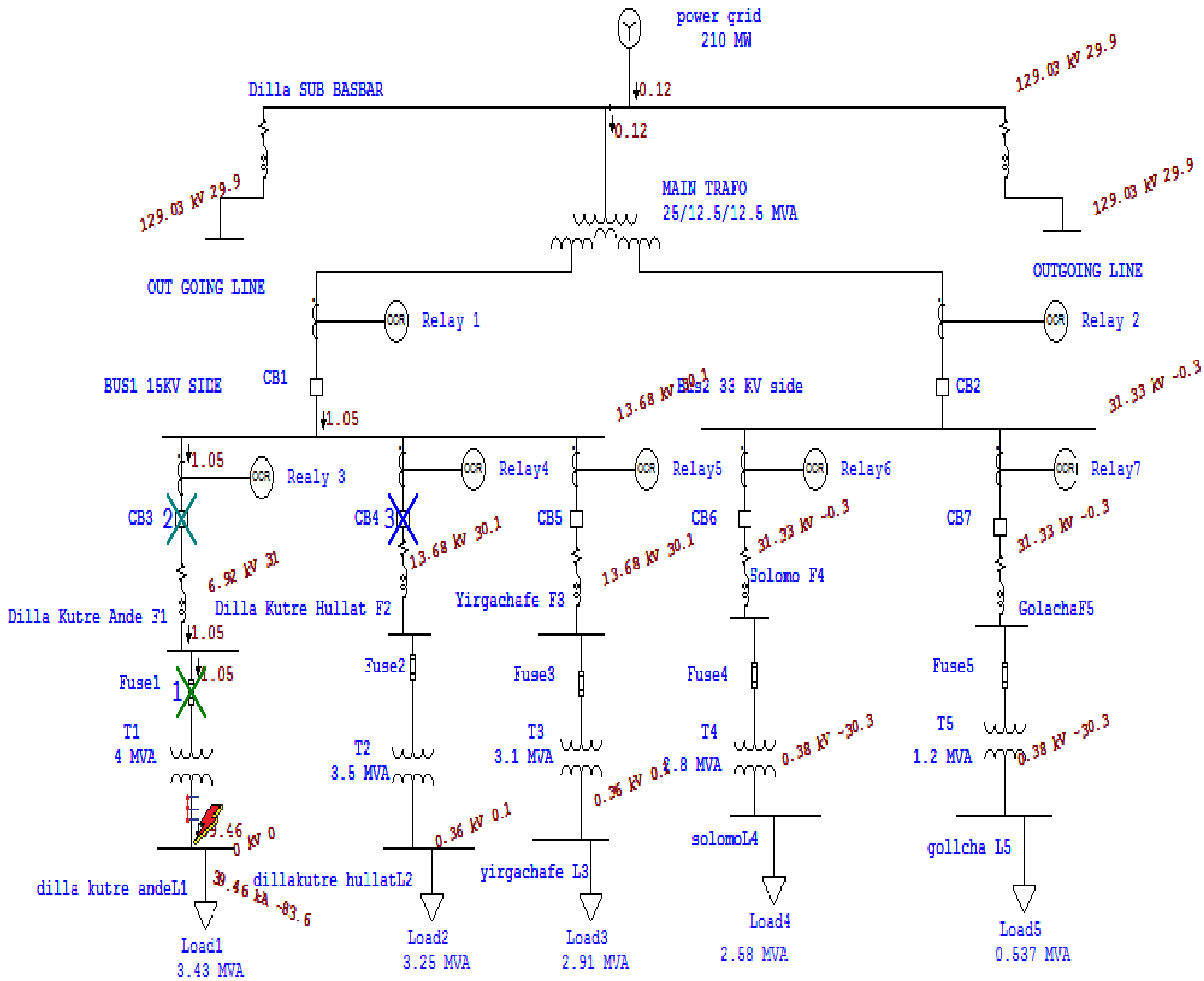

Figure 4.3: Fault at load bus dilla kutre ande primary protection.

4.3.2 Fault at Dilla Kutre Ande Secondary Protection

If the primary protection failed, then back protection must do action relay one senses the fault and sends a trip signal to the circuit breaker one.

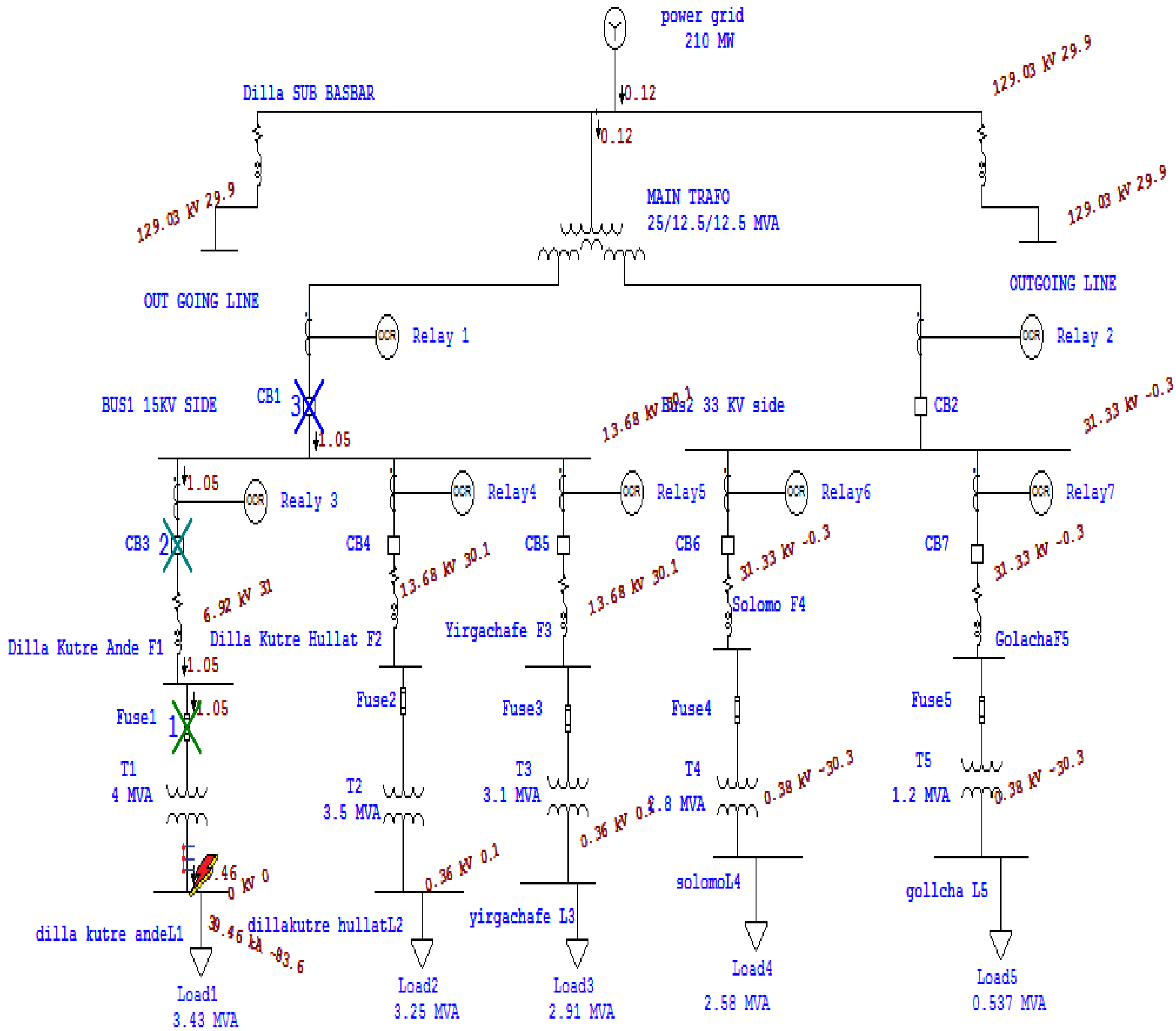

Figure 4.4: Fault at load bus dilla kutre ande secondary protection.

Table 4.2: Sequence of operation event summary fault at dilla kutre ande feeder one.

Sequence of Operation Event Summary Report					
Fault at Dilla kutre ande L1					
Total Time	Protective device	Fault current (KA)	Time 1(ms)	Time 2(ms)	Condition
13.7	Fuse1	1.052	<10	<13.7	
1731	Relay3	0.952	1731		Phase –OC1-51
1764	CB3		33.3		Tripped by relay 3
1781	CB4		50		Tripped by relay 4
1814	CB5		83.3		Tripped by relay 5
1864	CB1		133		Tripped by relay 6

When a fault occurs in Bus 15 KV side, Dilla Kutre Ande feeder first faults sense downstream of the fuse by 13.7 mill sec.This fuse is not protect the fault ,secondly operate upstream of the relay three sense fault send a signal to trip circuit breaker three by 33mill second. Thirdly, relay four sense fault sends trip signal circuit breaker four by 50 mill seconds. Thirdly relay five sense fault sends trip signal circuit breaker five for 83 mill seconds. Finally, the primary protection system relay three, relay four and relay five are fails then secondary protection system relay one is operate, therefore the secondary protection system relay one is sense fault send a signal to trip circuit breaker one by 133 mill seconds. The total operating time of relay in the primary and secondary protection system relay three 1.764 sec, relay four 1.781 sec, relay five 1.814 sec, and relay one 1.864 sec are respectively.

4.3.3 Fault at Solomo Primary Protection

The below figure shows in Bus 33 KV side, the Solomo feeder four faults occur the first fuse fails. Next, the relay six senses send a trip signal to the circuit breaker six. After, relay seven sends a trip signal to the circuit breaker seven, and that relays are the primary protection system.

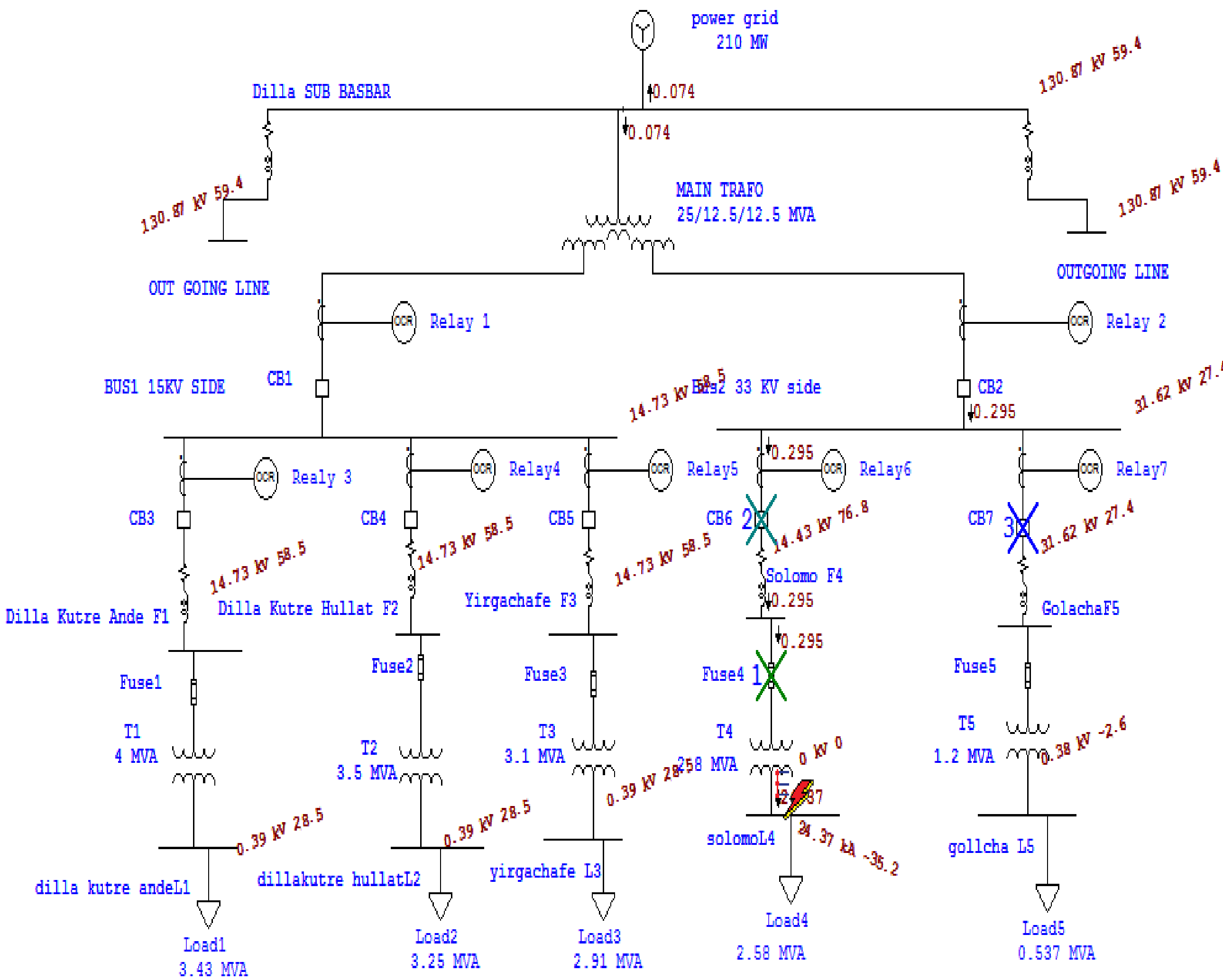

Figure 4.5: Fault at solomo load bus four primary protection.

4.3.4 Fault at Solomo secondary protection

If they primary protection failed the back protection must do action relay R2 senses the fault and sends a trip signal to the circuit breaker 2.

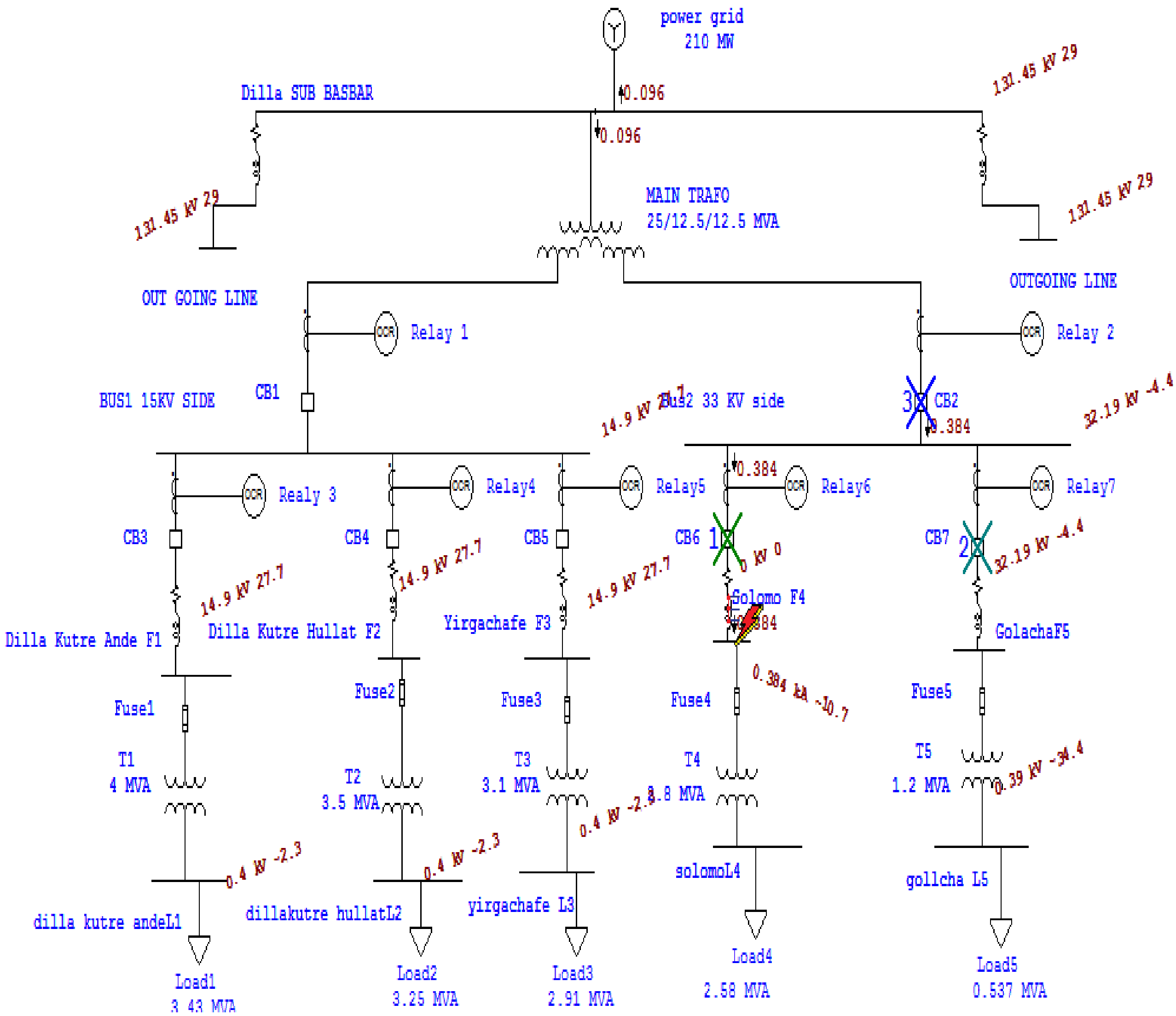

Figure 4.6: Fault at solomo feeder four secondary protection.

Table 4.3: Sequence of operation event summary fault solomo feeder four.

Sequence of Operation Event Summary Report					
Fault at Solomo Load bus four					
Total Time	Protective device	Fault current (KA)	Time 1(ms)	Time 2(ms)	Condition
13.6	Fuse 4	0.295	<10	<13.7	
1079	Relay 6	0.279	1079		Phase –OC1-51
1113	CB6		33.3		Tripped by relay 6
1129	CB7		50		Tripped by relay 7
1163	CB2		83.3		Tripped by relay 2

When Fault occurs in Bus 33 KV side Solomo Feeder four first fault sense downstream of the fuse by 13.6 mill sec. This fuse is not protect the fault ,secondly operate upstream of the relay six sense fault send a signal to trip circuit breaker three by 33mill second. Thirdly, relay seven sense fault send a signal to trip circuit breaker seven for 50 mill seconds. Finally, primary protection system relay six and relay seven are fails then secondary protection system relay two is operate, therefore the secondary protection system relay two sense fault sends signal trip circuit breaker two by 83.3 mill second. The total operating time of relay in the primary and secondary protection system relay six 1.113 sec, relay seven 1.129 sec and relay two 1.163 sec are respectively.

4.4 Coordination of Protective Devices by PSO and TLBO algorithm

Particle swarm optimization algorithm is widely used optimization algorithm in the power protection system, but teach learning-based optimization algorithm is a newly based algorithm that is the decided optimum and appropriate setting of overcurrent relay leading to exact coordination. When comparing the operating time of relay 15KV and 33KV side, more time delay and high interruption power happen for 15 KV side. Therefore, optimal coordination of protective device in the dilla power distribution system more concentrated on the 15KVside.

4.4.1 Total Operating Time of Relay Using TLBO algorithm

Table 4.4: Operating time of relay using TLBO algorithm.

	Operating Time of Relay(sec) by **TLBO**			
	Primary Protection system			Secondary Protection system
Fault	TOTR3	TOTR4	TOTR5	TOTR1
Fault At Feeder 1	0.1352	0.1370	0.1385	0.1497
Fault At Feeder 2	0.1354	0.1286	0.1557	0.1567
Fault At Feeder 3	0.1363	0.1346	0.1076	0.1390
Fault At Feeder 15kv side	0.1373	0.1292	0.1234	0.1054
Min (TOTR)	**0.1352**	**0.1286**	**0.1076**	**0.1054**

Fault occures at each feeder the minimum total operating time of relay the operating time is respectively, at feeder 1 the total operating time of relay three (TOTR3) is 0.1352sec , at feeder 2 the total operating time relay four (TOTR4) is 0.1286sec, at feeder 3 the total operating time of relay five (TOTR5) is 0.1076sec and at feeder 15 KV side the tota operating time of relay one (TOTR1) is 0.1054sec.Finaly, properly decreses operating time from primary protection system relay (TOTR345) to secandary protection system relay (TOTR1) based on teach learning based optimization algorithm.

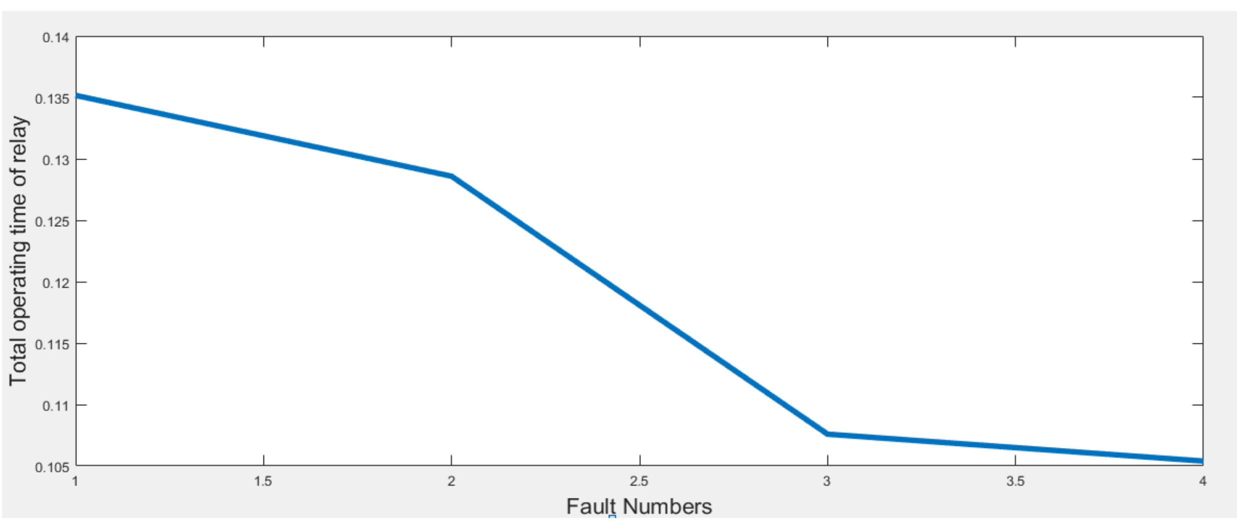

Figure 4.7: Convergence graph of teach learning based optimization algorithm.

4.2 Total Operating Time of Relay Using PSO algorithm

Table 4.5 Operating time of relay using PSO algorithm.

	Operating Time of Relay(sec) by PSO			
	Primary Protection system			Secondary Protection system
Fault	TOTR3	TOTR4	TOTR5	TOTR1
Fault At Feeder 1	0.1192	0.1948	0.1963	0.1984
Fault At Feeder 2	0.1505	0.1106	0.1766	0.1784
Fault At Feeder 3	0.1628	0.1612	0.1110	0.1673
Fault At Feeder 15kv side	0.1719	0.1139	0.1096	0.1064
Min (TOTR)	**0.1192**	**0.1106**	**0.1110**	**0.1064**

Fault occures at each feeder the minimum total operating time of relay the operating time is respectively, at feeder 1 the total operating time of relay three (TOTR3) is 0.1192sec , at feeder 2 the total operating time relay four (TOTR4) is 0.1106 sec, at feeder 3 the total operating time of relay five (TOTR5) is 0.1110 sec and at feeder 15 KV side the tota operating time of relay one (TOTR1) is 0.106 4sec.Finaly, properly decreses operating time from primary protection system relay(TOTR345) to secandary protection system relay (TOTR1) based on particular swarm optimization algorithm.

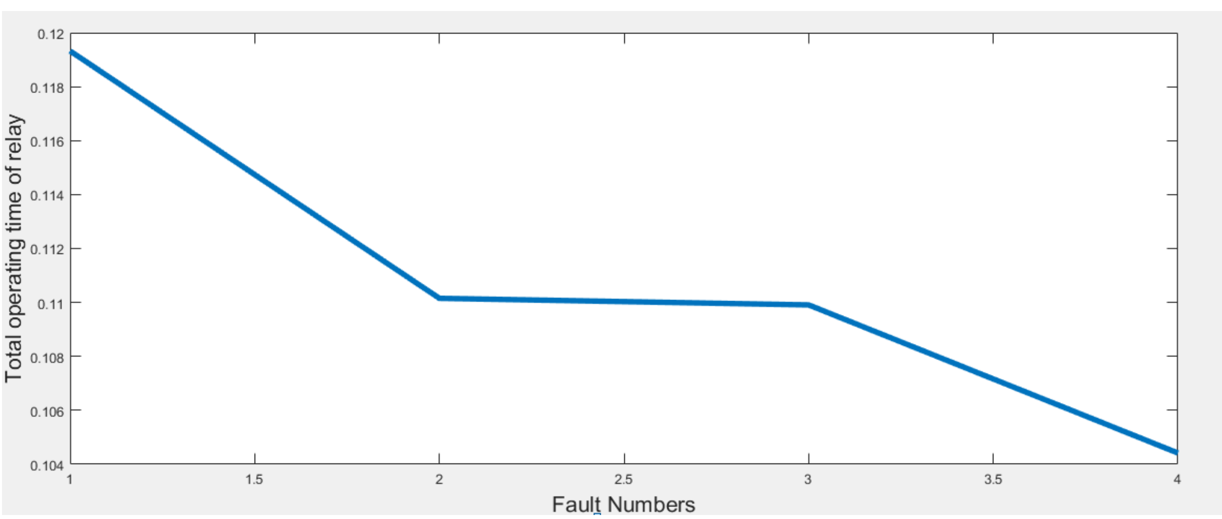

Figure 4.8: Convergence graph of particular swarm optimization algorithm.

When comparing the above two graph minimizing total operating time of relay primary protection system to secondary protection system at the TLBO case is 0.1238 sec to 0.1054 sec and PSO case is 0.1136 sec to 0.1054sec respectively. Therefore TLBO graph is the better minimizing total operating time of relay than PSO graph.

4.4.3 Comparison of Existing system, PSO and TLBO Operating Time of Relay

Table 4.6: Comparison of Normal, PSO and TLBO operating time of relay.

	Before optimization (at Existing case) total operating Time of Relay by sec				After optimization (at PSO case) total operating Time of Relay by sec			
	Primary Protection System			Secondary Protection System	Primary Protection System			Secondary Protection System
Fault	TOTR 3	TOTR 4	TOTR 5	TOTR 1	TOTR 3	TOTR 5	TOTR 4	TOTR 1
Fault At Feeder 1	1.764	1.781	1.814	1.864	0.119	0.1948	0.1963	0.1984
Fault At Feeder 2	1.517	1.5	1.55	1.6	0.150	0.1106	0.1766	0.1784
Fault At Feeder 3	1.373	1.34	1.323	1.423	0.162	0.1612	0.1110	0.1673
Fault At 15kv side	0.222	0.188	0.172	0.272	0.172	0.1139	0.1096	0.1064
Total sum	4.876	4.809	4.859	5.159	0.604	0.5867	0.5935	0.6505
Average	1.219	1.202	1.215	1.2898	0.151	0.1467	0.1484	0.1623

After optimization (at TLBOA case) total operating Time of Relay by sec				
Primary Protection System				Secondary Protection System
Fault	TOTR3	TOTR4	TOTR5	TOTR1
Fault At Feeder 1	0.1352	0.1370	0.1385	0.1497
Fault At Feeder 2	0.1354	0.1286	0.1557	0.1567
Fault At Feeder3	0.1363	0.1346	0.1076	0.1390
Fault At 15 KV side	0.1373	0.1292	0.1234	0.1054
Total Sum	0.5442	0.5294	0.5252	0.5508
Average	0.13605	0.13235	0.1313	0.1377

When the total sum average of total operating time of rely (TOTR345) in the primary protection system operating time before optimization (at the Existing case) is 1.212 sec, after optimization (at the PSO case is 0.14872 sec and at the TLBO case is 0.13323sec) respectively.

The total operating time of relay (TOTR1) in the secondary protection system operating time before optimization (at Existing case) is 1.28975 sec, after optimization (at the PSO case is 0.16525 sec, and at the TLBO case is 0.1377sec) respectively.

After, the total operating time of relay is compare before and after optimization in the primary protection system and secondary protection system for improving operating time.

After optimization minimizing total operating time of relay in the primary and secondary protection system by PSO case is 87.7%, 87.39% and TLBO case is 89%, 89.3% respectively.

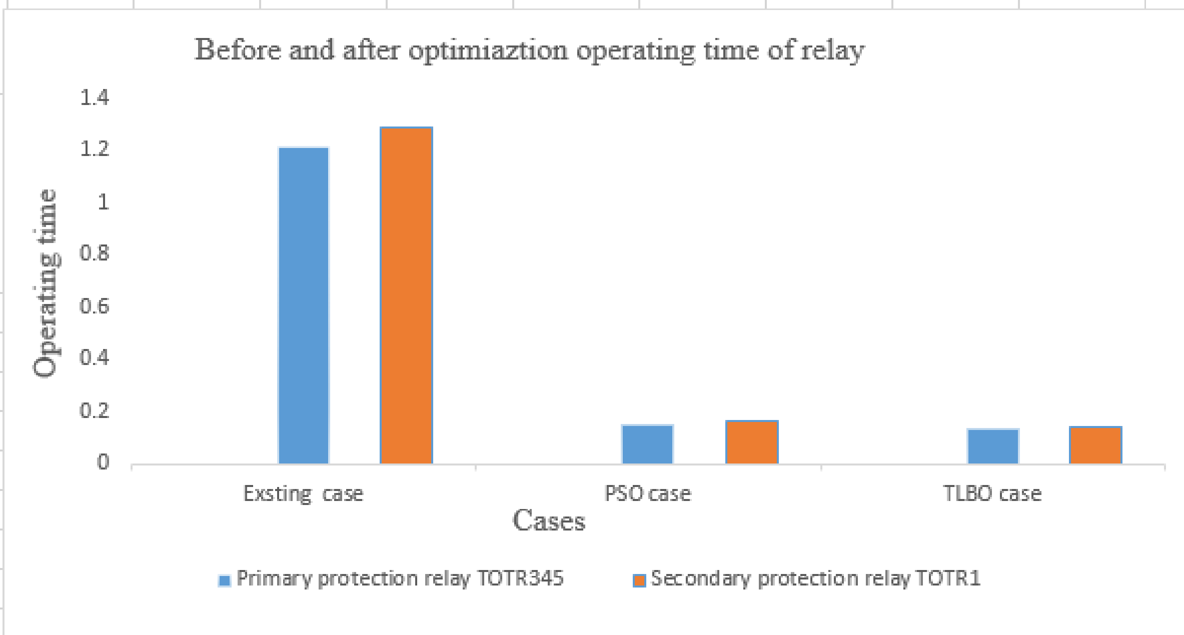

Figure 4.9: Before and after optimization operating time of relay

4.5 Selection of protective devices coordination

They are two types of selection of protective device coordination these are before selection of protective devices coordination and after selection of protective devices coordination. After proper selection rating of protective device in the power protection system to remove unnecessary power loss an affected load. The branch loss summary reports of below table model is found above figure 4.1.

Before selection of protective device coordination in the dilla power distribution system real power loss and reactive power loss 1371.6 and 1356.2 are respectively. Similarly, after proper selection of protective device coordination in the dilla power distribution system real power loss and reactive power loss 693.1 and 691.1 are respectively. In this way Table 4.8: after selection of protective device coordination better improvement of total real power loss in dilla power distribution system. After, proper selection of protective device coordination improvement of total real power loss is 49.5%.

Table 4.7: Before selection of protective devices coordination analysis power loss.

Branch Losses Summary Report

CKT / Branch	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop
ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
Line1	0.103	1.299	-0.007	-0.540	95.3	759.5	98.8	40.8	57.99
Line2	0.364	2.502	-0.029	-2.146	334.2	356.3	98.8	83.8	15.02
Line3	0.475	1.128	-0.009	-0.629	466.5	499.3	98.8	47.9	50.85
Line4	1.968	0.078	-1.545	-0.101	423.2	-23.4	99.3	77.9	21.42
Line5	0.522	-0.017	-0.519	-0.016	2.5	-32.5	99.3	98.9	0.47
T1	0.007	0.540	-0.005	-0.510	2.8	29.4	40.8	38.6	2.22
T2	0.029	2.146	-0.018	-2.020	11.1	126.1	83.8	78.8	4.93
Line out one	0.000	-0.426	0.000	0.000	0.0	-425.6	100.0	100.0	0.00
Line out two	0.000	-0.171	0.000	0.000	0.0	-171.4	100.0	100.0	0.00
T5	0.519	0.016	-0.514	0.000	5.1	15.9	98.9	97.8	1.02
T4	1.545	0.101	-1.531	0.000	14.3	101.3	77.9	77.0	0.88
T3	0.009	0.629	-0.005	-0.591	3.3	37.3	47.9	45.1	2.85
MAIN TRAFO	3.445	5.075	-0.941	-4.929	13.4	84.1	100.0	98.8	1.22
MAIN TRAFO	0.000	0.000	-2.490	-0.061			100.0	99.3	0.67
					1371.6	1356.2			

Table .4.8: After properly selection of protective device coordination analysis power loss.

Branch Losses Summary Report

CKT / Branch	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop
ID	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
Line1	0.057	2.961	-0.039	-2.812	18.6	149.0	98.1	93.1	4.95
Line2	0.055	2.925	-0.040	-2.909	15.1	16.1	98.1	97.5	0.55
Line3	0.363	2.009	-0.022	-1.621	340.4	388.0	98.1	76.9	21.12
Line4	2.239	0.125	-2.012	-0.132	227.2	-7.0	99.0	88.9	10.07
Line5	0.520	0.009	-0.519	-0.016	0.5	-6.9	99.0	98.9	0.11
T1	0.039	2.812	-0.024	-2.658	14.4	153.2	93.1	88.0	5.08
T2	0.040	2.909	-0.025	-2.738	15.0	170.9	97.5	91.8	5.74
Line out one	0.000	-0.426	0.000	0.000	0.0	-425.6	100.0	100.0	0.00
Line out two	0.000	-0.171	0.000	0.000	0.0	-171.4	100.0	100.0	0.00
T5	0.519	0.016	-0.514	0.000	5.1	15.9	98.9	97.8	1.02
T4	2.012	0.132	-1.993	0.000	18.6	131.8	88.9	87.9	1.01
T3	0.022	1.621	-0.014	-1.524	8.4	96.2	76.9	72.4	4.57
MAIN TRAFO	3.263	8.208	-0.475	-7.894	29.8	180.7	100.0	98.1	1.93
MAIN TRAFO	0.000	0.000	-2.759	-0.134			100.0	99.0	1.03
					693.1	691.1			

Table 4.9: Before and after selection of protective device comparison power loss.

selection rating of protective device	Real power loss by KW	Reactive power loss by KVAR
Before selection of protective devices coordination	1371.6	1356.2
After properly selection of protective devices coordination	693.1	691.1

The total energy loss before and after selection of protective device coordination in a year.

- Before selection of protective device coordination total power loss = 1371.6 KW.

Before selection of protective device coordination energy loss for one year= 365 X 1371.6 X 24h = 12,015,216KWh

- After properly selection of protective devices coordination total power loss = 693.1 KW

After properly selection of protective device coordination total energy loss for one year =365 X 693.1 X 24h = 6,071,556KWh

4.6 Feasibility Analysis

After properly selection of protective devices coordination total energy can be saved for one year is =6,071,556 KWh.

- By using current average electric sale bill of EEU it can be converting in ETB.
- Average electric sale bill = 0.54 cent per KWh
- Hence, 6,071,556,X 0.54 = 3,278,640.24 ETB = $81,761.6 per year

Table 4.10: Fuse specification15kv side and 33KV side

	Total no of fuse	Total price of fuse
15 KV side	$20 X 120	$2400
33 KV side	89*$57	$5,073
Total price fuse by 15 KV side and by 33 KV side		$7473

Table 4.11: Breaker specification 15kv side and 33KV side.

15 KV side	Single phase breaker used customers 4100	Price of Single phase breaker $2.4 price/piece 10 piece min order	Three phase breaker used customers 900	Price of three phase breaker $10 price/piece 1piece min order
Total no of price		4100$ X 2.4=$9,840		$10 X 900=$9,000
33 KV side	Single phase breaker used customers 5000	Price of Single phase breaker $2.4price/piece 10 piece min order	Three phase breaker used customers 1000	Price of three phase breaker $10price/piece 1piece min order
Total no of price	5000	5000 X $ 2.4=$12,000	1000	$10X1000=$10,000

Total no of price breaker by 15 KV side and by 33KV side is $40,840

Total price fuse and circuit breaker =$40,840+$7473=$48,313

Assuming that the installation costs are 10% and annual maintenance costs are 2%.

- 10% of $81,761.6=$8,176.16
- 2% of $81,761.6=$1,635.23
- Total investment cost = $48,813 +$8,176.16+ $1,635.23=$58624.4
- Difference(saved cost) $81,761.6- $58624.4=927,801.72ETB
- Back payment of cost with selective coordination by year Energy tariff in dilla distribution system
- Year of back payment = $\frac{\text{Total cost gained power loss}}{\text{Total investment cost}} = \frac{3{,}278{,}640.24\ \text{ETB}}{2{,}350{,}838.1\text{ETB}}$ =1.39
- Year of back payment = 1 Year,4Months and 20 Days

Chapter 5

Conclusions, Recommendations and Future Work

5.1 Conclusions

In a power system, power protection using protective devices is the most critical aspects to clear a short circuit or any electrical fault, so that system components are not damaged and as little of the system is taken down ensuring that the power system operate reliably and safely . In order to provide adequate protection for the circuit, load flow and fault analysis was conducted to determine the magnitude of the currents that flow during faults and comparing calculated values against the equipment ratings to ensure that the power system was safely protected. So the expected short-circuit currents were known and protection coordination study was performed to determine the optimum characteristics, ratings, and settings of the power system protective devices.

The goal of this thesis is to model the dilla power distribution system and analyse the existing power distribution protection coordination and determine optimum protective device coordination to achieve optimum equipment protection and selectivity. This time sequenced operation of a protection coordination study was done to determine the trip settings of each protective device in the power system so that maximum protection with very small area interruption for unsymmetrical faults that may happen in the system. In this work overcurrent protective devices coordination in the primary and secondary protection system was properly set and selected as a result, isolate faulty portion of the system from healthy portion selectively. The problem formulation and different types of constraint are used to coordinate protective device in power protection system. The purpose of this problem formulation is minimizing the total operating time of relay in the primary and secondary protections system using a teaching learning-based optimization algorithm and particle swarm optimization algorithm. For minimizing the total operating time of relay in the protection system more concentrated 15 KV bus side because a summary reports of ETAP result indicates high interruption power and more time delay happen in this side.

This papers focus minimizing total operating time of relay in the primary and secondary protection system for Dilla power distribution system using before optimization and compares result with after optimization. Before optimization, the total operating time of the relay in the primary and secondary protection system has been determined using Electrical Transient Analyzer Program (ETAP). Then after optimization, the total operating time of the relay in primary and secondary protection system has been determined using Teach Learning Based Optimization (TLBO) algorithm and Particle Swarm Optimization (PSO) algorithm.

Before optimization (at Existing case) the total operating time of relay in the primary and secondary protection system operating time are 1.212 sec and 1.28975 sec respectively.

After optimization the total operating time of relay in the primary and secondary protection system operating time at TLBO case are 0.13323sec and 0.1377 sec respectively. Similarly, the total operating time of relay in the primary and secondary protection system at PSO case are 0.14872 sec and 0.16525 sec respectively.

Then after optimization has been minimized the total operating time of relay in the primary and secondary protection system by TLBO has been found to be 89% and 89.3%, respectively. Similarly, has been minimized the total operating time of relay in the primary and secondary protection system by PSO case are 87.7% and 87.39% respectively. For in this case teaching learning-based optimization algorithms gives a better result in terms of the total operating time of relay and reliable coordination margin.

After, proper coordinated protective devices for the Dilla power distribution system, fault occurs at any feeder primary protection is failing secondary protection system is a trip fault properly.

The proper setting and selection of rating protective device for the Dilla power distribution system reduces total real power loss and cost. Finally, properly setting and selecting the rating protective devices for the Dilla power distribution system, total power loss is improved by 49.5%

5.2 Recommendations

Based on the results of this thesis, the following suggestions were advised for the concerned bodies:-

Before, coordinating protective devices in the power protection system to study load flow and fault analysis.

To replace the currently installed inverse definite minimum time settings with the new optimal settings for overcurrent relays at the Dilla power distribution system.

To use the newest ETAP software version. It achieves numerical calculations with great speed, automatically applies electrical power company accepted standards, and provides easy-to-follow output reports with others.

To recalculate all the spare feeders normal current before they are connected to any load.

5.3 Future Work

Future works may deal with deeper analysis of Protection coordination of protective device with distributed generation using TLBO algorithm. The radial distribution networks are designed for unidirectional power flows and are passive in nature. However, with the penetration of Distributed Generation (DG), the power flow becomes bidirectional and the network becomes active. The integration of DGs into distribution network creates many issues with this issues solved for proper placement and size Distributed Generation connected and by using directional over current relay. During this time better minimizing the total operating time of relay and power loss in the power distribution system.

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Appendix. A system input data for 2012

A.1 Input data

Feeder name	Feeder line	Line length in kilo matters	Conductor type &size	Voltage level
Dilla Kutre ande	Line 1	6	AAC 50mm^2	15KV
Dilla Kutre hullat	Line 2	5	AAC 50mm^2	15KV
Yirgachafe	Line 3	38	AAC 50mm^2	15KV
Solomo	Line 4	70	AAC 50mm^2	33KV
Gollcha	Line 5	27	AAC 50mm^2	33KV

A.2 Line Data

Line data	R	X	Z	Ro	Xo	B	Bo
	0.6961	0.5179	0.867	1.0875	1.4741	3.8259	1.8702

A.3 Transformer Rating

	Transformer type	Transformer Rating	Impedance value	No of transformer
Feeder name	Main Transformer	25 MVA	12%	1
Feeder 1	Distribution Transformer	4MVA	4.75%	50
Feeder 2	Distribution Transformer	3.5MVA	6%	42
Feeder 3	Distribution Transformer	3.1 MVA	8%	28
Feeder 4	Distribution Transformer	2.8 MVA	4.75%	55
Feeder 5	Distribution Transformer	1.2MVA	3.5%	34

A.4 Fuse specification

15 kv side	Total number of fuse	120
33 kv side	Total number of fuse	89

A.5 Peak load, Frequency and Duration of Interruption

Peak load, Frequency and duration of interruption									
Month	September 2012			October 2012			November 2012		
Feeder no	Total frequency of interruption no	Peak load mw	Total duration of interruption no	Total frequency of interruption no	Peak load mw	Total duration of interruption no	Peak load mw	Total duration of interruption no	
Feeder 1	28	2.5	35.64	68	2.6	73.99	2.6	149.8	
Feeder 2	22	3.13	27.38	37	2.91	42.82	2.91	127.4	
Feeder 3	47	2.18	63.28	48	2.28	118.42	2.28	186.8	
Feeder 4	45	1.09	113.46	83	1.09	205.4	1.09	356.1	
Feeder 5	14.05	1.09	71.57	21	1.09	153.11	1.09	389.8	

Month	December 2012			January 2012			February 2012	
Feeder no	Total frequency interruption	Peak load mw	Total duration Interruption	Total frequency interruption	Peak load mw	Total duration interruption	Peak load mw	Total duration of interruption no
Feeder 1	31	2.9	54.09	31	2.9	54.09	3.26	54
Feeder 2	23	3.3	28.88	23	3.3	28.88	3.5	54.48
Feeder 3	42	2.5	76.75	42	2.5	76.75	3	114
Feeder 4	56	1.09	81.59	56	1.09	81.59	1.33	165.05
Feeder 5	18	1.09	105.53	18		105.53	22	243.11

Peak load, Frequency and duration of interruption

Month	MARCH 2012			APRIL 2012			MAY 2012	
Feeder no	Total frequency of interruption no	Peak load mw	Total duration of interruption no	Total frequency of interruption no	Peak load mw	Total duration of interruption no	Peak load mw	Total duration of interruption no
Feeder 1	43	3.3	54.63	44	3	124	2.5	52
Feeder 2	45	4.08	80.96	57	4.2	94.69	4.04	9.23
Feeder 3	72	3.1	183.49	73	3.1	196.83	2.44	40.16
Feeder 4	63	1.3	209.7	67	1.4	216.94	2	31.28
Feeder 5	24		210.1	33		245.6	2.1	45.16

Month	JUNE 2012			JULY 2012			AUGUST 2012	
Feeder no	Total frequency of interruption no	Peak load mw	Total duration of interruption no	Total frequency of interruption no	Peak load mw	Total duration of interruption no	Peak load mw	Total duration of interruption no
Feeder 1	39	3.1	47.95	27.3	3.4	45.4	5.95	37.6
Feeder 2	35	3.7	50.47	29.5	0.8	25.3	5.06	40.6
Feeder 3	56	2.5	107.76	20.6	1.2	68.9	2.06	40.2
Feeder 4	49	1.2	115.47	44.4	2.36	33.2	4.8	78.4
Feeder 5	17		135.84	78	1.1	40.8	1.5	17.2

A.6 Current transformer ratio

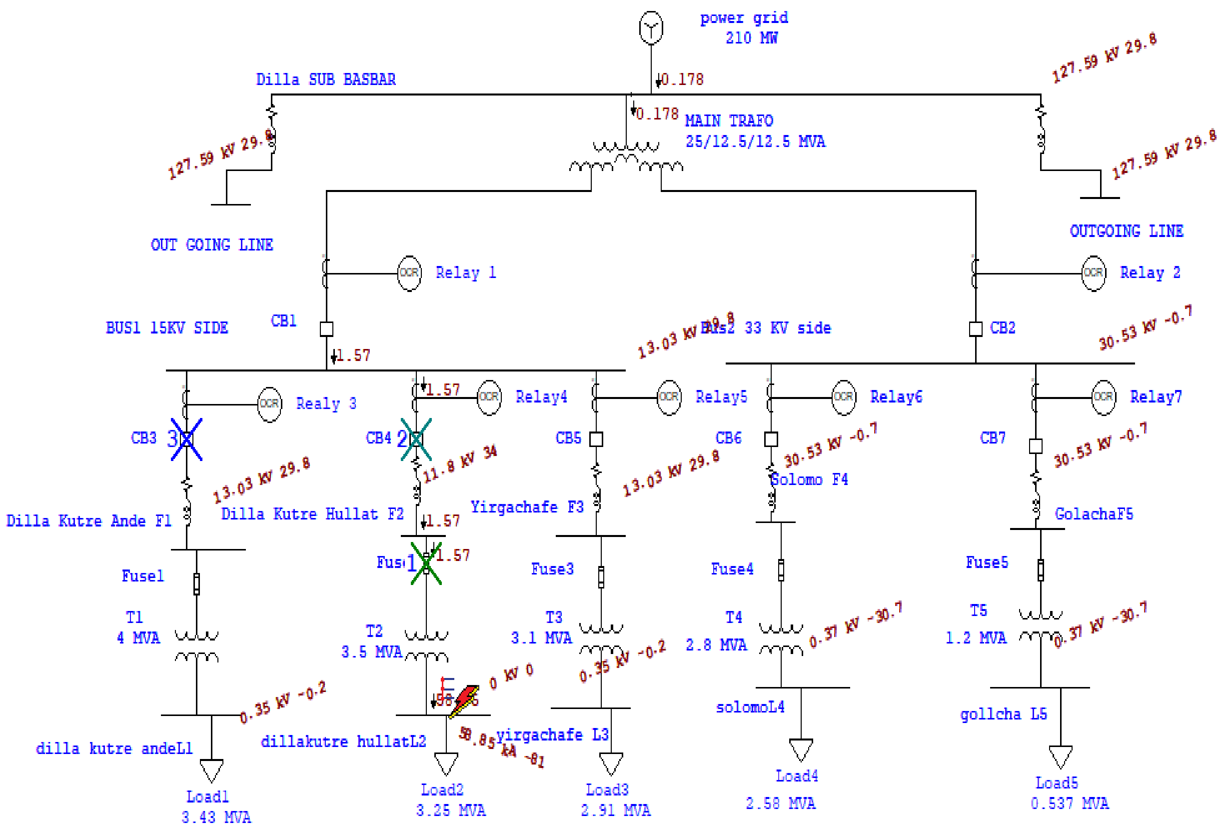
Feeder Name	Feeder1	Feeder2	Feeder3	Feeder 15kv side	Feeder4	Feeder5	Feeder 33kv side
CT ratio	300:1	300:1	300:1	500:1	150:1	150:1	300:1

A.7 Types of circuit breaker and numbers of customer used

Types of circuit breaker	Number of customer used 15 kv side	Number of customer used 33 kv side
Single phase circuit breaker	4100	900
Three phase circuit breaker	5000	10000

Appendix.B Analysis fault for coordinating protective device

B.1Fault dilla Kutre hullat at load Bus 2 Primary Protection



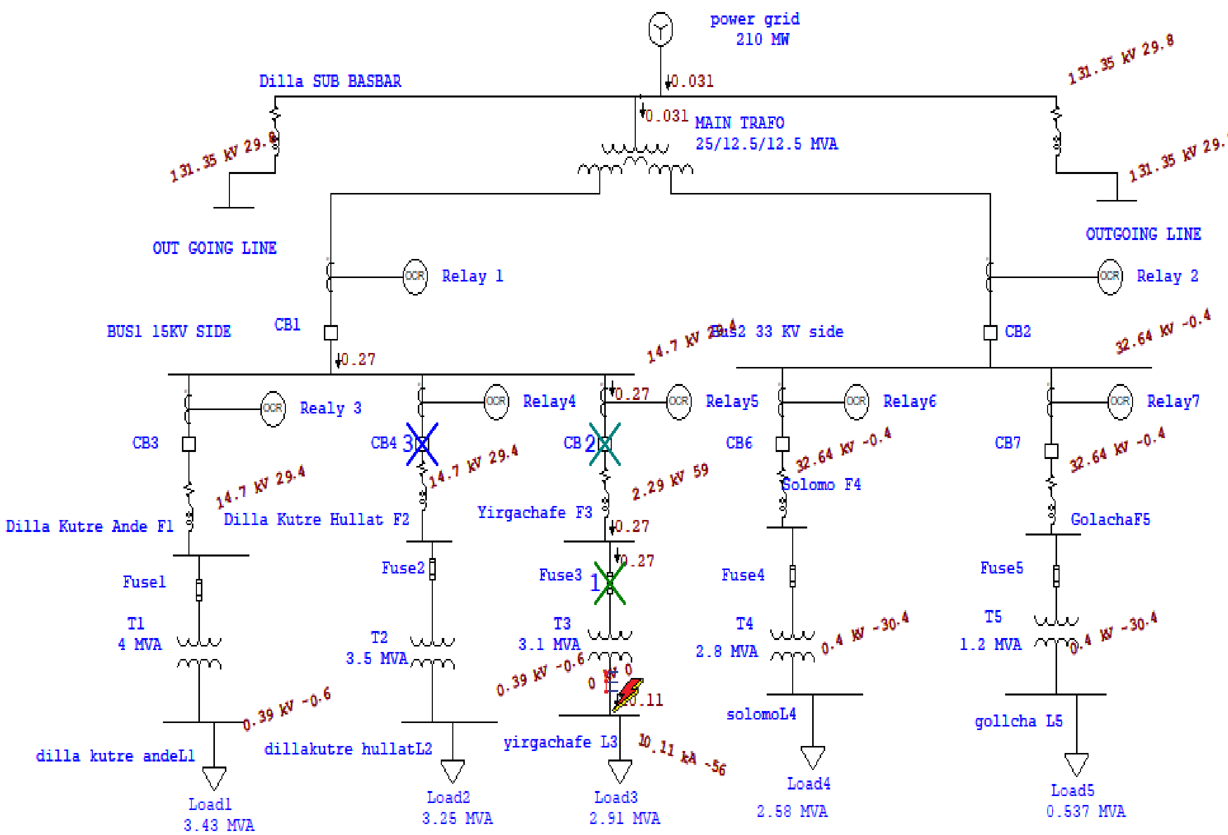
B1.1 Time sequence operation of protective device dilla Kutre hullat

Sequence-of-Operation Event Summary Report

Fault at dilla Kutre hullatL2.

Time	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
13.6	Fuse2	1.569	<10.0	<13.6	
1467	Relay4	1.459	1467		Phase - OC1 - 51
1500	CB4		33.3		Tripped by Relay4 Phase - OC1 - 51
1517	CB3		50.0		Tripped by Relay3 Phase - OC1 - 51
1550	CB5		83.3		Tripped by Relay5Phase - OC1 - 51
1600	CB1		133		Tripped by Relay1 Phase - OC1 - 51

B.2Fault yirgachafe at load Bus 3 Primary Protection



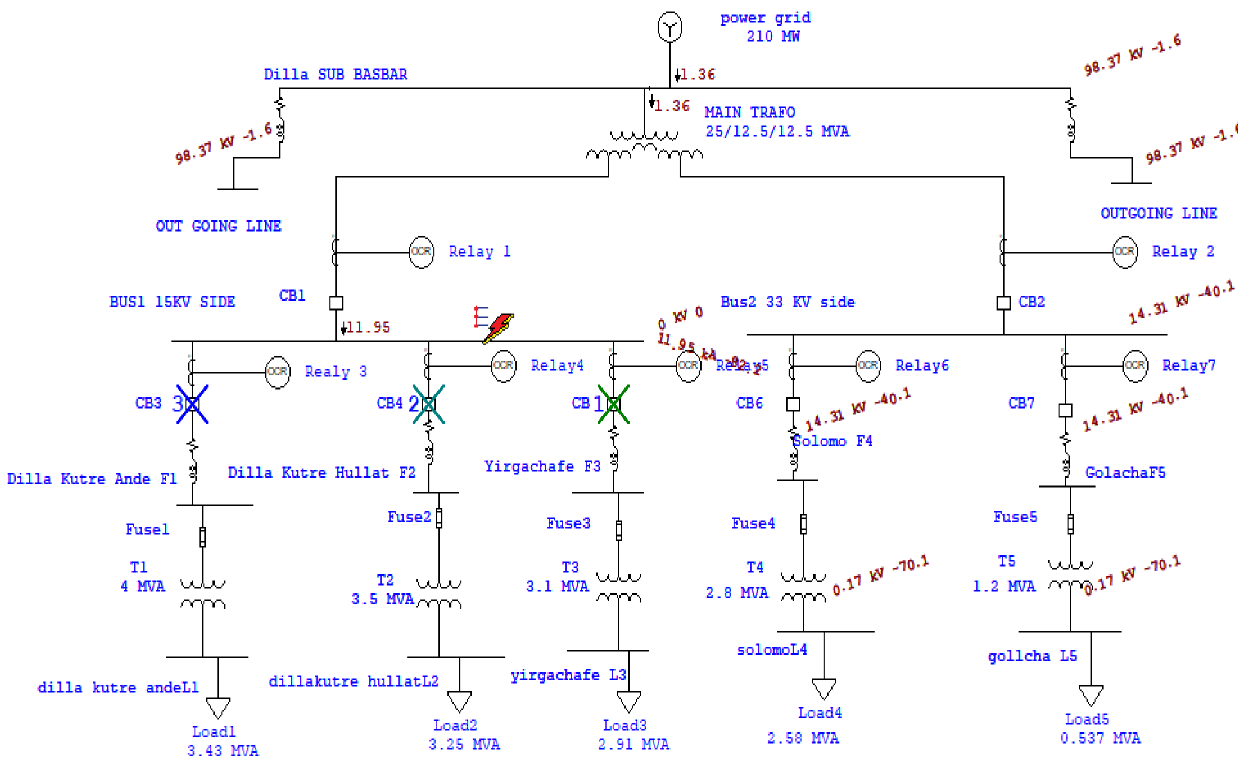
B.2.1Time sequence operation of protective device yirgachafe load bus3

Sequence-of-Operation Event Summary Report

Fault at yirgachafe L3.

Time	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
24.0	Fuse3	0.270	<10.0	24.0	
1290	Relay5	0.210	1290		Phase - OC1 - 51
1323	CB5		33.3		Tripped by Relay5 Phase - OC1 - 51
1340	CB4		50.0		Tripped by Relay4 Phase - OC1 - 51
1373	CB3		83.3		Tripped by Relay3 Phase - OC1 - 51
1423	CB1		133		Tripped by Relay1 Phase - OC1 - 51

B3. Fault at 15 kV side bus Primary Protection



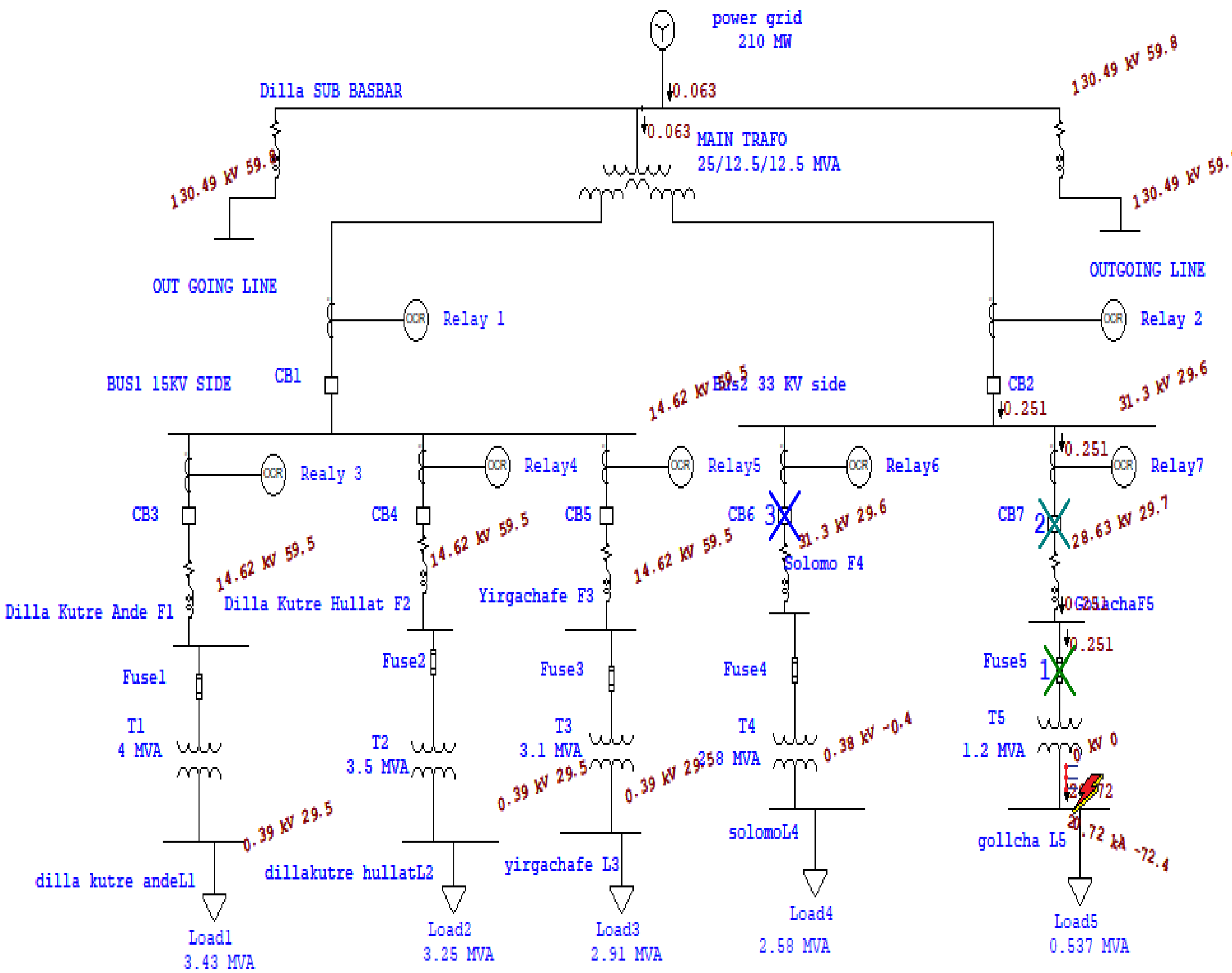
B.3.1 Time sequence operation of protective device bus 15 kV side

Sequence-of-Operation Event Summary Report

Symmetrical 3-Phase Fault at BUS1 15KV SIDE.

Time	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
138	Relay 1	11.951	138		Phase - OC1 - 51
172	CB5		33.3		Tripped by Relay 5 Phase - OC1 - 51
188	CB4		50.0		Tripped by Relay 4 Phase - OC1 - 51
222	CB3		83.3		Tripped by Relay 3 Phase - OC1 - 51
272	CB1		133		Tripped by Relay 1 Phase - OC1 - 51

B4.Fault Gollcha at load Bus 5 Primary Protection



Sequence of Operation Event Summary Report

Fault at Gollcha load bus four.

Time	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
13.6	Fuse5	0.251	<10.0	<13.6	
909	Relay7	0.19	909		Phase - OC1 - 51
942	CB7		33.3		Tripped by Relay 7 Phase - OC1 - 51
959	CB6		50.0		Tripped by Relay 6 Phase - OC1 - 51
992	CB2		83.3		Tripped by Relay 2 Phase - OC1 - 51

Appendix. C programing optimization algorithm

Appendix .C.1 Programing for Teach Learning based optimization algorithm

```
Format short
 Clear
  clc
Phase 1: input parameters
m=4; % number of faults at each feeder
lb= [0.1 0.1 0.1 0.1]; %lower bounded variables
ub= [0.2 0.2 0.2 0.2]; %upper bounded variables
maxiter= 50; %max number of iteration
n=4; %Number of Relay
PSmin=0.12; %minimum PS value for operating time of relay
PSmax=0.18; %maximum PS value for operating time of relay
TMS min=0.1; %minimum TMS value for operating time of relay
TMS max=0.15; %maximum TMS value for operating time of relay
Phase 2: Defining the objective function
function [x1,x2,x3,x4,t1,t2,t3,t4,fx ]=  fun(x)
I fault= [7385 6531 5599 19515];
x1= 0.2-(0.14.*TMS1)/ ((I fault (1)/ (PSM5.*300)). ^0.02-1);
x2= 0.2-(0.14.*TMS2)/((I fault (2)/ (PSM6.*300)). ^0.02-1);
x3= 0.2-(0.14.*TMS3)/((I fault (3)/ (PSM7.*300)). ^0.02-1);
x4= 0.2-(0.14.*TMS4)/ ((I fault (4)/ (PSM8.*500)). ^0.02-1);
t1=x (: 1);
t2=x (: 2);
t3=x (: 3);
t4= x (:4);
fx=(0.14.*TMS1)/((Ifault(1)/(PSM5.*300)).^0.021)+(0.14.*TMS2)/((Ifault(2)/(PSM6.*300)).
^0.021).+(0.14.*TMS3)/((Ifault(3)/(PSM7.*300)).^0.021).+(0.14.*TMS4)/((Ifault(4)/(PSM8.
*500)).^0.02-1);
```

```
end
phase3: Generate Initialize Number of Relay
for i=1: n
for j=1: m
pos(i,j)=lb(:,j)+rand.*(ub(:,j)-lb(:,j));%  position of total operating time of relay
end
end
TOTR=pos;
% Teaching Learning Based Optimization Algorithm Main Loop Start
%Phase 4 compute xbest & mean
fx= fun (pos);
[fnavl, fxind]= min (fx);
xbest=pos (fxind, :); %compute xbest
Mean=mean (pos); %compute mean
Tf=round (1+rand); %compute Teaching factor between 1 and 2
% phase 5: Teacher and learner phase
%Teacher Phase fx
Xnew= pos (i, :) + rand.*(xbest-Tf.*Mean); %new function of operating time of relay
%Check the Bounds
for j =1: m
    if Xnew (j) > ub (j)
    Xnew (j) = ub (j);
    else if Xnew (j) < lb (j)
    Xnew (j) = ub (j);
 end
 end
%%% Perform Greedy Selection
fnew= fun (Xnew);
if fnew <fx (: i)
```

```
Pos (i, :) =Xnew;
fx (: i) =fnew;
end
%%%Learner Phase
%%% select partner
Pa =1: n;
Pa =1: maxiter;
Partner=pa (randi (length (pa)));
%%%% Generate New Solution
Xp=pos (partner, :);
fp= fun (Xp);
X=pos (i, :);
if fx (: i) <fp
   Xnew= X+rand.*(X-Xp);
else
 Xnew= X-rand.*(X-Xp);
end
%Cheack the Bounds
for j =1: m
   if Xnew (j) > ub (j)
     Xnew (j) = ub (j);
     else if Xnew (j) < lb (j)
     Xnew (j) = ub (j);
 end
 end
%%% Perform Greedy Selection
fnew= fun (Xnew);
if fnew <fx (: i)
Pos (i, :) =Xnew;
```

```
fx (: i) =fnew;
end
%%Memorize the Best
[Opt Val, Optind]=min (TOTR); %minimum value of operating time of relay
Bestfx (: maxiter) =opt Val;
bestx (optind, :) =TOTR (optind, :); %optimal solution operating time of relay
%termination of iteration
%plot the result
Plot (min (TOTR))
Xlabel ('Fault Numbers');
Ylabel ('Total Operating Time of Relay');
```

Appendix .C2 Programing for Particle swarm optimization algorithm

```
 format short
clear
clc
%phase 1: input parameters
lb= [0.1 0.1 0.1 0.1]; %Lower bounded variables
ub= [0.2 0.2 0.2 0.2]; %Upper bounded variables
n=4; %number of relay
m=4; % number of faults at each feeder
Maxiter= 50; %max number of iteration
PSmin=0.12; %minimum PS value for operating time of relay
PSmax=0.18; %maximum PS value for operating time of relay
TMS min=0.1; %minimum TMS value for operating time of relay
TMS max=0.15; %maximum TMS value for operating time of relay
%phase 2: Defining the Objective Function
function [x1,x2,x3,x4,t1,t2,t3,t4,fx ]=  fns(x)
I fault= [7385 6531 5599  19515];
x1= 0.2-(0.14.*TMS1)/ ((I fault (1)/ (PSM5.*300)). ^0.02-1);
```

```
x2= 0.2-(0.14.*TMS2)/((I fault (2)/ (PSM6.*300)). ^0.02-1);
x3= 0.2-(0.14.*TMS3)/((I fault (3)/ (PSM7.*300)). ^0.02-1);
x4= 0.2-(0.14.*TMS4)/ ((I fault (4)/ (PSM8.*500)). ^0.02-1);
t1=x (: 1);
t2=x (: 2);
t3=x (: 3);
t4= x (:4);
fx=(0.14.*TMS1)/((Ifault(1)/(PSM5.*300)).^0.021)+(0.14.*TMS2)/((Ifault(2)/(PSM6.*300)).
^0.021).+(0.14.*TMS3)/((Ifault(3)/(PSM7.*300)).^0.021).+(0.14.*TMS4)/((Ifault(4)/(PSM8.
*500)).^0.02-1);
end
%phase 3: Initialization of Position and Operating Time of Relay
for i=1: n
for j=1: m
pos(i,j)=lb(:,j)+rand().*(ub(:,j)-lb(:,j));
end
end
TOTR=Pos;
%phase4: Function Evaluation
Iter=1;
Whileiter = maxiter;
   PS=PSmax-(iter/maxiter).*(PSmax-PSmin);
   TMS=TMSmax-(iter/maxiter).*(TMSmax-TMSmin);
 for i=1: n
    TOTR (i, :) =fun (pos (i, :));
 end
 % initial Pbest (initial particular best)
 Pbestval=TOTR;
Pbest=pos;
```

```
 %initial Gbest (initial global best)
 [fxminval, index]=min (TOTR);
 Gbestval=Pbest (index, :);
 % phase 5.compute Pbest and Gbest
 fx=    fns(pos);
 TOTR=fns (fx);
% update Pbest values
index= (TOTR<=Pbestval); %new min pbestval
Pbest (index, :) =fx (index, :); % update pbest position
Pbestval=TOTR (index, :); %update pbestval
%%% update Gbest values
 [fxPbestval, ind1]=min (Pbestval);
if fxPbestval<=fxminval
fxminval=fxPbestval;
 Gbestval =Pbest (index, :);
end
% phase .6. Update operating time of relay and position
for i=1: n
for j=1: m
%update operating time of relay
TOTR(i,j)=ps.*TOTR(i,j)+t1.*rand.*(pbest(i,j)-pos(i,j))+t2.*rand.*(Gbest(i,j)-pos(i,j));
%update position
Pos (i, j) =TOTR (i, j) +pos (i, j);
%Handling boundary constraint
Iter=iter+1;
if pos (i, j) <lb(j)
 Pos (i, j) =lb (j);
else if pos (i, j)>ub (j)
        Pos (i, j) =ub (j);
```

```
end
end
end
%phase 7: store best value
TOTR=Gbestval (index, :); %optimal solution total operating time of relay
[bestfns, index]=min (TOTR); % optimal value (TOTR)
%termination of iteration
%plot the result
Plot (min (TOTR))
Xlabel ('Fault Numbers’)
Ylabel ('Total operating time of relay')
```