ARTIFICIAL NEURAL NETWORK BASED FAULT CURRENT MINIMIZATION IN DISTRIBUTION SYSTEM USING SUPERCONDUCTING FAULT CURRENT LIMITER.

(CASE STUDY: HOSANNA SUBSTATION-DISTRIBUTION SYSTEM)

MASTER OF SCIENCE IN POWER SYSTEM AND ENERGY ENGINEERING

BY

ZENABU DUGUNO WAKERO

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

NOVEMBER,2021

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A THESIS SUBMITTED TO DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES.

HAWASSA UNIVERSITY

HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN POWER SYSTEM AND ENERGY ENGINEERING.

NOVEMBER,2021

Hawassa University

Institute of Technology

Department of Electrical and Computer Engineering

School of Graduate Studies

Advisor's Approval Sheet

This is to certify that the thesis entitled "Artificial Neural Network Based Fault Current Minimization in Distribution System Using Superconducting Fault Current Limiter. (Case Study: Hosanna Substation-Distribution System)" submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Engineering with specialization in Power system and Energy Engineering, the Graduate Program of the Department of Electrical and Computer Engineering, and has been carried out by Zenabu Duguno Wakero ID No. PGPSER/015/10, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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Advisor	Signature	Date
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School of Graduate Studies

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Examiner's Approval Sheet

We the under signed Board of examiners of the final open defense by Zenabu Duguno have read and evaluated his thesis entitled " Artificial Neural Network Based Fault Current Minimization in Distribution System Using Superconducting Fault Current Limiter. (Case Study: Hosanna Substation-Distribution System)” and examined the candidate. This is therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Power System and Energy Engineering.

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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.

Stamp of SGS ....

Declaration

This thesis is my original work and has not been presented for a degree in any other university and that all sources of material used for the thesis have been properly acknowledged.

Name

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Place:

Hawassa University, Hawassa, Ethiopia

Acknowledgement

"First of all, I would like to thank the Almighty of God"

I would like to express my sincere gratitude to my advisor **Dr. Baseem Khan** for his help throughout the thesis including suggesting this interesting idea and guiding me to the end. I also thank my co-advisor **Mr. Mesfin Jarso** for his advice and help. Next to that, I would like to express my sincere gratitude to my department head **Mr. Issaias Gidey** to assist everything to do my thesis work like facilitating laboratory room to need internet accesses. I would like to thank also Hossana substation and utility office workers, for giving and refining the distribution data used in this thesis work.

My deepest appreciation goes to my wife **Netsenet Elias**, for her unforgettable support throughout my education. Finally, I want to thank my friends, Power System and Energy Engineering students for their support and time we had together.

Abstract

High magnitude of short circuit fault current takes place in electric power distribution system. This unexpected high magnitude of short circuit fault current can cause the failure of Hossana substation switchgear equipment's and even if due to this problem most of industries sharing power from Hossana substation and end users of Hossana substation cannot get power properly. So, fault current minimization in distribution system is a critical issue and to minimize the maximum short circuit fault current in distribution system, superconducting fault current limiter (SFCL) device is applicable in this thesis work. By installing superconducting fault current limiter (SFCL) device to the Hossana substation distribution feeder especially for Gimbichu feeder maximum short circuit fault current to be minimized for different types of short circuit faults like, Line to Ground (L-G) fault, Line to Line (L-L) fault, Double line to Ground (LL-G) fault and balanced three phase faults in distribution feeder. Under this thesis work the case study area focus on Hossana Substation - Distribution system feeders especially from the nine of feeders Gimbichu 15KV feeder. The reason why this feeder is selected is because of this feeder *covers long distance approximately 150KM and high system interruption take place frequently. In this thesis work ANN controller is used to control the SFCL device and both ANN controller and SFCL device are modeled in MATLAB/Simulink. After developing SFCL in MATLAB and connect this device to the distribution feeder it is possible check the fault current magnitudes before and after installing SFCL device to the system. Before installing SFCL device to the system the magnitude of short circuit fault current is 20KA to 40KA for L-G fault, L-L fault, LL-G fault and balanced three phase faults in Gimbichu 15 KV feeder. But, after installing SFCL device to the case study area maximum short circuit fault current magnitude become minimized 140A up to 150A for all types of short circuit faults. Finally, the payback period is calculated after installing SFCL device to the 15KV Gimbichu feeder. Therefore, the calculated payback period is 1.14 years i.e., the year of back payment of this thesis work is 1 year,1 month and 21 days.*

Key words: Substation-Distribution, superconducting fault current limiter, artificial neural network, payback period, short circuit fault current

Table of Contents

List of Tables

List of Figures

List of Abbreviation

AC	Alternating Current
AEP	American Electric Power
ANN	Artificial Neural Network
CG	Conjugate Gradient
CRM	Current Reduction Margin
DC	Direct Current
DG	Distributed Generation
EMTP	Electromagnetic Transients Program
FLC	Fuzzy Logic Controller
GD	Gradient Descent
HIF	High impedance fault
HTS	High Temperature Superconductor
IED	Intelligent Electronic Device
IFDC	International File Distribution Cooperative
LIF	Low Impedance Fault
L-L	Line to Line
LL-G	Double Line to Ground
L-G	Line to Ground
MFCL	Matrix Fault Current Limiter
LMA	Levenberg-Marquardt Algorithm
MATLAB	Mathematics Library
MSE	Mean Square Error
MV	Medium Voltage
NM	Newton Method
PSCAD	Power System Computer Aided Design
QNM	Quasi-Newton Method
RSFCL	Resistive Superconducting Fault Current Limiter
SFCL	Superconducting Fault Current Limiter
YBC	Yttrium Barium Copper Oxide

Chapter One

Introduction

1.1 Background of the Study

Due to the increase in the scale of the power system by the interconnection of the distribution feeders to the substation system, high level fault currents might be caused during a contingency. The fault creates a surge of current through the electric power system that can cause serious damage to the substation equipment. Switchgears, such as relay, circuit breaker are deployed within transmission and substations to protect substation equipment's [1],[2]. This problem needs the upgrading such as the modification of substation or replacement of multiple circuit breakers. Conservative protection devices used for the protection of the current switchgear to decrease the fault current like the fuses, air-core reactors, circuit breakers, relays etc. could not limit the excessive increase in fault current [3],[4].

But, superconducting fault current limiter (SFCL) can be another to substitute the aforesaid conventional protective devices as it has the fitness to advance the transient stability of the power system by overturning the level of fault currents in effective method [5],[6]. The Substation-Distribution system is expected as the next generation of power which incorporates the 21st century communication technologies [7].

Until now, there were several research activities discussing the fault current issues of Substation-Distribution system, but the applicability of a SFCL into Substation-Distribution system was not yet [8]. Hence, the main alarm of this thesis work is to solve the problem of growing fault current in Substation-Distribution system by using SFCL knowledge [9]. In this thesis work, a resistive type SFCL model has been settled in Simulink and the effect of the SFCL and its location has been investigated seeing a feeder within a Substation-Distribution system model as one of the typical formations of the substation [10]. The impacts of the SFCL on the Substation-Distribution system as the strategic location of SFCL in a Substation-Distribution system which limits the fault current from all power sources and has no negative effect on the Distribution system has been suggested [11].

1.1.1 Distribution Systems

The electric power systems can be classified into generation plant, generation sub-station, transmission system, sub-transmission and distribution sub-stations. Usually, generation is source to the power transmission system which can be well-defined as the transporter of power from the generating places to the sub-transmission system, at voltage levels of 230 kV or greater. The sub-transmission system then transmits the power at voltage levels between 66 kV to 132 kV to the distribution substation systems. Lastly, the distribution substation system, at voltages below 33 kV, transports electricity to the end user [12]. Figure 1.1 illustrates a typical electric power system.

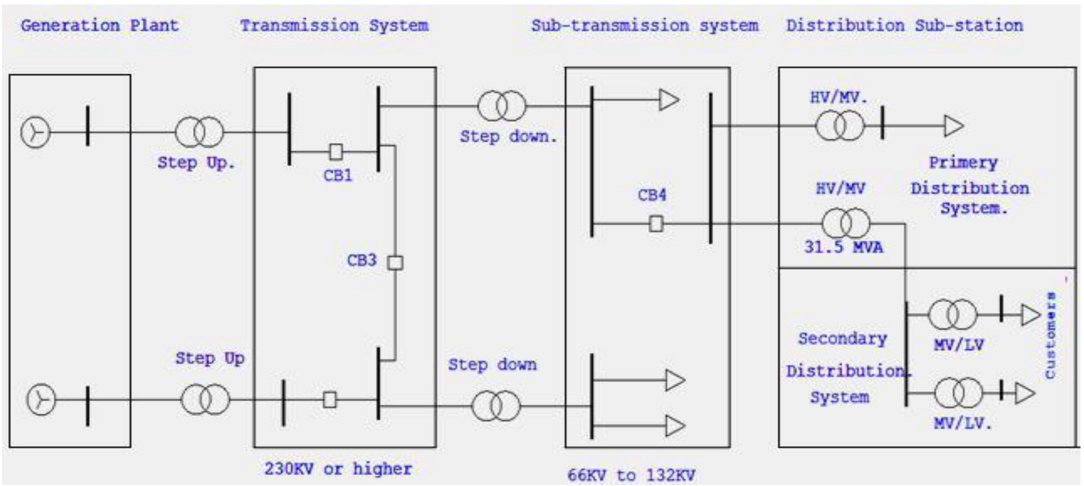


Figure 1.1. Basic power system structure [12]

The power distribution system is classified into primary and secondary systems. The primary distribution system consists of distribution substations and feeders. The distribution substations step down power from the sub-transmission system to between 33 kV and 15 kV. The primary distribution main feeders branch out from the substation and then lateral feeders to serve local areas. From the lateral, distribution transformers step the voltage down again to the secondary level at which most customers are served, generally at 220 V single phase and 380 V three phase.

1.1.2 A typical Configurations of distribution system

The significant characteristic of distribution systems is their arrangement, or how their lines are connected. There are three common configurations of distribution systems: radial, loop and meshed network. These two types of system are arranged in series or parallel or combinations of the two.

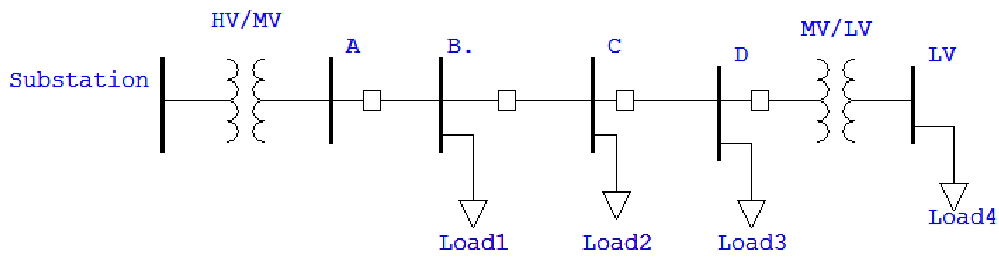


Figure 1.2. Radial Distribution System [13]

Radial configuration of distribution system is the simplest and typical used arrangement for the electric utility company. A radial distribution system consists of a set of components, transformers, lines, protective devices, and buses as shown in Figure 1.2. In this type of system configuration, the distribution feeders leave the substation and passes through all the system area without connection to any other power supply. The simplicity of this type of distribution configuration allows the easy system performance analysis and also the planning issues of related to maintenance, improvement or expansion of the system and it requires the lowest capital cost; however, it also has the lowest reliability, since any faults in the feeders will cause service interruptions at all points downstream.

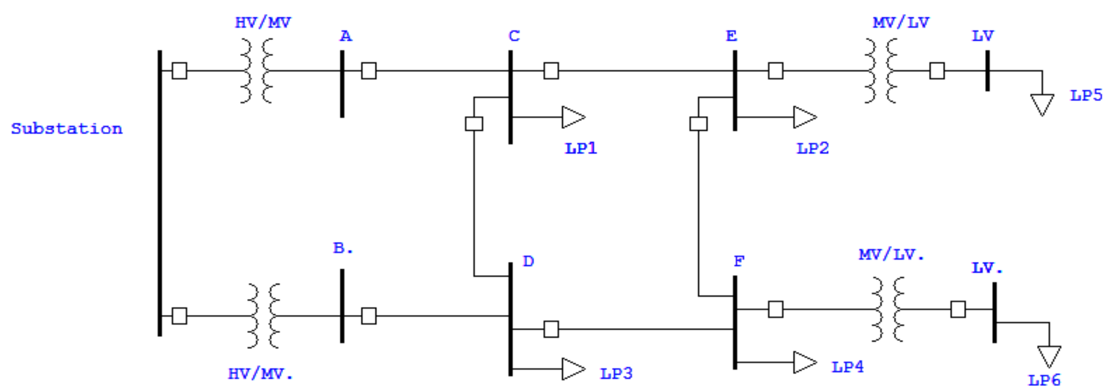


Figure 1.3. Distribution System - Meshed configuration [14]

Meshed distribution system configuration, it is more interconnected meaning that any two points are usually connected by more than one path and some lines form loops within the system. A meshed configuration is generally more reliable because there is exists more than one path for the power to flow, if a line fails. Economically, the cost of a meshed system is the highest because of its numerous feeders with associated protection and control systems.

Figure 1.3 shows a meshed arrangement of a distribution system. Loop shaped distribution systems fall in between the two in terms of cost and reliability. A loop configuration can be described as two radial systems separated by a normally open switch, a failure of one of the two substation transformers the switch can be locked and one unit of the distribution system energized through the other.

Distribution system designing and planning is facing a major modification in model due to deregulation of the power industry, policy changes and advancements in DG technologies. A distribution system design and planning are the key to determine the best expansion strategies to provide reliable and economic services to the customer. In classical planning, the load development typically is met by adding a new substation or advancement the present substation capacity along with their feeders. Today, the rapid advances in DG technology and their numerous benefits have made them an attractive alternative to the distribution companies in their planning tasks [14].

Most of the time in our country high amount of interruption is occur in distribution system rather than transmission system as we can compare the distribution system. In transmission system most of the time the size of conductor is large, the type of the tower is constructed from steel and the height of the tower is as much as higher than the distribution system tower. Due to these facts in Ethiopian electric power transmission line has less fault current interruptions. But in Ethiopian electric distribution system most of the time the size of conductor is less, the tower or pole type is wood type and the height of the tower is short. In Ethiopia most of the time the EEP institute use some techniques to minimize the fault current, like replacing the overhead distribution system by underground distribution system, wood pole type system by concrete pole type, plastic coating the whole distribution system conductors and also installing some fault clearing devices in substation like circuit breaker, fuses, line disconnector and etc.

1.2 Statement of the problem

The electrical power substation-distribution system is the interconnection of different types distribution feeders they can deliver power to different types of industries and load centers. So, during the interconnection of different types of distribution feeders to the substation there is maximum amount of short circuit fault current is flowing to the power system. The reason for high magnitude of short circuit fault current flowing to the system is in case distribution Earth fault, distribution Short Circuit, line breaks due to excessive loading and etc. Due to these problems the Substation-Distribution system can loss power. Due to these problems the load centers cannot get the power and different types of electrical and mechanical equipment's in the Substation-Distribution are not operating properly and damaged. Due to increase the interconnection of different types of distribution network to the substation can increase the possibility of abnormal operation in the systems. There may possibility of sudden change in the impedance of the power system, which lead to increase in magnitude of current, known as fault current. The equipment installed at power substation and at distribution system is very expensive and costly. Due to this problem this expensive substation switchgear equipment's are damaged. To save this expensive equipment from fault current the Superconducting fault current limiter (SFCL) device is required

The best information that I have got from direct visit and the substations' installation drawings, there is no any type of superconducting fault current limiter (SFCL) device is functional to limit short circuit fault current occurring at 33kV, and 15kV distribution feeder in Hossana substation. So, the autotransformer neutral point is connected to the ground solidly. Even though the secondary winding of current transformer (CT) is wound on the neutral wire the transformers, it is for ground fault detection. Therefore, in cause of lack of any short circuit fault current limiting method, there is an opportunity of SC current about the maximum breaking capacity of the related CB, after Wolkite Substation incoming line is energized. Therefore, the circuit breaker may be unable to interrupt this maximum expected SC current in limited cycle. This causes electromechanical stress and heating up of power system main device like transformer, circuit breaker, busbar, isolator and others. The heat decreases the expected life time of each device.

1.3 Objective

1.3.1 General Objective

The overall objective of this thesis is to minimize the fault current in distribution system using optimal placing of SFCL device.

1.3.2 Specific Objectives

- To analyze the magnitude of fault current in Gimbichu feeder without SFCL and with SFCL for L- G fault, L- L fault, LL- G fault and LLL- G fault.
- To develop the ANN controller in MATLAB, to control RSFCL.
- To increase the safety margin of CB of the substation by reducing the maximum fault current.

1.4. Scope of the study

The scope of this thesis work is:

- Cannot design SFCL to the case study area i.e., Gimbichu feeder, but I can be performed only in MATLAB simulation.
- SFCL device is only applicable for Gimbichu 15KV feeder from nine of Hossana substation feeders.
- Find the location of SFCL in Substation-Distribution system in the case study area.

1.5 Contribution of the Research

Fault Current minimization is an important task in power distribution system because most of the substation equipment's are connected to the distribution system. And also, most of the expensive devices i.e., loads are connected to the distribution system feeders. When the fault current is minimized the substation-distribution equipment's are protected from over voltage. Therefore, the contribution of this thesis work for the case study area is when the magnitude of fault current value is minimized by using SFCL most of the substation-distribution system equipment's are protected from different types of equipment distortion.

1.6 Thesis Organization Outline

Chapter 1: Gives an introduction to the power distribution system, statement of problem and an overview of the solution to address the problem as well as the main objective and the specific objectives of the thesis is described. And also, under this chapter the scope of the thesis work and the contribution of the thesis work is described.

Chapter 2: Describes about Literature Review and Overview of Distribution System, different types of faults in distribution system and the main causes of fault in distribution system, other fault current minimization methods and description of artificial neural network. Finally, about different types of ANN, benefits of ANN and different type of learning rules for ANN.

Chapter 3: Discusses the basic modeling and design of the system according to the case study area, collection of data from the case study area, modeling of RSFCL in substation-distribution system and modeling of fault current minimization formulas. And finally modeling of the system in MATLAB/Simulink to show the whole system.

Chapter 4: Discusses distribution network simulation results from MATLAB without superconducting fault current limiter (SFCL) and with superconducting fault current limiter (SFCL) for data generation and artificial neural network training processes are described in detail.

Chapter 5: Describes the conclusion, recommendation and future works of the thesis work.

Chapter Two

Literature Review and Overview of Distribution System

2.1. Literature review

Several works in progress on Superconducting Fault Current Limiter (SFCL). Some of the important literatures, which the investigator has gone through are discussed below.

The optimum resistive value of SFCL for attractive transient stability of a power system more efficiently. The optimum resistive rated value of the SFCL is connected in series with a transmission line in case of short-circuit fault is systematically determined by applying the equal-area criterion based on the power-angle curves. To confirm the effectiveness of the optimum value of the planned SFCL for decreasing the value of fault current, some case studies are carried out by both simulation and experimental tests, mostly including the 220-V/300-A-scale laboratory and 13.2-kV/630-A-scale distribution system hardware tests [15].

The design and performance test of a 10 kV, 200A resistive type SFCL prototype. A series of tests counting short circuit test, recovery test, auto-reclosure test, and LN2 boiling test have been achieved. This single phase SFCL is made from 15 current limiting modules. Some 1-m long Yttrium Barium Copper Oxide (YBCO) covered conductors arranged by Shanghai Jiaotong University are used to shape the current limiting element. Each module has 2 tapes connected in parallel to carry 200 A rated current and 6 tapes connected in series to withstand 700V to 800V voltage drop [16].

The combinations of AC and DC distribution grids are also considered for the efficient connection of renewable power resources. In this case, one of the serious problems due to these combinations is the extreme increase in the fault current because of the existence of DG within the smart grid. In order to protect the smart grid from increasing fault current, a SFCL could be applied, which has negligible power loss and capability to limit initial fault currents effectively. Transient analyses were performed for the worst-case faults with the different SFCL arrangements [17].

The design and expansion of coreless inductive SFCL for MV distribution systems. It is a very nice-looking design which reduces the weight of the device. The primary High Temperature Superconductor (HTS) and secondary HTS windings are magnetically coupled to one another. Copper primary winding connected parallel to the HTS primary winding is magnetically coupled to HTS windings to ensure that in case of lack of cooling or superconductor failure, the protected circuit will not be disrupted. In this paper coreless construction discussed which reduces the weight of the device and the size of the primary copper winding. The primary copper winding is linked parallel to HTS primary winding which gives well coupling with secondary HTS winding. This results in a reduction of the voltage drop on the limiter in nominal conditions when the HTS tape is in the superconducting state [18].

The current issues and commercialization problems of SFCL considering various aspects such as coordination with conventional relay, high voltage and high current issues, performance, cost, size, and life and maintenance issues. The viable method, hybrid superconducting fault current limiters in order to solve the practical problems of conventional superconducting fault current limiters was briefly introduced. Hybrid fault current limiters are the combined devices including superconductors, semiconductors, conventional fuse or circuit breaker and fast switches. The emerging solutions for fault current limiters are hybrid type fault current limiter which has several merits such as low cost, high performance, coordination with conventional systems [19].

Explore the impact of SFCL installed in the transmission system in coordination with the generator distance phase backup protection and the generator capability curve. The function of phase backup protection is to disconnect the generator if a symmetrical or unsymmetrical phase fault outside of the generator zone of protection has not been cleared by other protective devices after the enough time delay has passed. The result of these investigations shows that both the resistive and inductive type SFCL have an adverse effect on this coordination. Such an effect varies according to the fault type, the fault location, and the generator loading. The dynamic simulations have been conducted by using the PSCAD/EMTDC software [20]**.**

Showed feeder locations of power stations, of power station auxiliaries and of local generating unit's places of SFCL in an urban network up to a voltage of 110 kV, lists technical benefits and calculates the economical savings. Depending on the location, SFCL either limit the short-circuit capacity in case of a short circuit or result in a higher short-circuit capacity during normal conditions without increasing the short-circuit capacity during fault conditions. A high short-circuit capacity improves power quality and stability conditions. In this paper a method for the economical evaluation concentrates on the prospective savings by using SFCL [21].

The several applications of SFCL in the power system like limit the fault current, protected interconnector the network and decreases the voltage drop at distribution system. SFCL is expected as a solution for current electric networks. The emerging solutions for fault current limiters are SFCL which has several merits such as low cost, high performance, coordination with conventional systems [22].

Explained the various problems of conventional solution to fault current over duty such as major substation upgrades, splitting existing substation busses or multiple circuit breaker upgrades could be very expensive and require unwanted long outages and result in lower power system reliability. The act of a specific type of limiter, the Matrix Fault Current Limiter (MFCL) is presented. The custom of this device in a exact application in the American Electric Power (AEP) 138 kV transmission grid is also discussed. Here the MFCL is denoted by an HTS element as flexible resistance in parallel with a reactor. Under normal working conditions, the peak of the AC current level of the power transmission network is always under the critical current level of the superconductor, therefore there is really not voltage drop across the device and there are no losses. The device is “invisible” to the grid. When the fault occurs, the fault current level exceeds the critical current level of the superconductor, creating a quench condition [23].

Proposed an evaluation of a superconducting fault current limiter (SFCL) by modular superconducting device combined with a short-circuited transformer with a primary copper winding connected in series to the power line and the secondary part short-circuited by the superconducting device. The assessment tests were made with a likely current up to 2 kA, with the short-circuited transformer of 2.5 kVA, 220 V/660 V connected to a test facility of 100 kVA power capacity. The resistive type SFCL using a linked superconducting device was verified without degradation for a prospective fault current of 1.8 kA, achieving the limiting factor 2.78; the voltage achieved 282 V equivalent to an electric field of 11 V/m. The test performed with the combined SFCL (superconducting device + transformer) using series and toroidal transformers showed current limiting factor of 3.1 and 2 times, respectively [24].

Summary of Review paper's

In most of above literature review papers there is some limitations or research gaps like on some papers the application of SFCL is used for only fixed voltage and current levels. And also, in some papers the researchers used only single phase SFCL in their work. Another researcher uses SFCL only during the integration of distributed generation to the transmission grids. Some researchers use SFCL for the specified voltage levels like medium voltage levels, use only some specific country voltage level standards like American Electric Power for 138KV transmission grids and use the SFCL for the specified limiting factors.

In my thesis work all the above research gaps are mitigated. In my thesis work the type of SFCL is not single phase it is three phase type SFCL. And also, in my thesis work the application of SFCL is not applicable only for medium voltage level but it is applicable for all type of voltage levels i.e., from low voltage to high voltage levels. Generally, in my thesis work the application of SFCL is applicable for different types of power systems. Finally in my thesis work the limiting factor of SFCL is not fixed.

2.2 Overview of Distribution System

The portion of power system which allocates electric power for resident use is known as distribution system. In overall, the distribution system is the electrical system between the substation linked by the Transmission system and the end user's meters. It is generally containing feeders, distributors, and service mains.

i) Feeders

A feeder is a probe which connects the sub-station (or localized generating class) to the area where power is to be distributed. Typically, no tapping's are reserved from the feeder so that current in it remains the same through. The main reflection in the plan of a feeder is the current carrying volume.

ii) Distributor

A distributor is a probe from which tapping's are taken for source to the end users. In Fig. 2.1 AB, BC, CD and DA are called the distributors. The current over a distributor is not uniform because tapping's are taken at several parts along its distance. While constricting a distributor, voltage sag along its distance is the main attention since the legal limit of voltage differences is ± 6% of rated value at the end users' point.

iii) Service mains

A service main is commonly a small cable which links the distributor to the users' point.

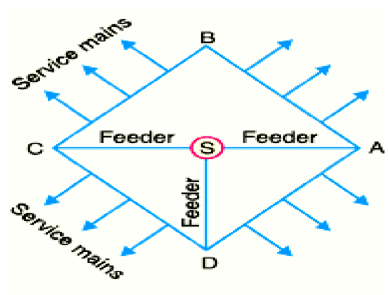


Figure 2.1. The main components of distribution system [25]

2.2.1 Distribution system fault detection and protection

The main objective of protection system is to minimize the duration of fault and to protect power equipment from damage. Distribution systems experience different type of series and shunt faults. The commonly used equipment for detecting and isolating the faulted circuits in a distribution system are fuses, relays, circuit breakers, and current and voltage transformers. Some of protection equipment are described below.

Fuse: is an over current protection device used in power system network. Under normal operating conditions, the heat built up in the fuse element is dissipated to the surrounding air and thus, the fuse remains at a temperature below its melting point. During fault conditions such as a short circuit, the heats become very great and cannot be dissipated fast enough.

Instrument transformers: These transformers are current transformers (CTs) and voltage transformers (VTs) measure the current and voltage in a network and provide low level signals to relays in order to detect abnormal conditions.

Relays: A protective relay is a device capable of detecting changes in the received signal and if the magnitude of the received signal is outside a preset range, it operates to initiate appropriate control action in order to protect the power system.

2.2.2 Classification of Distribution Systems

2.2.2.1 AC Distribution

Now-a-days electrical energy is generated, transmitted and distributed in the system of alternating current. One of significant cause for the common use of alternating current in preference to direct current is the evidence that alternating voltage can be suitably changed in degree by means of a transformer. Transformer has made it probable to conduct A.C power at high voltage and use it at a safe potential. High transmission and distribution voltages have critically decreased the current in the conductors and the resulting line losses. There is no fixed line between transmission and distribution according to voltage or high capacity. However, in overall, the A.C. distribution system is the electrical system between the step-down substation fed by the transmission system and the end users' meters. The A.C. distribution system is classified into:

i. Primary distribution system: It is that portion of A.C. distribution system which works at voltages somewhat greater than general use and holds large blocks of electrical energy than the average low-voltage consumer uses. The voltage consumed for primary distribution based upon the quantity of power to be taken and the distance of the substation required to be fed. The most frequently used primary distribution voltages are 11 kV, 15kV and 33 kV. Due to economic reflections, primary distribution is passed out by 3- phase, 3-wire system.

ii. Secondary distribution system: It is that portion of A.C. distribution system. The secondary distribution services 380/220V,3-phase,4wire system. The primary distribution circuit brings power to numerous substations, called distribution sub-stations. The substations are located near the end users' areas and contain step-down transformers. At each distribution substation, the voltage is stepped down to 380Vand power is transported by 3-phase,4-wire A.C. system. The voltage between any two phases is 380V and between any phase and neutralize 220V.The single-phase local loads are linked between any one phase and the neutral, whereas 3-phase 380V motor loads are coupled across 3- phase lines directly.

2.2.2.2 D.C. Distribution

It is a common fact that electric power is almost completely generated, transmitted and distributed as A.C. However, for certain claims, D.C. supply is absolutely essential. For example, D.C. supply is required for the action of variable speed machinery (D.C. motors), for electro-chemical work and for overfilled areas where storage battery reserves are necessary. For this purpose, A.C. power is changed into D.C. power at the substation by using changing machinery e.g., mercury arc rectifiers, rotary converters and motor-generator sets. The D.C. source from the substation may be found in the form of:

i. 2-wire for D.C system: As the name indicates, this system of distribution consists of two wires. One is the leaving or positive wire and the other is the return or negative wire. The loads such as lamps, motors etc. are linked in parallel between the two wires. This system is never used for transmission purposes due to low efficiency but may be working for distribution of D.C. power.

ii. 3-wire for D.C System: It contains of two outers and a central or neutral wire which is earthed at the substation. The electrical energy between the outers is double the voltage between either outer and neutral wire. Loads needing high voltage (e.g., motors) are linked across the outers, whereas lamps and heating circuits requiring fewer voltage are connected between either outer and the neutral [25].

2.2.3 Overhead Versus Underground System

The distribution system can be classified as overhead or underground. Overhead lines are commonly mounted on wooden, concrete or steel poles which are settled to transmit distribution transformers in addition to the conductors. The underground scheme customs conduits, cables and manholes under the surface of roads and sidewalks. The choice between overhead and underground system based upon a number of commonly opposing issues. Therefore, it is desirable to make an evaluation between the two.

i. public safety: The underground system is extra safe than overhead system since all distribution wiring is located underground and there are slight probabilities of any danger.

ii. Initial cost: The underground system is more costly than overhead due to the high cost of ditching, conduits, cables, manholes and other special equipment. The starting cost of an underground scheme might be five to ten times than that of an overhead system.

iii. Flexibility: The overhead structure is much more supple than the underground scheme. In the final case, manholes, duct lines etc., are always sited once installed and the load growth can only be met by placing new lines. However, on an overhead scheme, poles, wires, transformers etc., can be simply get rid of to meet the changes in load situations.

iv. Faults: The probabilities of faults in underground scheme are very small as the cables are laid underground and are generally provided with better insulation.

v. Appearance: The overall presence of an underground system is well as all the distribution lines are invisible. This reason is applying significant public pressure on electric source companies to switch over to underground scheme.

vi. Fault location and repairs: In overall, there are few probabilities of faults in an underground scheme. However, if a fault does happen, it is hard to find and repair on this scheme. On an overhead system, the conductors are observable and simply available so that fault locations and repairs can be simply made.

vii. Current carrying capacity and voltage drop: An overhead distribution conductor has a significantly complex current carrying volume than an underground cable probe of the same material and cross-section. On the other hand, underground cable conductor has much inferior inductive reactance than that of an overhead conductor because of nearer arrangement of conductors.

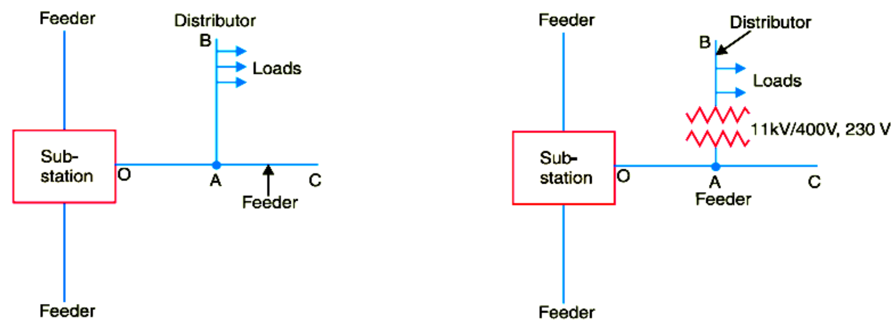
viii. Useful life: The useful life of underground system is abundant higher than that of an overhead scheme. An overhead scheme may have a useful life of 25 years, whereas an underground scheme may have a useful life of extra than 50 years.

ix. Maintenance cost: The maintenance cost of underground scheme is very low as compared with that of overhead scheme because of less probabilities of faults and provision interruptions from wind, ice, lightning as well as from traffic dangers.

2.2.4 Connection Schemes of Distribution System

All distribution of electrical energy is done by fixed voltage scheme. In training, the following distribution circuits are commonly utilized:

i. Radial System: In this scheme, isolated feeders' issue from a single substation and feed the distributors at one end only. Fig(a) shows a single line plan of a radial scheme for D.C. distribution where a feeder OC supplies a supplier AB at point A. Clearly, the supplier is fed at one end first i.e., point A is this case. Fig (b) indicates a single line drawing of radial system for A.C. distribution. The radial scheme is active only when power is generated at low voltage and the substation is placed at the midpoint of the load.



a) b)

Figure.2.2. D.c and A.c Radial distribution system [25]

This is the simple distribution circuit and has the last starting cost. However, it grieves from the following draw backs:

a) The end of the distributor nearest to the feeding point will be seriously overloaded.

b) The end users are dependent on a single feeder and single distributor. So, any fault on the feeder or distributor cuts off source to the end users who are on the side of the fault away from the substation.

c) The end users at the reserved end of the distributor would be endangered to serious voltage variations when the load on the distributor is vary. Due to these restrictions, this scheme is used for short distances only.

ii. Ring main system: In this scheme, the primary election of distribution transformers forms a circle. The circle circuit starts from the substation bus-bars, types of a circle through the area to be helped, and takings to the substation. Fig. 2.3 shows the single line illustration of ring main scheme for A.C distribution where substation supplies to the locked feeder LMNOPQRS.

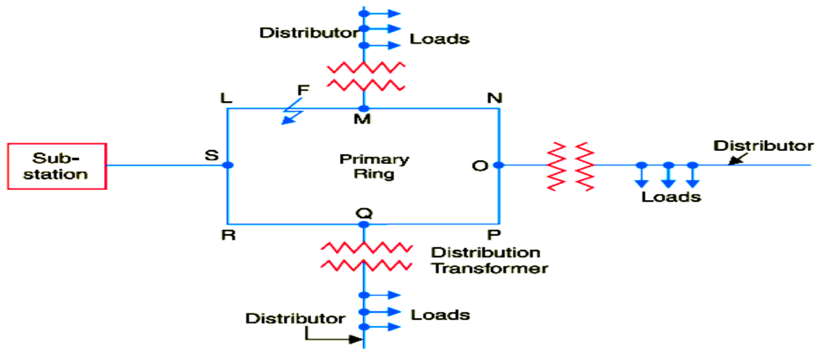


Figure 2.3. Ring main Distribution system [25]

iii. Interconnected system: When the feeder ring is energized by two or more than two power plant or substations, it is named as inter-connected scheme. Fig. 2.4 displays the single line diagram of interconnected scheme where the locked feeder ring ABCD is provided by two substations S and S at points D and C correspondingly [25].

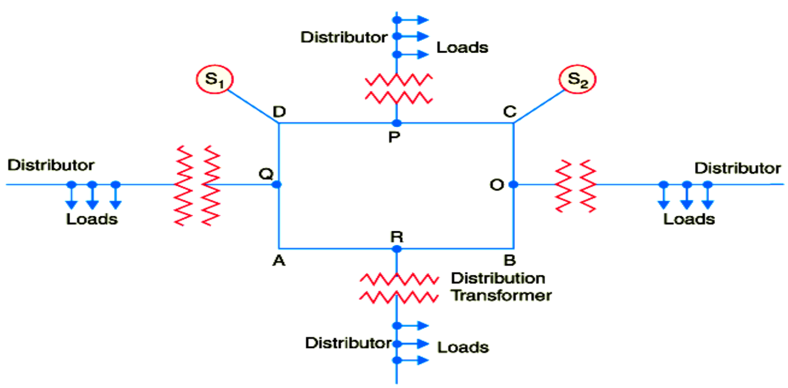


Figure 2.4. Interconnected Distribution system [25]

2.2.5 Different parameters calculation in A.C. Distribution

However, in A.C scheme, the voltage sags are due to the mutual things of resistance, inductance and capacitance. In an A.C. scheme, additions and subtractions of currents or voltages are computed vectorially. In an A.C. scheme, power factor (p.f.) has to be occupied into justification. Loads tapped off form the distributor are commonly at dissimilar power factors. There are two habits of denoting power factor viz, Power factors mentioned to receiving end voltage and Power factors mentioned to respective load voltages [24]**.**

In A.C distribution scheme calculations, power factors of various load currents have to be considered since currents in dissimilar units of the distributor will be the vector sum of load currents and not the math sum. The power factors of load currents may be given (i) with respect to getting or sending end voltage or (ii) with respect to load voltage itself. Each case shall be discussed distinctly.

Power factors referred to receiving end voltage: Reflect an A.C. supplier *AB* with concentrated loads of I_1 and I_2 tapped off at points *C* and B as revealed in Fig 2.5 below. Taking the getting end voltage V_B as the reference vector, let lagging power factors at C and B be cos φ_1 and cosφ_2 with respect to V_B. Let R_1, X_1 and R_2, X_2 be the resistance and reactance of segments AC and CB of the distributor.

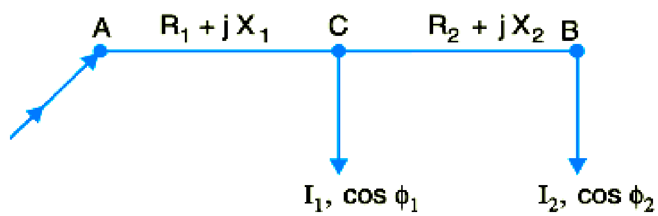


Figure 2.5. Power factors referred to receiving end voltage [24]

Impedance of section AC,

$$\mathbf{Z_{AC}} = R_1 + jX_1 \tag{2.1}$$

Impedance of section CB,

$$\mathbf{Z_{CB}} = R_2 + jX_2 \tag{2.2}$$

The load currents at point C,

$$\boldsymbol{I_1} = I_1(\cos \Phi_1 - j \sin \Phi_1) \tag{2.3}$$

The load current at point B,

$$\boldsymbol{I_2} = I_2(\cos \Phi_2 - j \sin \Phi_2) \tag{2.4}$$

Current in section CB,

$$\boldsymbol{I_{CB}} = \boldsymbol{I_2} = I_2(\cos \Phi_2 - j \sin \Phi_2) \tag{2.5}$$

Current in section AC, $I_{AC} = I_1 + I_2$

$$= I_1(\cos \Phi_1 - j \sin \Phi_1) + I_2(\cos \Phi_2 - j \sin \Phi_2) \tag{2.6}$$

Voltage drops in section CB,

$$\boldsymbol{V_{CB}} = \boldsymbol{I_{CB}}\boldsymbol{Z_{CB}} = I_2(\cos \Phi_2 - j \sin \Phi_2)(R_2 + jX_2) \tag{2.7}$$

Voltage drops in section AC,

$$\mathbf{V_{AC}} = \mathbf{I_{AC}}\mathbf{Z_{AC}} = (\mathbf{I_1} + \mathbf{I_2})\mathbf{Z_{AC}}$$

$$=[I_1(\cos \Phi_1 - j \sin \Phi_1) + I_2(\cos \Phi_2 - j \sin \Phi_2)][R_1 + jX_1] \tag{2.8}$$

Sending end voltage,

$$\mathbf{V_A = V_B + V_{CB} + V_{AC}} \qquad (2.9)$$

Sending end current,

$$I_A = I_1 + I_2 \qquad (2.10)$$

Power factors referred to respective load voltages: Assume the power factors of loads in the earlier Fig 2.5. are denoted to their individual load voltages. Then Φ_1 is the phase angle between V_C and I_1 and Φ_2 is the phase angle between V_B and I_2.

Voltage drops in section CB,

$$\boldsymbol{V_{CB}} = \boldsymbol{I_2 Z_{CB}} = I_2(\cos \Phi_2 - j \sin \Phi_2)(R_2 + jX_2) \qquad (2.11)$$

Voltage at point c,

$$V_C = V_B + \text{Drop in section CB} = V_C < \alpha \qquad (2.12)$$

Now,

$$\mathbf{I_1} = I_1 < -\Phi_1 \text{ w.r.t voltage } \mathbf{V_C}$$

Therefore;

$$\boldsymbol{I_1} = I_1 < -(\Phi_1 - \alpha) \qquad \text{w.r.t voltage } \boldsymbol{V_B}$$

i.e.

$$\mathbf{I_1} = I_1[\cos(\Phi_1 - \alpha) - j\sin(\Phi_1 - \alpha)] \qquad (2.13)$$

Now,

$$I_{AC} = I_1 + I_2$$

$$= \boldsymbol{I_1}[cos(\Phi_1 - \alpha) - jsin(\Phi_1 - \alpha)] + \boldsymbol{I_2}(\cos \Phi_2 - j \sin \Phi_2) \qquad (2.14)$$

Voltage drops in section AC,

$$V_{AC} = I_{AC} Z_{AC} \qquad (2.15)$$

Therefore; voltage drop at point A,

$$\mathbf{V_A} = \mathbf{V_B} + \text{Drop in CB} + \text{Drop in AC} \qquad (2.16)$$

2.3 Fault in Distribution System

Distribution system line faults are the most common faults, triggered by falling trees, lighting strikes or insulator string flashover and 85-87% of power system faults are occurring in the distribution lines. Most of the distribution system faults occurs on overhead lines, due to their inherent characteristics of being exposed to atmospheric conditions. Faults occur in the power scheme of several reasons. For example, lightning strike can overload the scheme's components and result in a failure of the insulation in overhead lines. The impedance of source connections is often very low, resulting in large currents flowing during faults. The energy checked in a fault current can rapidly produce extreme heating system or forces to components and can result in divesting explosions of equipment. Short-circuit reasons, over voltage interruptions with voltage sags harm the grid and producing main disturbances and cost. Faults occur in several different forms depending of the fault type and the procedure for calculating distance to fault will therefore vary. Faults on distribution overhead lines are in majority temporary single phase to ground, arcing fault [41].

2.3.1 Causes of Distribution system fault

The causes of faults in distribution system are numerous, for example:

- Lightning, heavy winds, trees falling across lines, vehicles colliding with towers or poles
- Birds shorting lines
- Aircraft colliding with lines
- Small animals entering switchgear
- Line breaks due to excessive loading

2.3.2 Consequences of faults

Fire is a serious effect of major uncleared faults, may terminate the equipment of its origin, but also may spread in the scheme causing total letdown. The short circuit, the most common type of fault that may have any of the following consequences as listed in [26]:

- A great decrease of the line voltage over a major part of the power scheme, leading to the breakdown of the electrical supply to the end user and may create wastage in construction,
- An electrical arc – often supplementary a short circuit may harm the other equipment's in the system,
- Harm to the other equipment's in the system due to high heating and mechanical forces,

- Disturbances to the stability of the electrical system and this may even lead to a complete shutdown of a given power scheme,
- Considerable decrease of voltage on well feeders connected to the system having fault, which can cause abnormal currents drawn by motors or the motors will be stopped (causing loss of industrial manufacture) and then will have to be resumed.

2.3.3 Fault Types

There are two types of faults which can occur on any distribution lines; balanced fault and unbalanced fault also known as symmetrical and asymmetrical fault respectively. Maximum of the faults that happen on the power schemes are unstable faults. In addition, faults can be categorized as shunt faults, series faults and combination of the two. Series faults are those types of faults which occur in impedance of the line and does not involve neutral or ground, nor does it involve any interconnection between the phases. In this type of faults there is rise of voltage and frequency and reduction of current level in the faulted phases. For example: opening of one or two lines by circuit breakers. Shunt faults are the imbalance between phases or between ground and phases [26]. This project only considers shunt fault. In this type of faults there is rise of current and reduction of frequency and voltage level in the faulted phases. Distribution system faults can be sub-divided into two main groups:

a) High impedance faults (HIFs): It can be defined as electrical contacts between a bare current carrying conductor and an insulated foreign object. This is frequently as a result of a current carrying conductor touching a maximum impedance area after breaking. Such surfaces can be the street, sand, grass, etc. and it is a threat to human life and the environment. Additional variant is when the current carrying conductor does not break but comes in touch with insulated grounded objects.

b) Low impedance faults (LIFs): It includes conventional shunt faults like:

- Single line-to-ground fault
- Line-to-line fault
- Double line-to-ground fault
- Balance 3 phase-to-ground fault

1.Phase to ground fault: This type of fault exists when one phase of any distribution lines establishes a connection with the ground either by ice, wind, falling tree or any other incident.

About 70% of all distribution lines faults are classified under this category. The following three different types of single-phase-to-ground faults are skilled

(a) Phase A-to-ground faults.

(b) Phase B-to-ground faults.

(c) Phase C-to-ground faults.

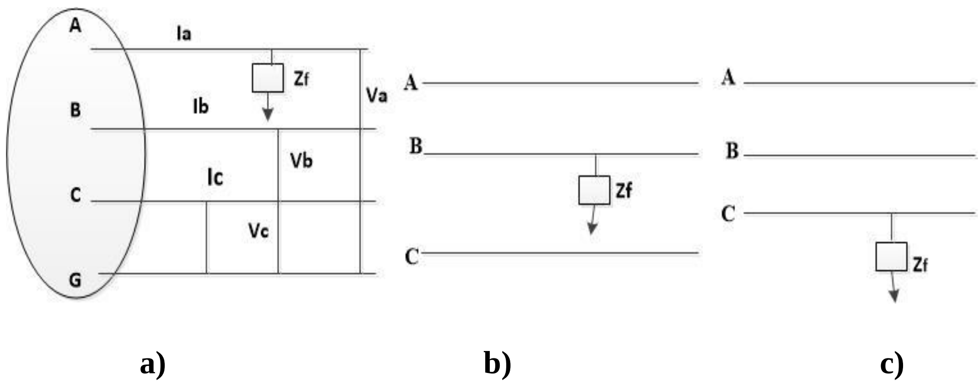


Figure.2.6. Single Line to ground fault [26]

Consider a single line-to-ground fault from phase A to ground (G) at the general three-phase bus shown in Figure 2-6 (a). For generality, we include fault impedance Z_f. In the case of a bolted fault $Z_f = 0$. Fault conditions in phase domain Single line-to-ground fault of phase A:

$$I_b = I_c = 0 \text{ and } V_a = Z_f I_a \quad (2.17)$$

Using the sequence transformation matrix fault conditions in sequence domain Single line-to-ground fault of phase A,

$$I_0 = I_1 = I_2 \text{ and } V_0 + V_1 + V_2 = Z_f(I_0 + I_1 + I_2) = 3Z_f I_1 \quad (2.18)$$

Where I_0, I_1, I_2 *and* V_0, V_1, V_2 zero, positive and negative sequence current and voltage respectively.

Equation (2.18) can be satisfied if interconnection is made in series the sequence networks as follows:

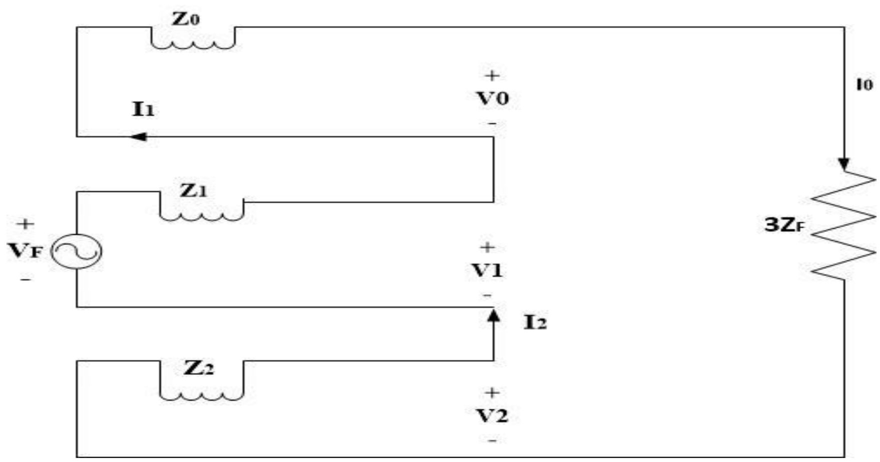


Figure 2.7. The sequence network connection for single phase to ground [26]

From the figure the sequence fault current at phase a can be calculated:

$$I_a = 3I_1 = \frac{3V_a}{Z_0+Z_1+Z_2+3Z_f} \qquad (2.19)$$

2.Phase to Phase fault: Because of high winds, one phase could touch anther phase & line-to-line fault takes place. Approximately 15% of all distribution lines faults are considered line-to-line faults. There are three different types of phase-to-phase faults that can be experienced on lines are as follows.

(a) Phase B-to-phase C faults.

(b) Phase C-to-phase A faults.

(c) Phase A-to-phase B faults.

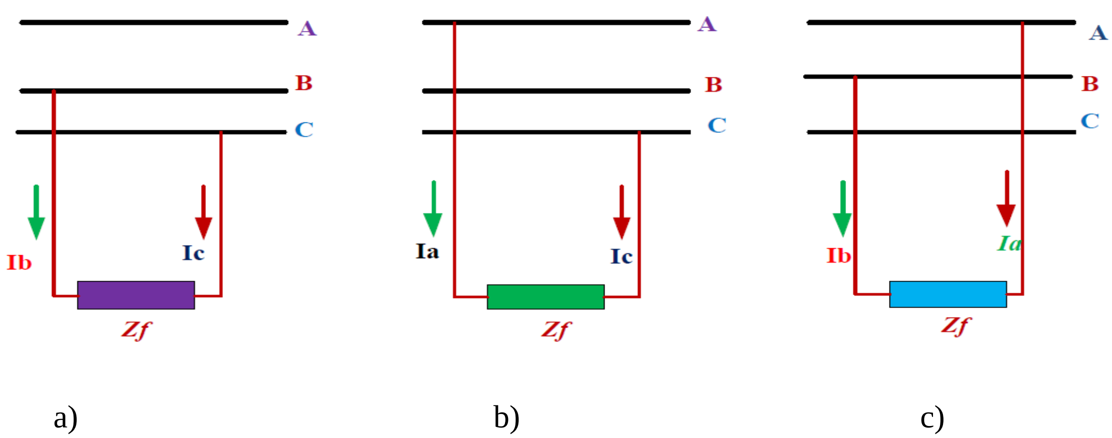


Figure 2.8. Line to line fault [27]

Consider a line-to-line fault from phase B and C to ground at the general three-phase bus shown in figure 2.8 (a). For generality, we include a fault impedance Z_f. Fault conditions in phase domain line-to-line fault of phase B and C:

$$I_a = 0, I_b = -I_c \text{ and } V_b - V_c = Z_f I_b \quad (2.20)$$

Using the sequence transforming matrix and transforming (2.20) to the fault conditions in sequence domain of line-to-line fault of phase B and C:

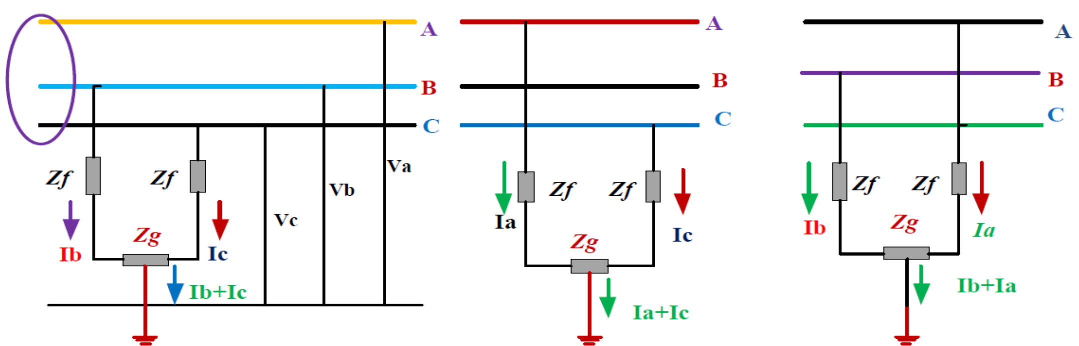
$$I_a = 0, I_1 = -I_2 \text{ and } V_1 - V_2 = Z_f I_1 \quad (2.21)$$

3.Double Line to ground fault: Dropping tree where two phases become in contact with the ground could lead to this type of fault. Two phases will be involved instead of one in the line-to-ground faults scenarios. 10% of all transmission lines faults are under this type of faults. Two-Line-to-ground faults are of the following three types.

(a) Line B and Line C-to-ground faults.

(b) Line C and Line A-to-ground faults.

(c) Line A and Line B-to-ground faults.



(a) b) c)

Figure 2.9. Double line-to-ground fault [40]

Consider a line-to-line-to-ground fault from phase B and C to ground at the general three-phase bus shown in figure 2-9 (a). For generality, we include a fault impedance Z_f. Fault conditions in phase domain line-to-line-to-ground fault of phase B and C:

$$I_a = 0 \text{ and } V_b = V_c = (\frac{Z_f}{2} + Z_g)(I_b + I_c) \quad (2.22)$$

Using the sequence transforming matrix and transforming (2.22) to the fault conditions in sequence domain line-to-line-to-ground fault of phase B and C:

$$I_0 + I_1 + I_2 = 0, V_0 - V_1 = \left(\frac{Z_f}{2} + 3Z_g\right) I_0 \text{ and } V_2 = V_1 \quad (2.23)$$

4. Balanced Three phase faults (3Φ Fault): In this case, falling tower, failure of equipment or even a line breaking and touching the remaining phases can cause three phase faults. In reality, this type of fault not always occurs which can be seen from its share of 5% of all distribution lines faults. Three phase faults that have the same fault resistances in the three phases are called balanced three-phase faults. These faults can be approximated at the terminals of unloaded synchronous machine.

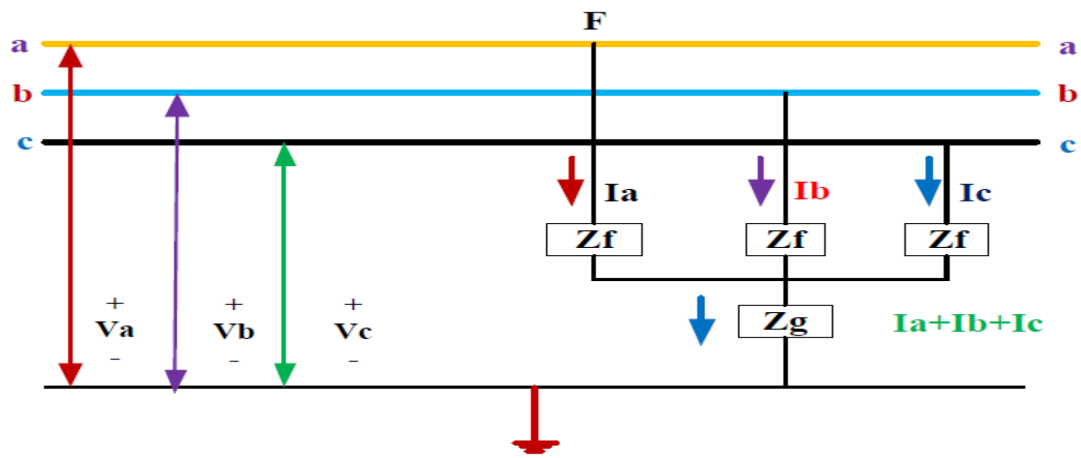


Figure 2.10. Balanced Three Phase fault [26]

Table 2. 1 Different types of fault occurrence and severity [29]

Types of faults	**Symbol**	**% Occurrence**	**Severity**
Line to Ground	L-G	75-80	Very less severe
Line to Line	L-L	10-15	Less severe
Double Line to Ground	LL-G	5-10	Severe
Three Phase	3Φ	2-5	Very severe

2.4 Description of Artificial Neural Networks (ANN)

Is a good technique which works like a brain of human being and also capable of learning, many trainings are required by ANN before it can be applied in a particular plant. ANN have set of neurons that are connected and arranged in many layers, its structure consists of inputs layers, hidden layers and output layers. An artificial Neural Network (ANN) is displayed later the way and custom the biological neural schemes work. They are equivalent computational schemes and are made of numerous processing fundamentals connected together in a certain way in order to achieve a certain task. ANNs are massively paralleled and have the skill to learn from training data and generalize to new conditions. This makes them efficient and robust for real world applications, hence, they are configured to perform tasks analogous to biological brains [31].

Furthermore, ANN learns to produce an output based on a given input data. The training of the network is accomplished by successively applying input vectors while correcting network weights. It is in training that the neural network learns to map the input into the output based on a given input data [32].

2.4.1 Applications of ANN

The power systems grow very fast and it is important to minimize the fault current on the system by using techniques which are quicker, reliable and accurate. ANN was proposed in this regard to deal with the classification of faults and minimization of fault current on the distribution feeders.

Testing of ANN: Fault resistances, fault magnitude and other types of faults were used to test ANN fault current minimization [32].

2.4.2 Training procedure flowchart of the ANN controller

Moreover, several structures of the artificial neural networks were extensively trained and the performance plot and confusion matrix of the ANN IFDC configuration that gave the best performance. The design and testing process are illustrated in the following flow chart in Figure below.

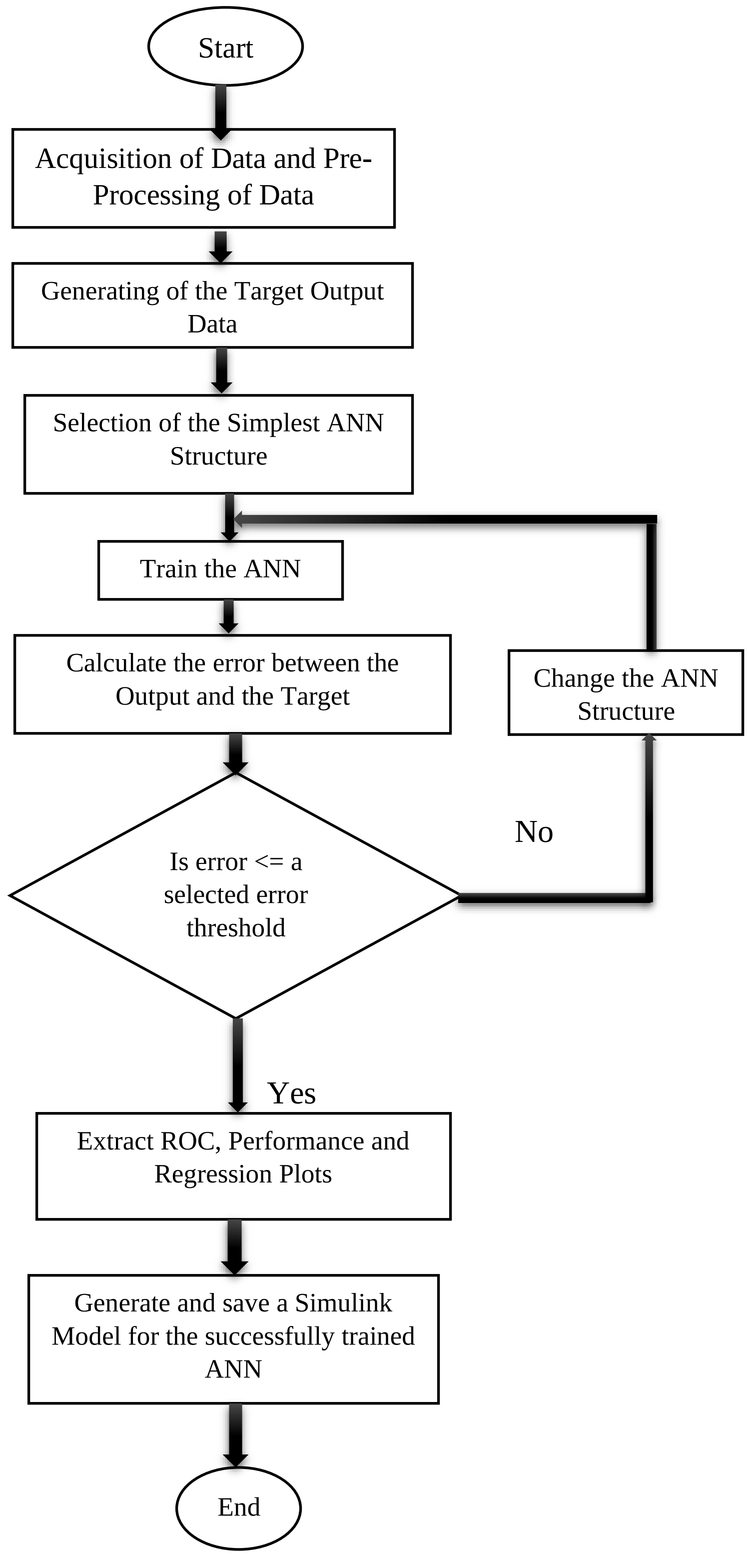


Figure 2.11. The Flow Chart for developing IFDC [31]

2.5 Training artificial neural network

The most significant property of a neural network is that it can train, and can improve its performance through training. Training is a process by which some parameters of a neural network i.e., synaptic weights and bias are adapted through a continuous process of stimulation in the environment in which the network is embedded. The network becomes more knowledgeable about the tasks after each iteration. The objective of the training process is to correct the ANN weights and biases to get minimal deviations between the target and the calculated ANN outputs in relation to the regular of all input samples. The finally found bias and weight matrices which applied to the network should hopefully map any input to a correct output.

2.5.1 Learning (training) Types

There are three different types of learning models namely, supervised learning, self-organized or unsupervised learning, and reinforced learning.

i)**Supervised Learning:** The learning algorithm would fall under this category if the desired output for the network is also provided with the input while training the network. By providing the neural network with both an input and output couple it is probable to calculate an error based on its target output and actual output. It can then use that error to make modifications to the network by improving its weights.

ii)Unsupervised Learning: In unsupervised learning, the weights and biases are modified in response to network inputs only. There are no target outputs available. This is particularly valuable in such applications as vector quantization.

iii)Reinforcement Learning: Reinforcement learning is the same to supervised learning, except that, instead of being provided with the correct output for each network input, the process is only given a grade. The grade is a degree of the network routine over few sequences of inputs.

2.5.2 Training (Learning) Rules

Learning rules (training algorithms) refer to a procedure for adjusting the weights and biases of neural networks with the aim of minimizing the differences between the network outputs and the training targets. The purpose of the learning rule is to train the network to perform some tasks. The process used to carry out the learning process in a neural network is named as optimization method (or optimizer).There are several different types of optimization systems. All have different features and performance in terms of memory requirements, processing speed, and numerical precision. Then, some important optimization processes are defined. Lastly, the memory, speed, and precision of those processes are compared. In case of incremental training, the network elements (weights) are updated after each training vector has been presented. Whereas, batch training, includes updating the weights and biases after all of the input and target vectors have been offered to the network. There are different kinds of learning process. For example, Gradient descent, Newton's method, Conjugate gradient, Quasi-Newton method, Levenberg-Marquardt, algorithm, quick propagation algorithm, some of these learning rules that help this thesis are discussed below.

a) Gradient descent (GD): Gradient descent is also called as steepest descent, it is the furthermost straight forward training process. It wants data from the gradient vector, and hence it is a first-order technique.

Let denote $f(\mathrm{W}^{(\mathrm{i})})=f^{(i)}$and $\nabla f\left(W^{(i)}\right) = g^{(i)}$.The method begins at a point $W^{(0)}$ and, until a stopping criterion is satisfied, moves from $W^{(i)}$ to $W^{(i+1)}$ in the training direction $d^{(i)} = -g^{(i)}$. So, the gradient descent technique iterates in the following way:

$$w^{(i+1)} = w^{(i)} - g^{(i)}\eta^{(i)} \qquad (2.24)$$

for i =0,1, …

Where: $\boldsymbol{w^{(i+1)}}$ = new parameters

$w^{(i)}$ = parameters

$g^{(i)}$ = loss gradient

$\eta^{(i)}$ = tearing rate

The constraint η is the training rate. This value can either set to a fixed value or originate by one-dimensional optimization along the training path at each stage. The best value for the training rate gained by line minimization at each consecutive step is commonly preferable. But there are still several software tools that only use a constant value for the training rate. The next image is an activity figure of the training process with gradient descent. As we can see, the parameter vector is upgraded in two steps: First step is, the gradient descent training direction is calculated. Second step is, a suitable training rate is found. The learning rate is frequently arranged at each epoch using line minimization.

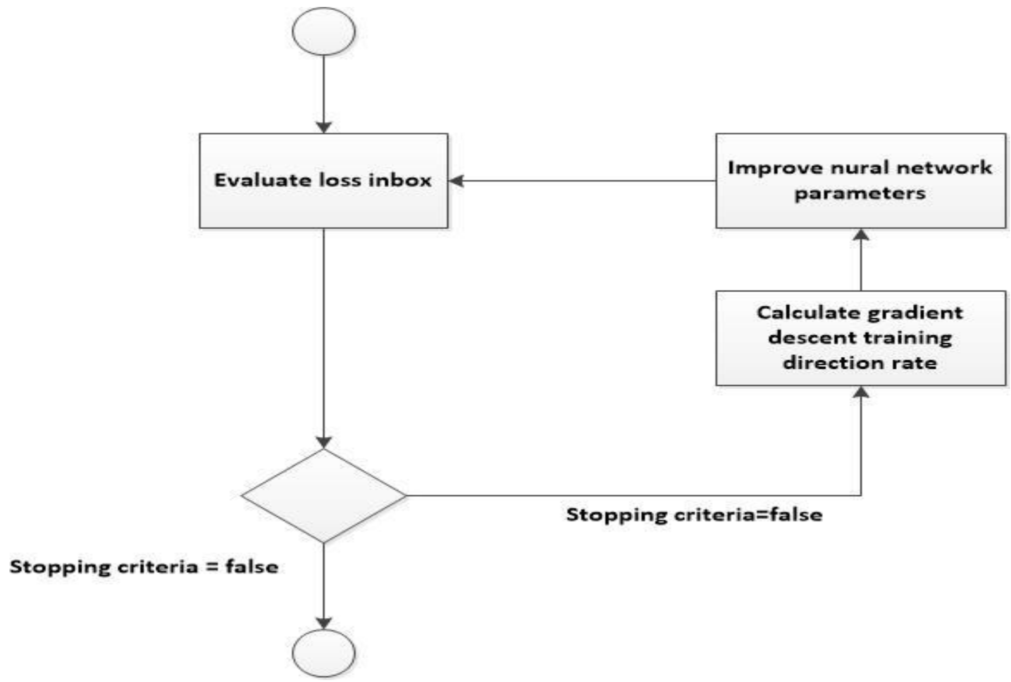


Figure 2.12. Activity training process diagram of gradient descent algorithm [32]

The gradient descent training technique has the less weakness of requiring numerous iterations for functions which have extended, slight valley structures. Certainly, the simple gradient is the way in which the loss function declines the most rapidly, but this does not essentially produce the fastest convergence. The above picture illustrates this matter.

b) Newton's method (NM): Newton's method is a second-order algorithm because it makes use of the Hessian matrix. This technique's objective is to discovery improved training orders by using the second derivatives of the loss function. Newton's technique uses the Hessian of the loss function, a matrix of second derivatives, to compute the learning direction. Since it uses high order data, the learning direction points to the lowest of the loss function with higher accuracy. The problem is that calculating the Hessian matrix is very computationally expensive.

The quasi-Newton method **(QNM)** is founded on Newton's method but does not want the calculation of second derivatives. In its place, the quasi-Newton method computes an estimation of the inverse Hessian at each iteration of the procedure, by only using gradient statistics.

$$\text{New parameters} = \text{Parameters} - \text{Inverse hessian approximation} \cdot \text{Gradient} \cdot \text{Learning\_rate} \qquad (2.25)$$

The learning rate is adjusted here at each epoch using line minimization.

c) Conjugate Gradient (CG): The conjugate gradient method can be viewed as somewhat middle between gradient descent and Newton's method. It is interested by the desire to accelerate the classically very slow convergence related with gradient descent. This technique also removes the statistics wants to be related with the evaluation, storage, and inversion of the Hessian matrix, as required by Newton's method. In the conjugate gradient training procedure, the exploration is achieved along with conjugate directions, which yield commonly quicker convergence than gradient descent directions. These training directions are conjugated about the Hessian matrix.

In the conjugate gradient procedure, the exploration is achieved along with conjugate directions, which produces normally faster convergence than gradient descent directions.

$$\text{New parameters} = \text{Parameters} - \text{Conjugate Gradient} \cdot \text{Learning\_rate} \qquad (2.26)$$

As already, the learning rate is adjusted at each value of epoch using line minimization.

d) Levenberg-Marquardt algorithm (LMA): The Levenberg-Marquardt procedure, also identified as the damped least-squares method, has been planned to work definitely with loss functions, which take the form of a sum of squared errors. It works without computation of the exact Hessian matrix. In its place, it works with the gradient vector and the Jacobian matrix.

Look at the loss function which can be expressed as a sum of squared errors of the form:

$$f = \sum_{i=1}^{m} e_i^2 \qquad (2.27)$$

Here m is the number of instances in the information set.

We can describe the Jacobian matrix of the loss function as that holding the derivatives of the errors concerning the constraints,

$$J_{i,j} = \frac{\partial e_i}{\partial w_j} \qquad (2.28)$$

for i=1…, m and j =1…, n

Where m is the number of instances in the information set, and n is the number of constraints in the neural network. Remember that the size of the Jacobian matrix is m· n.

The gradient vector of the loss function can be calculated as:

$$\nabla f = 2J^{T}.\, e \tag{2.29}$$

Here **e** is the vector of all error terms.

Finally, we can approximate the Hessian matrix with the following expression.

$$Hf \approx 2J^{T}.\, J + I\lambda \tag{2.30}$$

Where **λ** is a damping factor that safeguards the positivity of the Hessian and **I** is the identity matrix. The next appearance defines the constraints upgrading procedure with the Levenberg-Marquardt set of rules

$$W^{(i+1)} = W^{(i)} - \left(J^{(i)T}.\, J^{(i)} + \lambda^{(i)} I\right)^{-1}.\, (2J^{(i)T}.\, e^{(i)}) \tag{2.31}$$

for i = 1, …

When the damping constraint **λ** is zero, this is just Newton's method, using the estimated Hessian matrix. On the other side, when **λ** is maximum, this becomes gradient descent with a small training rate. The constraint **λ** is set to be maximum so that the first updates are few steps in the gradient descent way. If any iteration happens to result in a letdown, then **λ** is increased by some factor. Else, as the loss reduces, **λ** is decreased so that the Levenberg-Marquardt procedure approaches to the Newton method. This procedure classically accelerates the convergence to the minimum.

The figure below shows a state illustration for the training process of a neural network with the Levenberg-Marquardt procedure. The starting step is to compute the loss, the gradient, and the Hessian approximation. Then the damping constraint is adjusted to reduce the loss at each iteration [32].

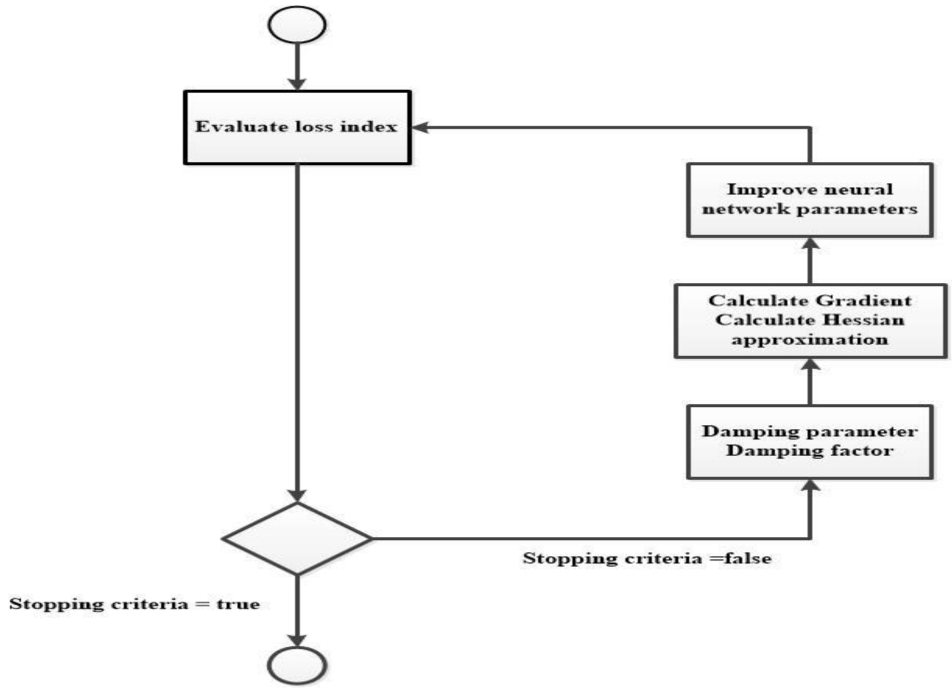


Figure 2.13. State diagram for the training process of a neural network with the Levenberg-Marquardt algorithm [32]

2.6 Other Fault Current Minimalization Methods

2.6.1 Application of Fuzzy Logic Controller

Fuzzy Logic Controller can be used as an effective tool for high-speed digital relaying and can be also used as the correct minimization is achieved within a cycle of the fault incident.

2.6.2 Fuzzy Logic Controller Techniques

Fuzzy Logic Controller settled with the aid of relational neural networks. Figure 2.14 shows the Fuzzy Logic Controller. Fuzzy Logic Control contains of the Inference Engine, where the decision assembly of the controller takes place, with Fuzzification and Defuzzification for relating with the process plant for regulator. Fuzzy sets and neural networks deal efficiently with the two very different areas of info processing. When we estimate the FLC and ANN, we get that FLC are good on information representation and ANN has effective scheme, reliable, accurate and capable of learning. Both methods have their advantages and disadvantages [30].

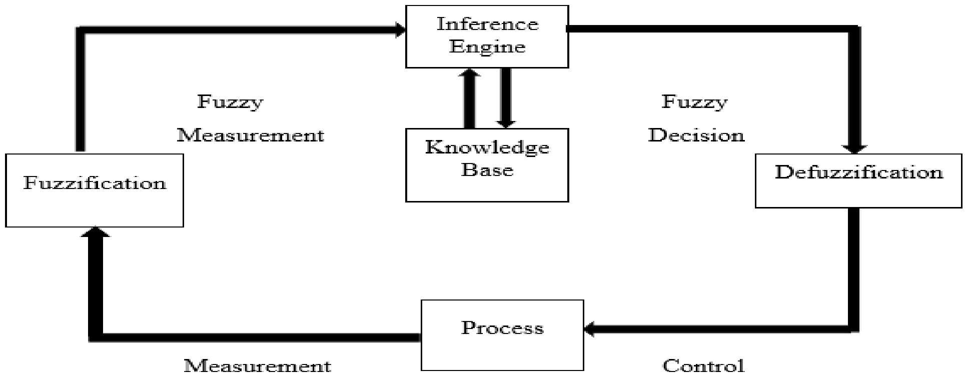


Figure 2.14. Fuzzy Logic Controller block diagram [30]

2.6.3 Advantages and Disadvantages of ANN and Fuzzy Logic

Table 2.2 below gives an overview of the advantages and disadvantages of ANN and compares it to the results of Fuzzy Logic Control. It is clear that both methods can solve a vast range of problems, each with their respective advantages and disadvantages. Each method, namely FLC and ANN can be applied to different problems, each with their specific application focus depending upon the nature and complexity of the problem to be solved. It should be noted that initial analysis, problem formulation and preparation into the problem to be solved must first be performed.

Table 2.2 A comparison between Fuzzy Logic and Artificial Neural Networks

Fuzzy Logic	**Artificial Neural Network**
Advantages	**Disadvantages**
Fast adaptation to changes	Learning ability via training
High degree of tolerance to uncertainty	Faster minimization of fault current magnitude
Smooth operation over control regimes	Protect power system intelligently
Reduce the effects of non-linearity	Faster computational times necessary
Learning ability limited, requires Intelligence	Adaptive features, to learn to new problems
Inherent approximation capability	It detects and minimize magnitude fault current
High accuracy of tolerance	Noise rejection capabilities via AI
Disadvantages	**Disadvantages**
Difficult to model mathematically and requires expert knowledge.	Requires careful analysis

Chapter Three

Modeling and System Analysis

3.1 Modelling

This chapter presents the modeling of different components that are very important to achieve the intended thesis objective.

3.1.1 About Case Study Area

Hossana substation-distribution system is one of the substation-distribution in Ethiopia, which is located in the SNNP region in the Hadeya zone in the capital city of Hossana. So, this substation-distribution is located at the eastern part of the city especially the main road of Addis Ababa. The Hossana substation-distribution system is located at the latitude and longitude of $7^0 33' N 37^0 51' E$ with the elevation of 2177 meters above sea level. It was part of Limo and surrounded by it. This substation-distribution system delivers the electricity to the Hossana city and deliver the electricity to the rural areas located at around the Hadeya zone and to some parts of Kambata Tambaro zone rural areas. So, before the Hossana substation is installed the Hossana city can get power from the desal engine. Totally the Hossana substation gets the power from the Gilgal-Gib I and from the Wolkta Substation i.e., the incoming transmission lines and deliver power to the Halaba substation i.e., the outgoing transmission lines. The Hossana substation has two main transformers, one the power transformer and the other is auto-transformer. By the help of these two transformers the substation delivers power to the utility customers. The total number of feeders in the Hossana substation is nine feeders. The six feeders are from the power transformer i.e., the rating of voltage is 15KV and the remaining three are from the auto transformers i.e., the rating of voltage is 33kv.

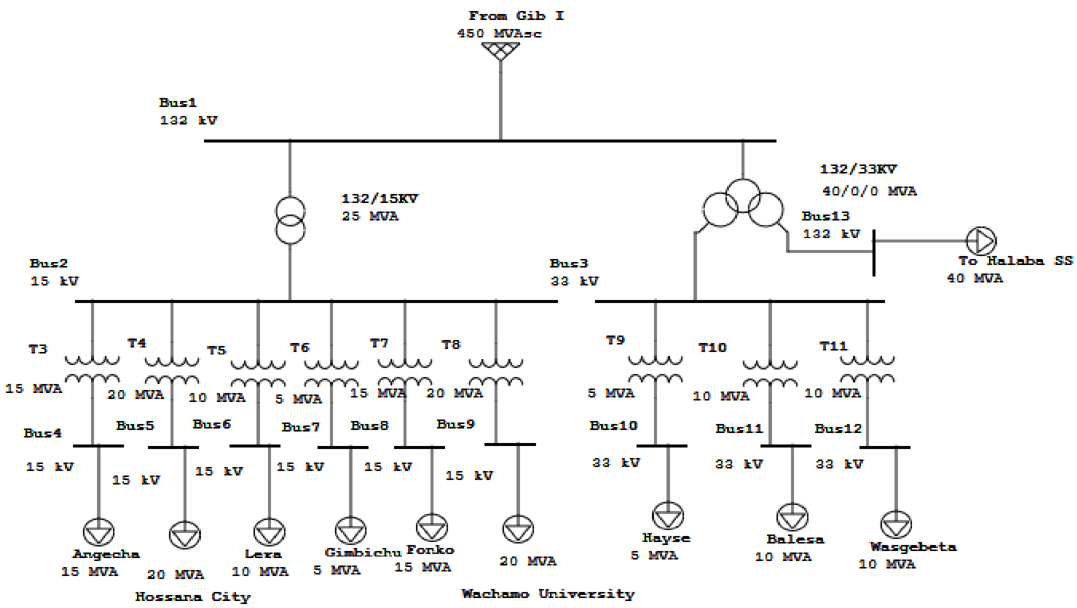


Figure 3.1. Single line diagram of Hossana Substation in ETAP

Table 3.1 Local name and voltage rating of Hossana substation-distribution system feeders.

No,	Feeder	Local name	Voltage Rating
1	1	Angacha	15 KV
2	2	Fonko	15 KV
3	3	Lera	15KV
4	4	Gimbichu	15 KV
5	5	Hossana City	15 KV
6	6	Wachamo University	15 KV
7	7	Hayese	33KV
8	8	Wasigabata	33KV
9	9	Balessa	33KV

From the above feeders I select feeder 4 or Gimbichu feeder, because of most of the time high percentage of interruption is take place in this feeder. This feeder mostly covers wide area as we can compare with other feeders. Mostly Gimbchu feeder covers from Hadeya zone Soro worada and from Kambata Tambaro zone Tambaro worada. There are different types of faults occurs in this feeder because of the whole feeder line poles are constructed from wood pole type, the geographical land structure of Gimbchu feeder covers is not suitable and the feeder lines can across under different forest trees. The distance covers this feeder is very high i.e., up to 150 Km from the starting point of Hossana substation. So, due to this factor most of the time the end users cannot get electricity properly.

3.1.2 Data collected from Gimbichu Feeder

The data can be collected to my thesis work is in different ways from the Gimbchu feeder. The way of collecting data is by using secondary data collection technique and primary data collection technique. The secondary data is collected from the documented materials in the Hossana substation and the primary data is collected by the self-observation of feeder line and by interviewing the utility service workers. The basic feeder data required to do this thesis work is:

- Total number of buses
- Types of conductors
- Distribution feeder line length
- Rating and types of transformers
- Total loads
- Types of circuit breaker

Table 3.2 Summary of taps length, conductor types and distribution transformer quantity in the test feeder

Rural villages	**MV line tap length**	**Conductor type and Area**	**Transformer rating used & Qty.**	**Circuit components**
Jawe	25KM from HS	AAAC95mm^2	1x200kVA	DT and loads
Digiba	5KM from Jawe	AAAC95mm^2	2x50kVA	DT and loads
Jajura	45KM from HS	AAC50mm^2	2x100kVA	DT and loads
Gimbichu City	51.5Km from HS	AAAC95^2	2x100kVA	DT and loads
Jacho	135 Km from HS	AAC50mm^2	2x100kVA	DT and loads
Hamusi Mera	12Km from Gimbichu	AAC50mm^2	2x100kVA	DT and loads
Akama	12 Km from Hamusi Mera	AAAC95mm^2	2x100kVA	DT and loads
Bitana	85Km from HS	AAC50mm^2	2x100kVA	DT and loads
Chafi Mera	5Km from Bitana	AAC50mm^2	1x50kVA	DT and loads
Sani Mera	7Km from Chafi Mera	AAC50mm^2	2x100kVA	DT and loads
Dansa	88Km from HS	AAC50mm^2	1x25kVA	DT and loads
Mudulla City	98Km from HS	AAAC95^2	2x100kVA	DT and loads
Ambukuna	12Km from Mudulla	AAAC95^2	2x100kVA	DT and loads
Kalata	11Km from Mudulla	AAAC95^2	1x50kVA	DT and loads
Bultuma	10 Km from Mudulla	AAC50mm^2	2x100kVA	DT and loads

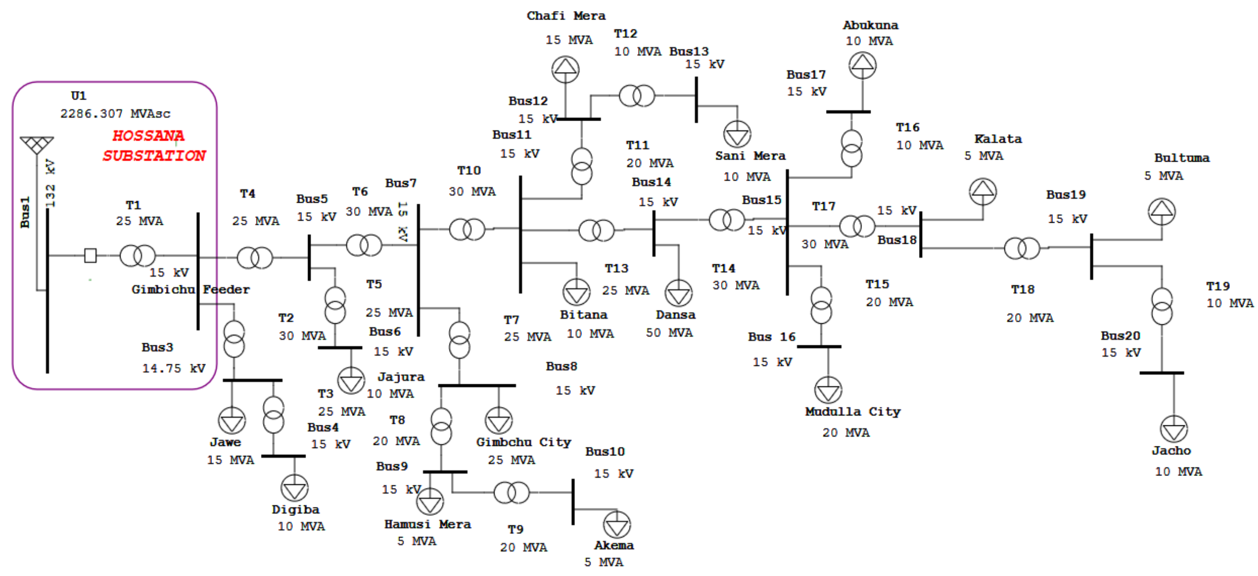


Figure 3.2. Single line diagram of Gimbichu feeder in ETAP

3.1.3 Causes for Power Interruption in the Gimbichu Distribution Feeder

In Gimbichu Distribution Feeder, major faults occurring frequently are earth fault, short circuit, blackout and system over load. And there are planned outages for working and preservation purpose. The major faults occurring can be either momentary or sustained type. Momentary (Temporary) interruptions with duration of less than 5 minutes interruptions whereas Permanent (Sustained) interruptions are long-duration interruptions which last longer than 5 minutes [28]. Usually, only information on sustained interruptions is informed to the controlling authority. Many of the distribution problems are momentary and mainly caused by animal contact, Tree and whether condition. They can simply be solved with little or no interference from the structure. Then by easily reclosing, the structure will be re- energized. Then sustained faults can't be restored by simple re-energizing. Sustained faults can be caused by equipment malfunction, cable failure, down line or persistent tree contact [29].

Sustained interruptions can be divided as planned and unplanned interruptions [28]. Planned interruptions (operational outages) occur mainly for the purpose of construction, preventative maintenance or repair. A planned interruption happens at a certain time less difficult for the end users and the customers have been informed beforehand of the interruption. On the other hand, if the existence time of the interruption has not been selected, then the interruption is unplanned. Unplanned interruption happens, for instance, due to fault clearing, unwanted action of the protection scheme or due to unplanned start of opening action of a switching device by a human. Sustained interruption: are the results of the following faults.

Distribution Earth fault: This fault occurs when there is a conducting connection between any electric conductor and any conducting material that is grounded or that may become grounded. Electricity continuously needs to find a route to the ground. In a ground fault, electricity has found a path to ground, but it is a path the electricity was never intended to be on, such as through a person's body. The earth fault, produced by an insulation loss among a live conductor and an exposed conductive part, denotes a plant engineering problem, which might reason for harm.

Distribution Short Circuit: Short circuit is the most frequently used term to define the cause of a power failure. It occurs when an electric current travel along a path that is different from the intended one in an electrical circuit. When this occurs, there is an extreme electric current which can lead to circuit harm, fire, and explosion. In fact, short circuits are one of the primary causes of electrical fires throughout the world. It also happens when the insulation of the wiring used breaks down. It can also happen due to the existence of an outside conducting material (such as water) that is presented accidently into the circuit. Electrical batteries can explode if they are exposed to a large current. Short circuits can even happen when electric motors are forced to work when the moving parts are blocked. This can result in irregular buildup of current, finally leading to a short circuit.

Distribution Line Overload: Increasing demands for electric power have caused existing power grids to become overloaded. Overloading is a common reason of line voltage variations. Inadequate power generation and inadequate distribution systems are also cause of line voltage problems. Improper or poorly planned power adaptable devices may produce voltage variations. Loose or corroded connections at the electric service user end can create voltage irregularities. The same situations on the distribution power lines may also disturb voltage. Several voltage variation problems can be sketched back to short infrastructure.

System overload: is an entire loss of electric service in all part. It can be occurred when the generating size is less than the load demand.

3.1.4 Types of Faults in Gimbichu outgoing Feeder

Gimbichu outgoing feeder consist of different types of faults, which interrupt the power supply to the end user. Some of the faults were explained according to the average frequency and duration of interruptions for the year of 2019 to 2020 in the next tables and graph.

Table 3.3: Average frequency of interruption for 2019 year based on types of faults

No	Type of faults and others	Gimbichu Feeder(15KV)
1	Earth Fault	89
2	Short Circuit	125
3	Black out	5
4	SOL	67
5	Over Load	65
6	Operation	75

SOL = System over Load (when generated power is below the total demand)

Where, Short circuit, Earth Fault and over Load are distribution faults while SOL, Black out and operation are a type of other faults.

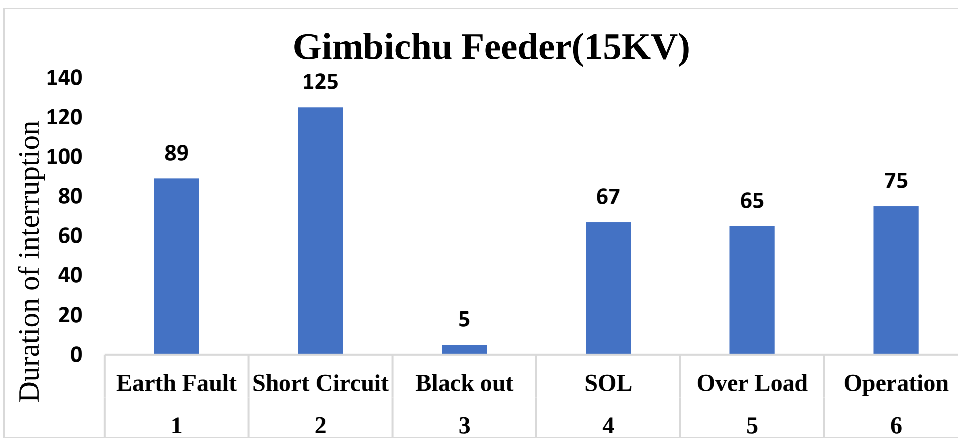


Figure 3.3. Average frequency of interruption for 2019 year based on types of faults

Table 3.4 Average frequency of interruption for 2020 year based on types of faults

No	Type of faults and others	Gimbichu Feeder(15KV)
1	Earth Fault	95
2	Short Circuit	133
3	Black out	20
4	SOL	66
5	Over Load	38
6	Operation	45

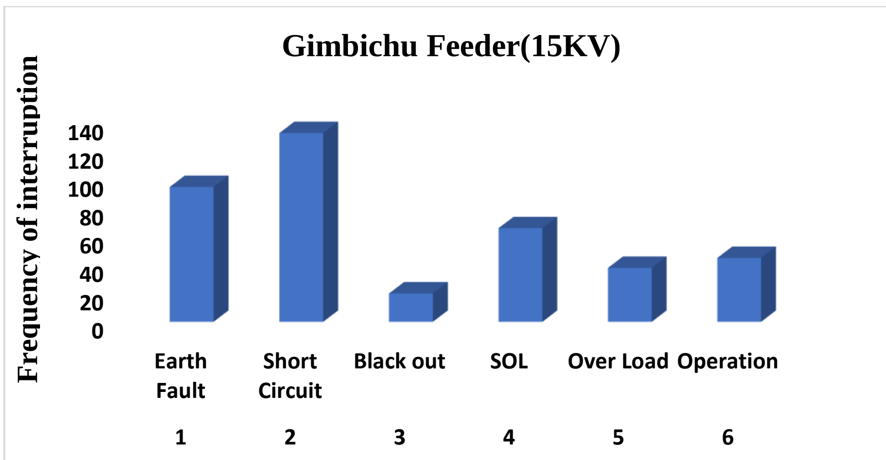


Figure 3.4. Average frequency of interruption for 2020 year based on types of faults

Figure 3.3 and 3.4 shows the average frequency of interruptions due to the distribution faults and others faults for the years of 2019 and 2020 for the Gimbichu feeder of Hossana substation-distribution. Types of the faults typically subdivided into distribution faults and others faults. Among the cases short circuit took greatest contribution of the interruption in Hossana substation

3.2. SFCL installation flow chart

In case of installation of SFCL in the system noduled the following steps are needed:

Step 1: Start the installation procedure of SFCL.

Step 2: Compute and store steady state load flow. Under this step we must check if the system is under normal operating condition or not.

Step 3: Initialize the parameters for the SFCL. So, in this step all the parameters like response time, minimum and maximum resistance and triggering current parameters are initialized.

Step 4: Allocate SFCLs according to strategy K. Under this step place the SFCL in the more faulted points in the system.

Step 5: Initialize faults. In this step initialize the fault types, it may be L-L, L-G, LL-G and 3Φ faults.

Step 6: Generate current flow information for the entire system. Under this step check the magnitude of all fault types in step 5 and observe it carefully.

Step 7: Check the out values of the minimized fault current and check no. of successfully limited points.

Step 8: If no. of successfully limited points (L_k) and no. of measured points (C_m) are equal go to the next step otherwise go back to the step 4.

Step 9: Maximal current of initialized parameter is greater than maximal current minimization, go the next step, otherwise go back to step 4.

Step 10: When maximal current minimization is equal to maximal current of initialized parameters go the final step.

Step 11: Install the SFCL to the identified points successfully.

The SFCL installation scheme was found by following the algorithm shown in Fig. 3.6.

Where Parameters being initialized during the third step: number of k = 1; number of installed SFCL S**k** = 1; maximal current minimization Rm = 0; current reduction margin of one additional SFCL= CRM; number of measured points Cm; optimal strategy OP = 0 [28].

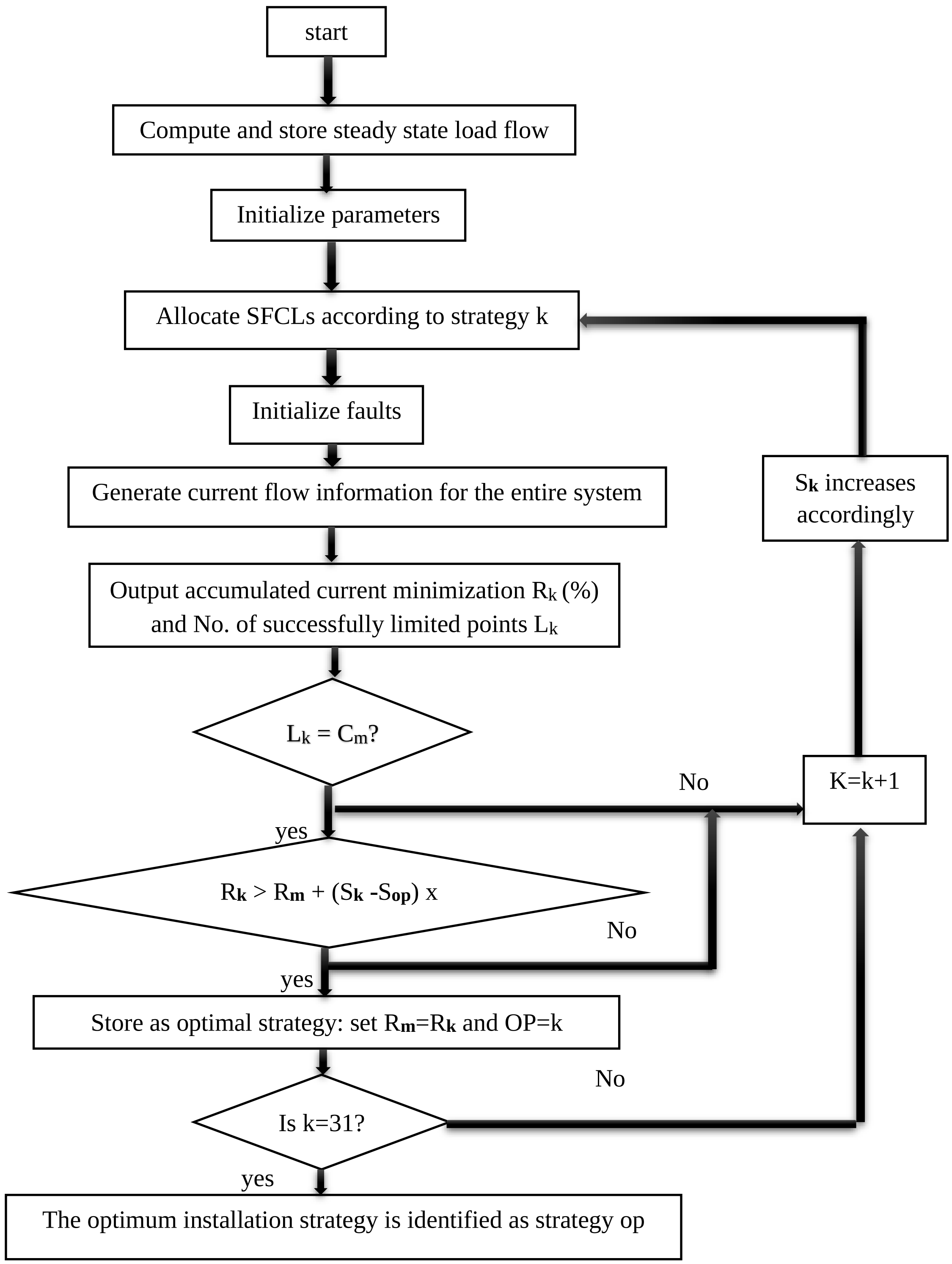


Figure.3.5. Flow chart of SFCL location [28]

3.3 Modeling of SFCL and Substation-Distribution Power System

3.3.1 Resistive SFCL Model

Superconducting fault current limiter (SFCL) is one of the most significant current limiters to avoid the short-circuit current from increasing in degree owing to its rapid current limiting ability. Different types of models for the SFCL have been established, these are resistive type, reactive type, transformer type, and hybrid type SFCLs. From the many types of SFCLs, the resistive type SFCL is chosen for the reason of its better principle and compacted structure of small size. In this paper, the proponent has modeled a resistive type SFCL using mathematical expressive equations [33].

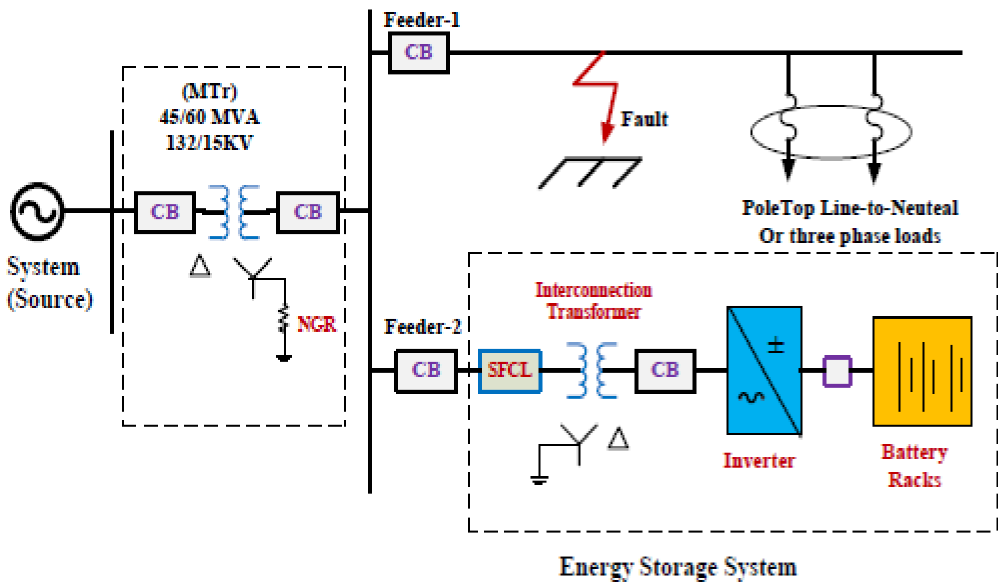


Figure 3.6. Power distribution system with an energy storage system [33]

The time development of the resistive type SFCL impedance as a function of time t is given by:

$$R_{SFCL}(t) = R_n\left[1 - \exp\left(-\frac{(t-t_0)}{T_F}\right)\right], \; t_0 \le t < t_1 \tag{3.1}$$

$$R_{SFCL}(t) = a_1(t - t_1) + b_1 \tag{3.2a}$$

$$R_{SFCL}(t) = a_2(t - t_2) + b_2 \tag{3.2b}$$

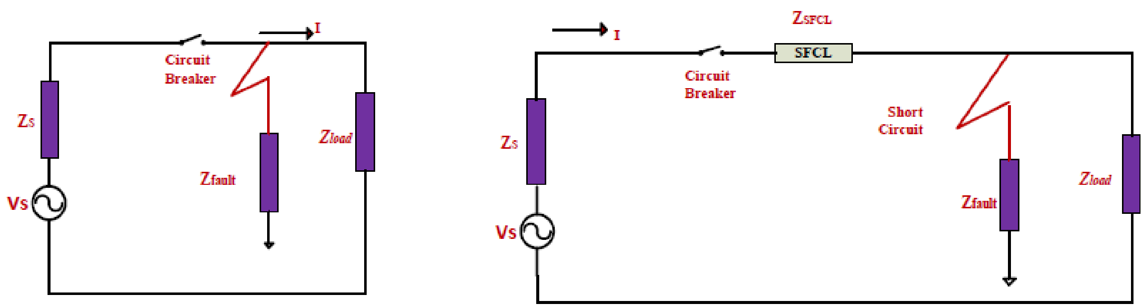
Where: $\mathbf{R_n}$ and $\mathbf{T_F}$ are the convergence resistance and time constant respectively, $\mathbf{t_0}$, $\mathbf{t_1}$, and $\mathbf{t_2}$ represent the quench starting time, first starting time of recovery, and second starting time of recovery, respectively. In addition, $\mathbf{a_1}$, $\mathbf{a_2}$, $\mathbf{b_1}$, and b_2 are the coefficients of the first-order linear function denoting the experimental results for the recovery characteristics of an SFCL [32].

And also, the fault current I_F is written by using nodal analysis formula: -

$$I_{FAULT} = I_{Mtr} + I_{feeder2} \tag{3.3}$$

3.3.1.1 Operating principle of the SFCL

Look at a simple of power system model, in the following Figure 3.7 below. This model contains a source of rated voltage V_s, internal impedance Z_s, load Z_{load}, and fault impedance Z_{fault}.



a) Simplified power circuit b) Modified power circuit

Figure 3.7. Equivalent diagram of a simple power circuit (a) without and (b) with SFCL [34]

When the system is in a steady state, the current flowing through the line is defined by:

$$I_{line} = \frac{V_s}{Z_s + Z_{load}} \tag{3.4}$$

Then, when a fault occurs as shown in Figure 3.8 (a), the current flowing through the line is defined by:

$$I_{line} = \frac{V_s}{Z_s + Z_{fault}}, \text{where } Z_{fault} \ll Z_{load} \tag{3.5}$$

Because the source impedance, Z_s, is very smaller than the load impedance, so equation 3.5 shows that the short circuiting of the load substantially increases the current flow. However, if an SFCL is placed in series, as shown in Figure 3.7 (b), we must define I_{fault} as follows:

$$\mathrm{I_{line}} = \frac{\mathrm{V_s}}{\mathrm{Z_s + Z_{SFCL} + Z_{fault}}} \qquad (3.6)$$

Equation (3.6) shows that by injection of an SFCL, the fault current becomes a function of not only the source impedance, Z_s, and the fault impedance, Z_{fault}, but also the impedance of the SFCL. Hence, for a given source voltage, the fault current I_{fault} decreases as the Z_{SFCL} increases [34].

3.4 Fault current Minimization

Many reasons can cause a fault in a power scheme. The fault current level can be moderately huge, which may harm equipment in the power scheme and even basis for permanent failure. Power systems have to be designed to withstand mechanical and thermal stresses during a fault. Power system protection devices detect fault conditions and operate circuit breakers and other devices to limit the damage [35]. Nowadays, fault current levels in land-based distribution structures are of growing concern since they are commonly rising due to the growing size of connected distributed generation. Growing fault current levels will need luxurious network investment in advancement of equipment such as circuit breakers and transformers. There is an increasing need so for fault current limiting devices fixed into electrical systems to avoid a bulky scale and expensive upgrade of existing switchgear. SFCLs are expected to reduce fault current levels without adding additional impedance during normal operation. The capital cost of purchasing and installing SFCLs must be less than the cost of upgrading the existing equipment before they can be attractive for commercial applications [36].

3.4.1 Operating principles of fault current limitation

Later a short circuit happens in a power system, the fault current will rise quickly. The rate of current increase based on the source voltage, source impedance and fault phase angle. A typical prospective short circuit current is shown in the following figure below.

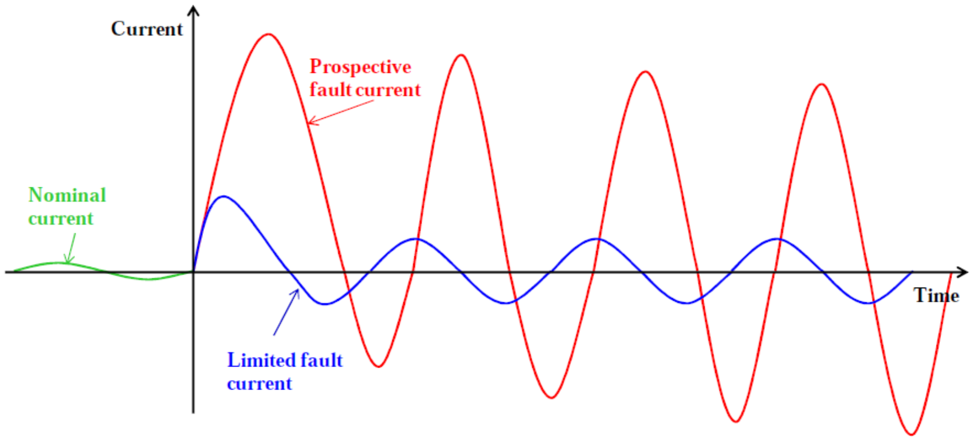


Figure 3.8. Typical fault current waveforms with and without fault current limiting [37]

3.5 Objective Function Formulation

Installing superconducting fault current limiters in the distribution system is mostly used to minimize the fault current level, minimization of power loss in the system and also used to balance the voltage drop in the distribution system. The objective functions are formulated in the following section by using mathematical formulas.

3.5.1 Fault Current Minimization

The basic equation for the fault current minimization is given as:

$$I_{MMFC} = I_{PFC} - I_{LFC} \tag{3.7}$$

Similarly,

$$\text{Min, } I_{MFC} = I_{without\ SFCL} - I_{with\ SFCL} \tag{3.8}$$

Where:

I_{MMFC}= of minimized fault current

I_{PFC} = prospective fault current

I_{LFC} = limited fault current

In consideration of the SFCL's effects on the induced overvoltage, the qualitative analysis is presented in [38]. In order to compute the overvoltage's made in the other two phases (phase B and phase C), the symmetrical component technique and complex sequence networks can be used, and the coefficient of grounding G in this state can be expressed as:

$$G = \frac{-1.5m}{(2+m)\pm j\sqrt{\frac{3}{2}}} \tag{3.9}$$

where m = R0/R1, and R0 is the distribution network's zero-sequence resistance, R1 is the positive-sequence resistance. Additionally, the amplitudes of the B-phase and C-phase overvoltage's can be defined as:

$$V_{BO} = V_{CO} = \sqrt{3}\left|\sqrt{\frac{G^2+G+1}{G+2}}\right|V_{AN} \quad (3.10)$$

Where V_{AN} is the phase-to-ground voltage's root mean square (RMS) under normal condition.

3.5.2 Minimization of Response Time

The SFCL is able to minimize the fault and reduce the fault current below the required level. It is desirable to reclose onto the power system as soon as possible after a fault is cleared. The time required before installing SFCL is greater than the time after installing SFCL for the response of fault.

$$min, T_r = T_{r,withoutSFCL} - T_{r,withSFCL} \quad (3.11)$$

Where: T_r is minimum response time

$T_{r,withoutSFCL}$ time response before installing SFCL

$T_{r,withSFCL}$ time response after installing SFCL

3.5.3 Voltage Drop Minimization

By installing the SFCL, the proposed method will try to minimize the voltage drop (VD) by minimizing the gap between the rated voltage that is usually one and the actual voltage of the bus nearer to zero. Therefore, it improves the voltage stability and the network performance.

$$\text{Min}, V_D = \sum_{i=1}^{B_n} (V_{bi} - V_{rated})^2 \quad (3.12)$$

Where;

B_n is total number of buses.

b_i is receiving bus number

V_{bi} is voltage of bus b_i

V_{rated} is the rated voltage

3.5.4 Constraints

The goal is to minimize the objective function formulated above to various inequality and equality operational constraints so that to satisfy the electrical requirements for the distribution network.

i) Fault Current Limits Constraints: When the RSFCL is installed in the distribution feeder, there is the upper and the lower limits constraints values. The fault current limits are between the system current under normal condition and fault condition without installing RSFCL for the system i.e.:

$$I_{NC} \leq I_{RSFCL} \leq I_{without\ RSFCL} \qquad (3.13)$$

Where; I_{NC} is current values under normal operating condition.

I_{RSFCL} fault current magnitude values of after installing RSFCL.

$I_{without\ RSFCL}$ is magnitude of fault current without installing RSFCL.

ii) Real and Reactive Power Loss Limits Constraints: Under real and reactive power losses limits I consider different power factors limits are listed during installation of RSFCL in Gimbichu distribution feeder.

- Power flow constraints for real and reactive power.

Real power balance:

$$P_{RSFCL} - P_{li} - P(V,\theta) = 0 \qquad (3.14)$$

Reactive power balance

$$Q_{gi} + Q_{RSFCL} + Q_{li} - Q(V,\theta) = 0 \qquad (3.15)$$

- Control variables limits for different types of distribution system equipment's.

Transformer tap change limits:

$$T_l^{min} \leq T_l \leq T_l^{max} \qquad (3.16)$$

Voltage source controller limits of reactive power in KVAr.

$$Q_{RSFCL}^{min} \leq Q_{RSFCL} \leq Q_{RSFCL}^{max} \qquad (3.17)$$

Real power limits after installing of RSFCL.

$$P_{RSFCL}^{min} \leq P_{RSFCL} \leq P_{RSFCL}^{max} \qquad (3.18)$$

Where;

P_{RSFCL} is real power flow after installing RSFCL.

P_{li} is load real power flow.

Q_{gi} is generation side reactive power flow.

Q_{RSFCL} is reactive power after installing RSFCL.

Q_{li} is load reactive power flow.

T_l^{min} is minimum transformer tap change.

T_l is transformer tap change.

T_l^{max} is maximum transformer tap change.

Q_{RSFCL}^{min} is minimum reactive power flow after installing RSFCL.

Q_{RSFCL}^{max} is maximum reactive power flow after installing RSFCL.

P_{RSFCL}^{min} is minimum real power flow after installing RSFCL.

P_{RSFCL}^{max} is maximum real power flow after installing RSFCL.

iii) Voltage drops balance constraints: Under the voltage drop balance constraints I want to formulate different types of bus voltage limits.

- PV bus voltage limits

$$V_{gRSFCL}^{min} \leq V_{gRSFCL} \leq V_{gRSFCL}^{max} \quad (3.19)$$

- PQ bus voltage limits.

$$V_{iRSFCL}^{min} \leq V_{iRSFCL} \leq V_{iRSFCL}^{max} \quad (3.20)$$

Where;

V_{gRSFCL}^{min} is minimum voltage after installing RSFCL in PV bus.

V_{gRSFCL} is voltage after installing RSFCL in PV bus.

V_{gRSFCL}^{max} is maximum voltage after installing RSFCL in PV bus.

V_{iRSFCL}^{min} is minimum voltage after installing RSFCL in PQ bus.

V_{iRSFCL} is voltage after installing RSFCL in PQ bus.

V_{iRSFCL}^{max} is maximum voltage after installing RSFCL in PQ bus.

3.6 Application of SFCL

SFCL is multipurpose equipment's for fault current organization(minimization) can be applied at different locations within a typical network. Applications of SFCL can be given as:

Feeder Application: Depending on the protecting function, the RSFCL can be utilized either in the incoming feeders, e.g., as transformer feeder, or in the outgoing feeders as shown in Fig

3.9 This inline application protects all elements from the downstream of the point of installation. Obviously, the ranking of the device changes according to the selected location.

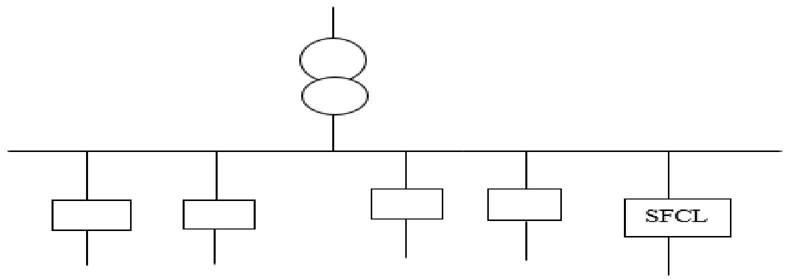


Figure.3.9. SFCL in Feeder Location [36]

Busbar Coupling: The RSFCL is specifically beneficial for busbar couplings, as completely redundant feed-in is probable without generally related increase in short-circuit currents as shown in Fig.3.10. In case of a fault, the limiter ensures that the short-circuit contribution from the un-faulted bus is strongly reduced.

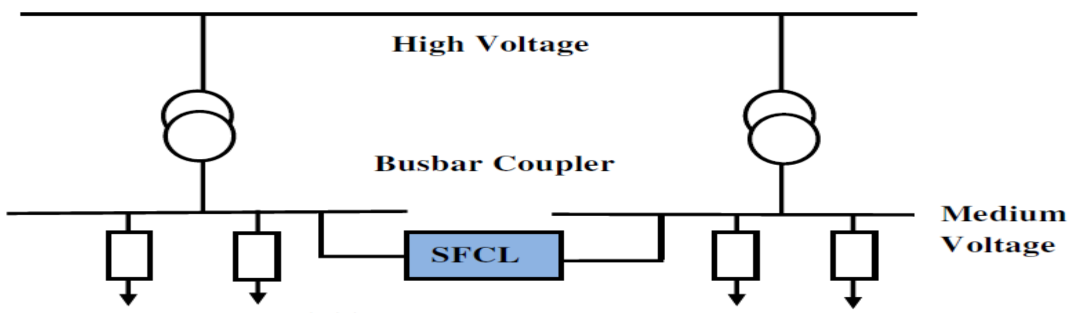


Figure.3.10. SFCL in Busbar Coupling Point [37]

SFCL in a Transformer Feeder Location: Placing a SFCL in a transformer feeder location offers great flexibility in reducing substation fault levels to accommodate switchgear ratings as shown in Fig.11. One or more SFCLs may be installed, depending on the fault reduction required, with minimal changes to existing protection settings.

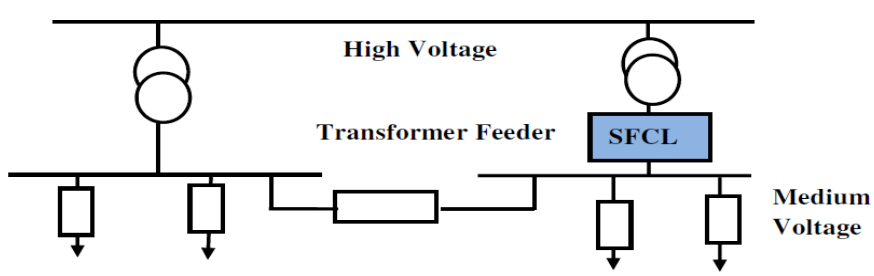


Figure.3.11. SFCL is placed in Transformer Feeder Point [37]

One or more SFCL may be installed, depending on the bus-bar topology and fault reduction required, with minimal changes to existing protection settings. It also enables paralleling of bus SFCL High Voltage Medium Voltage Transformer Feeder SFCL High Voltage Medium Voltage Bus-Tie Location sections in previously split substations, allowing interconnectivity, more flexible running arrangements and improved power quality.

3.6.1 Types of Superconducting FCLs

Depending on the structure and operating principle, superconducting fault current limiters (SFCLs) can be categorized as different types: non-inductive reactor, inductive, transformer, resistive, hybrid, flux-lock and magnetic-shield.

Non-Inductive Type SFCL: A schematic diagram of non-inductive type SFCL is shown in Figure 3.12 which is made of two superconducting coils.

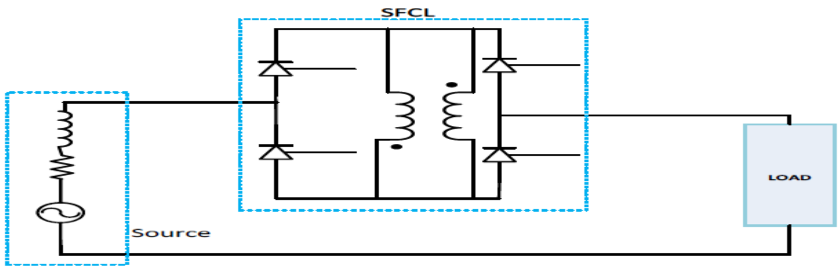


Figure.3.12. Basic circuit diagram of non-inductive superconducting fault current limiter (SFCL) with single phase circuit [38].

Inductive Type SFCL: consumes two coaxial windings and an optional magnetic core. Primary winding is made up of copper, however secondary winding is made up of a high temperature superconductor (HTS). The SFCL is airconditioned in a fluid nitrogen bath. The electrical connection figure of inductive SFCL is exposed in Figure 4.13 [39].

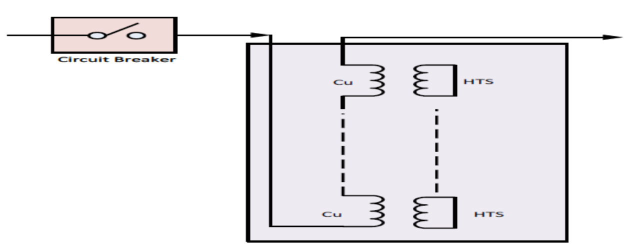


Figure.3.13. Inductive SFCL [39]

Transformer Type SFCL: Enhancement of supply reliability and power system stability have been observed with the transformer type SFCL. The primary side of the transformer type SFCL is linked in series with the load while the secondary side is also linked in series with superconductors. The transformer type fault current limiter with vacuum interrupter is shown in the Figure 3.14. In Figure 3.14, L1 and L2 are the inductance in primary and secondary respectively. M is the mutual inductance between the primary and secondary coils of the transformer [38].

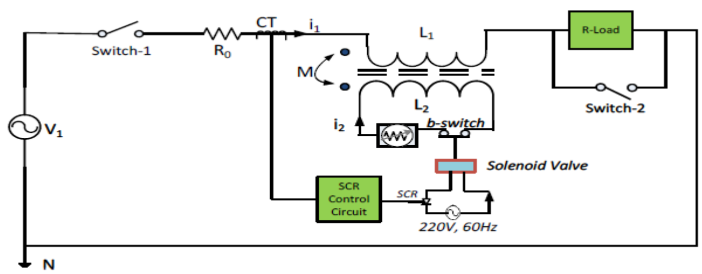


Figure.3.14. Transformer Type SFCL with load in single phase circuit [38]

Resistive type SFCL: A resistive SFCL is the simplest and most compact SFCL design which directly uses the natural characteristics of the superconductor material. The representation circuit of a resistive SFCL is shown in Fig.3.15. A resistor or inductor is usually placed in parallel with the superconducting element to remove overvoltage if the resistance of the superconductor increases too quickly after a fault occurs. During normal operation, the superconducting element carries the full DC current in the superconducting state with negligible resistance. Once a fault occurs, the current through the superconductor increases quickly. When the current in the superconductor exceeds the critical current level, the superconductor reduces and develops resistance, limiting the fault current level. The resistance of the superconductor increases quickly and therefore a high percentage of the fault current is diverted into the parallel resistor or inductor which helps to limit the fault current [45]. Resistive type SFCL can advance the transient stability of the power scheme by overturning the level of fault currents in a fast and effective manner [39].

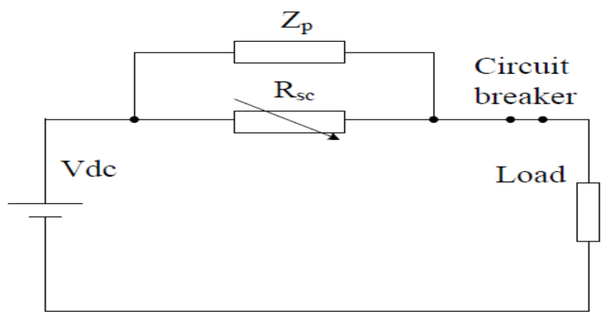


Figure.3.15. Electric circuit of a resistive SFCL with parallel impedance [39].

3.6.2 Modeling of Gimbichu distribution Feeder Line parameters

Now calculate positive sequence resistance (ohm/km), capacitance (F/km) and inductance (H/km) and zero sequence resistance(ohm/km), capacitance (F/km) and inductance(H/km) in distribution feeders.

$$\mathrm{R_{actual}} = \mathrm{R_{base}} * \mathrm{R_{pu}} \quad (3.21)$$

$$\mathrm{X_{actual}} = \mathrm{X_{base}} * \mathrm{X_{pu}} \quad (3.22)$$

$$B_{actual} = B_{base} * B_{pu} \quad (3.23)$$

Where, $R_{base} = X_{base} = \frac{V_{base}^2}{S_{base}}$ and $B_{base} = \frac{S_{base}}{V_{base}^2}$

Therefore**,**

$$\frac{\mathrm{R_1(\Omega)}}{\mathrm{Km}} = \frac{\mathrm{R_{actual}}}{\text{Line length of feeder}}$$

$$= \frac{\frac{\mathrm{V_{base}^2}}{\mathrm{S_{base}}} * \mathbf{R_{pu}}}{\textbf{Line length of feeder}} \quad (3.24)$$

Zero sequence resistance is given by:

$$\mathrm{R_0}(\Omega/\mathrm{Km}) = 3\mathrm{R_1}(\Omega/\mathrm{Km}) \quad (3.25)$$

$$\boldsymbol{C_{actual}} = \frac{\mathrm{B_{actual}}}{2\pi \mathrm{f}}$$

$$\mathrm{C_1}(\mathrm{F}/\mathrm{Km}) = \frac{\mathrm{C_{actual}}}{\text{Line length of feeder}} \quad (3.26)$$

$$\mathrm{C_0} = 3\mathrm{C_1}(\mathrm{F}/\mathrm{Km})$$

Similarly, now find the value of positive sequence inductance zero sequence inductance:

$$\mathrm{L_{actual}} = \frac{\mathrm{X_{actual}}}{2\pi \mathrm{f}} \quad (3.27)$$

$$L_1(H/_{Km}) = \frac{L_{actual}}{\text{Line length of feeder}} \quad (3.28)$$

$$L_0(H/_{Km}) = 3L_1(H/_{Km}) \quad (3.29)$$

The following data is collected from the case study areas of Hossana substation for Gimbichu feeder lines. The given resistance in per unit value is (R_{PU} = 0.0103), reactance in per unit value is (X_{PU} =0.0725) and susceptance in per unit value is (B_{PU} = 0.1507). The distribution line has the base voltage and base apparent power is 15kv/5MVA and also the total length is 150km. Now calculate positive sequence resistance (ohm/km), capacitance (F/km) and inductance (H/km) and zero sequence resistance(ohm/km), capacitance (F/km) and inductance(H/km). Now calculate this parameters values by using equations (3.21 to 3.29)

Table 3.5 Shows the calculate line parameters values of positive and zero sequence

No,	Line parameters	Calculated Values
1	Positive Sequence Resistance	0.00309 Ω/Km
2	Zero Sequence Resistance	0.00927 Ω/Km
3	Positive Sequence Inductance	0.0693 µH/Km
4	Zero Sequence Inductance	0.231 µH/Km
5	Positive Sequence Capacitance	71.1017 µF/Km
6	Zero Sequence Capacitance	213.305 µF/Km

3.6.3 Design of the RSFCL model

The three-phase SFCL model is constructed by assuming five basic parameters for the prototyping of a resistive type SFCL:

- The transition time, between the superconducting state to the normal state, simply called the SFCL response time, i.e., the time period after which the fault current limiter responds to a short-circuit fault current.
- The minimum impedance, i.e., the impedance of the SFCL during normal operation (superconducting state).

- The maximum impedance, i.e., impedance of the SFCL under a short-circuit fault, also called the quench state.
- The triggering current, i.e., the amount of current required for quenching the SFCL.
- The recovery time, i.e., the time period after which the SFCL is restored from the quenched state to its superconducting state, and the fault is cleared out of the power system.

In a three-phase power system, each phase of the SFCL must be simulated separately as each phase is triggered by only the current flowing in its own phase. In particular, under the condition of an unbalanced primary system fault, which is actually the predominant mode of faults in power distribution systems (especially in overhead systems), within the first cycle of fault current during a three-phase-to-ground fault, each phase of the SFCL will quench slightly asynchronously, which leads to an instantaneous unbalance of the phase. Furthermore, unbalanced faults can also lead to the occurrence of a quench in only one or two phases of the entire SFCL. From now, independent parts for each one of the three phases have to be considered in order to agree for exact simulation of the RSFCL's effects on the complete power grid, and for all types of faults at diverse locations. The structure of the SFCL module built in this project is shown in Figure 3.16.

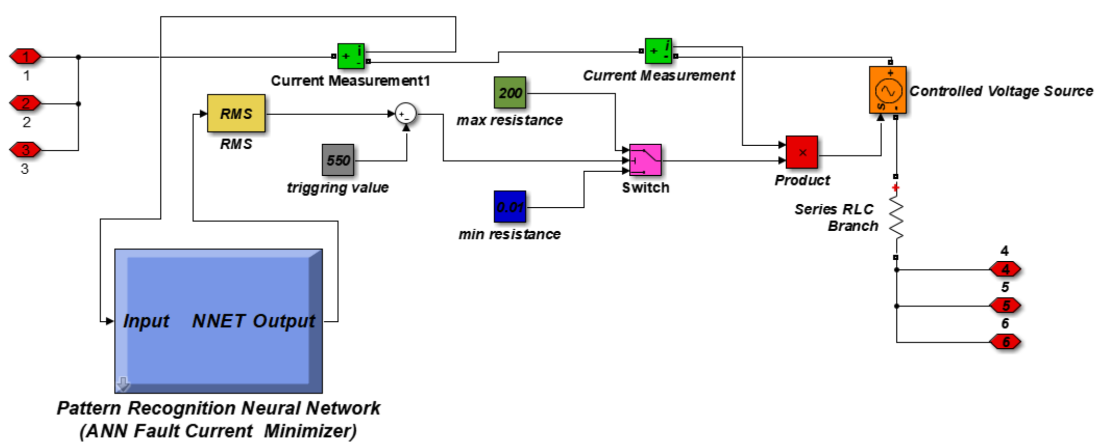


Figure 3.16. SFCL model developed in the MATLAB/Simulink

The values of the basic parameters of a resistive type SFCL as explained above are listed in Table 3.6 Basic parameters of the RSFCL model

No.	SFCL Parameters	Values
1	Transition/Response Time	0.1 ms
2	Minimum/Normal Operating Resistance	0,01Ω
3	Maximum/Quenching Resistance	20Ω
4	Triggering Current	550A

3.7 Different types of Techniques for Fault Current Minimization

3.7.1 Fuzzy Logic Controller

Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value.

The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used, but the shape is generally less important than the number of curves and their placement. From three to seven curves are generally appropriate to cover the required range of an input value, or the "universe of discourse" in fuzzy jargon. As discussed earlier, the processing stage is based on a collection of logic rules in the form of IF-THEN statements, where the IF part is called the "antecedent" and the THEN part is called the "consequent". Typical fuzzy control systems have dozens of rules.

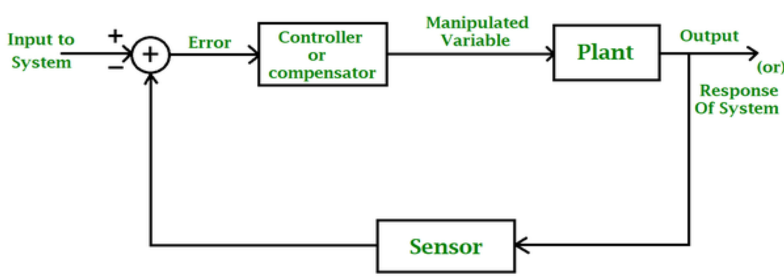


Figure 3.17. Fuzzy Logic Control System [40]

3.7.2 Nuro-Fuzzy Logic Controller

A neuro-fuzzy controller was designed and implemented by using both neural network and fuzzy logic over a mobile robotic platform. The controller is based on fuzzy clusters, neural networks, and search techniques. The neuro-fuzzy controller was split in two parts: the position controller and the evasion controller against collisions.

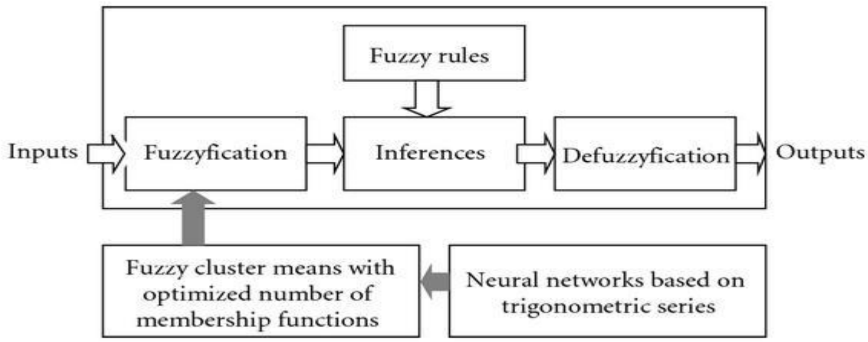


Figure 3.18. Nuro-Fuzzy Control Scheme [41]

3.7.3 Binary Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a heuristic optimization algorithm generally applied to continuous domains. Binary PSO is a form of PSO applied to binary domains but uses the concepts of velocity and momentum from continuous PSO, which leads to its limited performance.

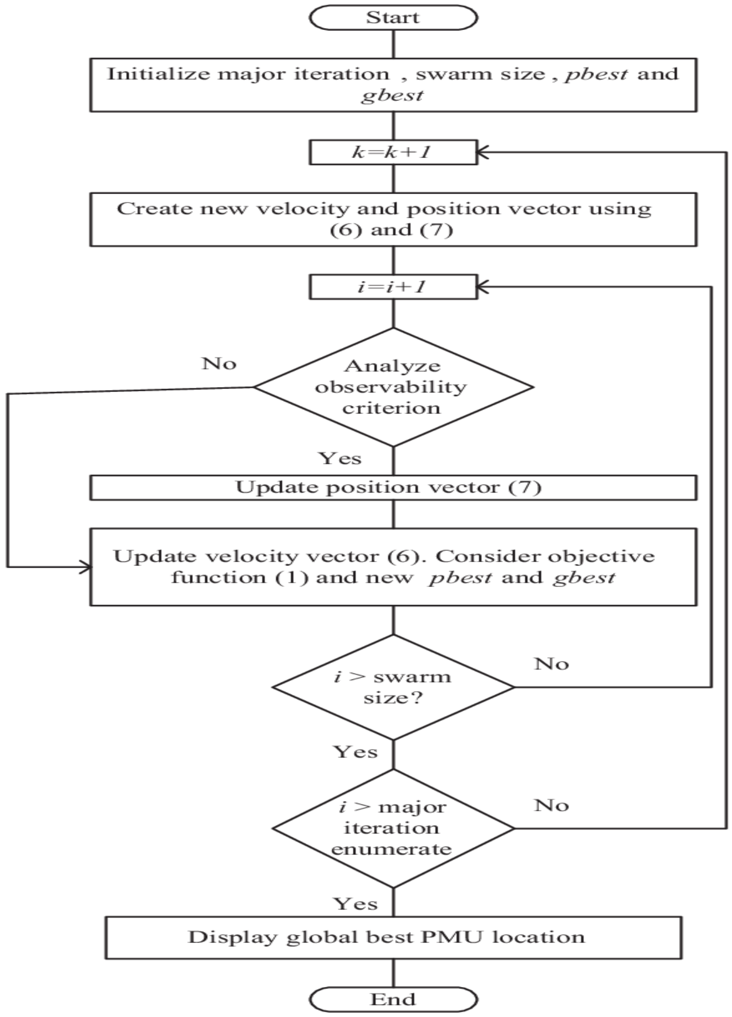


Figure 3.19. BPSO Flow Chart [42]

3.7.4 Teaching Learning Based Optimization (TLBO)

Teaching-learning-based optimization (TLBO) is a population-based metaheuristic search algorithm inspired by the teaching and learning process in a classroom. It has been successfully applied to many scientific and engineering applications in the past few years. In the basic TLBO and most of its variants, all the learners have the same probability of getting knowledge from others. However, in the real world, learners are different, and each learner's learning enthusiasm is not the same, resulting in different probabilities of acquiring knowledge [43]. The TLBO process is carried out through two basic operations: teacher phase and learner phase.

In the teacher phase, the best solution in the entire population is considered as the teacher, and the teacher shares his or her knowledge to the learners to increase the mean result of the class. Assume $X_i = (x_i^1, \dots, x_i^d, \dots, x_i^D)$ the position of the *i* th learner, the learner with the best fitness is identified as the teacher $X_{teacher}$, and the mean position of a class with *NP* learners can be represented as $X_{mean} = (1/_{NP}) \sum_{i=1}^{NP} X_i$. The position of each learner is updated by the following equation:

$$X_{i,mean} = X_{i,old} + \boldsymbol{rand}.(X_{teacher} - T_F.X_{mean} \quad (3.30)$$

where $\boldsymbol{X}_{i,new} = (x_{i,new}^1, \dots, x_{i,new}^d, \dots, x_{i,new}^D)$ and $\boldsymbol{X}_{i,old} = (x_{i,old}^1, \dots, x_{i,old}^d, \dots, x_{i,old}^D)$ are the *i*th learner's new and old positions, respectively, is a random vector uniformly distributed within $[0.1]^D$, $T_F$is a teacher factor, and its value is heuristically set to either 1 or 2. If $\boldsymbol{X}_{i,new}$ is better than $\boldsymbol{X}_{i,old}, \boldsymbol{X}_{i,new}$, is accepted, otherwise $\boldsymbol{X}_{i,old}$ is unchanged

In the learner phase, a learner randomly interacts with other different learners to further improve his/her performance. Learner X_i randomly selects another learner $X_j(j\#i)$ and the learning process can be expressed by the following equation:

$$\boldsymbol{X}_{i,new} = \begin{cases} \boldsymbol{X}_{i,old} + \boldsymbol{rand}.\left(\boldsymbol{X}_i - \boldsymbol{X}_j\right), if\ f(\boldsymbol{X}_i) \leq f(\boldsymbol{X}_j) \\ \boldsymbol{X}_{i,old} + \boldsymbol{rand}.\left(\boldsymbol{X}_j - \boldsymbol{X}_i\right), if\ f(\boldsymbol{X}_i) > f(\boldsymbol{X}_j) \end{cases} \quad (3.31)$$

where $f(x)$ is the objective function with *D*-dimensional variables and $X_{j,old}$ is the old position of the *j*th learner. If $X_{i,new}$ is better than $X_{i,old}, X_{i,new}$ is used to replace $X_{i,old}$.

3.8 Simulink Model of Hossana Distribution Feeder in MATLAB

Simulations and verification of the procedures correctness and methodology are a significant task in order to make a reliable tool for future simulations and calculation. All algorithms have various weaknesses in the fault current magnitude minimization. In order to document and verify the weaknesses and strengths of the simulation model we can developed the Simulink.

The model has three-phase sources at each side of substation, three-phase transformer, three-phase V-I measurements, three-phase breakers, capacitive and resistive loads, three-phase PI-section lines, SFCL and powergui in the design power system model according to (Figure

3.20). Simulation model is developed with variable input value and the data is imported to the MATLAB model for analysis of fault current magnitude minimization.

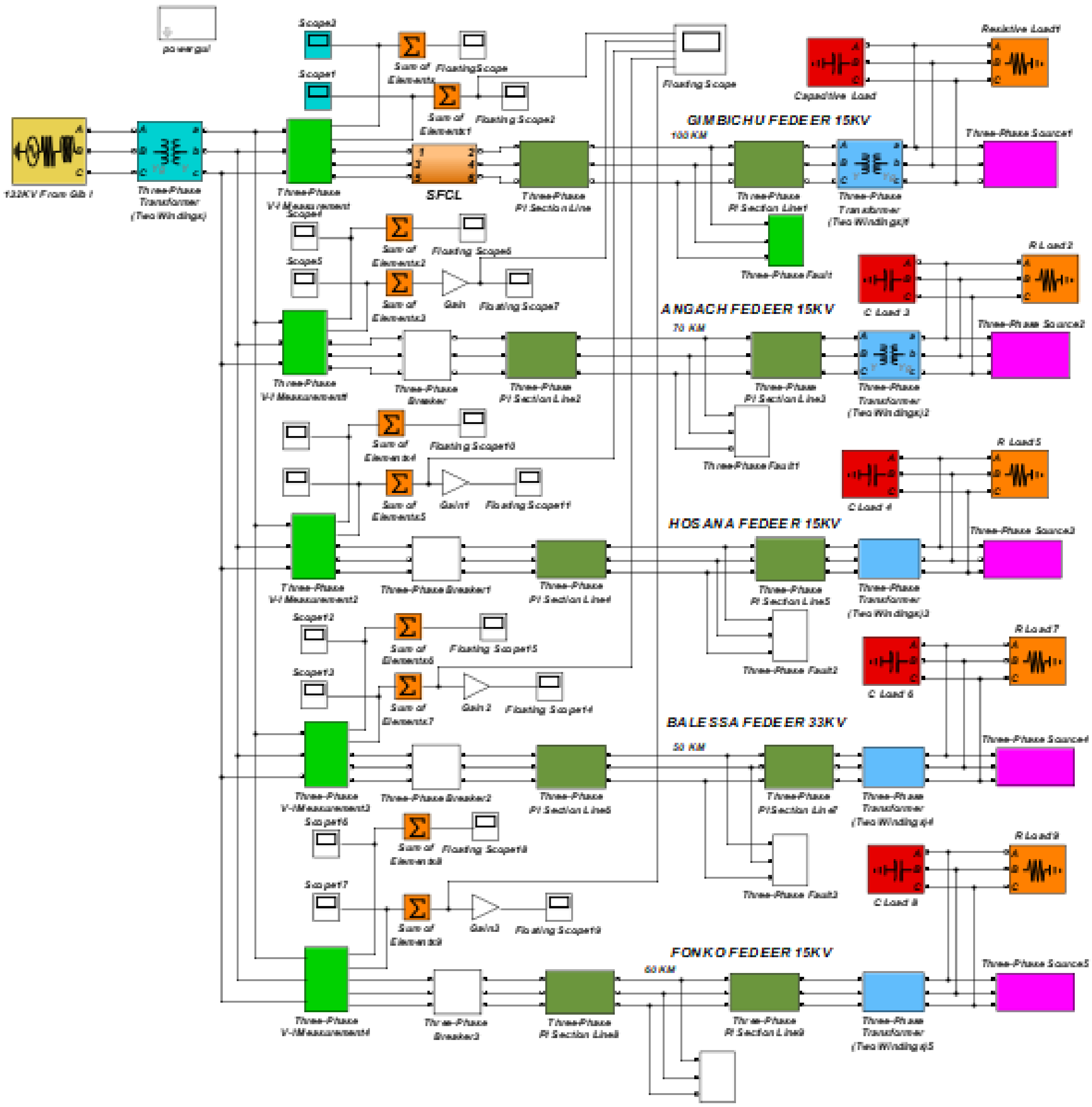


Figure 3.20. Simulink model for verification of fault current minimization

Chapter Four

Results and Discussion

4.1 Introduction

After designing and implementation of model of resistive type SFCL in simple three phase system in MATLAB/Simulink the results are obtained. Because resistive type SFCL is the simplest and most compact SFCL design which directly uses the natural characteristics of the superconductor material. The current and voltage waveforms are compared with and without SFCL in different operating conditions like steady state, fault etc. In the substation-distribution system, the current waveforms of all the feeders in steady state, fault without SFCL and fault with SFCL in different locations are analyzed and compared.

4.2 The Implementation of SFCL in Three Phase Systems

Due to the improved fault-level currents, SFCL is more probable to enter into a low voltage and medium voltage distribution network to expand their stability and lower the electric devices size. Therefore, it is significant to model a SFCL in power system to evaluate its act and learning its appearances. A SFCL model is combined into a three-phase system to simulate its performance in a grid.

4.2.1 Distribution Systems steady state model

The three-phase system shown in Fig.4.1 is in steady state condition or normal condition that means there is no fault in this condition. The three-phase scheme has been started at time 0.1 s and takes till the end of the simulation. The magnitude of current and voltage is 10A and 15 kV as shown in Fig.4.2 and Fig.4.3 respectively.

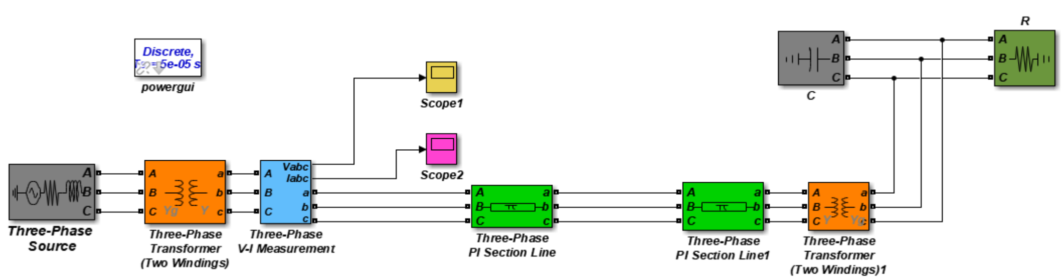


Figure 4.1. The Simulink model of the three-phase under normal condition

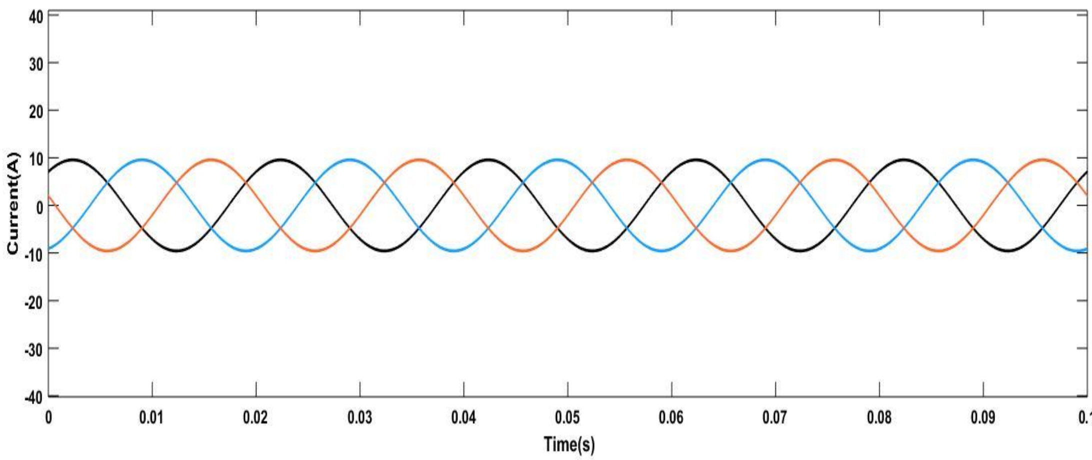


Figure 4.2. Three Phase Current Waveform at Steady State Condition

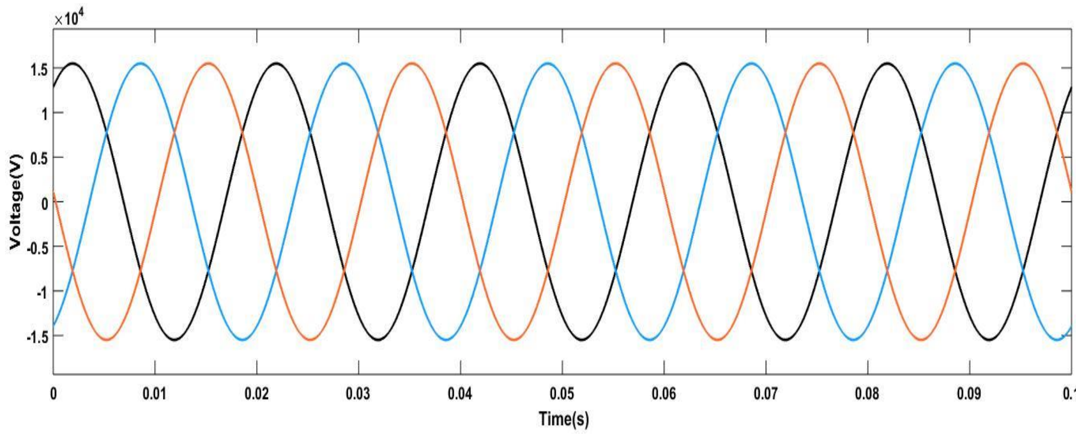


Figure 4.3. Three Phase Voltage Waveform at Steady State Condition

4.2.2 Three Phase Systems in Fault Condition Without SFCL

As shown in Fig.4.4, the simulation power system includes a power source, and a load. The three-phase to ground fault has been started at time of 0.1s and takes till the end of the simulation. From Fig.4.4, it could be noted that when there is no SFCL applied in the system, the peak value of the three-phase fault current could be as high as about 40KA. Fig.4.5. shows that voltage drop to 12.5KV in faulty condition.

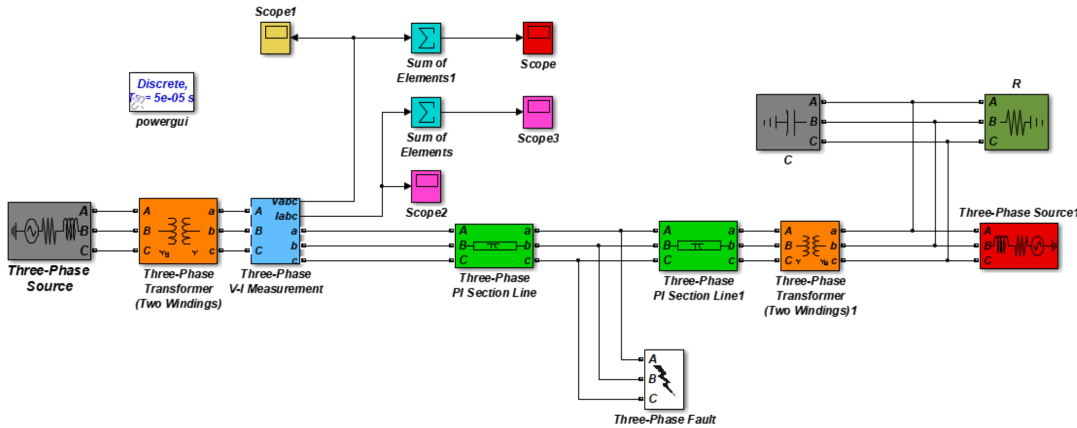


Figure 4.4. Three Phase System in Fault Condition without SFCL

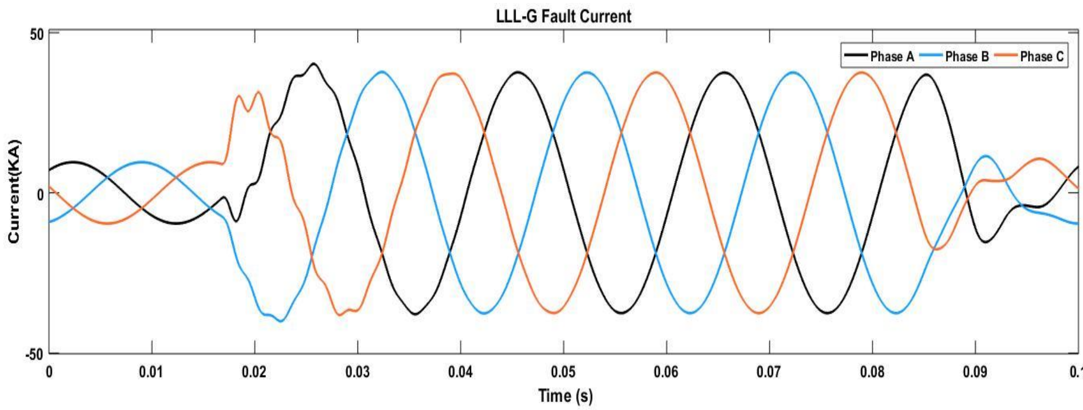


Figure 4.5. Three Phase Current Waveform during Fault Condition without SFCL

Under figure 4.5 the system fault current magnitude is minimum up to the time 0.02 sec. When the three phase LLL- G fault is applied to the system the magnitude of fault current is very high or the three phases are disturbed i.e., from the time 0.02 sec to the time 0.09 sec maximum fault current magnitude. Then after the time 0.09 sec when the system fault is cleared the magnitude of fault current is stable or minimum value.

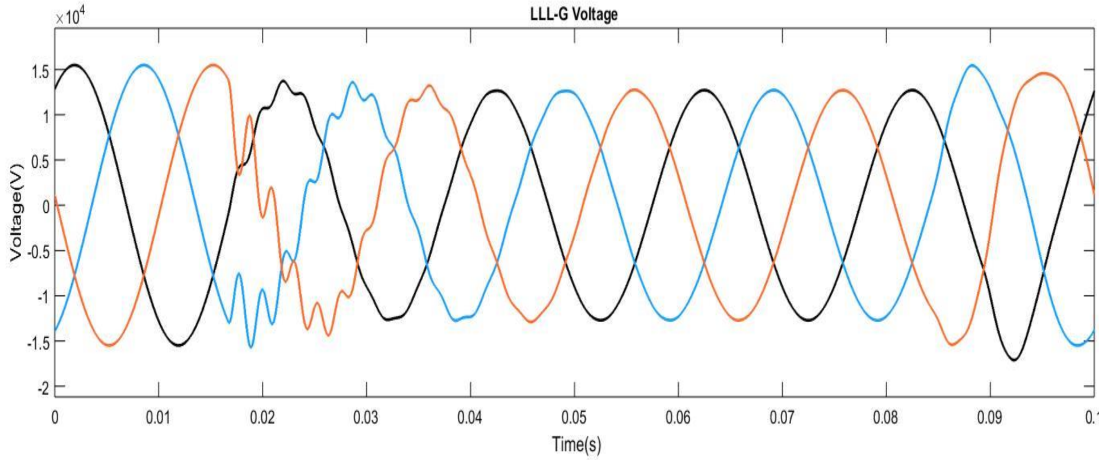


Figure 4.6. Three Phase Voltage Waveform during Fault Condition without SFCL

Figure 4.6 shows that the system voltage magnitude is less than the rated voltage values i.e., there is a voltage drop to the system. Before three phase fault is applied to the system the rated voltage value for Gimbichu feeder is 15 KV. After LLL-G fault is applied to the system magnitude of voltage is 12.5KV from the time 0.02 sec to 0.09 sec.

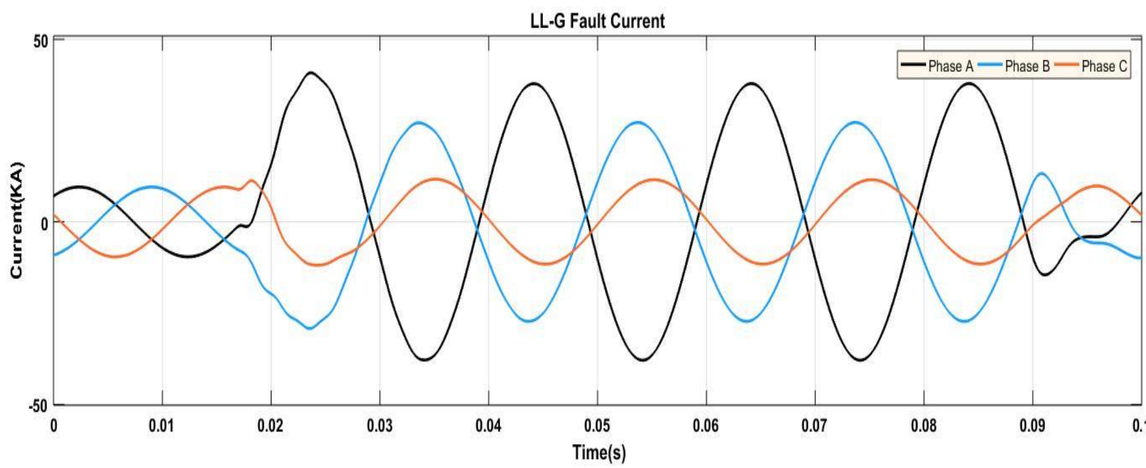


Figure 4.7. LL-G Fault Current without SFCL

Under figure 4.7 the system fault current magnitude is minimum up to the time 0.02 sec. When the LL- G fault is applied to the system the magnitude of fault current is very high or the two phases (phase A and phase B) are disturbed i.e., from the time 0.02 sec to the time 0.09 sec maximum fault current magnitude. Then after the time 0.09 sec when the system fault is cleared the magnitude of fault current is stable or minimum value.

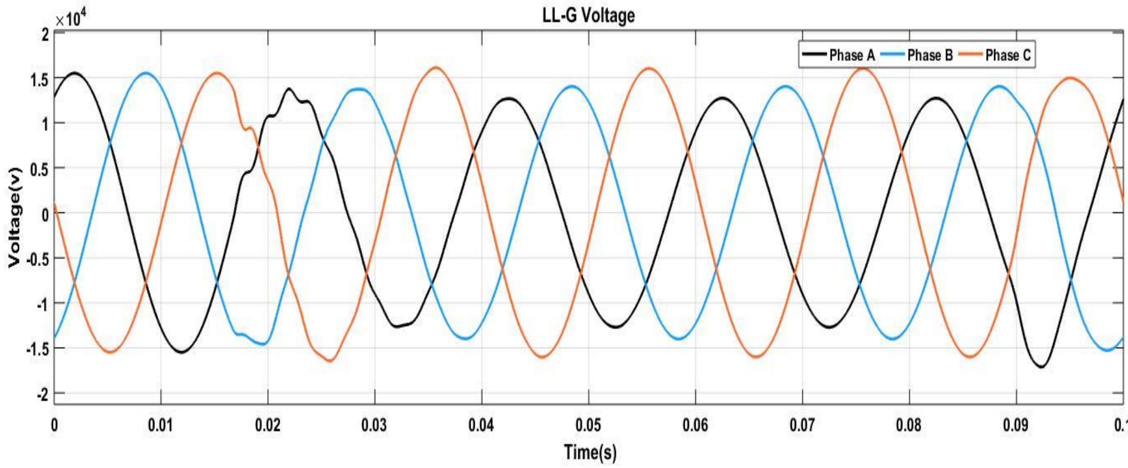


Figure 4.8. LL-G Voltage without SFCL

Figure 4.8 shows that the system voltage magnitude is less than the rated voltage values for the two phases i.e., there is a voltage drop to the system. Before LL- G fault is applied to the system the rated voltage value for Gimbichu feeder is 15 KV. After LL-G fault is applied to the system magnitude of voltage is 12.5KV from the time 0.02 sec to 0.09 sec. But the remain phase C have normal voltage magnitude.

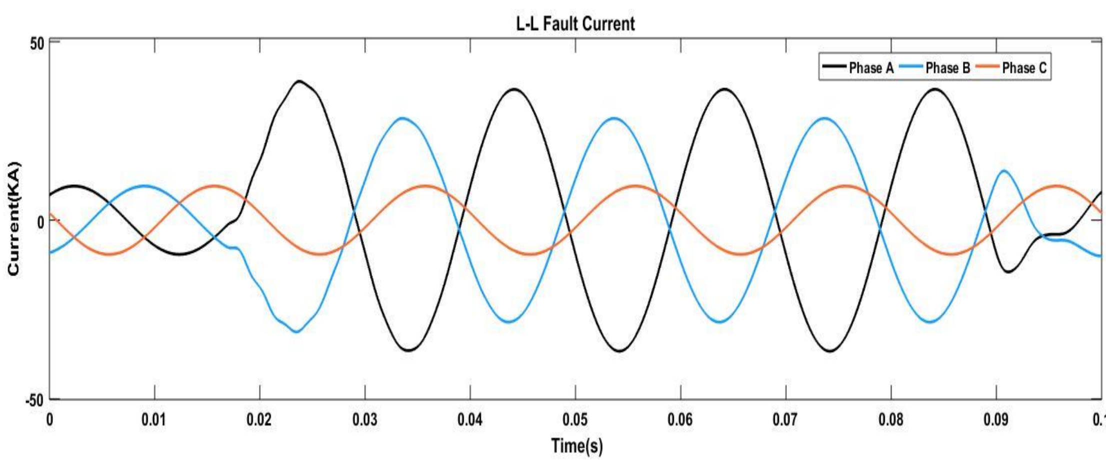


Figure 4.9. L-L Fault Current without SFCL

Under figure 4.9 the system fault current magnitude is minimum up to the time 0.02 sec. When the L-L fault is applied to the system the magnitude of fault current is very high or the two phases (phase A and phase B) are disturbed i.e., from the time 0.02 sec to the time 0.09 sec maximum fault current magnitude. Then after the time 0.09 sec when the system fault is cleared the magnitude of fault current is stable or minimum value. This is the reason of absence of superconducting fault current limiter (SFCL) to the system or the system is without SFCL.

Figure 4.10 shows that the system voltage magnitude is less than the rated voltage values for the two phases i.e., there is a voltage drop to the system. Before L-L fault is applied to the system the rated voltage value for Gimbichu feeder is 15 KV. After L-L fault is applied to the system magnitude of voltage is 12.5KV from the time 0.02 sec to 0.09 sec. But the remain phase C have normal voltage magnitude.

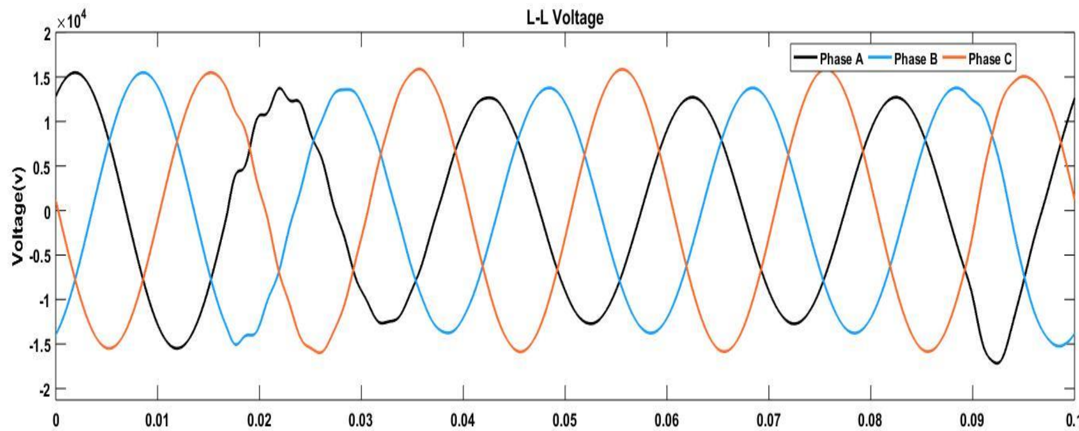


Figure 4.10. L-L Voltage without SFCL

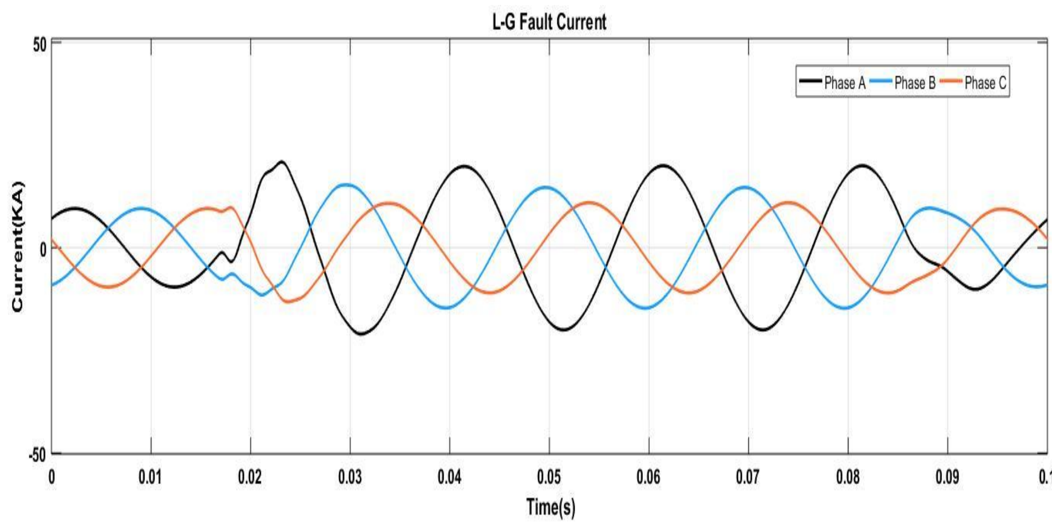


Figure 4.11. L-G Fault Current without SFCL

When the single line to ground fault is occurred in the system, i.e., the system is without superconducting fault current limiter (SFCL) then the system fault current magnitude is as much as very high magnitude as compared with the remaining two phases. By considering figure 4.11 the fault current magnitude is approximately 20KA from time of 0.02 sec to 0.09 sec but, before 0.02 sec the magnitude of the three phases has normal and also there is voltage drop in the system, i.e., the normal system voltage rating is 15KV. So, single line to ground fault is applied to the system there is voltage drop to the system from 15KV to 14.5KV in figure 4.12.

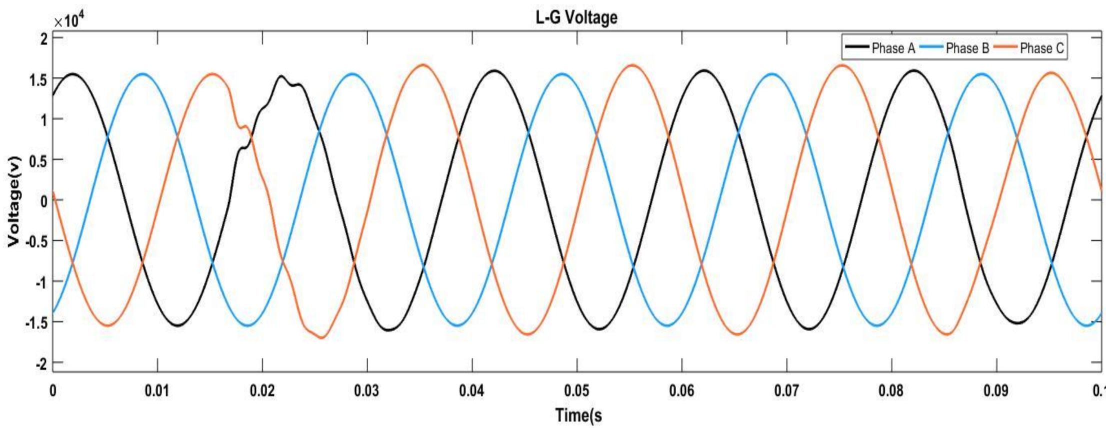


Figure 4.12. L-G Voltage without SFCL

4.2.3 Three Phase Systems in Fault Condition With SFCL

Under this case how to check the fault current magnitude with superconducting fault current limiter (SFCL). When SFCL is installed at each feeder in distribution lines.

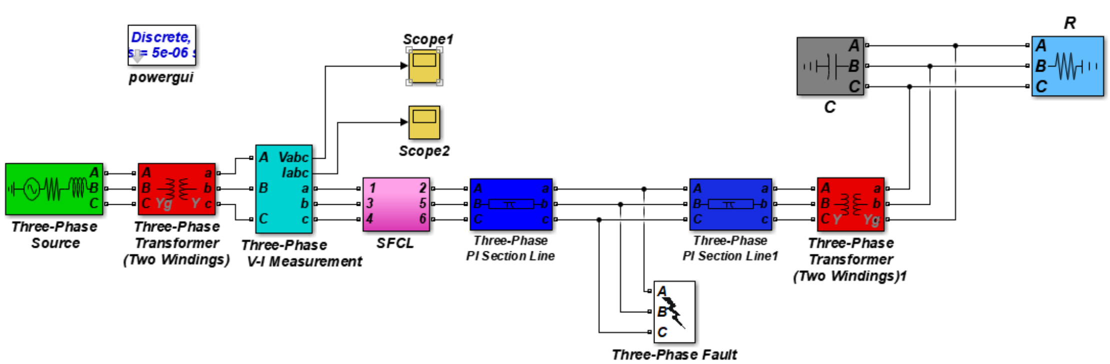


Figure 4.13. Three Phase System in Fault Condition with SFCL

In faulty condition the magnitude of fault current could be high as about 40 KA. This high magnitude of fault current has to be reduced within the rating of protective equipment's. This can be achieved by implementing the SFCL in three phase systems as shown in Fig.4.4. The presence of SFCL in the system reduces the peak value of three phase fault current to 140A as shown in Fig.4.14. When flowing current is greater than critical current and temperature is greater than critical temperature of superconducting material then there is transition from superconducting state to normal state, in normal state it adds higher resistance (20ohm). The product of this resistance and flowing current is applied to the input of controlled voltage source. This controlled voltage source builds up voltage in fault condition, thus reduces the current automatically. The critical current and critical temperature has been taken as 550A and -193ºC respectively.

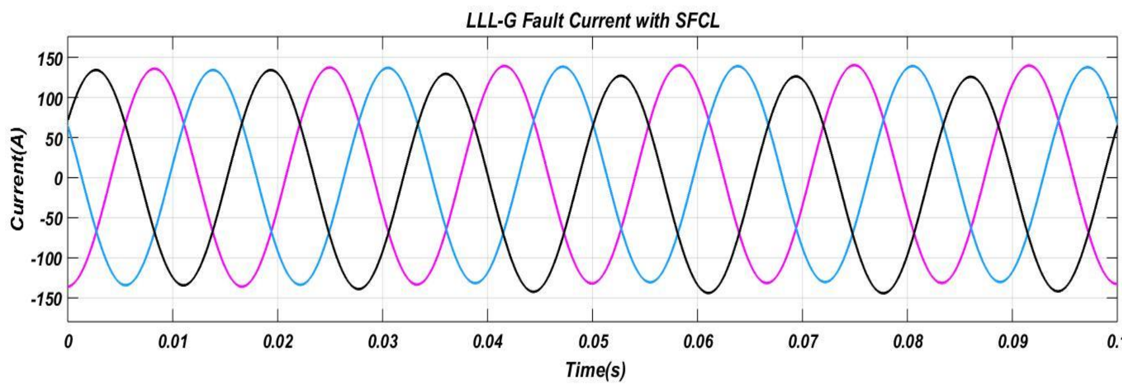


Figure 4.14. The three Phase Fault Current with SFCL

4.2.4 The Three Phase Fault Single Line to Ground (L-G) Fault

After installing of superconducting Fault Current Limiter (SFCL) device to the system the fault current magnitude is minimized, i.e., from high magnitude of 20KA fault current values to less magnitude of 150A fault current. The fault current magnitude values are minimized in all fault types, i.e., under subtopic 4.2.5 and 4.2.6.

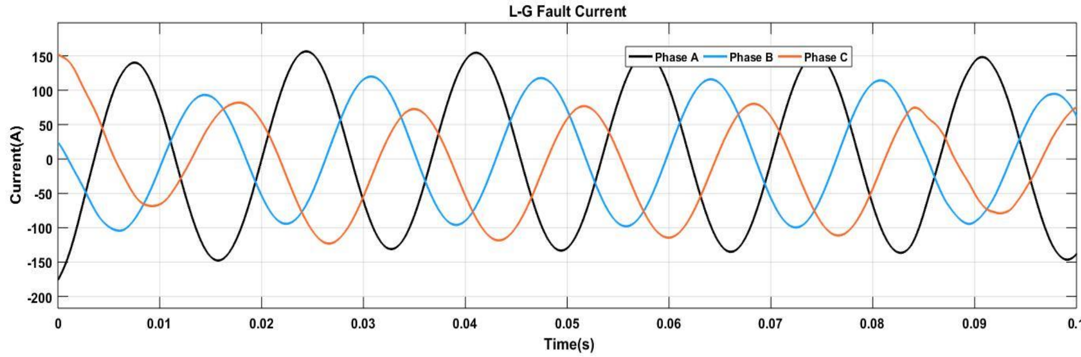


Figure 4.15. L-G Fault current with SFCL

4.2.5 The Three Phase Fault Double Line to Ground (LL-G) Fault

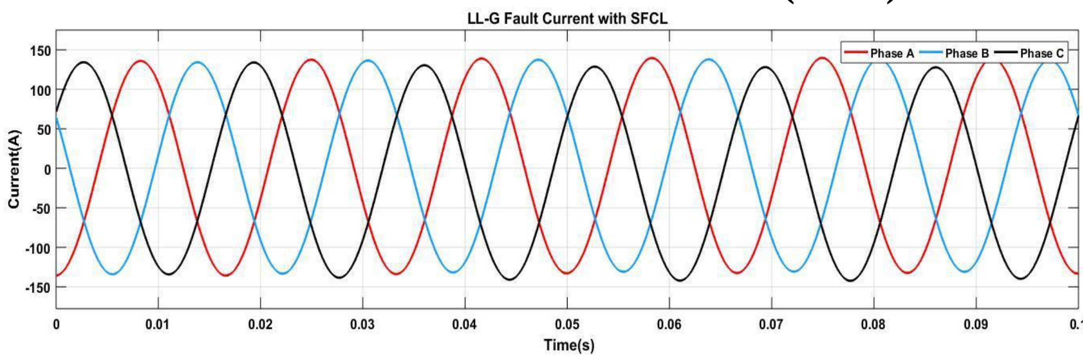


Figure 4.16. LL-G Fault Current with SFCL

Figure 4.16 shows the magnitude of short circuit fault current after installing superconducting fault current limiter (SFCL) device to the system. Before installing SFCL device to the system the magnitude of short circuit fault current is 40KA. Then after installing SFCL device to the system magnitude of short circuit fault current is minimized into 130A

4.2.6 The Three Phase Fault with Line to Line (L-L) Fault

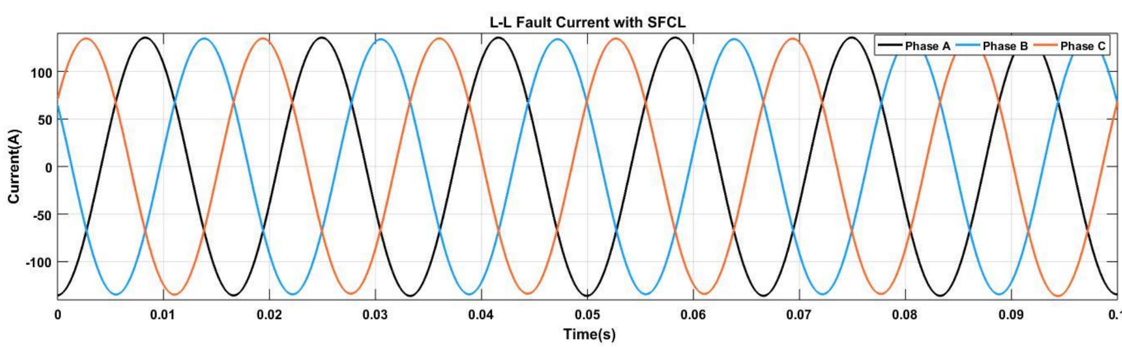


Figure 4.17. L-L Fault Current with SFCL

Figure 4.17 shows the magnitude of short circuit fault current after installing superconducting fault current limiter (SFCL) device to the system. Before installing SFCL device to the system the magnitude of short circuit fault current is 40KA. Then after installing SFCL device to the system magnitude of short circuit fault current is minimized into 150A

4.3 Results during Comparison of Different Techniques for Fault Current Minimization

Under this topic how to compere the fault current values. The techniques used for the comparison are fuzzy logic controller, Nuro-fuzzy controller, particle swarm optimization and teaching learning optimization with artificial neural network.

4.3.1 Comparison of Short Circuit Fault Current of ANN with Fuzzy Logic Controller

When comparing the fault current magnitudes in case of Artificial Nural Network and Fuzzy Logic controller, the performance to minimize the fault current, i.e., in case of ANN the short circuit current magnitude is less than Fuzzy Logic controller techniques.

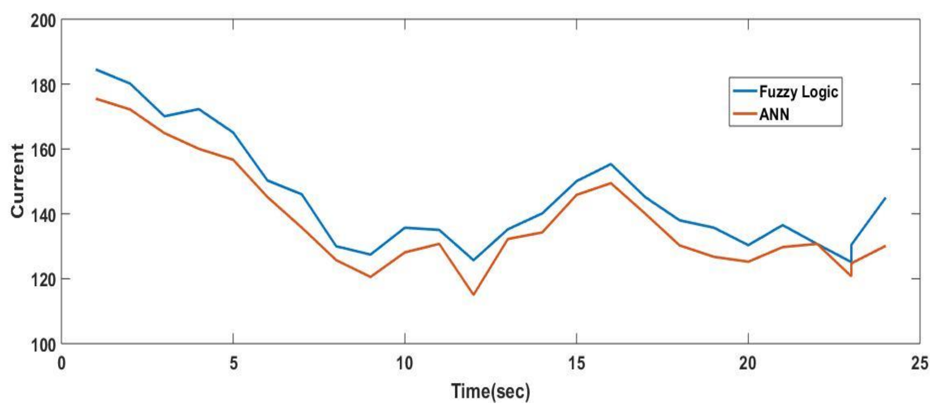


Figure 4.18. Comparison of Fault Current of ANN with Fuzzy Logic Controller

Figure 4.18 shows the comparison result of both ANN and Fuzzy logic controller techniques. Under this comparison there are two portions. The first portion covers the time intervals from 0 sec to 9 sec. In the first portion the magnitude of short circuit fault current becomes decreasing from 180A to 120A. This is the reason of system impedance value becomes increasing. The second portion covers the time intervals from 9 sec to 25 sec. Under this portion the short circuit fault current is less than the first portion. As I can compare the first portion with the second portion, the second portion has best performance of ANN techniques i.e., magnitude of short circuit fault current is 125A to 150A.

4.3.2 Comparison of Short Circuit Fault Current of ANN with Nuro - Fuzzy Logic Controller

When comparing the fault current magnitudes in case of Artificial Nural Network and Nuro - Fuzzy Logic Controller, the performance to minimize the fault current, i.e., in case of ANN the short circuit current magnitude is less than Nuro - Fuzzy Logic Controller techniques.

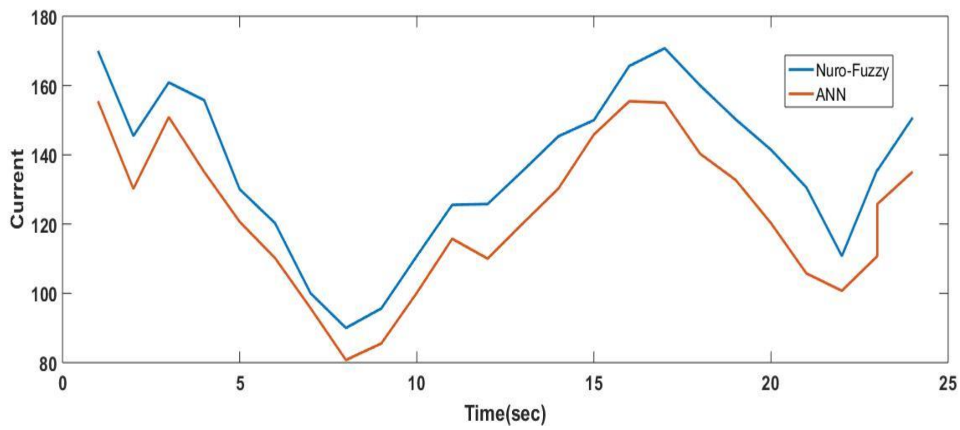


Figure 4.19. Comparison of Fault Current of ANN with Nuro - Fuzzy Logic Controller

In figure 4.19 the comparison result of ANN and Nuro-fuzzy logic controller is divided in to three portions. In portion one the comparison results of ANN and Nuro-fuzzy controller covers the time from 0 sec to 8 sec. In this portion the magnitude of short circuit fault current values can be decrease for both techniques. This is the reason for the system impedance value become increase. The second portion covers the time from 8 sec to 17.5 sec. In this portion the magnitude of the short circuit fault current becomes increasing. This is the reason of the system impedance values become decreasing. So, this portion indicates maximum short circuit fault current magnitude for both techniques as compared with portion one and portion three. The third portion covers the time intervals from 17.5 sec to 25 sec. In this portion magnitude of short circuit fault current for both techniques are decreasing. This is the reason when the magnitude of system impedance is increasing. Under this portion the magnitude of short circuit current is greater than portion one and less than portion two. During comparison of ANN with Nuro-fuzzy controller techniques portion one is minimum short circuit current i.e.,175A to 80A.

4.3.3 Comparison of Short Circuit Fault Current of ANN with TLBO

When comparing the fault current magnitudes in case of Artificial Nural Network and TLBO, the performance to minimize the fault current, i.e., in case of ANN the short circuit current magnitude is less than TLBO techniques. So, in case of comparison of the two techniques the short circuit current magnitude is a little difference, i. e, approximately the same magnitude of fault current values I can consider from the graph.

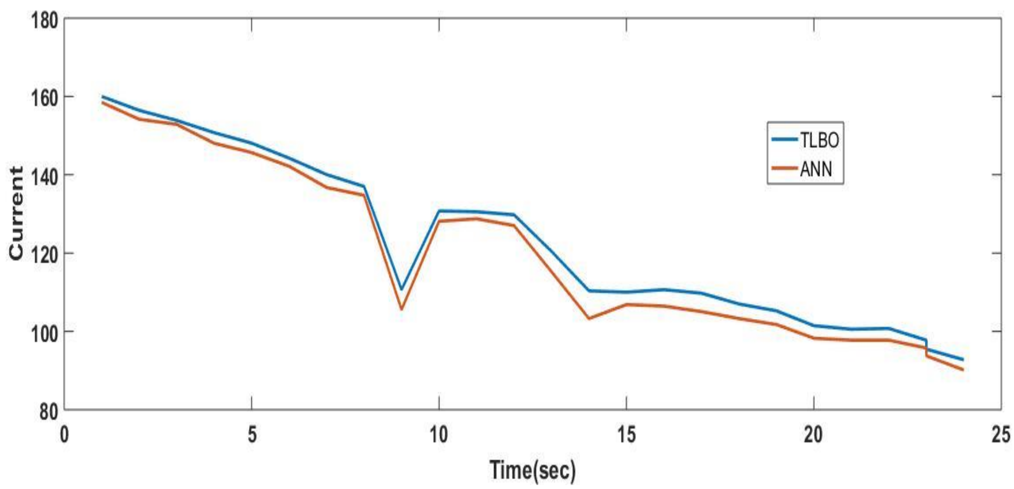


Figure 4.20. Comparison of Fault Current of ANN with TLBO

4.3.4 Comparison of Short Circuit Fault Current of ANN with BPSO

When comparing the fault current magnitudes in case of Artificial Nural Network and BPSO, the performance to minimize the fault current, i.e., in case of ANN the short circuit current magnitude is less than BPSO techniques. So, in case of comparison of the two techniques the short circuit current magnitude is a little difference, i. e, approximately the same magnitude of fault current values I can consider from the graph.

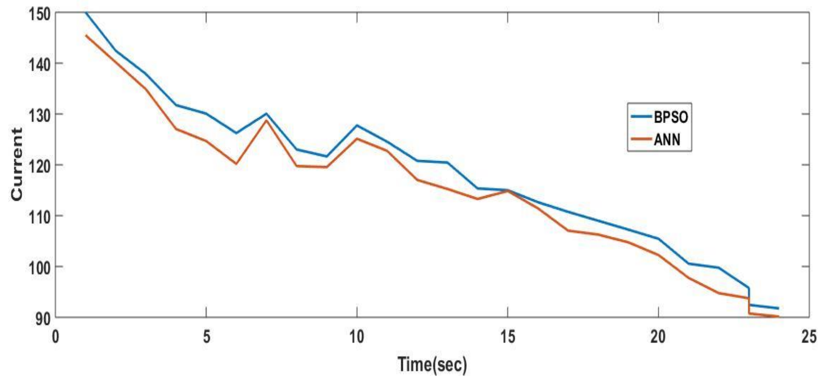


Figure 4.21. Comparison of Fault Current of ANN with BPSO

Figure 4.21 shows the comparison results of ANN and BPSO. Under this comparison short circuit fault current magnitude is decreasing from the starting point i.e., when the recovery time is increasing magnitude of fault current is decreasing for both techniques. Under this figure the comparison results have two portions. The first portion includes from the time starting 0 sec to 10 sec. This portion fault current magnitude is greater than the second portion fault current. Under this portion the fault current magnitude decreases from 150A to 130A for both techniques. The second portion covers the time intervals from 10 sec to 25 sec. This portion have best performance as compared to the first portion i.e., magnitude of short circuit fault current decrease from 130A to 90A for both techniques.

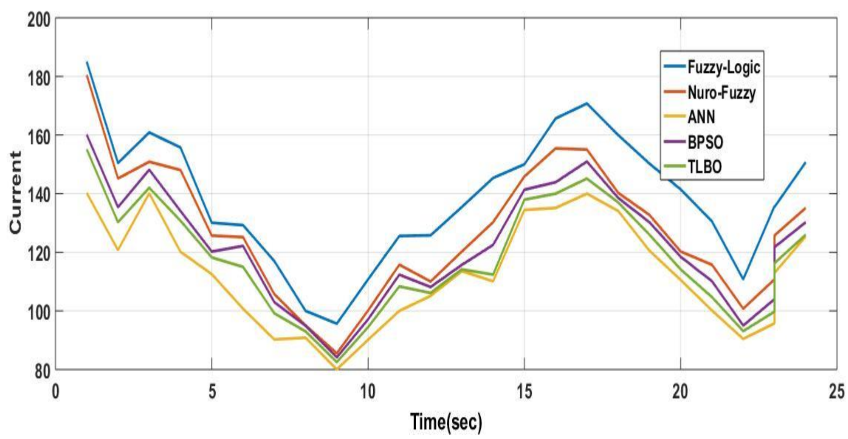


Figure 4.22. Different Comparison Techniques

4.4 Artificial Neural Network Training Results from ANN tool bar

Artificial neural network toolbar is one of the MATLAB libraries which is used to train the input data by using the target data to get required results. Under the artificial neural network toolbar, we can train the epoch values, the time required to get the expected outputs, the performance of the ANN tool and how to check the validation of the result. During the training state the ANN toolbar needs Levenberg-Marquardt algorithm (LMA). Artificial neural network training process starts by using the data collected from the substation-distribution monthly total impedance values and the monthly total over and under voltages values. To do unique the generated data can be putted in actual intelligent electronic device (IED) to read fault in transformer to the corresponding voltages and currents in the feeder lines.

The implementation of ANN is performed by using the matrix forms of the inputs, target, weights and biases of vectors. In my work the graphic ANN training method is used to train the network. Before training the network, I would be randomly dividing the data 70% for data training,15% for the validation test and finally 15% for testing set. Advantages of dividing training test is used to compute the gradients of the weight updates; validation set is used to test the train network to be not fit over and testing set is used to check the trained network. The weights and biases are initialized by MATLAB as default. The weight and bias are the random values between the input values range; so, we can change the bias and weight starting values as we use.

2-10-1 ANN Network configuration

This network is trained using the neural fitting tool with the tansig activation function between the input and the hidden layer and purelin between the hidden and output layer, with two input neurons, with 10 neurons in hidden layer and 1 neuron in the output layer. Figure 4.23 shows the overview of ANN training. The feed forward back propagation topology, one-layer neural network is used. The Levenberg Marquardt variation back propagation learning instruction is applied. As there is no defined rule for the selection of number of neurons and layers in the hidden layer for back propagation algorithm, trial and error is made till well trained network is obtained.

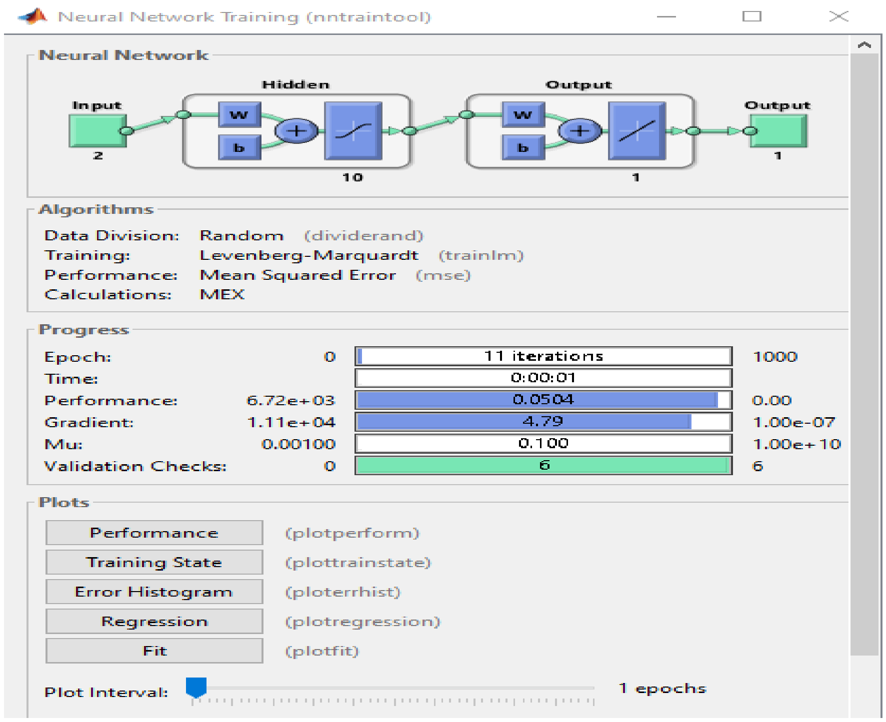


Figure 4.23. 2-10-1 Network ANN Training result from toolbar

During the training state of the network the gradient, the Marquardt adjustment parameter and the validation check is shown in figure below. As shown in the figure 4.24 the gradient value varies during training and finally 4.79 at epoch 11. The validation check is made at different epochs and for continuous 6 validation checks made at epoch 5 to 11 and training stops. The training parameters during training are as follows: minimum gradient is 10^{-7}, performance goal set to 0 in order to achieve maximum possible training performance.

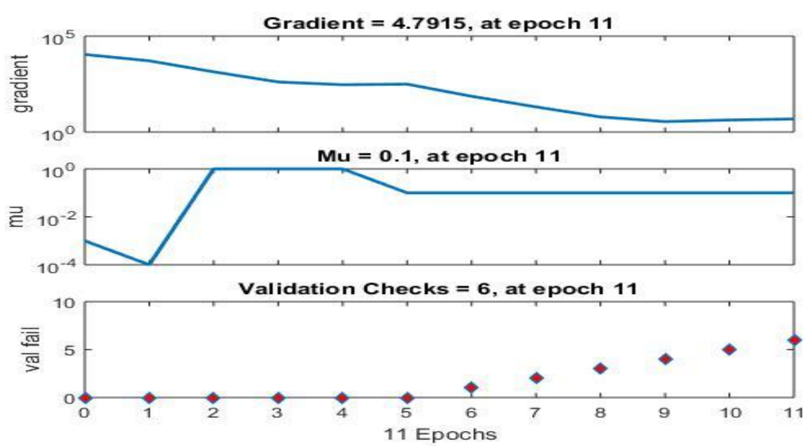


Figure 4.24. Training state result from ANN toolbar

The performance of the trained neural network was based on their regression result, MSE and error histogram values are shown in figure 4.25 and figure 26 below. As shown in this figure the mean square error (MSE) of the validation data set at epoch 5 is 7.2093 and the error which is the difference between the target and network output distribution is ranges from -2.705 to -2.257 and 3.568 to 4.016 most of the data concentrated near to zero.

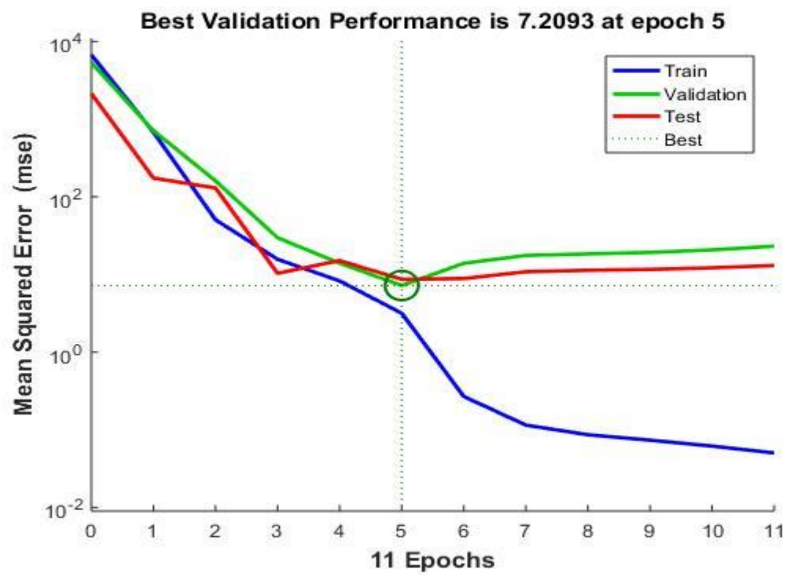


Figure 4.25. Performance result of ANN training test

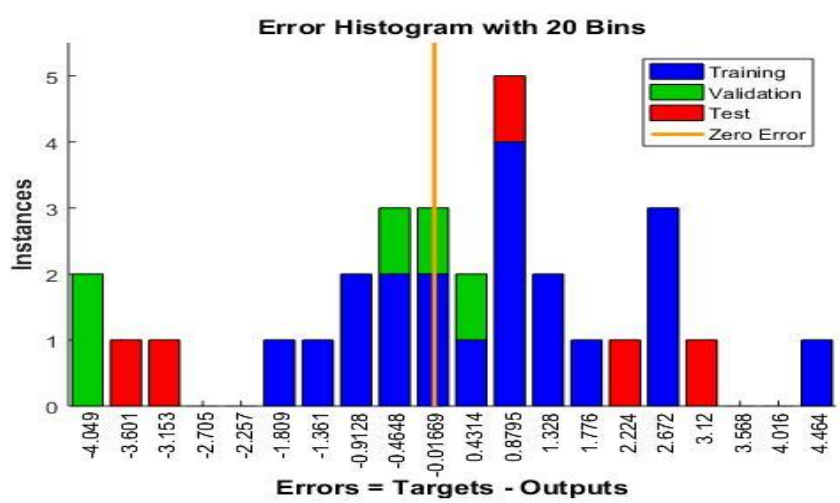


Figure 4.26. Error Histogram result from ANN toolbar

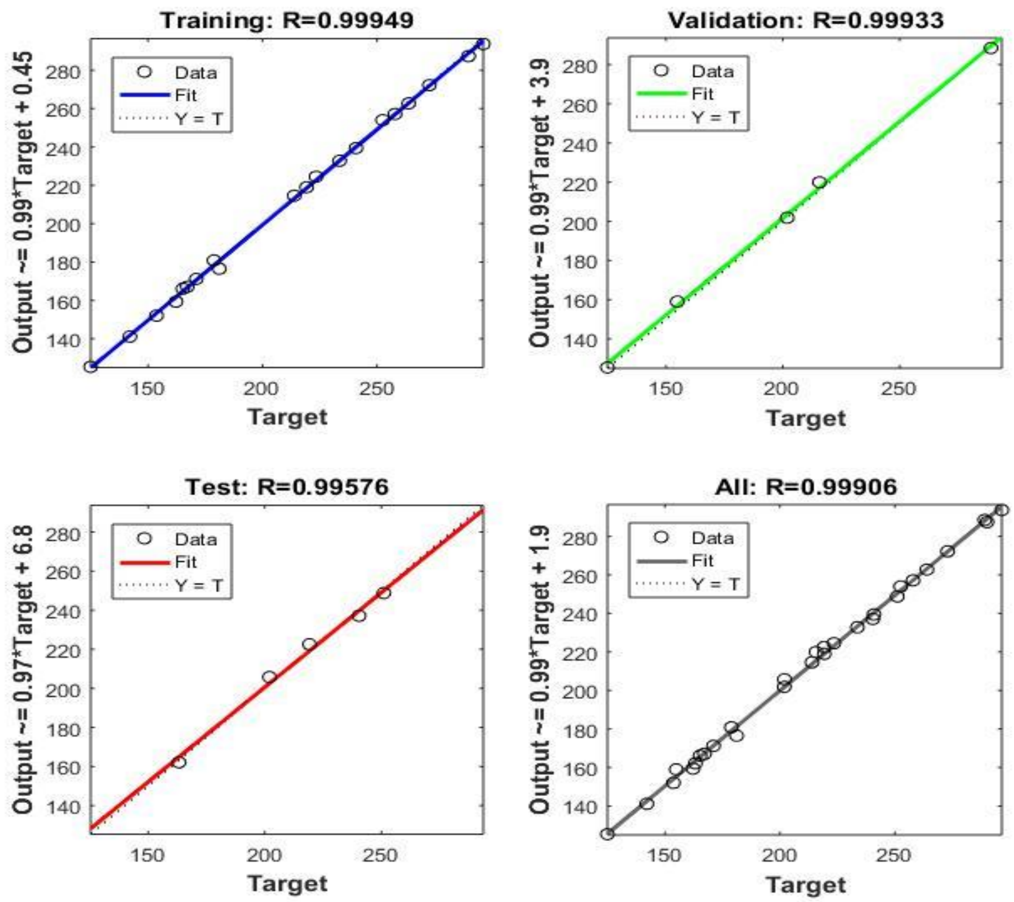


Figure 4.27. Regression value result from ANN toolbar

Another performance measure of trained neural network is the regression plot of the trained network training set, validation set and testing set. The figure above shows the correlation of the trained network output and the target values of the train, test and validation as well as overall. The correlation coefficient (R) is a degree of how well the neural network's targets can trail the variations in the outputs (0 being no correlation at all and 1 being complete correlation). The correlation coefficient in this case has been found to be 0.99906 which indicates good correlation.

4.5 Cost Analysis

Under this topic how to find the pay back of the thesis work based on the gained result from my work.

The real and reactive power loss with and without installing SFCL in the distribution feeder.

Real power loss without installing SFCL = 975KW

Real power loss after installing SFCL = 750KW

The total energy loss without and with installing SFCL in a year.

- Without installing SFCL total power loss = 975KW.
- Total interruption time in year = 355.35Hrs

Before installing SFCL total energy loss for one year= 975 X 355.35h= 346466.25KWh

- With installing SFCL total power loss = 750 KW

After installing SFCL total energy loss for one year = 750 X 355.35h = 266437.5KWh

- By using current average electric sale bill of EEU it can be converting in ETB.
- Average electric sale bill = 0. 6943 cent per KWh
- Hence, 266437.5 X 0.6943 =184,987.55625 ETB = $4283.11082 per year

Assuming that the installation costs is 10% and annual maintenance costs are 2% from after installing SFCL [44].

- 10% of $4283.11082=$428.311082
- 2% of $4283.11082=$85.6622164
- Total investment cost = $428.311082 + $85.6622164=$513.9732984
- Difference (saved cost) $4283.11082 - $513.9732984 =$3769.1375216(162,789.04956 ETB) per year.
- Back payment cost with installing RSFCL by year of Energy tariff for Hossana substation-distribution system for Gimbichu feeder is: -
  - Year of back payment $= \frac{\text{Total cost gained power loss}}{\text{Total saved cost}}$

$$= \frac{184{,}987.55625\text{ETB}}{162{,}789.04956\text{ ETB/Year}}$$

$= 1.14$ Year

Year of back payment = 1 Year,1 Months and 21 Days

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

The main task of this thesis work is to reduce the fault current in distribution feeder lines in Hossana substation-distribution system by using superconducting fault current limiter (SFCL). When the superconducting fault current limiter (SFCL) is placed at the each of the feeder connection points of substation-distribution lines there is some advantages for the system. The main advantage or use of placing SFCL at each point of feeder connection, it reduces or minimize the fault current levels by some number of percentages. When the fault current level is minimized the different types of substation equipment's are protected from some damaging issues. And also, different types of end user electronic devices are protected from damaging issues.

Resistive type Superconducting fault current limiter (RSFCL) provide the scope to improve distribution system equipment operation and decrease the requirements of reinforcement. In current years, RSFCL technology which depends on superconductivity has engaged better attention. This is because of the growth of High Temperature Superconductor (HTS) wires, this decreases the cooling costs effectively. When a resistive type of superconducting fault current limiter (RSFCL) in the line, the limiter decreases the phase shift between voltage and current during short circuit, this strongly decreases the buses, cables, transformers and circuit breakers downstream of a limiter can have much lower rating. This saved the notable cost of the equipment's.

5.2 Recommendation

- This fault current minimization technology i.e., Resistive type superconducting fault current limiter (RSFCL) is design methodology can be used for any transmission system which is long to reduce the fault current in a condition where the substation operators and the maintenance crew are well organized.
- With the similar methodology for sub transmission line's RSFCL design can be applied.
- It is also possible to use the RSFCL for ring type distribution systems, on express feeders and line feeders if sufficient real time operation data of distribution networks are available.

5.3 Feature Work

For the future work, my thesis work will be done in some related areas that I can do my thesis work in this paper. Also, on my future work I will design the prototype in the distribution feeders of Hossana Substation.

- In the same manner I will do my thesis work in the Electric Power Grid system to limit fault current.
- And also, I will need in my future work some latest optimization techniques, like whale optimization, GWO and ALO.

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Appendix A: Data used for Gimbichu feeder (15KV)

3-Winding Transformer Data from Nameplate data of IEEE				
Rated Power, Prated (HV)	25 MVA			
Rated Power, Prated (MV)	12.5 MVA			
Rated Power, Prated (LV)	12.5 MVA			
Rated Voltage				
HV, **V**nom [1]	230 KV			
MV, **V**nom [2]	66 KV			
LV, **V**nom [3]	33 KV			
% Impedance (HV/MV)	11			
% Impedance (HV/LV)	6.25			
% Impedance (MV/LV)	4.26			
Vector Group	YNyn0d11			
HV SIDE Primary-winding 1, CT Ratio (**I**nom, a)	200	1	A	(200/1A)
MV SIDE Primary-winding 2, CT Ratio (**I**nom, b)	300	1	A	(300/1A)
LV SIDE Primary-winding 3, CT Ratio (**I**nom, c)	600	1	A	(600/1A)
OLTC Range	+12.5%			
OLTC Range	-12.5%			
Highest voltage tolerance, Vmax	148.5 KV			
Lowest voltage tolerance, Vmin	115.5 KV			

2-Winding Transformer Data from Nameplate data of IEEE		
Rated Power, Prated (HV)	25 MVA	
Rated Power, Prated (LV)	25 MVA	
Rated Voltage		
HV, **V**nom [1]	132 KV	
LV, **V**nom [2]	15 KV	
% Impedance (HV/LV)	11	
Vector Group	YNyn0d11	
OLTC Range	+	12.5 %
OLTC Range	-	12.5 %
Highest voltage tolerance, Vmax	148.5 KV	
Lowest voltage tolerance, Vmin	115.5 KV	

Substation relay (REF 615) setting		
Over current	0.8In	In= 150 CT ratio=75-150/1/1A
Earth fault	0.2In	In= 150 CT ratio=75-150/1/1A
Over voltage	1.15Un	Un=100 VT ratio 33kV/110V
Under voltage	0.90Un	Un=100 VT ratio 33kV/110V

Cable data power cable single core XLPE	
Resistance	0.099
Reactance	0.02

Grid parameters of Hossana 132kv Substation	
MVA Sc (1P)	2286.307
MVA Sc (3P)	3429.461
Isc (3P)	15
Isc(1P)	12.857
x/R	14

Appendix B

Average Duration of interruption for 2019 year based on type's faults

No	Type of fault	Feeders Name							
		Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5	Feeder 6	Feeder 7	Feeder 8
1	Earth Fault	87.75	75.4	50.45	45.35	65.25	60.55	66.25	70.05
2	Short Circuit	95.6	80.125	645.85	48.55	70.55	65.75	71.25	73.15
3	Black out	15.25	10.25	5.25	5.5	6.85	6.5	4.5	10.5
4	SOL	8.25	5.55	15.5	18.25	12.25	4.65	9.5	3.75
5	Overload	45.5	36.75	20.45	35.35	5.65	3.75	5.125	4.25
6	Operation	38.75	25.05	10,12	6.05	25.25	35.5	23.265	30.5

Feeder1=Gimbichu, Feeder2=Angacha, Feeder3=Hossana city, Feeder4=Wachamo University, Feeder5=Hayse, Feeder6=Fonko, Feeder7=Wasi Gabata and Feeder8=Balesa

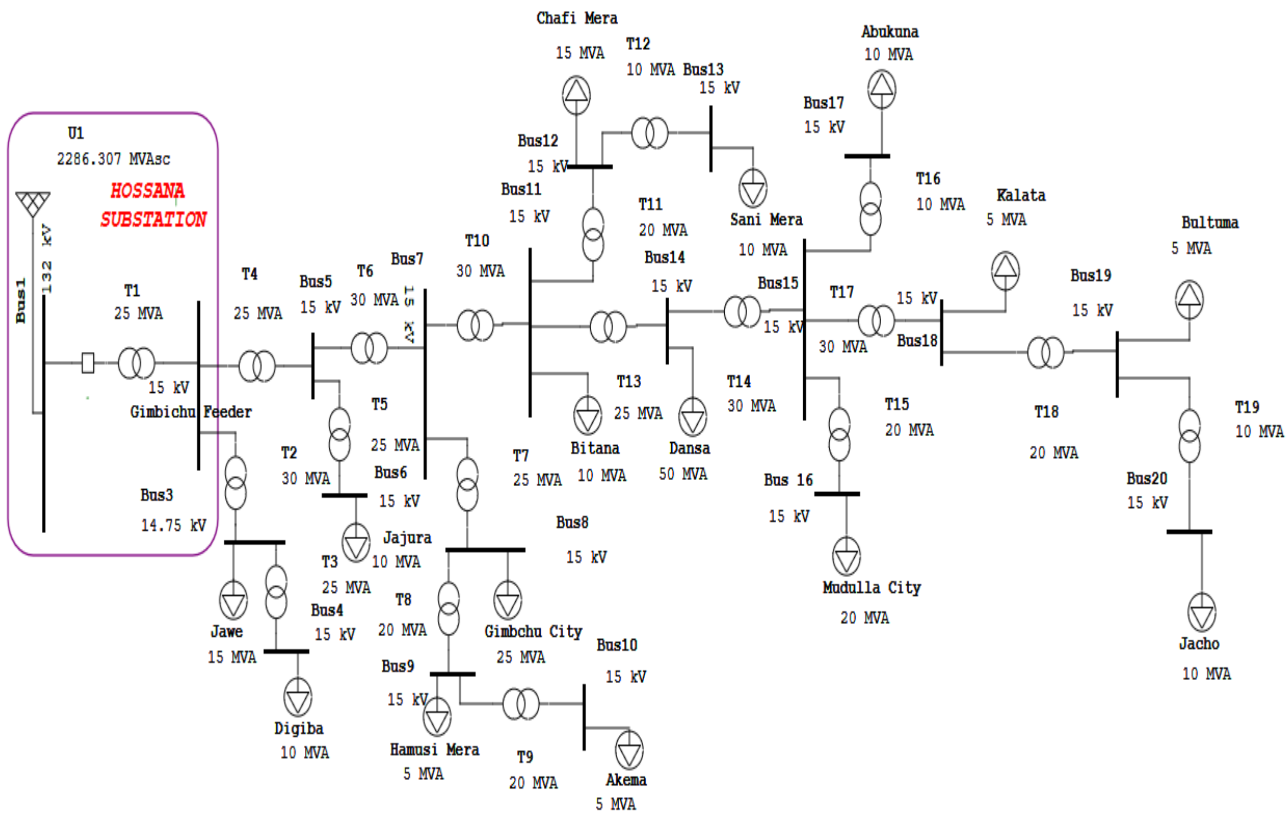
Average duration of interruption for 2020 year based on types of faults

No	Types of faults	Feeders Name							
		Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5	Feeder 6	Feeder 7	Feeder 8
1	Earth Fault	90.5	65	75	85	50.55	45.65	70.75	85.15
2	Short Circuit	100.25	85.75	80.25	55.65	45.45	90.5	75.85	55.45
3	Black out	10	8.25	6.65	9	7.75	4.5	6.75	9.75
4	SOL	10.75	10.25	6.45	5.55	7.25	8.5	9.75	10
5	Overload	50.75	45	55.25	35	25.4	45.75	35	30.75
6	Operation	75	60.05	45	35	65	70	55	50

Feeder1=Gimbichu, Feeder2=Angacha, Feeder3Hossana city, Feeder4=Wachamo University, Feeder5=Hayse, Feeder6=Fonko, Feeder7=Wasi Gabata and Feeder8=Balesa

Appendix C

Gimbichu Feeder Configuration



1.Configuration of feeder line

From bus	To bus	Length	Type/Size of conductor	Total distance from substation
B1	B2	100m	AAAC95mm^2	5km
B2	B3	10Km	AAC50mm^2	12km
B3	B4	7Km	AAAC95mm^2	15.5km
B2	B5	15Km	AAAC95mm^2	20km
B5	B6	16Km	AAAC95mm^2	33km
B5	B7	12Km	AAAC95mm^2	45km
B7	B8	13Km	AAC50mm^2	58km
B8	B9	20Km	AAAC95mm^2	65km
B9	B10	8Km	AAC50mm^2	75km
B7	B11	14.5Km	AAC50mm^2	68.5km
B11	B12	9Km	AAAC95mm^2	75km
B12	B13	17Km	AAC50mm^2	80km
B11	B14	21.25Km	AAC50mm^2	130km
B14	B15	15Km	AAC50mm^2	132km
B15	B16	14Km	AAC50mm^2	135km
B15	B18	9Km	AAAC95mm^2	136.5km
B18	B19	8Km	AAC50mm^2	141km
B19	B20	11km	AAAC95mm^2	150km

Appendix D

ANN MATLAB Code for Fault Current minimization

```
function [y1] = myNeuralNetworkFunction(x1)
%MYNEURALNETWORKFUNCTION neural network simulation function.
%
% Generated by Neural Network Toolbox function genFunction,
03-Mar-2021 13:15:20.
%
% [y1] = myNeuralNetworkFunction(x1) takes these arguments:
%   x = Qx2 matrix, input #1
% and returns:
%   y = Qx1 matrix, output #1
% where Q is the number of samples.
%#ok<*RPMT0>
% ===== NEURAL NETWORK CONSTANTS =====
% Input 1
x1_step1.xoffset = [90.5;24.75];
x1_step1.gain = [0.0182648401826484;0.242424242424242];
x1_step1.ymin = -1;
% Layer 1
b1 = [5.1686181447770592;-3.2509840793964639;-
2.6513405642904133;-1.5685654723350453;-
0.15148619096189544;0.47032522451022374;-1.4538429614330632;-
2.062674371879567;-3.9494514975858102;4.5327344758072883];
IW1_1 = [-2.8651201802122284 -2.2477185734048812;-
0.078046635971625075 4.5268849823417012;2.4304324683521874 -
4.0132128580111734;2.6354004854398734
3.0747656974332305;3.8413016065799055 -
1.3534941581167681;0.66347372356016476 -4.3042790626451017;-
3.8086070505846443 -2.1370318676555073;-3.8389689234462518
```

```
1.1368584196329197;-3.9618362621985628 -
0.21840291488707886;4.2917984008485996 -1.2758862200348664];
% Layer 2
b2 = 0.11429330243669061;
LW2_1 = [0.38672883509760603 0.086333877730160755 -
0.22569232245466725 -0.1192754885835681 -0.19899786082088003 -
0.084828476581981269 0.057063377679271471 0.31086389009985665
0.16771075669065433 -0.35595219373160214];
% Output 1
y1_step1.ymin = -1;
y1_step1.gain = 0.0116631677163518;
y1_step1.xoffset = 125;
% ===== SIMULATION ========
% Dimensions
Q = size(x1,1); % samples
% Input 1
x1 = x1';
xp1 = mapminmax_apply(x1,x1_step1);
% Layer 1
a1 = tansig_apply(repmat(b1,1,Q) + IW1_1*xp1);
% Layer 2
a2 = repmat(b2,1,Q) + LW2_1*a1;
% Output 1
y1 = mapminmax_reverse(a2,y1_step1);
y1 = y1';
end
% ===== MODULE FUNCTIONS ========
% Map Minimum and Maximum Input Processing Function
function y = mapminmax_apply(x,settings)
y = bsxfun(@minus,x,settings.xoffset);
y = bsxfun(@times,y,settings.gain);
```

```
y = bsxfun(@plus,y,settings.ymin);
end
% Sigmoid Symmetric Transfer Function
function a = tansig_apply(n,~)
a = 2 ./ (1 + exp(-2*n)) - 1;
end
% Map Minimum and Maximum Output Reverse-Processing Function
function x = mapminmax_reverse(y,settings)
x = bsxfun(@minus,y,settings.ymin);
x = bsxfun(@rdivide,x,settings.gain);
x = bsxfun(@plus,x,settings.xoffset);
end
```