PROJECT REPORT

ON

An approach for Power System Ground Fault Detection based on LabVIEW

Submitted for partial fulfillment of degree of Bachelor of Technology in Electrical Engineering

from

THDC Institute of Hydropower Engineering and Technology

Submitted by

Group Members	University Roll No.
Manish Pant	**160704105023**
Anubhav Gupta	**160704105005**
Mahendra Pratap	**160704105021**
Shubham Bharti	**160704105053**

Under the guidance of

Mrs. Himani Kala

Asst.Professor, DEPARTMENT OF ELECTRICAL ENGINEERING

THDC Institute of Hydropower Engineering and Technology

affiliated to

Uttarakhand Technical University

CERTIFICATE

*This is to certify that the project report entitled "**AN APPROACH FOR POWER SYSTEM GROUND FAULT DETECTION BASED ON LABNVIEW**" submitted by **Manish Pant, Anubhav Gupta, Mahendra Pratap and Shubham Bharti** for $7^{th}/8^{th}$ semester examination have been prepared following the guidelines of B. Tech degree in Electrical Engineering, awarded by the Uttarakhand Technical University. They have carried out the project work under my supervision.*

Nitin Kumar Gupta
Head of the department
Electrical Engineering
THDC-IHET
Bhagirathipuram
Tehri Garhwal, Uttarakhand

Himani Kala
Project Supervisor
Assistant Professor, EE dept.
THDC-IHET
Bhagirathipuram
Tehri Garhwal, Uttarakhand

ACKNOWLEDGEMENT

We would like to record our acknowledgement and sincere gratitude to Mr. Nitin Kumar Gupta , HOD, EE, THDC IHET and Assistant Professor Mrs. Himani Kala, EE, THDC IHET for their kind support, inspiration, advice and valuable guidance for preparation of the project.

We would also like to thanks our friends who have helped us a lot to give a final shape to the report.

MANISH PANT

(160704105023)

Abstract

The analysis of Power Systems under fault condition represents one of the most important and complex task in Power Engineering. The studies, analysis and detection of these faults are of utmost importance to ensure the reliability and stability of the power system as a whole as well as to determine the necessary safety measures and required protection systems to guarantee the safety of public and prevent damage to the equipments.

In this project, power system fault detection based on LabVIEW has been proposed using current samples only. Different kinds of power system fault (L-G, L-L-G) has been simulated in MATLAB/ Simulink. From simulation results, three phase current samples from different buses has been collected & from these samples Zero and Positive Sequence components has been calculated using Fortescue's theorem in LabVIEW. The magnitude of sequence components is used to detect the type of faults & from phase angles; the faulty phases can be identified. A fault detection algorithm has been done in LabVIEW block diagram from which the nature of fault was analyzed. To validate the proposed algorithm, the same model has also been made in MiPower & from results the algorithm is verified in LabVIEW.

TABLE OF CONTENTS

I

LIST OF TABLES

II

LIST OF FIGURES

Chapter – 1

INTRODUCTION

1.1 Objectives

The objectives of the project is

i) Simulation of different kind of ground fault with different buses in MATLAB/Simulink.

ii) Detection of types of faults with faulty phase and bus using current samples in LabVIEW.

iii) Verification of above algorithm by modeling the ‘ Power Transmission Line’ model in MiPower and check the accuracy of fault detection system.

1.2 Overview

From the very outset energy has played a vital role in the development of civilization. Many functions necessary to present-day living grind to halt when the supply of energy stops. There has been a universal basic drive towards better living through expanded utilization of energy. The history of civilization shows a close relationship between the utilization of energy and the progress of mankind. The degree of energy used is the symbol of the progress of a country. The greater the per capita consumption of energy in a country, the higher is the standard of living of its people. Energy consciousness in the people has created interests in them to tap new sources of energy from time to time. Of the various forms so far discovered, the electrical energy has contributed a lot to the world's energy requirements due to its multiple advantages. Hence, it is the responsibility of electrical personnel also to make the use of energy fault-free and ensure safety of the public and the systems.

During normal operating conditions, current flows through all elements of the electrical power system within pre-designed values which are appropriate to these elements' ratings [1].

Unfortunately, faults could happen as a result of natural events or accidents where the phase will establish a connection with another phase, the ground or both in some cases. A falling tree on a transmission lines could cause a three-phase fault where all phases share a point of contact called fault location. In different occasions, fault could be a result of insulation deterioration, wind damage or human vandalism. Lightning is another common cause of fault in power systems. In US, there is almost 30 million lightning strikes per year.

Faults can be defined as the flow of a massive current through an improper path which could cause enormous equipment damage which will lead to interruption of power, personal injury, or death. In addition, the voltage level can affect the equipment insulation in case of an increase or could cause a failure of equipment start-up if the voltage is below a minimum level. As a result, the electrical potential difference of the system neutral will increase [1]. Hence, People and equipment will be exposed to the danger of electricity which is not accepted.

In order to prevent such an event, power system fault analysis was introduced. Power system fault analysis is the process of determining the magnitude of system voltages and line currents during the occurrence of various types of faults. The magnitude of these currents depends on the internal impedance of the generators plus the impedance of the intervening circuit. It can be of the order of tens of thousand of amperes. The process of evaluating the system voltages and currents under various types of short circuits can determine the necessary safety measures and the required protection system [2]. It is essential to guarantee the safety of public. The analysis of faults leads to appropriate protection settings which can be computed in order to select suitable fuse, circuit breaker size and type of relay [1].

The severity of the fault depends on the short-circuit location, the path taken by fault current, the system impedance and its voltage level. In order to maintain the continuation of power supply to all customers which is the core purpose of the power system existence, all faulted parts must be isolated from the system temporary by the protection schemes. When a fault exists within the relay protection zone at any transmission line, a signal will trip or open the circuit breaker isolating the faulted line. To complete this task successfully, fault analysis has to be conducted in every location assuming several fault conditions. The goal is to determine the optimum protection scheme by determining the fault currents & voltages. In reality, power system can consist of thousands of buses which complicate the task of calculating these parameters without the use of computer software such as Matlab, Mi Power etc. In 1956, L.W. Coombe and D. G. Lewis proposed the first fault analysis program [2].

In the Literature Review portion of this project, we shall try to summarize what are the different types of faults in power systems and the methods used to detect and analyze the faults. In Mathematical Model portion, we shall try to analyze faults on mathematical angels. Use of various electrical softwares is now a must for accurate analysis and detection of faults. In this project, we have used Matlab for simulation purpose and after collecting the data from Matlab, we have put it in the Labview for analysis purpose.

Chapter – 2

THE LITERATURE SURVEY

2.1 General

Electric power is generated, transmitted and distributed via large interconnected power systems. The generation of electric power takes place in a power plant. Then the voltage level of the power will be raised by the transformer before the power is transmitted. Electric power is proportional to the product of voltage and current this is the reason why power transmission voltage levels are used in order to minimize power transmission losses [2].

The primary objective of all power systems is to maintain the continuous power supply. During normal operating conditions, a power system operates under balanced conditions. But various unwanted external & internal causes make the system unbalanced. Natural events such as lightning, weather, ice, wind, storm, failure in related equipments and many other unpredictable factors may lead to undesirable situations and connection between the phases conductors of a transmission lines or the phase conductors to ground, these types of events are known as faults. A falling tree on a transmission lines could cause a three-phase fault where all phases share a point of contact called fault location. In different occasions, fault could be a result of insulation deterioration, overloading of underground cables, wind damage or human vandalism. Sometimes, small animals like rats, lizards etc. enter switchgear to create short circuit faults [1, 2].

Faults can be defined as the flow of a massive current through an improper path which could cause enormous equipment damage which will lead to interruption of power supply, personal injury or death. In addition, the voltage level will alternate which can affect the equipment insulation in case of an increase or could cause a failure of equipment start-up if the voltage is below a minimum level. As a result, the electrical potential difference of the system neutral will increase. Hence, People and equipment will be exposed to the danger of electricity which is not accepted [1]. Hence, the main purpose of the fault analysis is to ensure safety of the people and the system from abnormal conditions within minimum time.

Fault can damage and disrupt power systems in several ways. Faults give rise to abnormal operating conditions, usually excessive voltages and currents at certain points on the system. Large voltages stress insulation beyond their breakdown value while large currents result in overheating of power system components. Sustained overheating may reduce useful life of the equipments. Sometimes faults lower system voltages below their permissible limits. Faults can cause the three-phase system to become unbalanced with the result that three-phase equipment operates improperly. Hence, it is necessary that upon the occurrence of the fault, the faulty section should be disconnected as rapidly as possible in order that the normal operation of the rest of the system is not affected. If this is not done, the equipment may be damaged and the power supply is disrupted. The relays should immediately detect the existence of the fault and initiate circuit breaker operation to disconnect the faulty section.

Any power system can be analyzed by calculating the value of system voltages and currents at different points of the system under normal & abnormal scenarios, determination of the ratings of the required circuit breakers and selection of appropriate schemes of protective relaying [1].

The process of evaluating the system voltages and currents under various types of short-circuits is called fault analysis which can determine the necessary safety measures & the required protection system to guarantee the safety of public [2].

The analysis of faults leads to appropriate protection settings which can be computed in order to select suitable fuse, circuit breaker size and type of relay [1].

The severity of the fault depends on the short-circuit location, the path taken by fault current, the system impedance and its voltage level. In order to maintain the continuation of power supply to all customers which is the core purpose of the power system existence, all faulted parts must be isolated from the system temporary by the protection schemes. When a fault exists within the relay protection zone at any transmission line, a signal will trip or open the circuit breaker isolating the faulted line [2].

To complete this task successfully, fault analysis has to be conducted in every location assuming several fault conditions. The goal is to determine the optimum protection scheme by determining the fault currents & voltages. In reality, power system can consist of thousands of buses which complicate the task of calculating these parameters without the use of computer software's such as Matlab etc. [2].

Many exiting texts offer an extensive analysis in fault studies and calculation. Two worth mentioning are Analysis of Faulted Power System by Paul Anderson and Electrical Power Transmission System Engineering Analysis and Design by Turan Gonen. In addition to offer a very illustrative and clear analysis in the fault studies, they also offer an impressive guideline for the power systems analysis understanding in general.

2.2 Type of Faults

There are two types of faults which can occur on any transmission lines; balanced faults and unbalanced faults also known as symmetrical and unsymmetrical faults respectively. In a symmetrical fault, system remains balanced. These faults are relatively rare, but are the easiest to analyze. In unsymmetrical fault, system is no longer balanced. It is very common type of fault, but more difficult to analyze. Most of the faults that occur on power systems are not the balanced three-phase faults, but the unbalanced faults. In the analysis of power system under fault conditions, it is necessary to make a distinction between the types of fault to ensure the best results possible in the analysis.

2.2.1 Symmetrical/Balanced Faults

The fault on the power system which gives rise to symmetrical fault currents (i.e. equal fault currents in the lines with 120 degree displacement) is called a symmetrical fault. There is probably no other subject of greater importance to an electrical engineer than the question of determination of short circuit currents under fault conditions.

The symmetrical faults are very severe faults and occur not very frequently in power systems. These are also called as balanced faults and are of two types namely a) **line to line to line to ground (L-L-L-G) and b) line to line to line (L-L-L)**

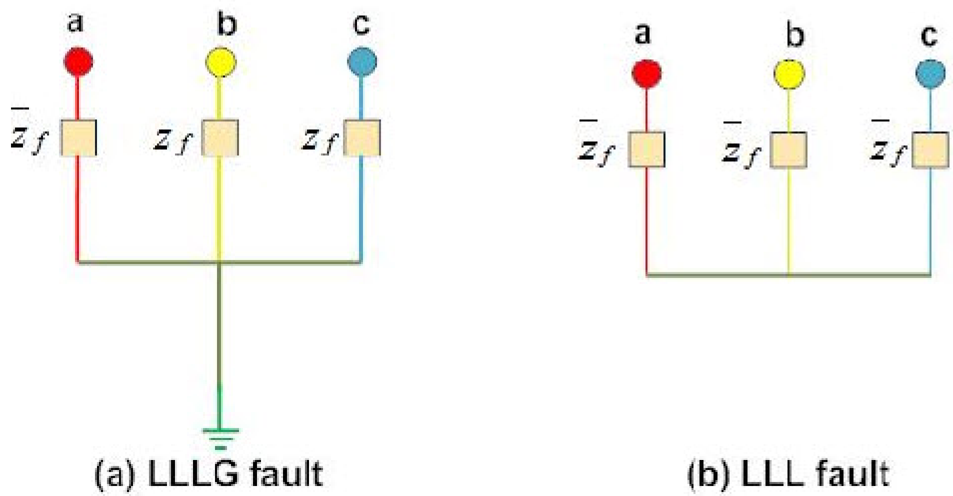


Fig. 1. LLLG & LLL symmetrical faults

The symmetrical fault occurs when all the three conductors of a 3-phase line are brought together simultaneously into a short-circuit condition as shown in Figure – 2.1 .This type of fault gives rise to symmetrical currents i.e. equal fault currents with 120 degree displacement. Because of balanced nature of fault, only one phase need to be considered in calculations since condition in the other two phases will also be similar.

Only 2 to 5 percent of system faults are symmetrical faults. If these faults occur, system remains balanced but results in severe damage to the electrical power system equipments due to high current flow.

2.2.2 Unsymmetrical / Unbalanced faults

These are very common and less severe than symmetrical faults. These are also called unbalanced faults since their occurrence causes unbalance in the system. Unbalance of the system means that that impedance values are different in each phase causing unbalance current to flow in the phases. These are more difficult to analyze and are carried by per phase basis similar to three phase balanced faults.

In order to analyze any unbalanced power system, C.L. Fortescue introduced a method called symmetrical components in 1918 to solve such system using a balanced representation. This method is considered the base of all traditional fault analysis approaches of solving unbalanced power systems [2]. The theory suggests that any unbalance system can be represented by a number of balanced systems equal to the number of its phasors. The balanced systems representations are called symmetrical components. In three-phase system, there are
three sets of balanced symmetrical components i.e. the positive, negative and zero sequence components. The symmetrical components theory will be discussed into more details in chapter 3 (The Mathematical Model) of this project.

There are mainly three types namely line to ground (L-G), line to line (L-L) and double line to ground (LL-G) faults.

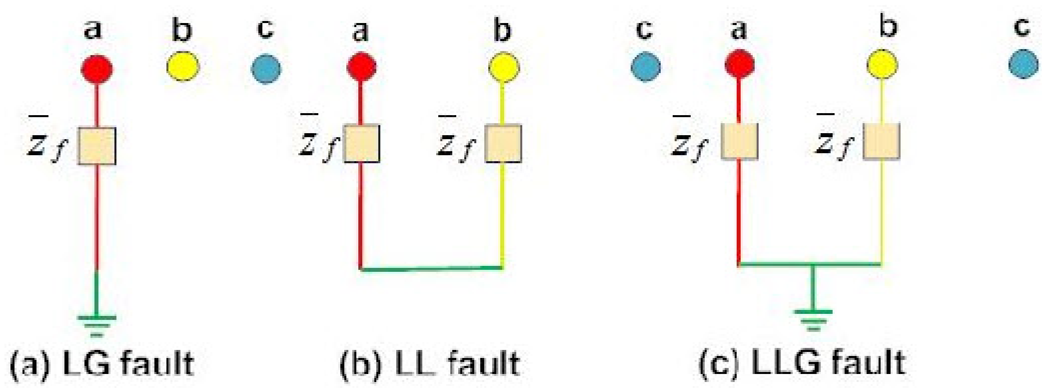


Fig. 2. LG, LL & LLG unsymmetrical faults

(a) **Line-to-ground fault:** this type of fault exists when one phase of any transmission lines establishes a connection with the ground either by ice, wind, falling tree or any other incident. 70% of all transmission lines faults are classified under this category [3].

(b) **Line-to-line fault:** as a result of high winds, one phase could touch another phase & line-to-line fault takes place. 15% of all transmission lines faults are considered line-to-line faults [3].

(c) **Double line-to-ground:** falling tree where two phases become in contact with the ground could lead to this type of fault. In addition, two phases will be involved instead of one at the line-to-ground faults scenarios. 10% of all transmission lines faults are under this type of faults [3].

Chapter – 3

THE MATHEMATICAL MODEL

3.1 Introduction

The chapter describes the mathematical model this is used in the analysis of faulted power systems and the assumption that are used in this project's analysis.

3.2 Fortescue's Theorem

A three-phase balanced fault can be defined as a short circuit with fault impedance called Z_f between the ground and each phase. The short circuit will be called a solid fault when Z_f is equal to zero. This type of fault is considered the most sever short circuit which can affect any electrical system. Fortunately, it is rarely taking place in reality. Fortescue segregated asymmetrical three-phase voltages and currents into three sets of symmetrical components in 1918 [4]. Analyzing any symmetrical fault can be achieved using impedance matrix method or Thevenin's method. Fortescue's theorem suggests that any unbalanced fault can be solved into three independent symmetrical components which differ in the phase sequence. These components consist of a positive sequence, negative sequence and a zero sequence.

3.2.1 Positive Sequence Components

The positive sequence sets have three phase currents/voltages with equal magnitude, with phase b lagging phase a by 120°, and phase c lagging phase b by 120°. The positive sequence currents and voltages follow the same cycle order of the original source. The sequence is called the "abc" sequence and usually denoted by the symbol "+" or "1". Positive sequence sets have zero neutral current [5].

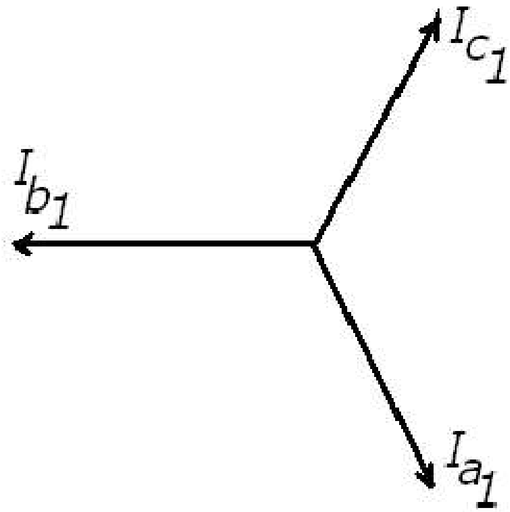


Figure 3.1: Positive sequence components

3.2.2 Negative Sequence Sets

The negative sequence sets have three phase currents/voltages with equal magnitude, with phase b leading phase a by 120°, and phase c leading phase b by 120°. Negative sequence sets are similar to positive sequence, except the phase order is reversed. This sequence occurs only in case of an unsymmetrical fault in addition to the positive sequence components. The negative sequence is identified as the "acb" sequence and usually denoted by the symbol "–" or "2" [5]. Negative sequence sets have zero neutral current.

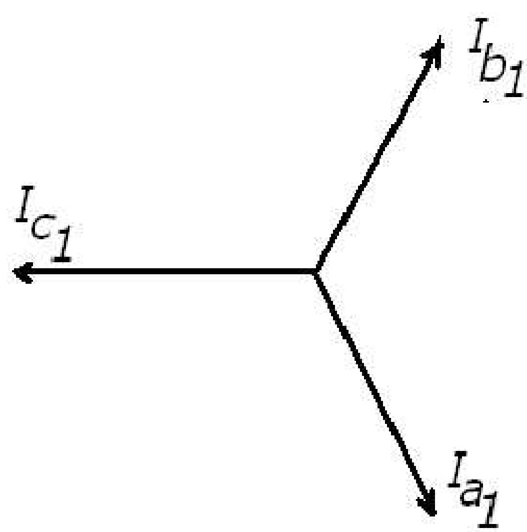


Figure 3.2 : Negative sequence components

3.2.3 Zero Sequence Sets

In this sequence, its components consist of three phasors which are equal in magnitude and angle as before but with a zero displacement. Zero sequence sets have neutral current. The phasor components are in phase with each other. This is illustrated in Fig 3.3. Under an unsymmetrical fault condition, this sequence symbolizes the residual electricity in the system in terms of voltages and currents where a ground or a fourth wire exists. It happens when ground currents return to the power system through any grounding point in the electrical system. In this type of faults, the positive and the negative components are also present. This sequence is known by the symbol “0” [5].

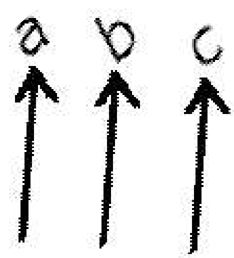


Figure 3.3 : Zero sequence components

3.3 Fault Analysis in Power Systems

In general, fault is an event, balanced or unbalanced situation that interferes with the normal condition of the power system network and forces voltages and currents to differ from each phases. When the fault is caused by an unbalance in the line impedance and does not involve a ground, or any type of inter-connection between phase conductors it is known as a series fault. On the other hand, when the fault occurs and there is an inter-connection between phase-conductors or between conductor(s) and ground and/or neutral it is known as a shunt fault.

3.3.1 Three Phase Faults:

By definition a three-phase fault is a symmetrical fault. Even though it is the least frequent fault, it is the most dangerous. Some of the characteristics of a three-phase fault are a very large fault current and usually a voltage level equals to zero at the site where the fault takes place. [3] A general representation of a balanced three-phase fault is shown in Figure 3.4 where F is the fault point with impedances Zf and Zg. Figure 3.5 shows the sequences networks interconnection diagram.

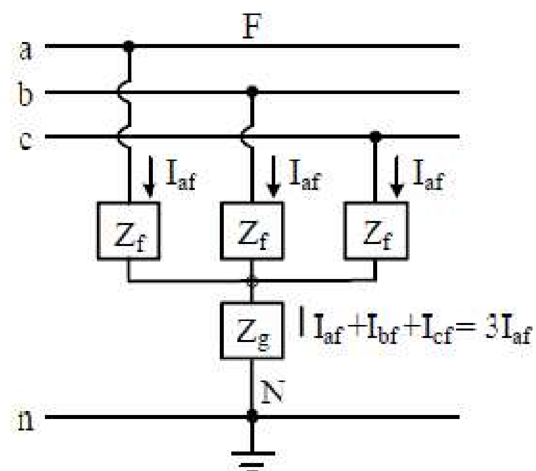


Figure 3.4 : Balanced three-phase fault

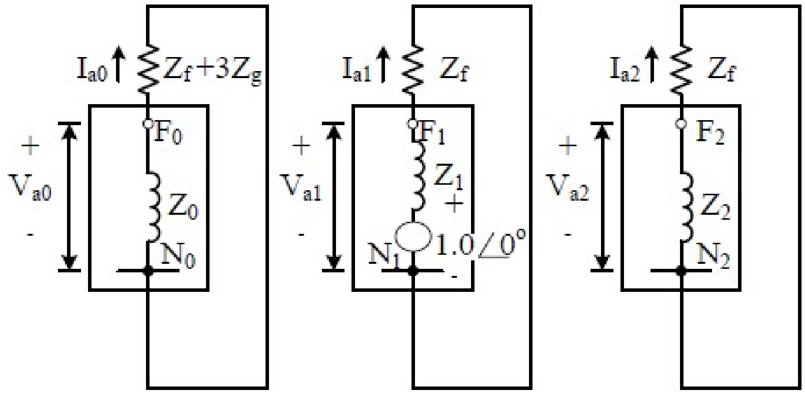


Figure 3.9 Sequence network diagram of a balanced three-phase fault

From Figure 3.9 it can be noticed that the only one that has an internal voltage source is the positive-sequence network. Therefore, the corresponding currents for each of the sequences can be expressed as

$$
\begin{aligned}
I_{a0} &= 0 \\
I_{a2} &= 0 \\
I_{a1} &= \frac{1.0\angle 0°}{Z_1 + Z_f}
\end{aligned}
\tag{3.37}
$$

If the fault impedance Z_f is zero,

$$I_{a1} = \frac{1.0\angle 0^\circ}{Z_1} \tag{3.38}$$

If equation is substituted into equation

$$\begin{bmatrix} I_{af} \\ I_{bf} \\ I_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 0 \\ I_{a1} \\ 0 \end{bmatrix} \tag{3.39}$$

Solving Equation 3.39

$$\begin{aligned} I_{af} &= I_{a1} = \frac{1.0\angle 0^\circ}{Z_1 + Z_f}, \\ I_{bf} &= a^2 I_{a1} = \frac{1.0\angle 240^\circ}{Z_1 + Z_f}, \\ I_{cf} &= aI_{a1} = \frac{1.0\angle 120^\circ}{Z_1 + Z_f} \end{aligned} \tag{3.40}$$

Since the sequence networks are short-circuited over their own fault impedance

$$\begin{aligned} V_{a0} &= 0 \\ V_{a1} &= Z_f I_{a1} \\ V_{a2} &= 0 \end{aligned} \tag{3.41}$$

If Equation is substituted into Equation

$$\begin{bmatrix} V_{af} \\ V_{bf} \\ V_{cf} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 0 \\ V_{a1} \\ 0 \end{bmatrix} \tag{3.42}$$

Therefore,

$$
\begin{aligned}
V_{af} &= V_{a1} = Z_f I_{a1} \\
V_{bf} &= a^2 V_{a1} = Z_f I_{a1} \angle 240^\circ \\
V_{cf} &= a V_{a1} = Z_f I_{a1} \angle 120^\circ
\end{aligned} \tag{3.43}
$$

The line-to-line voltages are

$$
\begin{aligned}
V_{ab} &= V_{af} - V_{bf} = V_{a1}\left(1 - a^2\right) = \sqrt{3} Z_f I_{a1} \angle 30^\circ \\
V_{bc} &= V_{bf} - V_{cf} = V_{a1}\left(a^2 - a\right) = \sqrt{3} Z_f I_{a1} \angle -90^\circ \\
V_{ca} &= V_{cf} - V_{af} = V_{a1}\left(a - 1\right) = \sqrt{3} Z_f I_{a1} \angle 150^\circ
\end{aligned} \tag{3.44}
$$

If Z_f equals to zero,

$$
\begin{aligned}
I_{af} &= \frac{1.0\angle 0^\circ}{Z_1} \\
I_{bf} &= \frac{1.0\angle 240^\circ}{Z_1}, \\
I_{cf} &= \frac{1.0\angle 120^\circ}{Z_1}
\end{aligned} \tag{3.45}
$$

The phase voltages becomes,

$$
\begin{aligned}
V_{af} &= 0 \\
V_{bf} &= 0 \\
V_{cf} &= 0
\end{aligned} \tag{3.46}
$$

And the line voltages,

$$
\begin{aligned}
V_{a0} &= 0 \\
V_{a1} &= 0 \\
V_{a2} &= 0
\end{aligned} \tag{3.47}
$$

3.3.2 <u>Single Line-to-Ground Fault (L-G)</u>

This is the most common fault on a three-phase system. It is illustrated using the following simple network:

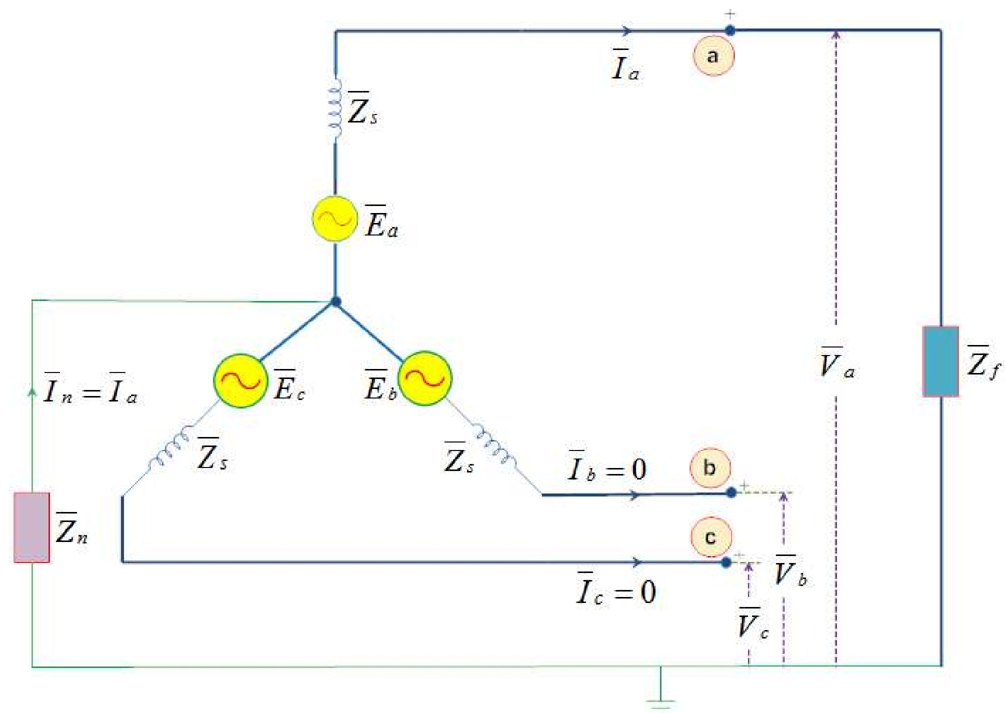


Figure 3.6 : Single Line-to-Ground fault

Since the generator is unloaded, the following terminal conditions exist at the fault point:

$$\overline{V}_a = \overline{Z}_f \overline{I}_a$$

$$\overline{I}_b = 0$$

$$\overline{I}_c = 0$$

Substituting $\overline{I}_b = \overline{I}_c = 0$ in equation (4.86), the symmetrical components of currents can be calculated as:

$$\begin{bmatrix} \bar{I}_{a0} \\ \bar{I}_{a1} \\ \bar{I}_{a2} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \mathbf{a} & \mathbf{a^2} \\ 1 & \mathbf{a^2} & \mathbf{a} \end{bmatrix}\begin{bmatrix} \bar{I}_a \\ 0 \\ 0 \end{bmatrix}$$

Solving the above equation, the values of the symmetrical components of fault current $\bar{I}_a$ are:

$$\bar{I}_{a0} = \bar{I}_{a1} = \bar{I}_{a2} = \frac{1}{3}\bar{I}_a \tag{4.98}$$

The voltage of **phase a** can be expressed in terms of symmetrical components from equation (4.83), as

$$\bar{V}_a = \bar{V}_{a0} + \bar{V}_{a1} + \bar{V}_{a2} \tag{4.99}$$

Substituing in the equation the values of $\bar{V}_{a0}, \bar{V}_{a1}$ and $\bar{V}_{a2}$ from equation (4.94) into equation (4.99), $\bar{V}_a$ can be written as (with $\bar{I}_{a0} = \bar{I}_{a1} = \bar{I}_{a2}$ from equation (4.98)):

$$\bar{V}_a = \bar{E}_a - (\bar{Z}_0 + \bar{Z}_1 + \bar{Z}_2)\bar{I}_{a0} \tag{4.100}$$

From equations (4.96) and (4.98), $\bar{V}_a = \bar{Z}_f\bar{I}_a = 3\bar{Z}_f\bar{I}_{a0}$. Hence, equation (4.100) can be expressed as:

$$3\bar{Z}_f\bar{I}_{a0} = \bar{E}_a - (\bar{Z}_0 + \bar{Z}_1 + \bar{Z}_2)\bar{I}_{a0}$$

or,

$$\boxed{\bar{I}_{a0} = \frac{\bar{E}_a}{\bar{Z}_0 + \bar{Z}_1 + \bar{Z}_2 + 3\bar{Z}_f}} \tag{4.101}$$

The fault current, therefore, is:

$$\boxed{\bar{I}_f = \bar{I}_a = 3\bar{I}_{a0} = \frac{3\bar{E}_a}{\bar{Z}_0 + \bar{Z}_1 + \bar{Z}_2 + 3\bar{Z}_f}}$$

From equations (4.98) and (4.101), it be easily interpreted that the three sequence networks are connected in series as shown in Fig. 4.55.

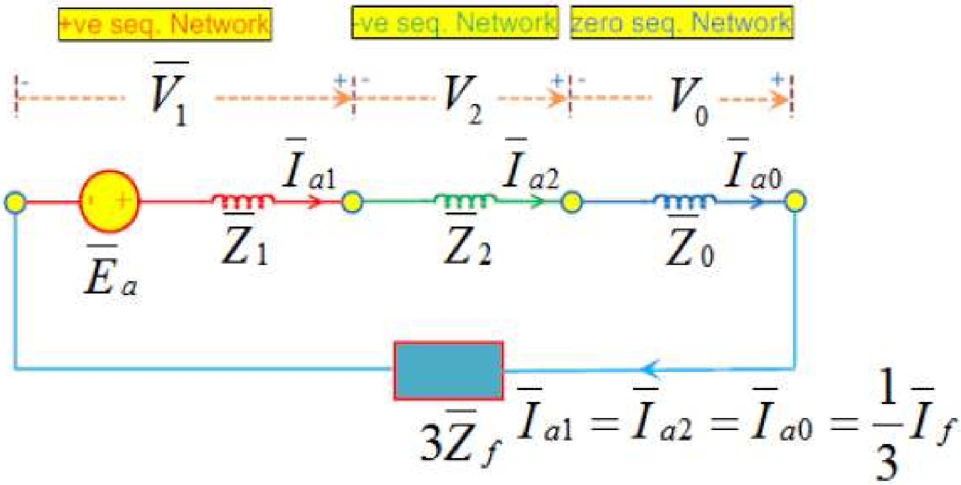


Figure 3.7: Interconnection of sequence networks to simulate LG fault

3.3.3 <u>Line-To-Line Fault (L-L)</u>

Fig. 3.8 shows a line to line (LL) fault on phases ‘b’ and ‘c’ through an impedance $\overline{Z}_f$ on an unloaded three phase generator. The terminal conditions at the fault point are:

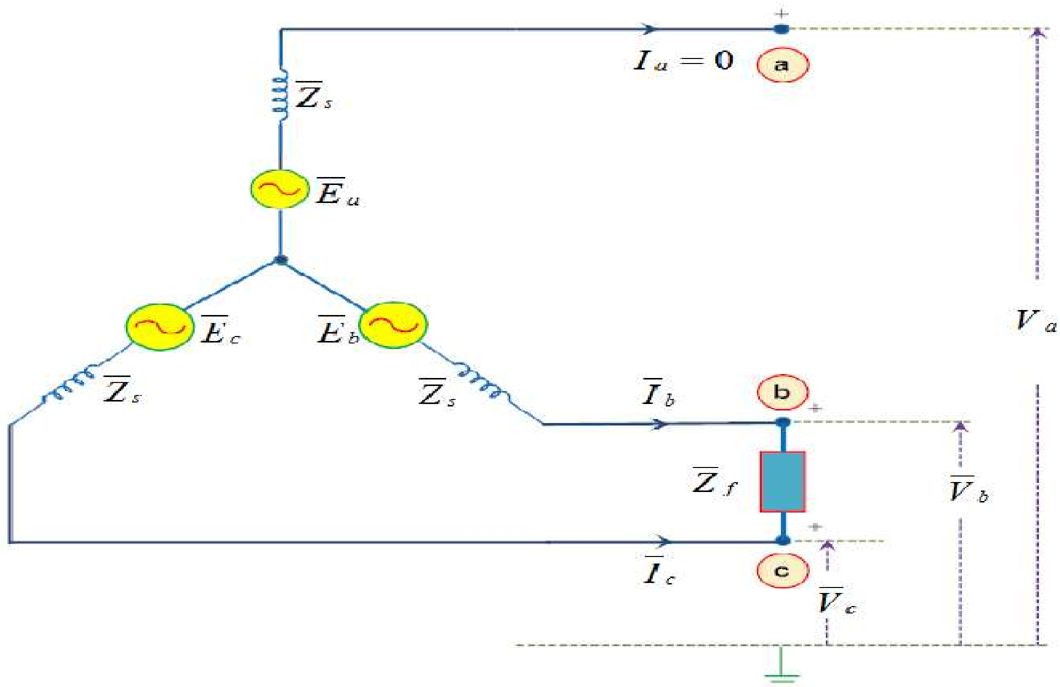


Figure 3.8 : Line to Line fault

$$\bar{V}_b - \bar{V}_c = \bar{Z}_f \bar{I}_b$$

$$\bar{I}_b + \bar{I}_c = 0$$

$$\bar{I}_a = 0$$

Substituting $\bar{I}_a = 0$ and $\bar{I}_b = -\bar{I}_c$ in equation (4.86), the symmetrical components of cuurents can be calculated as:

$$\begin{bmatrix} \bar{I}_{a0} \\ \bar{I}_{a1} \\ \bar{I}_{a2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \mathrm{a} & \mathrm{a}^2 \\ 1 & \mathrm{a}^2 & \mathrm{a} \end{bmatrix} \begin{bmatrix} 0 \\ \bar{I}_b \\ -\bar{I}_b \end{bmatrix} \tag{4.104}$$

Solving the above equation, the values of the symmetrical components of the current $\bar{I}_a$ are:

$$\bar{I}_{a0} = 0$$

$$\bar{I}_{a1} = \frac{1}{3}(\mathrm{a} - \mathrm{a}^2)\bar{I}_b \tag{4.105}$$

$$\bar{I}_{a2} = \frac{1}{3}(\mathrm{a}^2 - \mathrm{a})\bar{I}_b = -\bar{I}_{a1}$$

From equation (4.83), we have

$$\bar{V}_b - \bar{V}_c = (\mathrm{a}^2 - \mathrm{a})(\bar{V}_{a1} - \bar{V}_{a2}) = \bar{Z}_f \bar{I}_b \tag{4.106}$$

Substituting $\bar{V}_{a1}$ and $\bar{V}_{a2}$ from equation (4.94) and noting that $\bar{I}_{a1} = -\bar{I}_{a2}$, one can write:

$$(\mathrm{a}^2 - \mathrm{a})\left[\bar{E}_a - (\bar{Z}_1 + \bar{Z}_2)\bar{I}_{a1}\right] = \bar{Z}_f \bar{I}_b \tag{4.107}$$

Also from equation (4.105),

$$\bar{I}_b = \frac{3\bar{I}_{a1}}{(\mathrm{a} - \mathrm{a}^2)} \tag{4.108}$$

Substituting this value of $\bar{I}_b$ in equation (4.107), we get:

$$\left[\bar{E}_a - (\bar{Z}_1 + \bar{Z}_2)\bar{I}_{a1}\right] = \frac{3\bar{Z}_f \bar{I}_{a1}}{(\mathrm{a} - \mathrm{a}^2)(\mathrm{a}^2 - \mathrm{a})}$$

Since, $(\mathrm{a} - \mathrm{a}^2)(\mathrm{a}^2 - \mathrm{a}) = 3$, the above expression can be simplified and written as:

$$\boxed{\bar{I}_{a1} = \frac{\bar{E}_a}{(\bar{Z}_1 + \bar{Z}_2 + \bar{Z}_f)}} \tag{4.109}$$

The phase currents during fault can be calculated as:

$$\begin{bmatrix} \bar{I}_a \\ \bar{I}_b \\ \bar{I}_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \mathbf{a^2} & \mathrm{a} \\ 1 & \mathrm{a} & \mathbf{a^2} \end{bmatrix} \begin{bmatrix} 0 \\ \bar{I}_{a1} \\ -\bar{I}_{a1} \end{bmatrix} \tag{4.110}$$

Solving for the phase currents, the expressions for $\bar{I}_b$ and $\bar{I}_c$ can be written as:

$$\boxed{\bar{I}_b = -\bar{I}_c = (\mathrm{a}^2 - \mathrm{a})\bar{I}_{a1}}$$

The phase currents during fault can be calculated as:

$$\begin{bmatrix} \bar{I}_a \\ \bar{I}_b \\ \bar{I}_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} 0 \\ \bar{I}_{a1} \\ -\bar{I}_{a1} \end{bmatrix}$$

Solving for the phase currents, the expressions for $\bar{I}_b$& $\bar{I}_c$ can be written as

$$\boxed{\bar{I}_b = -\bar{I}_c = (a^2 - a)\bar{I}_{a1}}$$

Substituting $\bar{I}_b$ from equation (4.111) in equation (4.106) one gets:

$$(\bar{V}_{a1} - \bar{V}_{a2}) = \bar{Z}_f \bar{I}_{a1}$$

The equivalent circuit of the fault in terms of the sequence networks is shown in Fig. 4.57. Thecircuit has been drawn on the basis of equation (4.105) and the above equation. It shows that thepositive sequence and negative sequence networks are connected in phase opposition bridged by thefault impedance $\bar{Z}_f$. Also, since $\bar{I}_{a0} = 0$, the zero sequence network is open circuited and hence isnot shown in the diagram.

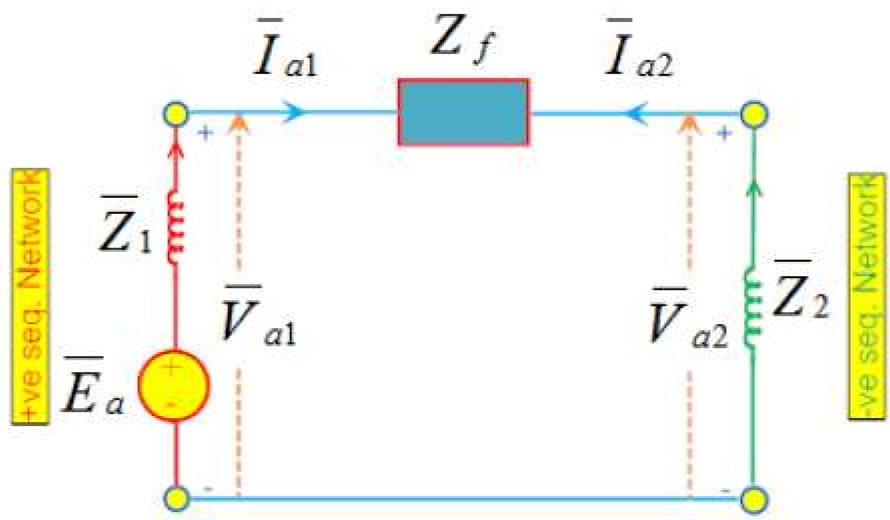


Figure 3.9 : Interconnection of sequence networks to simulate LL fault

Extending the above concept to LL fault calculations in a power system, it can be concluded that, the Thevenin's equivalent positive and negative sequence networks, as seen from the fault point, can be connected in phase opposition through the fault impedance for calculating fault current.

3.3.3 <u>Double Line-to-Ground Fault</u> (L-L-G)

Fig. 4.58 shows a double line to ground (LLG) fault on phases 'b' and 'c' through an impedance $\bar{Z}f$ on an unloaded three phase generator. The terminal conditions at the fault point are:

$$\bar{V}_b = \bar{V}_c = \bar{Z}_f \bar{I}_f = \bar{Z}_f(\bar{I}_b + \bar{I}_c)$$

$$\bar{I}_a = \bar{I}_{a1} + \bar{I}_{a2} + \bar{I}_{a0} = 0 \qquad (4.112)$$

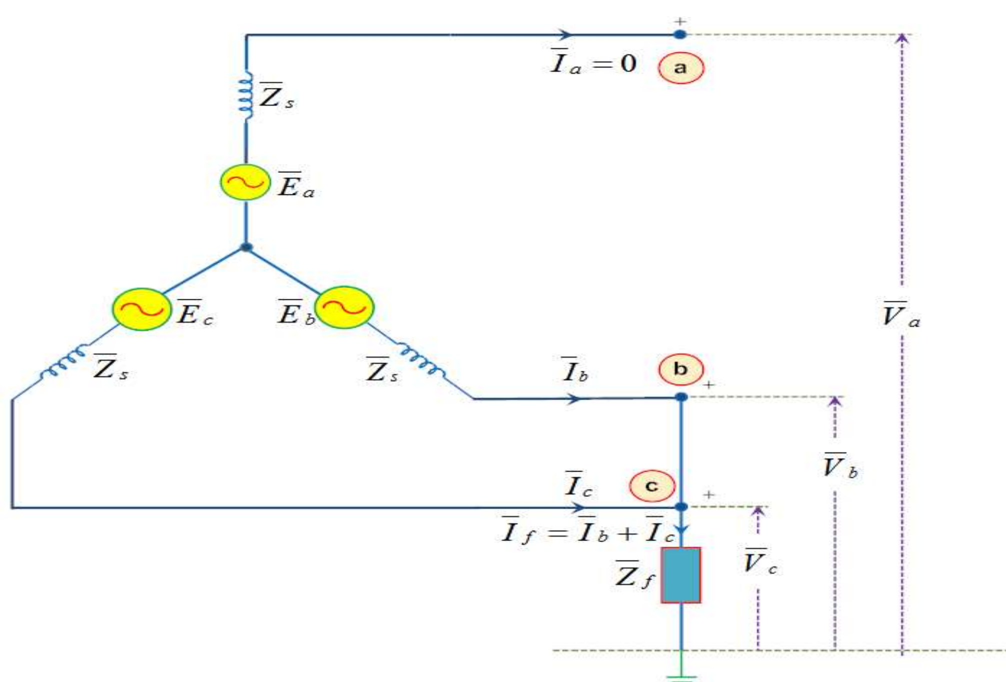


Figure 3.10 : Double line to Ground fault

From equation (4.83), Vb and Vc can be written as:

$$\bar{V}_b = \bar{V}_{a0} + \mathbf{a}^2\bar{V}_{a1} + \mathbf{a}\bar{V}_{a2}$$

$$\bar{V}_c = \bar{V}_{a0} + \mathbf{a}\bar{V}_{a1} + \mathbf{a}^2\bar{V}_{a2} \tag{4.113}$$

Since $\bar{V}_b = \bar{V}_c$, from equation (4.113), one can write

$$\bar{V}_{a1} = \bar{V}_{a2} \tag{4.114}$$

Substituting $\bar{I}_b$ and $\bar{I}_c$ in terms of their sequence components from equation (4.85), voltage of phase 'b' can be expressed as:

$$\bar{V}_b = \bar{Z}_f(\bar{I}_{a0} + \mathbf{a}^2\bar{I}_{a1} + \mathbf{a}\bar{I}_{a2} + \bar{I}_{a0} + \mathbf{a}\bar{I}_{a1} + \mathbf{a}^2\bar{I}_{a2})$$

$$\begin{aligned}\bar{V}_b &= \bar{Z}_f(\bar{I}_{a0} + \mathrm{a}^2\bar{I}_{a1} + \mathrm{a}\bar{I}_{a2} + \bar{I}_{a0} + \mathrm{a}\bar{I}_{a1} + \mathrm{a}^2\bar{I}_{a2}) \\ &= \bar{Z}_f(2\bar{I}_{a0} + (\mathrm{a}^2 + \mathrm{a})(\bar{I}_{a1} + \bar{I}_{a2})) \\ &= \bar{Z}_f(2\bar{I}_{a0} - (\bar{I}_{a1} + \bar{I}_{a2}))\end{aligned}$$

Since $1 + \mathrm{a} + \mathrm{a}^2 = 0$ and $\bar{I}_a = \bar{I}_{a1} + \bar{I}_{a2} + \bar{I}_{a0} = 0$, hence

$$\bar{V}_b = 3\bar{Z}_f\bar{I}_{a0} \tag{4.115}$$

Further substituting ¯ Vb from equation (4.115) and the condition of equation (4.114) in equation (4.113), we get:

$$\begin{aligned}3\bar{Z}_f\bar{I}_{a0} &= \bar{V}_{a0} + (\mathrm{a}^2 + \mathrm{a})\bar{V}_{a1} \\ &= \bar{V}_{a0} - \bar{V}_{a1}\end{aligned} \tag{4.116}$$

Substituting $\bar{V}_{a0}$ and $\bar{V}_{a1}$ from equation (4.94) in equation (4.116), the zero sequence component of

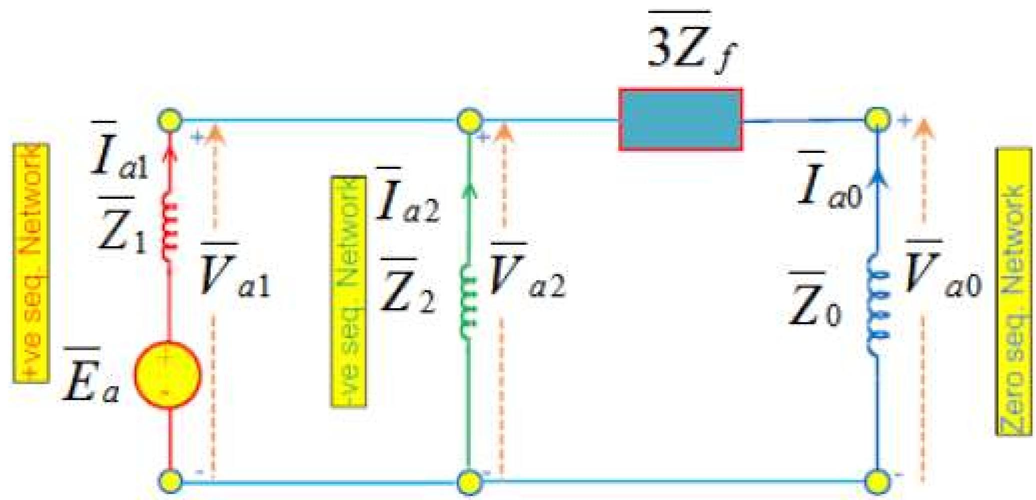


Figure 3.11 : Interconnection of sequence networks to simulate LLG Fault

Current $\bar{I}_{a0}$ is given by:

$$\boxed{\bar{I}_{a0} = -\frac{(\bar{E}_a - \bar{Z}_1\bar{I}_{a1})}{(\bar{Z}_0 + 3\bar{Z}_f)}}$$

For calculating the negative sequence component of current, $\bar{I}_{a2}$, substitute $\bar{V}_{a1}$ and $\bar{V}_{a2}$ from equation (4.94) in equation (4.114). The expression for $\bar{I}_{a2}$ is:

$$\boxed{\bar{I}_{a2} = -\frac{(\bar{E}_a - \bar{Z}_1\bar{I}_{a1})}{\bar{Z}_2}}$$

Finally, by substituting $\bar{I}_{a0}$ and $\bar{I}_{a2}$ from equations (4.117) and (4.118) in equation (4.112), the value of the positive sequence component of current $\bar{I}_{a1}$ is found out as

$$\boxed{\bar{I}_{a1} = \frac{\bar{E}_a}{\bar{Z}_1 + \dfrac{\bar{Z}_2(\bar{Z}_0 + 3\bar{Z}_f)}{(\bar{Z}_0 + \bar{Z}_2 + 3\bar{Z}_f)}}} \qquad (4.119)$$

Since $\bar{V}_b = \bar{Z}_f \bar{I}_f$, from equation (4.115) one can conclude that

$$\boxed{\bar{I}_f = 3\bar{I}_{a0}} \quad (4.120)$$

The equivalent circuit for the fault in terms of the sequence networks is shown in Fig. 4.59. The circuit shown in Fig. 4.59 is based on equations (4.114) and (4.116). For LLG fault calculations in a power system, the Thevenin's equivalent of the three sequence networks, as seen from the fault point, are found out. The positive and negative sequence equivalents are connected in parallel and the combination is then connected to the zero sequence network through $3\bar{Z}_f$.

Chapter – 4

SIMULATION USING MATLAB

4.1 Introduction to MATLAB

MATLAB, developed by Mathswork [7], is a high-level programming language having an interactive environment for numerical computation, visualization, technical computation and programming. Using MATLAB, we can analyze data, develop algorithms, and create models and applications. The language, tools, and built-in math functions enable us to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages, such as C/C++ or Java.

We can use MATLAB for a range of applications, including signal processing and communications, image and video processing, control systems, test and measurement, computational finance, and computational biology. More than a million engineers and scientists in industry and academia use MATLAB, the language of technical computing.

Matlab is selected as the simulation tool in this project due to several reasons. Our background of Matlab was the main reason behind this choice. In addition, any code can be edited and modified easily to handle any future cases using the command edit window. Also, Matlab contains many built-in functions to resolve different electrical problems.

4.2 MATLAB Model

4.2.1 Model of 'L-G' Fault

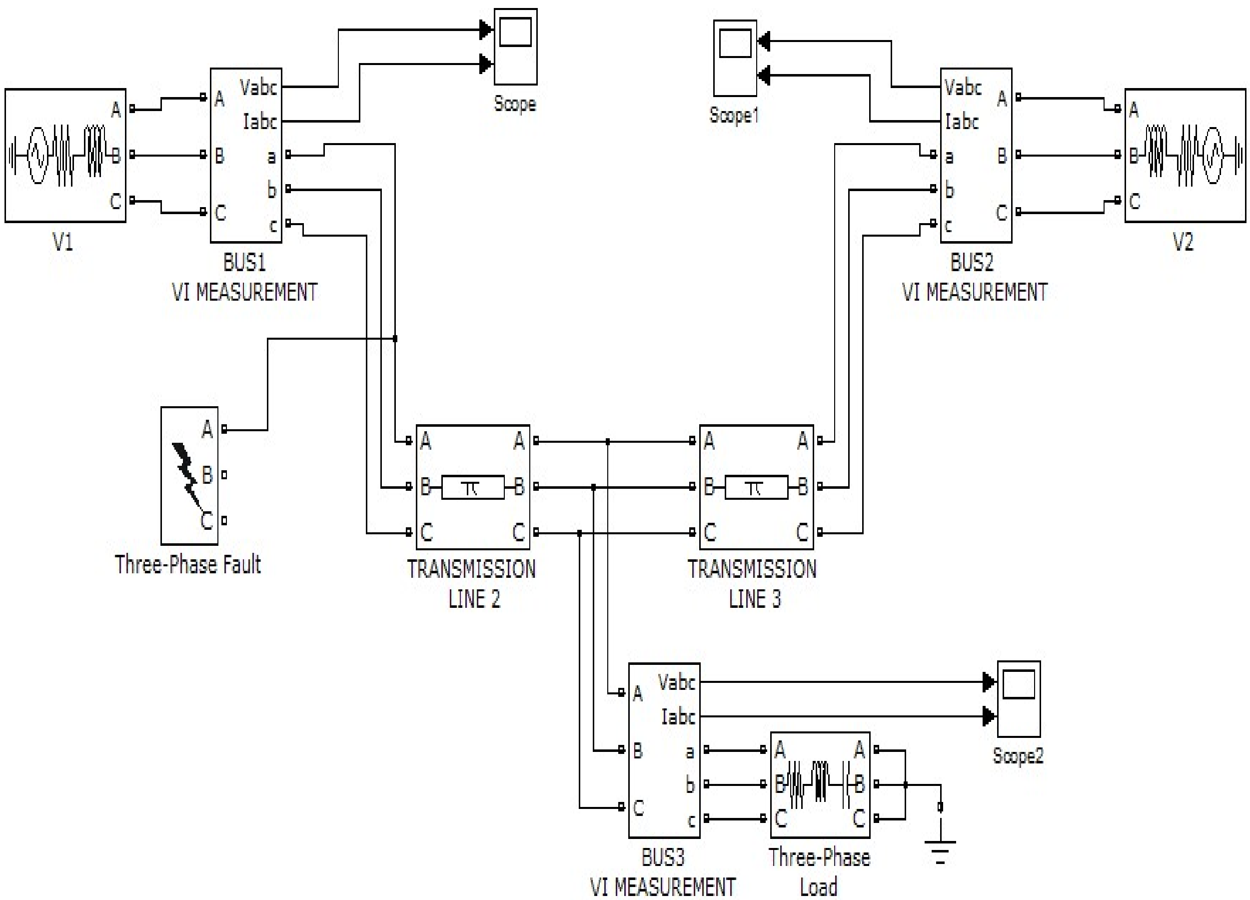


Figure 4.1 : MATLAB Model of LG Fault at Bus1

4.2.1.1 Current waveform of ‘L-G’ fault

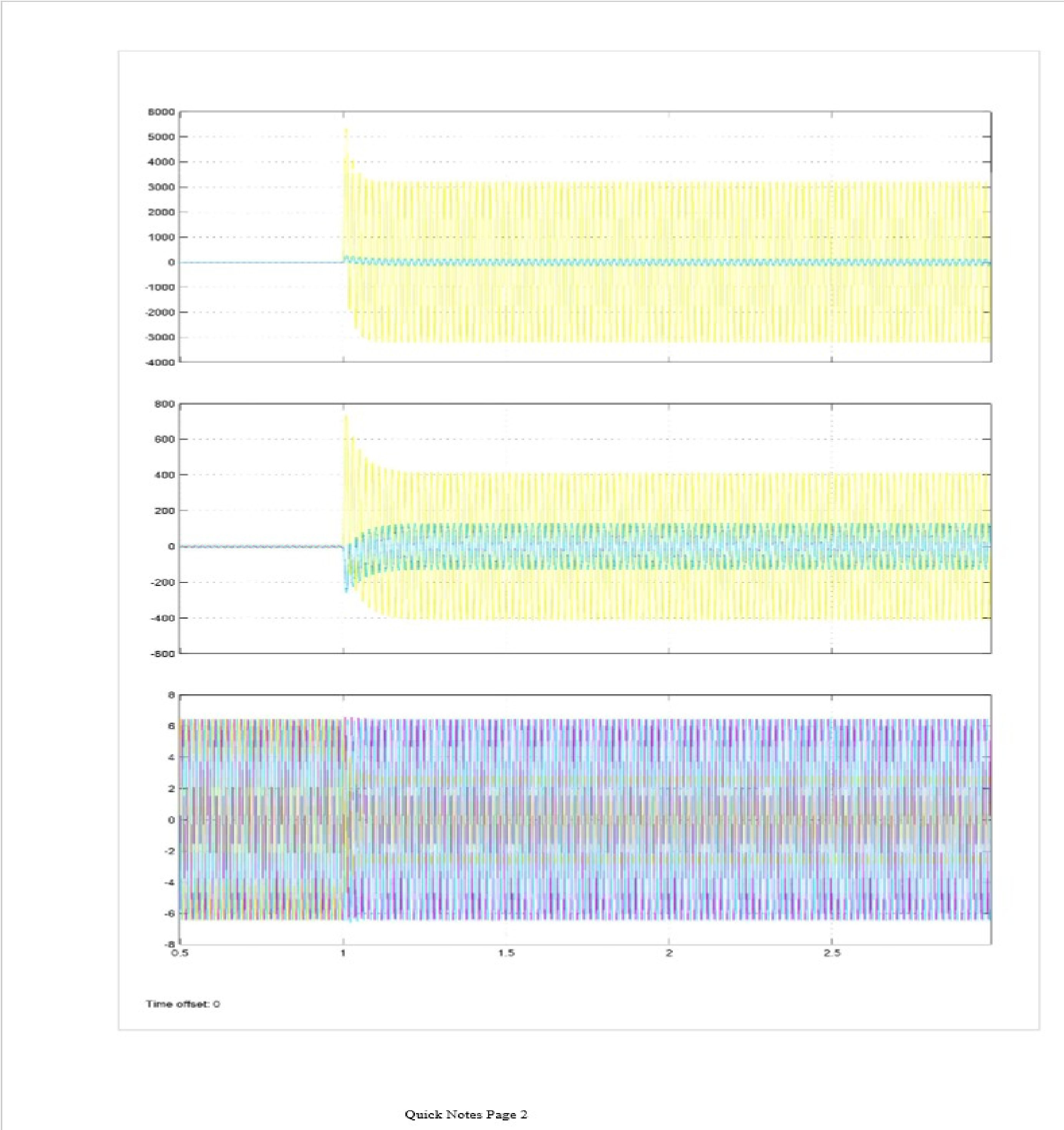


Figure 4.2 : Current waveform of Bus 1,2,3 when a ‘L-G’ fault occurs at Bus 1

4.2.2 Model of 'L-L-G' Fault

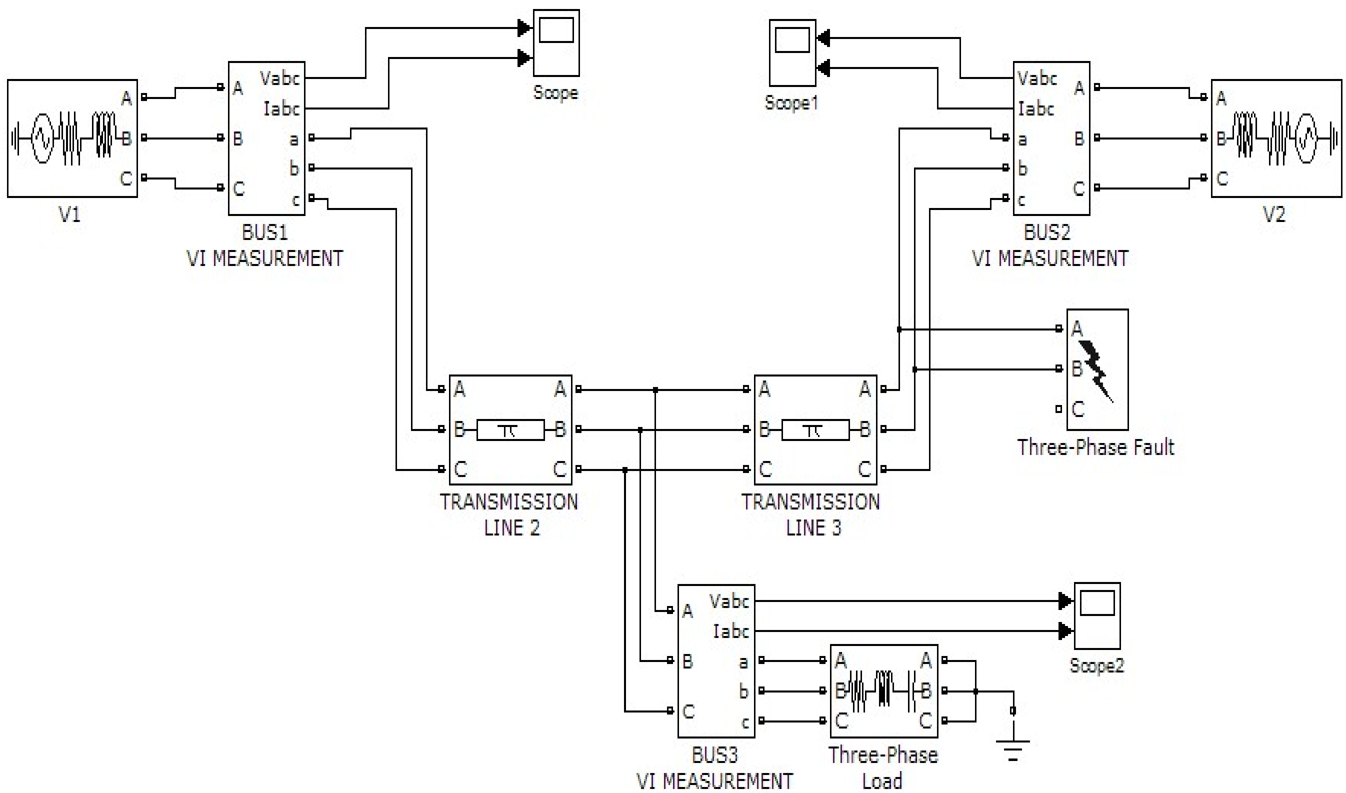


Figure 4.3 : MATLAB Model of LLG Fault at Bus 2

4.2.2.1 Current waveform of ‘L-L-G’ fault

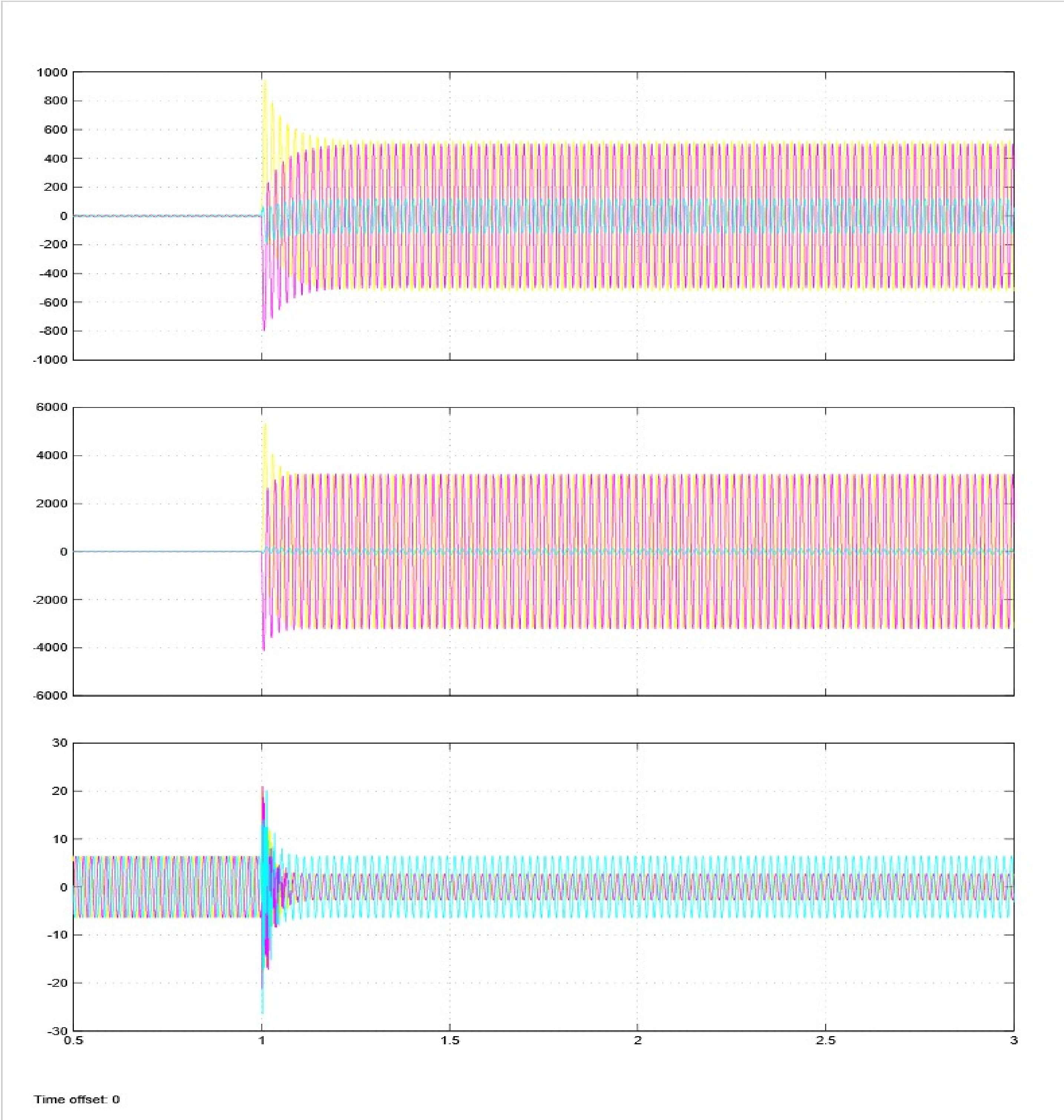


Figure 4.4 : Current waveform of Bus 1,2,3 when a ‘L-L-G’ fault occurs at Bus 2

4.3 Table for MATLAB Results

Fault Type	Faulty Bus	Faulty Phase	I_a	I_b	I_c
L-G	BUS 1	A			
		B			
		C			
	BUS 2	A			
		B			
		C			
	BUS 3	A			
		B			
		C			
L-L-G	BUS 1	A			
		B			
		C			
	BUS 2	A			
		B			
		C			
	BUS 3	A			
		B			
		C			

Table 4.1: Zero Sequence Component

TYPE OF FAULT	NAME OF THE BUS	ZERO SEQUENCE COMPONENT (I_0rms)		
		BUS1	BUS2	BUS3
Line to Ground(LG)	Bus1	817.39	37.38	2.8396
	Bus2	37.43	818.1	2.8227
	Bus3	125.88	125.88	250.76
Double Line to Ground (LLG)	Bus1	790.5	35.79	0.834
	Bus2	35.79	790.5	0.834
	Bus3	86.3	86.3	171.5

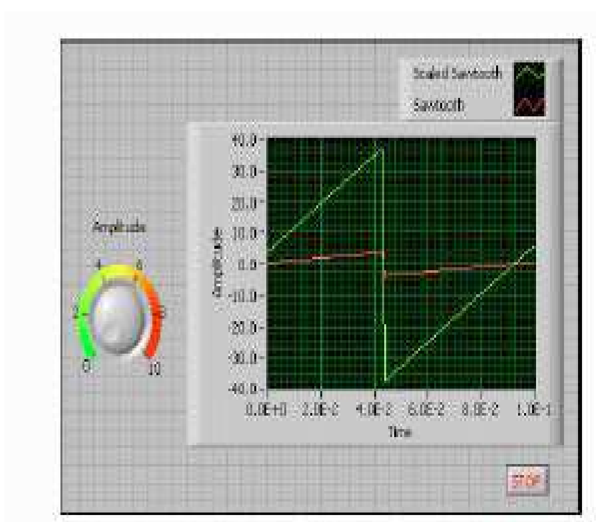
Chapter - 5

ANALYSIS USING LabVIEW

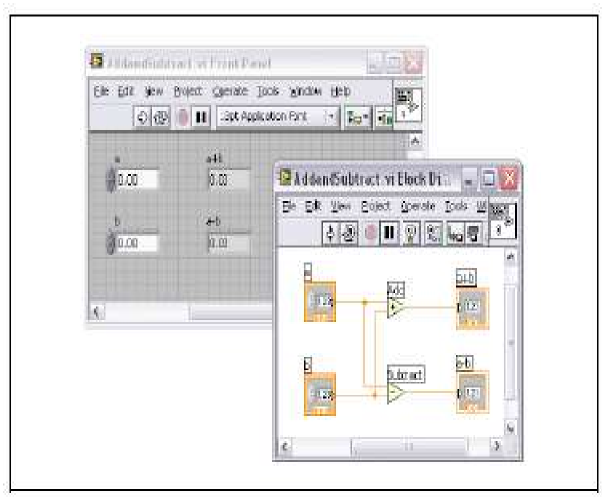
5.1 Introduction to LabVIEW

LabVIEW (short for Laboratory Virtual Instrument Engineering Workbench) is a system-design platform and development environment for a visual programming from National Instruments. It is a **"program development application"**. LabVIEW is a **graphical programming language**, as opposed to a text-based language, used to create programs in a block diagram form.

LabVIEW programs/subroutines are called virtual instruments (VIs). Each VI has three components: a block diagram, a front panel and a connector panel. The last is used to represent the VI in the block diagrams of other, calling VIs. The front panel is built using controls and indicators. Controls are inputs – they allow a user to supply information to the VI. Indicators are outputs – they indicate, or display, the results based on the inputs given to the VI. The back panel, which is a block diagram, contains the graphical source code. All of the objects placed on the front panel will appear on the back panel as terminals. The back panel also contains structures and functions which perform operations on controls and supply data to indicators.



Front Panel window



Block Diagram window

The graphical approach also allows non-programmers to build programs by dragging and dropping virtual representations of lab equipment with which they are already familiar. The LabVIEW programming environment, with the included examples and documentation, makes it simple to create small applications.

LabVIEW is a "general-purpose programming system." The LabVIEW is used for

- Data acquisition
- Signal Processing(Analysis)
- Hardware Control

LabVIEW software is ideal for any measurement or control system, and the heart of the NI design platform. Integrating all the tools that engineers and scientists need to build a wide range of applications in dramatically less time, LabVIEW is a development environment for problem solving, accelerated productivity, and continual innovation.

<u>Fault Detection Algorithm:</u>

5.2 LabVIEW Model

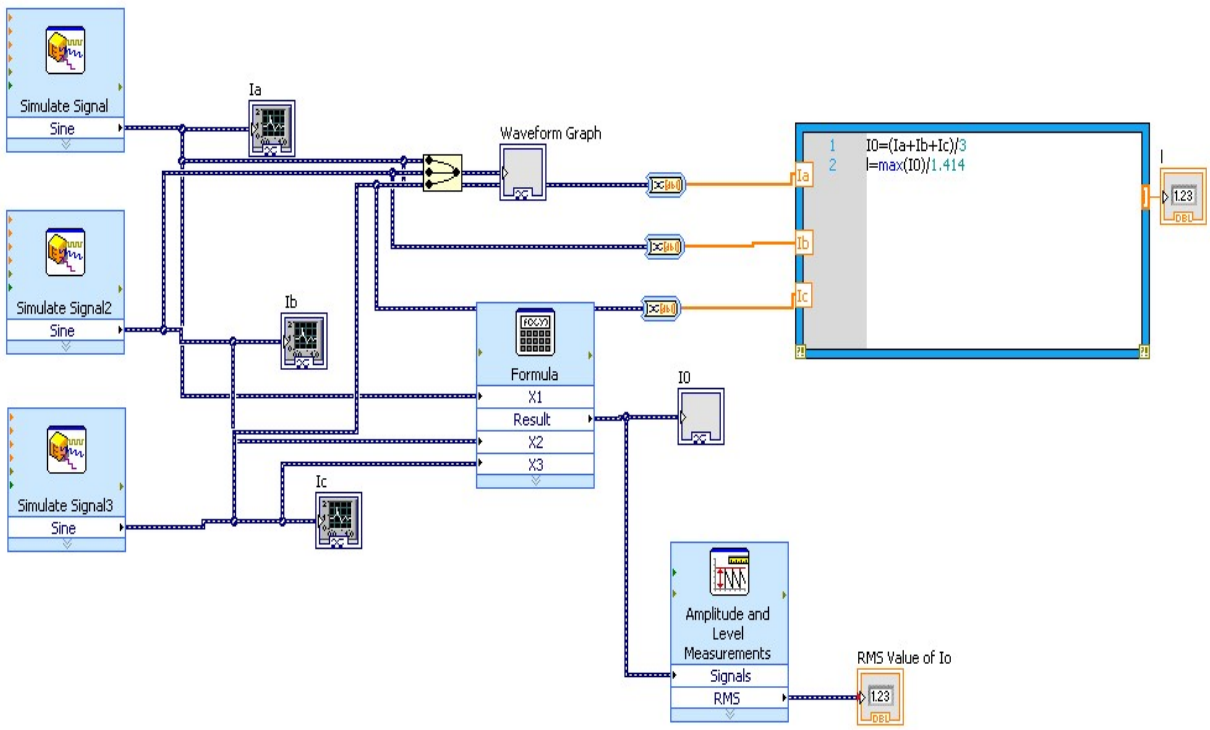


Figure 5.1 : Block Diagram for calculating rms value of Zero sequence current component

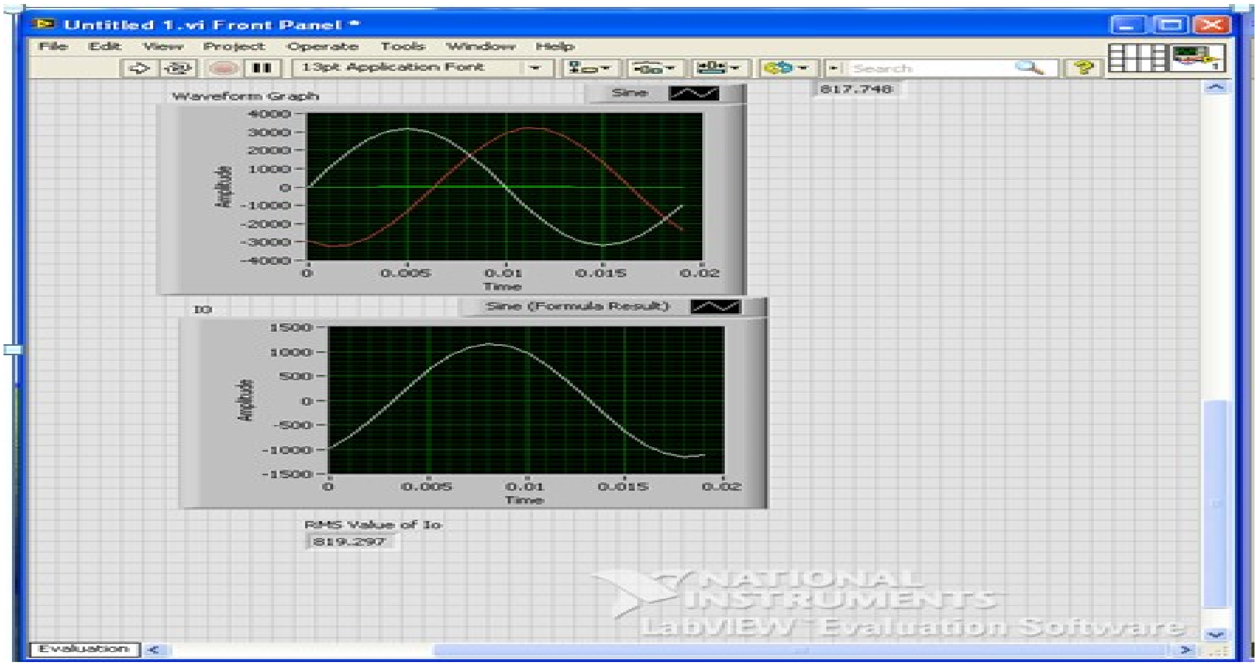


Figure 5.2 : Zero Sequence Current (max rms value) waveform

38

5.3 <u>Table for zero sequence component</u>

Table No. 5.1 : Zero Sequence Component in LabVIEW

TYPE OF FAULT	NAME OF THE BUS	ZERO SEQUENCE COMPONENT (I_0 rms)		
		BUS1	BUS2	BUS3
Line to Ground(LG)	Bus1	817.27	36.079	2.8396
	Bus2	35.824	752.69	2.8227
	Bus3	126.13	126.14	251.02
Double Line to Ground (LLG)	Bus1	819.203	40.85	0.84
	Bus2	40.85	819.3	0.84
	Bus3	115.75	116.5	231.52

REFERENCES

[1] Paul M. Anderson, “Analysis of Faulted Power Systems”, The Institute of Electrical and Electronics Engineers, Inc., 1995.

[2] Jun Zhu. “Analysis Of Transmission System Faults the Phase Domain”, Texas A&M University. Master Thesis, 2004.

[3] Hadi Saadat. Power System Analysis. Milwaukee Scholl of Engineering. WBC McGraw-Hill.

[4] Norliana B. Salimun. “Phase Coordinates In Faulted Power System Analysis”, Universiti Teknologi Malaysia. Master Thesis, 2010.

[5] John Horak, “A Derivation of Symmetrical Component Theory and Symmetrical Component Networks,” Georgia Tech Protective Relaying Conference, April 2005.

[6]. D. Povh.Retzmanna D. Rittiger J “Benefits of simulation for operation of large power system & system interconnection” 4th IERE General Meeting & IERE Central & Eastern Europe Forum, 19-21 Oct,2004.

[7] www.mathworks.com

[8] Miroslav D. Markovic, “Fault Analysis in Power Systems by Using the Fortescue Method”, TESLA Institute, 2009.

[9] C.L. Wadhwa, “Electrical Power Systems”, pp 306, New Age International, 2006.

[10] “Electrical Power System” Mehta & Mehta