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ZONE PROTECTION SYSTEM OF TRANSMISSION LINE BY DISTANCE RELAY

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I, Rakesh Kumar, Roll No. 2K17/PSY/14 student of M.Tech. (Power System), hereby declare that the project Dissertation titled "Zone Protection System of Transmission Line by Distance relay" which is submitted by me to the Department of Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology/Bachelor of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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CERTIFICATE

I, Rakesh kumar, Roll No. 2k17/PSY/14 student of M. Tech. (Power System), hereby declare that the dissertation/project titled “Zone Protection System of Transmission Line by Distance Relay” under the supervision of Prof. Jitendra Nath Rai of Electrical Engineering Department Delhi Technological University in partial fulfillment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any Degree.

Place: Delhi **RAKESH KUMAR**
Date: 15/07/2019

Prof. JITENDRA NATH RAI

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ABSTRACT

In this thesis design and modeling of Distance Relay has been done using MATLAB-SIMULINK. When microprocessor technology was implemented in the relay designing technique it gave birth to a new type of protection methodology known as Numerical relay. Numerical relays can interact with the peripheral devices and other numerical relays also, resulting in overall economy of the protection system equipments. A power system network and the distance relay model has been developed and the response of the distance relay has been verified by plotting the data generated by the relay on R-X diagram. The input voltage and current signal from the power system network contains dc offset values and higher order harmonics these are the unwanted quantities of the signal which need to be filtered out for proper functioning of the relay, Discrete Fourier Transform (DFT) can easily isolate these unwanted quantities from the signals. DFT has been used for the designing of the proposed distance relay.

This report tells about the necessities of this relays in a power system and why these are so important for generator only and why not for others. This model in Simulink is treated with different types of faults such as line and ground fault. This report also tells about the brief discussion about the excitation system relating to the generator protection and coordinating with other devices.

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LIST OFABREVIATONS

C.T.	Current Transformer
P.T.	Potential Transformer
VLSI	Very Large Scale Integration
LLLG	Three-line to Ground
LLG	Double-line to Ground
LL	Line to line
SLG	Single line to Ground
GUI	Graphical user Interference
EHV	Extra High Voltage
KV	Kilovolts
V	Relay sensing Voltage
I	Relay sensing Current
R	Resistance
X	Reactance
Z	Impedance
Φ	Angle between voltage and current
ELD	Economic Load Dispatch
T	Time
T_s	Sample time
V_s	Imaginary component of Voltage
V_c	Real component of Voltage
I_s	Imaginary component of Current
I_c	Real component of Current
HHT	Hilbert-Huang Transform

AC	Alternating Current
DC	Direct Current

NOMENCLATURE

V_a	Voltage of phase-a
V_b	Voltage of phase-b
V_c	Voltage of phase-c
I_a	Current of phase-a
I_b	Current of phase-b
I_c	Current of phase-c
K_o	Residual compensation factor
I_o	Zero-sequence current

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

A power system includes generators, transformers, power transmission lines and so on. Short circuits and the other abnormal state sometimes arise in a power system. If the protection of each segment of the power system is not supplied with appropriate protective relays and circuit breakers, it is probable that the heavy current connected with small circuits would harm the equipment. If a power system unit failure happens, the defective component must be isolated as soon as possible by an automatic protective device, so that the healthy system segment can continue to operate continuously. The fault must be fixed within a fraction of a second.

A protection scheme involves circuit breakers and protection relays to isolate from healthy regions the faulty portion of the system. If the protective relay is called, the damaged part of the system can be disconnected by a circuit breaker. A fault must be identified and diagnosed, and for the protective relay work a command is issued to disconnect the defective device.

Relay is a device that senses faulty conditions in a power system by constantly monitoring the electrical characteristics of the system that differ under normal and abnormal conditions. The main electrical quantities that are likely to change in uncommon conditions are current, voltage, phase angle, and frequency.

1.2 NATURE AND CAUSES OF FAULTS

Faults are induced either by faults in insulation or faults in the path. Insulation failure results in very adverse short circuits as they can harm some power system devices. Most transmission line and distribution line faults are generated by overvoltage owing to lighting or switching surges, or by external conductive objects that fail on overhead lines. Overvoltage produced by lighting or switching surges leads short circuits to flash on the surface of the insulators. Isolators are punctured or damaged at times.

String and pine insulators sometimes accumulate on the surface some foreign particles such as fine cement dust or soot in industry or coastal salt or any dirt. This decreases their isolation power and creates flashes.

1.3 EVOLUTION OF PROTECTIVE RELAYS

In the early days of the power sector, small generators were used for supplying local loads and fuses were the only automatic elements for isolating malfunctioning devices. Their performance was effective and quite satisfactory for small devices.

Electromagnetic relays of a attracted type armature were first introduced. They were quick, easy and inexpensive. Because of their simplicity and low price, their use will continue even in the future as additional relays. In the early 1920s, inverse time-current relays of the induction disc type were created to satisfy the selectivity requirement. They were used to protect against over-current. Induction cup type devices have been commonly used worldwide for directional and distance relays. Because of its greater torque / inertia proportion, an induction cup type system was quick and precise. Polarized dc relays have been used since 1939 to increase sensitivity and precision.

Comparators of type bridge rectifier were developed in Norway and Germany in 1947. The position of relays of the induction cup type was challenged by polarized dc relays, powered by rectifier bridge comparators. They are currently widely used for the realization of characteristics of distance relays.

In 1949, shortly after the transistor's development, the first transistor relay was created. Different types of static relays were created in the fifties using solid state devices. Multi-input comparators were created in the sixties with quadrilateral features. Static relays have small burden benefits for the C.T. And P.T., quick operation, lack of mechanical inertia and contact disturbances, lengthy service life and less maintenance. Since static relays have proved superior to electromagnetic relays, they have been used to protect significant lines, power stations and sub-stations.. With the increasing complexity of contemporary power networks, the demand for the future will be quick, precise and reliable protective systems. There is increasing interest in the use of digital computers for security online. But they cost fifteen to twenty times more than standard protection systems.

To replace standard digital and electromechanical logic systems, microprocessors are used in the former region. They are used as the basis of all kinds of pcs in the latter region. Sophisticated microprocessors and single-chip microcomputers are being created with the latest innovations in VLSI technology. The intrinsic benefit of microprocessor-based protection systems is their flexibility over current statics relays with one or a very restricted spectrum of apps. Microprocessor implementation to protective relays will also lead in quicker, more precise and more reliable relay units being available. Due to its programmable strategy, a microprocessor improves the flexibility of a relay. It can provide low price security and compete with standard relays.

1.4 ZONES OF PROTECTION

A power system consists of generators, transformers, bus bars, transmission and delivery lines, and so forth. Therefore, an electricity system is split into several protective zones. One or two of the most components of a power system are covered by a protective area.

Adjacent protective zones must overlap, without which there can be no fault in any one of the zones at the boundary, and therefore no circuit breaker would travel. There is thus an inevitable overlap between the surrounding region. If a defect occurs in the overlap zone, more circuit breakers than is the minimum necessary to isolate the faulty system element would be used in a properly protected system. A relative small overlap decreases the likelihood of defects in this region, so too many disruptors are not frequently triggered.

1.5 TECHNOLOGY BASED PROTECTIVE RELAYS

Depending on the technology they use for their building and operation, protective relays can be widely categorized into the following categories.

- ***Electromagnetic relays:*** Electromagnetic relays include attracted armature relays, moving spiral, induction discs and induction cup relays. An electromagnetic relay exists and there is a moving element. If the actuating amount exceeds a default value, a working torque is created that is applied to the moving part. This leads to the moving part being traveled and finally a contact being closed to energize the travel belt of the interrupter.
- ***Static relays:*** Static relays comprise electronic circuits that may include transistor parts, ICs, diodes, and other parts of electronics. The relay includes a comparator circuit comparing two or more currents or voltages and providing either a slave relay or a thyristor circuit with an output. The slave transmits an electromagnetic relay that finally closes the contact. A slave relay is a semi-static relay. A relay using a thyristor circuit is a static relay. The advantages of static relays are low C.T. And P.T., fast operation, absence of mechanical inertia and contact problems, long life and less service maintenance.
- ***Microprocessor-based relays:*** The latest development in this area is microprocessor-based protective relays. Sophisticated and quick microprocessor are coming up with innovations in VLSI technology. Power engineers are currently interested in their solutions to the issues of protective relaying systems. Because of their programmable approach, the inherent advantages of microprocessor-based relays over static relays with or very limited application range are attractive flexibility.

- ***Adaptive relaying:*** A latest philosophy of protecting electrical power systems is adaptive relaying. Adaptive relaying uses the constantly evolving power system status as the grounds for digital relay settings on-line modification. It therefore offers the flexibility needed to achieve a very high level of system reliability. These systems are perfect for implementing adaptive relaying concepts by digital relays with appropriate software and communication capacity.

1.6 PRESENT WORK OBJECTIVES

Considering the study gap, the primary goal of the work described in this thesis is to create various kinds of digital distance relaying systems that eliminate the mistakes generated by standard digital distance relays while protecting the transmission lines from the various kinds of faults mentioned as follows:

1. Symmetrical Faults
2. Unsymmetrical Faults
    - Single phase to ground (L-G) fault
    - Two phase to ground (2L-G) fault
    - Phase to phase (L-L) fault

1.7 THESIS ORGANIZATION

The work presented in the thesis is divide in seven chapters:

- ***Chapter 1:*** The first chapter deals with the implementation of issues, fundamental security system specifications, and discusses the significance of main and back-up relaying. This section presents the background of the growth of protective relays from electromechanical relays of the first generation to the current digital / adaptive relays. This section highlights digital privacy study possibilities.
- ***Chapter 2:*** The second Chapter deals with literature review of the topic, basic work that has been done by the different researchers on the same topic with different approach.
- ***Chapter 3:*** The third Chapter deals with introductory part of the Distance relay, its types, its properties, and area where they are used for protection of transmission line.
- ***Chapter 4:*** The fourth Chapter deals with discrete Fourier transform (DFT), its signal representation, extraction of the fundamental component, computation of the apparent impedance.

- ***Chapter 5:*** The fifth Chapter deals with the modelling of system foe distance relay. It includes the modelling of transmission line, low-pass filter, sampling, conversion of analog signal to the discrete signal, fault calculation algorithm and automatic fault detection
- ***Chapter 6:*** The sixth Chapter deals with the simulation results, conclusion and future scope. It includes output wave form of voltage and current sense by relay, impedance trajectory on *R-X* plane with three zone protection for three different fault.

CHAPTER 2

LITERATURE REVIEW

Protection relays are one of the primary parts of power systems that can have a very strong effect on the stability and reliability of the power system. One of the protecting relays used in the power system is the distance or impedance relay that is used primarily in the transmission system. Distance relay may be used as protection for the principal or backup. The transmission line or power transformer can be protected using it. The electromechanical and static distance relays have now been commonly replaced by numerical range relays. Compared to other protection relays, understanding the operation of distance relay is quite hard due to its complicated concepts and philosophies.

The most commonly used technique for protecting transmission lines is distance protection. The basic concept of distance Relying is based on local voltage and current measurement, where the Relay reacts to the impedance between the relay terminal and the place of the fault [1]. There are many kinds of distance relay characteristics such as mho, reaction, admission, polarized-mho quadrilateral, mho offset etc. There are distinct planned functions and theories behind each sort of characteristics [5]. To understand Relay's function, software relay models need to be realized, protective relay modeling offers an economical and viable solution to studying protective relay efficiency. Relay models were used in a variety of tasks for a long time, such as designing new relay algorithms and optimizing relay settings. Using computer-based relay models, electrical power utilities verify how the relay would perform during system disturbances and ordinary working circumstances and make the required corrective adjustment to the relay environments. [3][6]

This project defines the modeling of the Matlab / Simulink package for the remote relay and area security system. For thorough modeling of distance relay, transmission line and simulation of faults, the Sim Power System toolbox was used. Single line to floor (SLG) fault was selected in the modeling to be the sort of fault and impedance type range feature was selected to be the protective system. A graphical user interface (GUI) has been created for the model developed using the GUI package inside Matlab. In this project fault (L-G) is applied externally by using a block called 'three phase fault' only for a certain amount of time. In this document, fault is implemented only for stage A. Only up to the circuit breaker opening is simulated when there is a fault in the line but not up to the circuit breaker reclosing. The waveforms of voltages and currents are also noted by simulating the line of transmission with and without errors [7].

Here Author proposed a new impedance trajectory method after errors represents the impedance calculation numerical output. The findings of the output demonstrate the model's behavior under distinct fault places and distinct arc resistances. The presented simulation research demonstrates the significance and need for precise dynamic modeling of range safety relays[3,8].

This document introduces the design and modeling of Distance Relay with the assistance of MATLAB / SIMULINK. A transmission line network was developed due to various symmetrical and unsymmetrical errors, plotting fault voltages and generated currents. The input voltage and current to the transmission line network comprises of DC offset values and higher order harmonics during fault conditions. As these are unwanted signals, they need to be filtered out. The Discrete Fourier Transform (DFT) is used to function the distance relays correctly, which can easily remove these unwanted signals. The proposed distance relay model response was plotted by an R-X diagram. Results for single-line ground fault (SLG), double-line fault (LLG) and three-stage fault (LLLG) were purchased at distinct locations on an energy system network with a 250 kilometre long transmission line.

CHAPTER 3

DISTANCE RELAY

3.1 DISTANCE PROTECTION

Distance protection is a commonly used protection system to protect the transmission and sub-transmission lines of elevated and extra high voltage (EHV). This system uses a set of distance relays to assess impedance at the relay place or some of the line impedance parts. The quantity measured is proportional to the length of the line between the relay location and the point at which the fault occurred. Due to the proportion of the measured quantity to the line range, the measuring relay is called a range relay.

Modern range relay provides clearance of high-speed errors. They are used where overcurrent relays are slow and it is hard for complex networks to grade time-overcurrent relays. They are used at 220kV, 132kV, 66kV, and 33kV to protect transmission and sub-transmission lines. The latest application for carrier safety is for 132kV and 220kV schemes. The relay devices used in airline safety are relays of scope. They operate under control of carrier signals. In case of carrier signal loss, they act as back-up protection. A system of remote protection is a system of non-unit safety. A single unit provides both main and back-up safety.

The most important and versatile family of relays is the distance-relay group. It includes the following types:

- Impedance relays
- Reactance relays
- MHO relays
- Quadrilateral relays

3.1.1 IMPEDANCE RELAY

An impedance relay measures the line's significance at the place of the line relay. The impedance measured is the impedance segment between the place of the relay and the fault point when fault occurs on the protected line section. The line distance is proportional and therefore proportional to the line length.

Operating Principle of an Impedance Relay

The current at the relay location is compared with the voltage to recognize the characteristics of an impedance relay. The current produces a positive torque (working torque) and a negative torque (restraining torque) is generated by the voltage. The operating torque equation of an electromagnetic relay can be written as

$$T = K_1 I^2 - K_2 V^2 - K_3 \qquad \text{………….. (3.1)}$$

Where K1, K2 and K3 are constants, because of the control-spring impact, K3 is the torque.

The torque equation can be written as neglecting the impact of the spring used, which is very tiny.

$$T = K_1 I^2 - K_2 V^2 \qquad \text{………… (3.2)}$$

The following condition should be met for relay operation.

$$K_1 I^2 > K_2 V^2 \; or \; K_1 I^2 < K_2 V^2$$

Or

$$\frac{V^2}{I^2} < \frac{K_1}{K_2}$$

Or

$$\frac{V}{I} < K \quad \text{where K is a constant}$$

Or

$$Z < K$$

I is compared with V for static and microprocessor-based relays. The following condition should be satisfied for relay operation.

$$K_1 I > K_2 V \quad or \quad K_2 V < K_1 I$$

or

$$\frac{V}{I} < \frac{K_1}{K_2} \quad or \quad Z < K$$

The above expression explains that the relay is on the verge of operation when the ratio of V to I, i.e. the measured value of line impedance is equal to a given constant. The relay operates when the measured impedance Z is less than the specified constant.

Impedance Relay Characteristic

Figure 3.1 demonstrates the voltage and present working characteristics of an impedance relay. In the event of an electromagnetic relay, owing to the control spring impact, the feature is slightly bent near the origin. The feature will be a straight line in the event of a microprocessor-based or static relay.

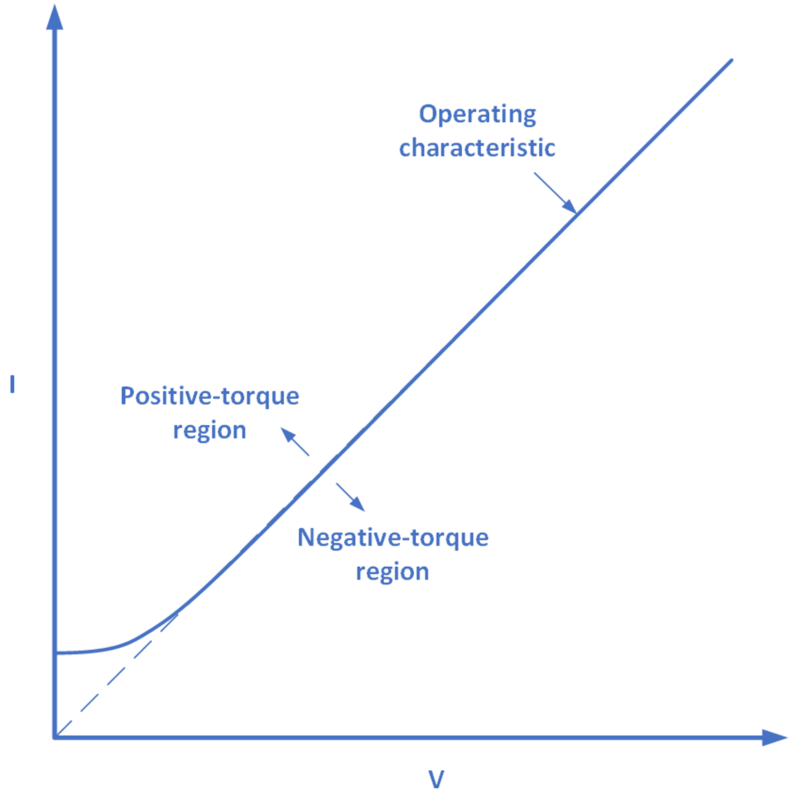


Figure 3.1 Operating characteristic of an impedance relay

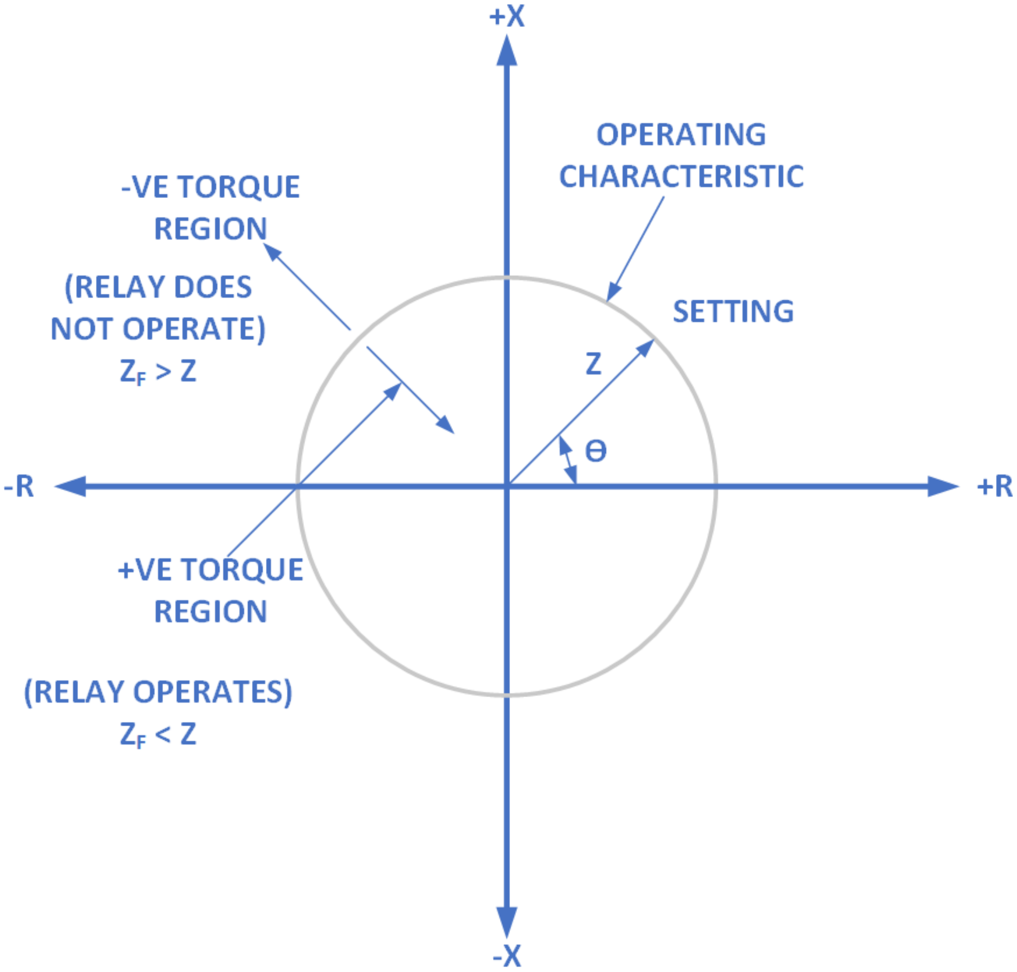


Figure 3.2 Operating characteristic of an impedance relay on the R – X diagram

A more helpful way is to draw on the R-X diagram a distance relay feature. Figure 3.2 demonstrates a characteristic impedance relay on the R-X diagram where Z= K represents a circle and Z < K displays the region within the circle. Thus, the area within the circle is the relay's working area. Its radius is Z= K, the relay environment. K is equivalent to the line's impedance to be protected. Each is the angle of the stage between V and I. Since the working feature is a circle, the operation of the relay is independent of the angle of the stage. The surgery relies on the Z magnitude.

3.1.2 REACTANCE RELAY

A reaction relay measures the line's reaction at the place of the relay and is not influenced by resistance variation. Therefore, during the event of fault, its output stays unaffected by arc resistance. The measured reaction is the reaction of the line between the place of the relay and the fault point in the event of a fault on the protected line. It has a straight line feature on the R-X diagram, parallel to the R-axis as shown in figure 3.3.

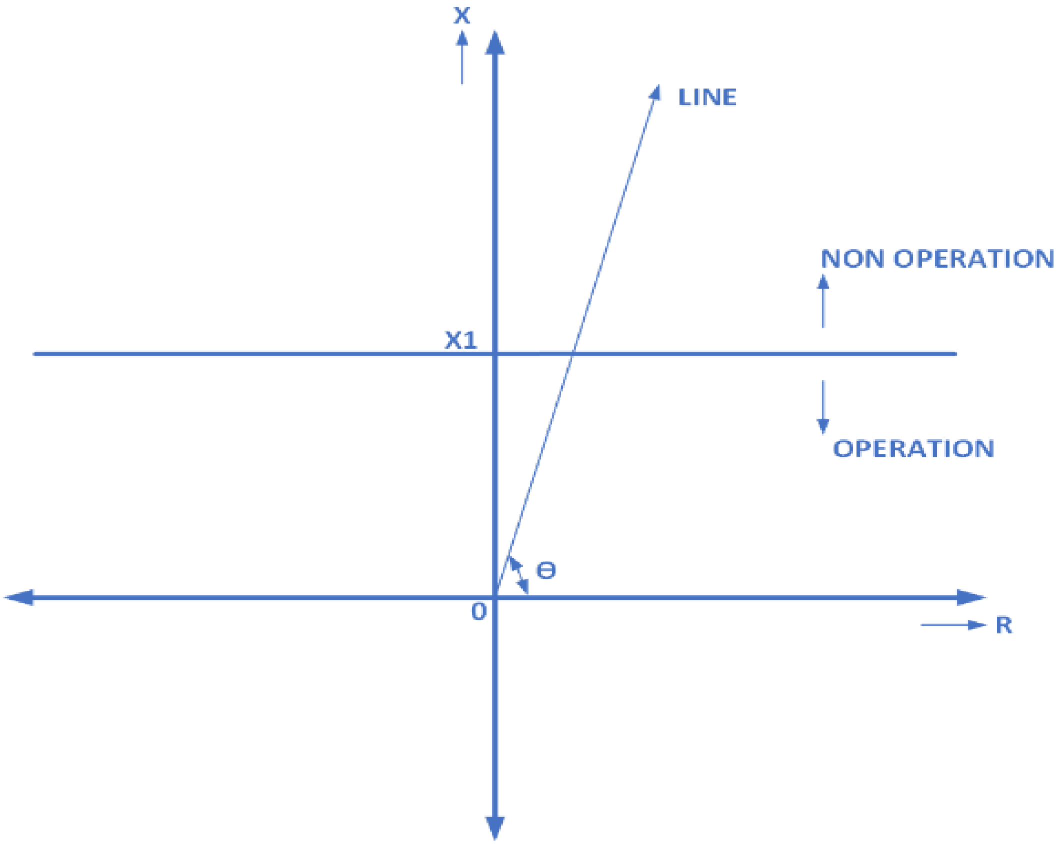


Figure 3.3 Operating characteristic of a reactance relay

The torque equation of the relay is given by

$$T = K_1I^2 - K_2VIcos(90 - \Phi) - K_3$$

$$= K_1I^2 - K_2VIsin\Phi - K_3 \qquad \ldots\ldots\ldots\ldots (3.3)$$

The restraining torque is proportional to VI cos (90–Φ). To realize the desired characteristic, the angle between the actuating quantities that are proportional to V and I can be changed. In this situation, the angle between the amounts of actuation is maintained (90 –range). The relay works when sinking K1I2 > K2VI, neglecting K3 which is a constant for the torque of the spring. So we got

$$\frac{V}{I}sin\Phi < \frac{K_1}{K_2}$$

Z sinΦ < K or X < K

Figure shows the trait of the reaction relay on the R-X diagram. When measured value K, it will work. It's not a directional relay because it will work for X's adverse values as well. X's adverse value implies the fault lies behind the place of the relay.

Using a microprocessor, a reaction relay can be realized by comparing I_{dc} with V sin. Alternatively, X can be evaluated at the relay place using differential equations, Fast Fourier transformations, walsh functions or any other digital method and can be compared to X's current value.

3.1.3 MHO RELAY

A MHO relay measures an admission element. But its characteristic is a circle plotted on the impedance diagram (R-X diagram) that runs through the origin. It is fundamentally a directional relay as it only detects the fault forward. This is evident from its circular trait, as shown in figure 3.4, passing through the origin. It's also called a relay for admission. It is called a MHO relay because, when plotted on an admission diagram, its feature is a straight line.

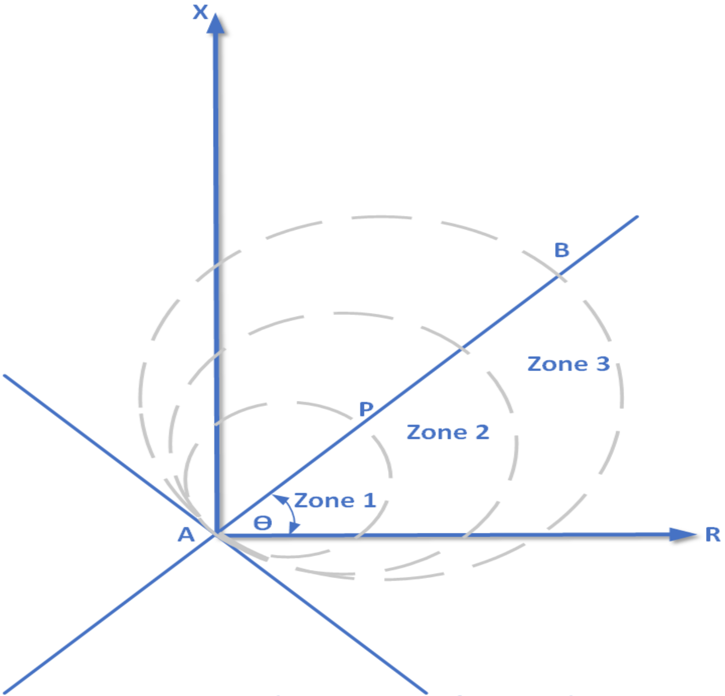


Figure 3.4 Characteristic of MHO relay

The torque equation is given by

$$T = K_1 VIcos(\Phi - \alpha) - K_2 V^2 - K_3 \qquad \ldots\ldots\ldots\ldots (3.4)$$

3.1.4 QUADRILATERAL REAY

ELD lines are best suited for a quadrilateral trait. It has the feature of an optimal distance relay. It can be intended to contain the fault region of the line to be protected. Power surges, fault strength, and overloads affect such a characteristic least. A quadrilateral feature is thus seen as an optimal feature for ELD lines protection. It is well suited for brief and medium lines as well. A static relay provides a better quadrilateral feature than an electromagnetic relay mixture.

A multi-input stage comparator is used to realize a quadrilateral or any other multilateral feature. For a comparator that has more than two outputs, the word multi-input comparator is used.

The relay will be quicker than a single multi-input comparator if more than one two-input comparator is used to realize a complicated trait. But the drawback of the two-input comparator mixture is that each comparator's outputs are not active simultaneously. The output of each comparator must be extended for a short time to overcome this trouble, which sometimes leads to erratic tripping.

A multi-input comparator to realize a quadrilateral trait, as shown in Fig. 3.5, it's a job. All input signals are contrasted with each other in a multi-input comparator. The resulting feature is the region enclosed by all these comparisons arising from the lines and circles.

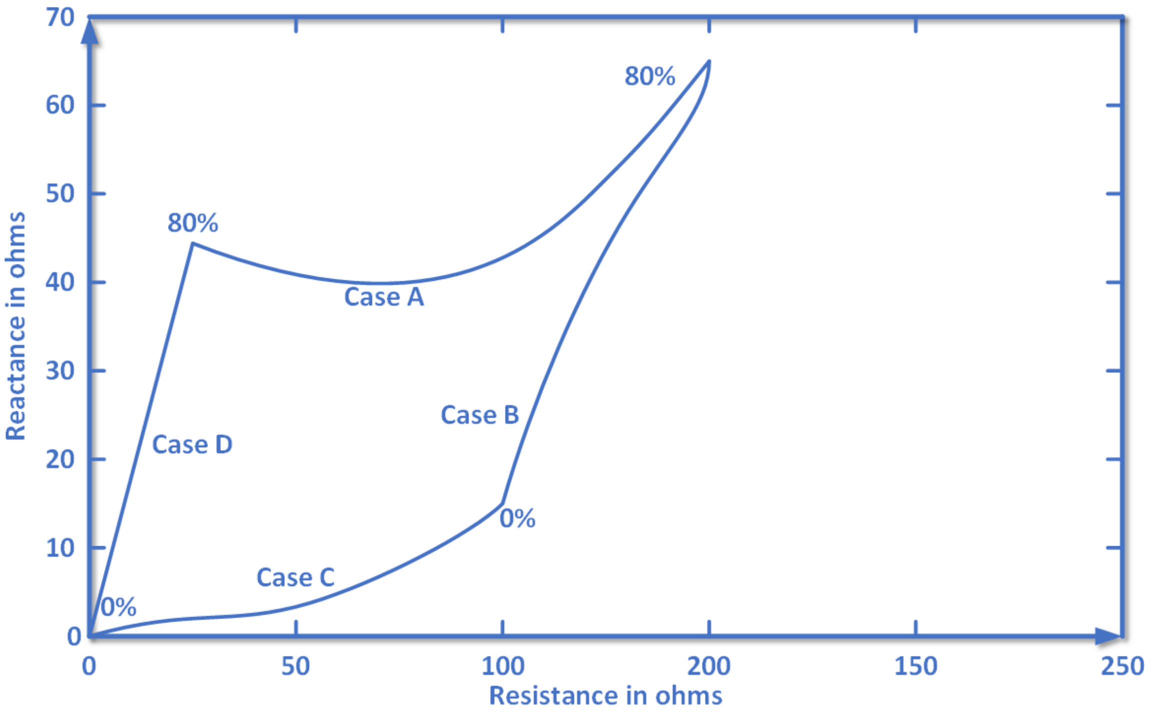


Figure 3.5 Operating Characteristic of Quadrilateral relay

3.2 DISCRETE FOURIER TRANSFORM TECHNIQUE

In this method, a discrete Fourier transformation is based on the algorithm to remove the fundamental frequency elements from the complicated post-fault relay signals. A discrete information sequence of Fourier conversion (DFT) is used to assess the coefficients of Fourier.

In this method, the basic coefficients of Fourier sine and cosine are achieved by correlating the incoming data specimens with the stored samples of the basic reference sine and cosine waves. The basic coefficients of Fourier sine and cosine are equivalent to the true and imaginary components of the fundamental wave element, respectively. The actual and imaginary parts of the basic phasors of the present frequency voltage are calculated using the DFT. From these four quantities, the true and imaginary parts (R and X) of the line's apparent impendence are then calculated.

3.2.1 Fourier Representation of Signals

Fourier series are used to break down regular signals into the total of suitable amplitude sinusoidal parts. The frequencies of the sinusoidal elements in the Fourier series are essential multiples of the basic frequency (1/T) if the periodic signal has a period of T (seconds).

3.2.2 Discrete Fourier Transform (DFT)

Fourier's discrete transformation (DFT) is used to assess the N x(t) sample coefficients generated by Fourier at t=0, Ts, 2Ts,....... (N –1)Ts, where Ts= T / N is the sampling interval. The input to the DFT is therefore a sequence of specimens (numbers) rather than a constant x(t) function. A discrete time signal is referred to as the sample sequence (i.e. data sequence) resulting from regular x(t) continuous signal sampling at Ts intervals. A sampled data system is called a system with continuous and discrete time signals. A model is called a discrete-time system with only discrete signals.

The DFT can be considered as a method for discrete signal processing to evaluate the Fourier coefficients. The equation DFT is derived from the equation

$$C_{fk} = \frac{1}{T}\int_0^T x(t)\, e^{-jkwt}\, dt \qquad \text{………..} (3.5)$$

Replace continuous functions with discrete time values and integrate them with a summation. If at the sampling interval of Ts, the periodic function x(t) is sampled N times per period, the N samples are the period T, so T= NTs. These x(t) N samples from the xm, m = 0, 1, 2,. (N –1)

Therefore, the DFT of a data sequence x_m, m = 0, 1, 2, . . .(N -1) is defined as:

$$C_{fk} = \frac{1}{N}\sum_{m=0}^{N-1} x_m\, e^{-j2\pi km\backslash N}, \quad k = 0,1,2,\ldots.(N-1) \text{ ………… (3.6)}$$

The DFT utilizes x 0,x 1, ... ,x (N-1) N information samples, which enables us to fix unknown coefficients for only N. The amount of cycles in span T is determined by the transform coefficient amount k and the frequency is identified as k / T Hz.

Using Eq. (3.6) to calculate Fourier coefficients includes a complex arithmetic that makes microprocessor computing hard. Therefore, separate equations for real and imaginary parts used for microprocessor execution of the DFT, rather than using the DFT equation in complicated form.

Equation (3.6) can be written as follows.

$$C_{fk} = \frac{1}{N}\sum_{m=0}^{N-1} x_m \left(cos\ \frac{2\pi km}{N} - j\sin\frac{2\pi km}{N}\right) \text{ ………… (3.7)}$$

$$or \quad \frac{1}{2}(a_k - jb_k) = \frac{1}{N}\sum_{m=0}^{N-1} x_m \left(cos\ \frac{2\pi km}{N} - j\sin\frac{2\pi km}{N}\right), \qquad k = 0,1,2,\ldots\ldots\ldots N-1$$

Therefore,

$$a_k = \frac{2}{N}\sum_{m=0}^{N-1} x_m\, cos\ \frac{2\pi km}{N}, \quad k = 0, 1, 2, \ldots N-1 \text{ ………… (3.7)}$$

$$and \qquad b_k = \frac{2}{N}\sum_{m=0}^{N-1} x_m\, sin\ \frac{2\pi km}{N}, \quad k = 0, 1, 2, \ldots N-1 \text{ ………… (3.8)}$$

The Eq of the DFT. In order to achieve the Fourier coefficients corresponding to any frequency element, microprocessors (3.7) and (3.8) can be readily introduced. The k value shows the frequency.

3.2.3 Extraction of the Fundamental Frequency Components

The basic frequency phasor's true and imaginary parts are calculated using the DFT Eq. (3.7) and (3.8) respectively k = 1. The equations are as follows for the basic frequency elements.

$$b_1 = \sqrt{2}\ \ F_1 = \frac{2}{N}\sum_{m=0}^{N-1} x_m \, sin\ \frac{2\pi m}{N} \qquad \ldots\ldots\ldots\ldots (3.9)$$

$$a_1 = \sqrt{2}\ \ F_2 = \frac{2}{N}\sum_{m=0}^{N-1} x_m\ cos\ \frac{2\pi m}{N} \qquad \ldots\ldots\ldots\ldots.. (3.10)$$

Using either full-cycle window or half-cycle window, these parts can be calculated. By using the sampled values of voltage and current, the actual and imaginary parts of fundamental frequency voltage and present phasors are calculated. The basic Fourier coefficients (F_1 and F_2) are given as $F_{1(v)}$, $F_{2(v)}$, and $F_{1(i)}$ and $F_{2(i)}$ respectively for the voltage signal and present signal. If V_s, V_c, and I_s, I_c, respectively, denote the true and imaginary parts of the basic frequency voltage and present phasors

$$F_{1(v)} = V_s, \qquad F_{2(v)} = V_c$$

$$F_{1(i)} = I_s,\ F_{2(i)} = I_c \qquad \ldots\ldots\ldots\ldots.. (3.11)$$

3.2.4 Computation of the Apparent Impedance

The primary purpose of the digital range relay of the transmission lines is to determine the phasor representations of the voltage and show signals from their sampled values and then calculate the obvious impedance of the line from the relay to the fault point to determine whether or not the fault lies within the protective area of the relay. Because linear system impedance is described in terms of basic frequency voltage and present sinusoidal waves, the basic frequency elements of voltage and present signals need to be extracted from the complicated post-fault voltage and present signals.

The basic frequency voltage phasor's true and imaginary parts, i.e. Vs and Vc, and the true and imaginary parts of the present phaser of fundamental frequency, i.e. Is and is acquired from Ic.

Knowing Vs, Vc, Is and Ic phasor representations of the basic frequency elements of voltage and present signals are described in a complicated form as follows:

$$V = V_s + jV_c \qquad \text{…………. (3.12)}$$

$$I = I_s + jI_c \qquad \text{…………. (3.13)}$$

The magnitude (rms) and phase angles of the basic frequency voltage and present phaser are determined by

$$V = \sqrt{{V_s}^2 + {V_c}^2} \qquad \text{…………. (3.14)}$$

$$\phi_v = \tan^{-1}\frac{V_c}{V_s} \qquad \text{……….. (3.15)}$$

$$I = \sqrt{{I_s}^2 + {I_c}^2} \qquad \text{…………… (3.16)}$$

$$\phi_i = \tan^{-1}\frac{I_c}{I_s} \qquad \text{…………. (3.17)}$$

The phase difference ϕ between voltage and current is given by

$$\phi = \phi_v - \phi_i \qquad \text{…………… (3.18)}$$

When the signal pair is correctly chosen for a particular fault, the voltage-to-current ratio provides the line's obvious impedance.

The voltage and current are expressed in polar from as

$$V = |V|\angle\phi_v \qquad \text{………….. (3.19)}$$

$$I = |I|\angle\phi_i \qquad \text{………….. (3.20)}$$

The apparent impedance is then given by

$$Z = \frac{V}{I} = \frac{|V|\angle\phi_v}{|I|\angle\phi_i}$$

$$= \frac{\sqrt{{V_s}^2+{V_c}^2}}{\sqrt{{I_s}^2+{I_c}^2}}\angle(\phi_v - \phi_i) = Z\angle\phi \text{………. (3.21)}$$

Apparent Eq impedance calculation. (3.21) involves time-consuming squaring and square rooting operations. Therefore, to avoid the square-rooting operation, the real and reactive sections (R and X) of the apparent impedance are calculated as follows.

$$Z = \frac{V_s + jV_c}{I_s + jI_c} = \frac{V_sI_s + V_cI_c}{{I_s}^2 + {I_c}^2} + j\frac{V_cI_s - V_cI_s}{{I_s}^2 + {I_c}^2}$$

$$= R + jX \qquad \text{…………..} \; (3.22)$$

$$R = \frac{V_sI_s + V_cI_c}{{I_s}^2 + {I_c}^2} \qquad \text{…………..} \; (3.23)$$

$$X = \frac{V_cI_s - V_cI_s}{{I_s}^2 + {I_c}^2} \qquad \text{…………..} \; (3.24)$$

Equations (3.23) and (3.24) are programmed to determine R and X from the actual and imaginary parts of the basic frequency voltage, i.e. the present phaser. Vs, Vc, Is, Ic.

The program flowchart for the computation of R and X using half-cycle data window DFT algorithm is shown in Fig. 3.6

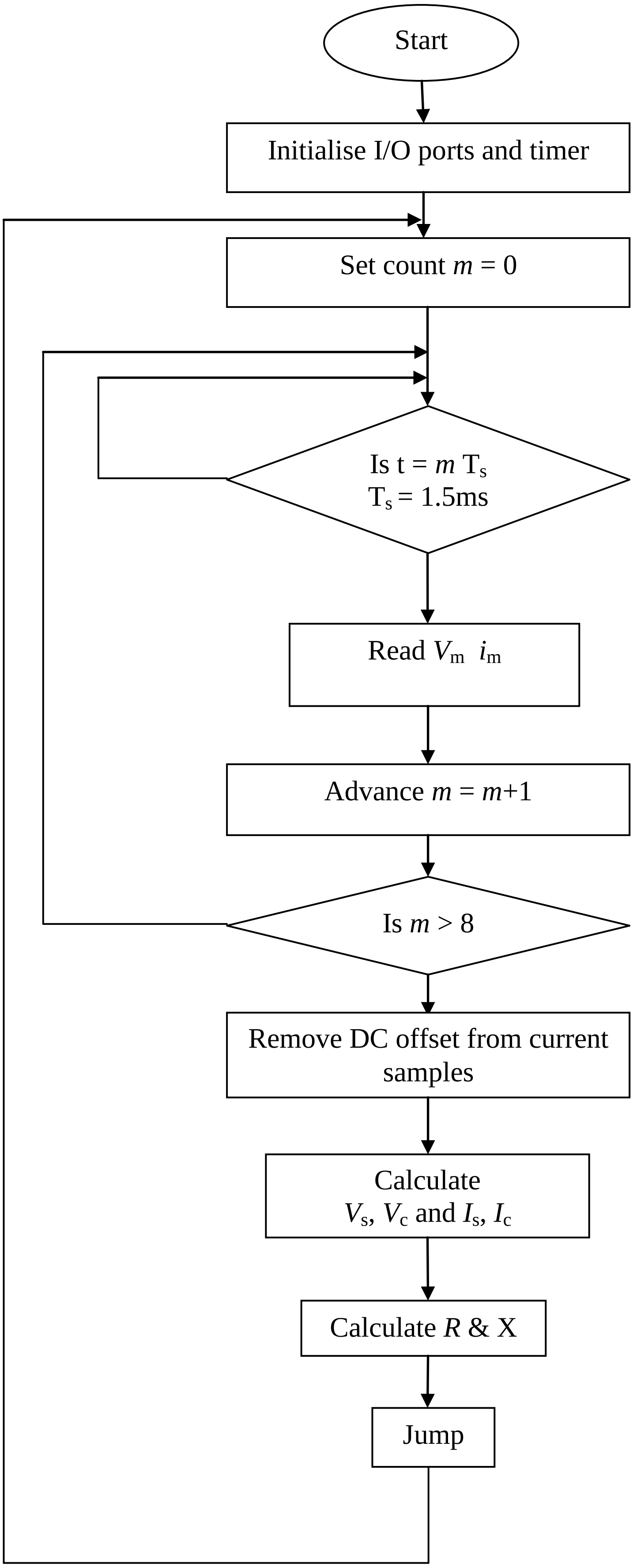


Figure 3.6 Program flowchart for computation of *R* and *X*

CHAPTER 4

RESULTS

4.1 MODELLING OF SYSTEM FOR DISTANCE PROTECTION

In this study, three-phase current and voltage waveforms are first assessed using instrument transformers and filtered using a discrete second-order filter to remove the DC offset and harmonic components present due to arcing failure[1]. The analog input is supplied to the filter and high frequency sections are divided, eliminating the effect of aliasing. The waveforms are then screened at the selected sampling frequency by a sample-hold (S / H) circuit before using the relay. This produces a momentary discreet signal. To maintain the information in the signal, the sampling velocity must be chosen. This is ensured twice by sampling the largest input signal frequency.

The output of the sampler is then fed into a Discrete Fourier Transform block. The Discrete Fourier Transform (DFT) is a processing method used to assess Fourier's coefficients. A Fourier series represents a regular signal as a summation of suitable components of the sinusoidal amplitude. The fundamental features of Fourier's sine and cosine are the Fourier coefficients of the incoming signal's fundamental frequency sine and cosine components. These coefficients will be assessed by comparing input samples with stored specimens of reference sine and cosine components. The true and imaginary components are the coefficients of the fundamental sine and cosine.

The actual and imaginary sections of the fundamental frequency element of incoming voltage and present phasers can therefore be evaluated. DFT is best suited for components with relatively different features and some additional computations can be performed in a simple manner, while wavelet and HHT are the best multidimensional base algorithms and require distinctive signal analysis programs. Using the fault impedance calculation algorithm[2], the real and reactive line impedance segments as seen by the relay (R and X) can then be calculated. The relay then compares the reference impedance to the measured impedance and passes the relay if the defect is within the protected area and vice versa

Matlab is an efficient evaluation software for modeling energy system parts using the Sim Power Systems toolbox inside the Simulink package. Many components of affordable energy systems can be used in AC or DC applications in this toolbox, such as 3-phase transformer, 3-phase load, distributed line parameters, 3-phase source, circuit breaker, etc.[3]. All these components are ready for use where only customers have to drag the components into the model file and enter the values of the parameter.

Transmission line modeling and loading, respectively, using distributed line parameters and three-phase load block sets. Fig. 4.1 Shows the transmission line and the generated load model. From the photograph. 4.1, The transmission line is divided into two equal lines. This is because at a stage along the transmission line a fault is simulated where the first line simulates the distance between the substation terminal and the fault point while the second line simulates the distance between the fault point and the transmission line end. The "default" power scheme, transmission line and load data used in the simulation is shown in Table I.

Table I. TRANSMISSION LINE PARAMETER

Sl. No.	Transmission Line Parameter	Values
1.	Transmission Line Length	200 Km
2.	Rated Frequency	50 Hz
3.	Positive and Negative Sequence Resistance	0.01273
4.	Positive and Negative Sequence Inductance	0.9337 x 10-^{3}
5.	Positive and Negative Sequence Capacitance	12.74 x 10^{-9}
6.	Zero Sequence Resistance	0.3868
7.	Zero Sequence Inductance	4.1264 x 10-^{3}
8.	Zero Sequence Capacitance	7.751 x 10^{-9}
9.	Total Positive Sequence Impedance	$29.63\angle 87.51^{o}$
10.	Total Zero Sequence Impedance	$135\angle 73.386^{o}$

4.2 TRANSMISSION LINE MODELLING

The contemporary energy scheme comprises of a three-phase generator of 132 KV linked to a grid of 132 KV through a length of 200 km. At both end of the scheme, the load of 100MW, 132 KV in order is linked. The transformer of this model is linked to star / star. Under distinct circumstances of fault, tension and present waveforms, i.e. three-phase, double line to floor and single line to ground defects, were noted. Impedance plots (R-X) were also plotted for distinct faults and distances (70 km, 110 km, 140 km) between relay location and fault case. In the table below, the magnitude of the different line parameters used in the simulation model is provided:

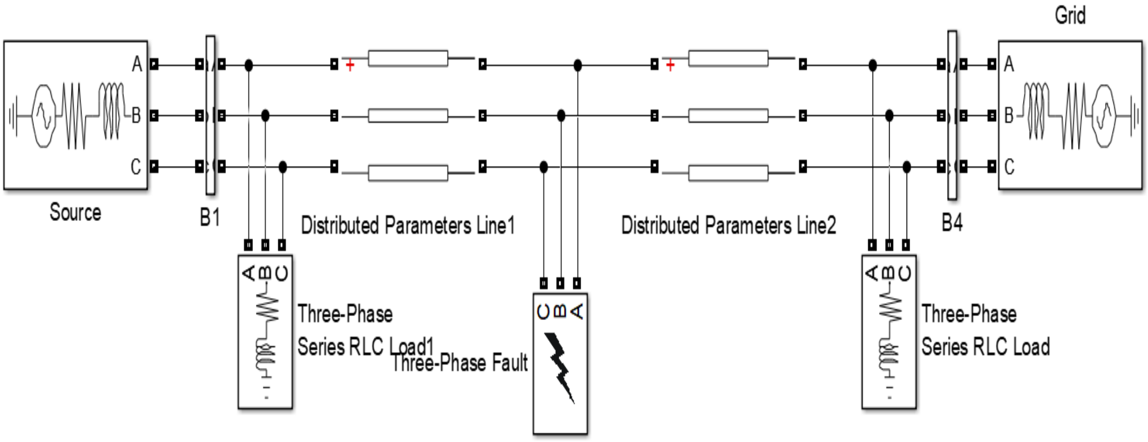


Figure 4.1 Transmission line model

4.3 DISCRETE FOURIER TRANSFORMATION

In this study, three-phase current and voltage waveforms are first assessed using instrument transformers and filtered using a discrete second-order filter to remove the DC offset and harmonic components present due to arcing failure[1]. The analog input is supplied to the filter and high frequency sections are divided, eliminating the effect of aliasing. The waveforms are then screened at the selected sampling frequency by a sample-hold (S / H) circuit before using the relay. This produces a momentary discreet signal. To maintain the information in the loop, the sampling rate must be chosen. By sampling the biggest input signal frequency, this is assured twice.

The output of the sampler is then fed into a Discrete Fourier Transform block. The Discrete Fourier Transform (DFT) is a processing technique used to assess Fourier coefficients. A series of Fourier represents a periodic signal as a summary of suitable sinusoidal components of amplitude. The fundamental features of sine and cosine Fourier are the Fourier coefficients of the incoming signal's fundamental frequency sine and cosine components. These coefficients will be assessed by comparing input samples with stored specimens of reference sine and cosine components. The fundamental sine and cosine coefficients are the true and imaginary components. Thus, the real and imaginary components of the basic frequency component of incoming voltage and current phasors can be evaluated.

The simulation block for low pass filter, sample and hold and Fourier transform three-phase voltage and three-phase current are shown below:

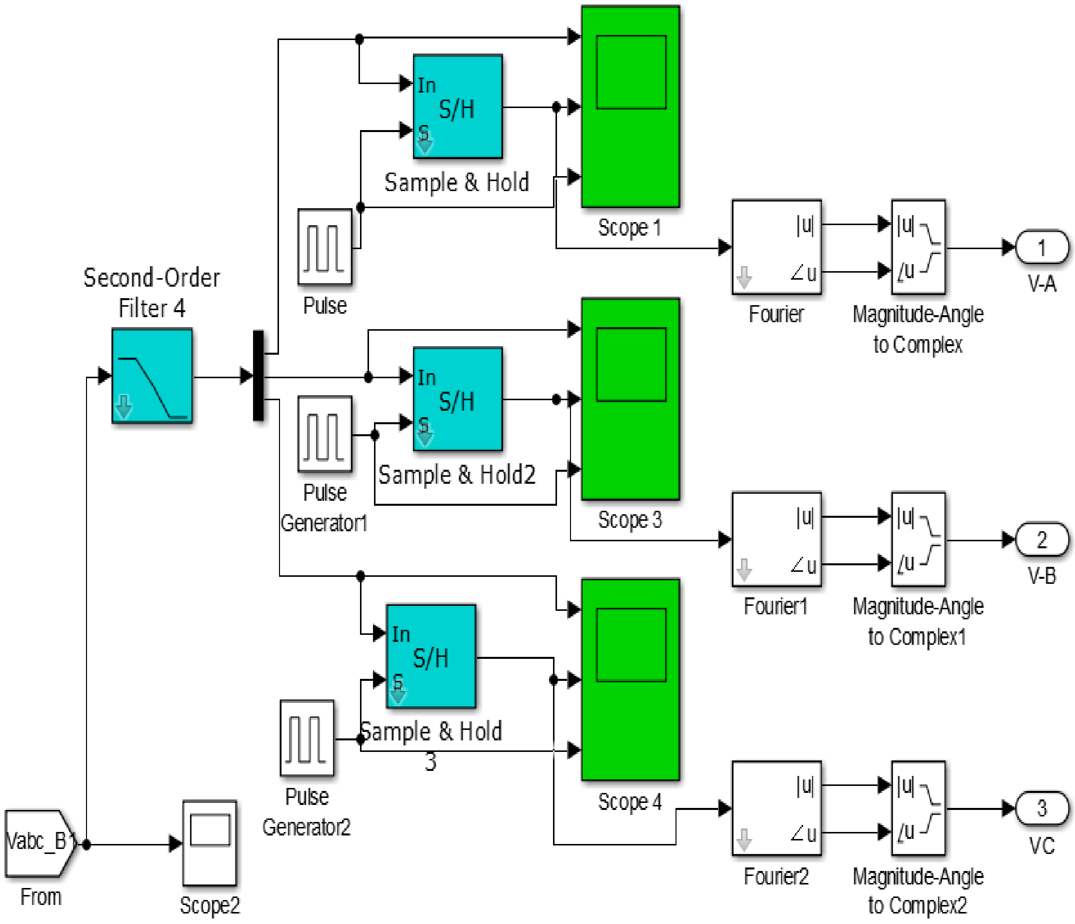


Figure 4.2 Model of discrete Fourier transform for bus voltage (Vabc_B1)

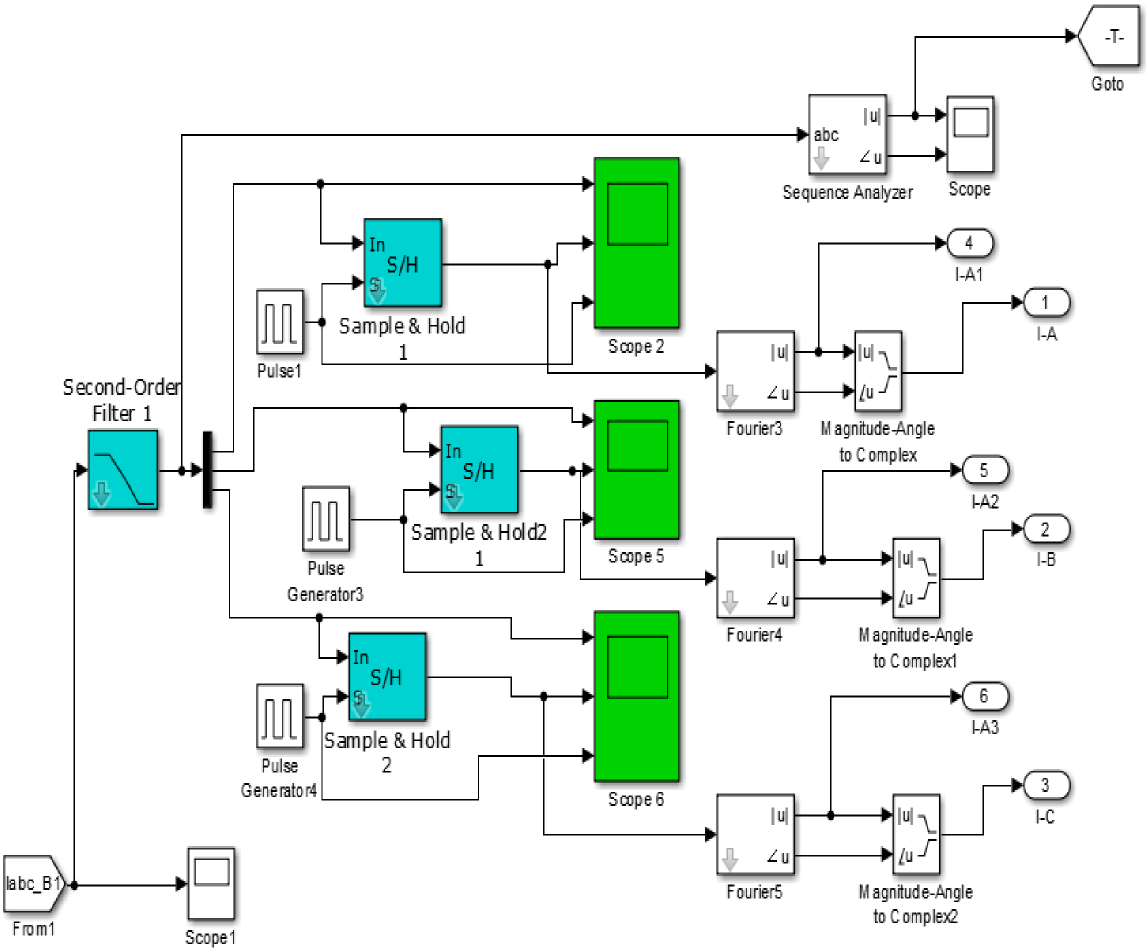


Figure 4.3 Model of discrete Fourier transform for bus current (Iabc_B1)

4.4 FAULT IMPEDANCE CALCULATION ALGORITHIM

A power system fault can be classified as a symmetric or unsymmetric fault. The only symmetrical fault is the three-phase fault in which all stages are in touch. The failure of line-to-line (LL), double line-to-floor (LLG) and single line-to-floor (SLG) is categorized as unsymmetric errors[4]. The range relay basically measures the impedance between the defective stages in the case of LL failure or floor failure between defective stages and neutral conductor when a fault happens on a transmission line. Table II shows the various algorithms used to evaluate impedance of fault for distinct kinds of fault[3]. Distance relay will first use the internal phase selection feature to determine the type of fault and then determine which algorithm to use for impedance measurement.

Table II. IMPEDANCE CALCULATION

Fault Types	Function
AB or ABG	$(V_a - V_b)/(I_a - I_b)$
BC or BCG	$(V_b - V_c)/(I_b - I_c)$
AC or ACG	$(V_b - V_c)/(I_b - I_c)$
AG	$V_a/(I_a + 3 * K_0 * I_0)$
BG	$V_b/(I_b + 3 * K_0 * I_0)$
CG	$V_c/(I_c + 3 * K_0 * I_0)$
ABC or ABCG	V_a/I_a or V_b/I_b or V_c/I_c

Here A, B, C is the system's faulty phase and G is the ground fault

Where,

$Va = A -$ phase voltage

$Vb = B -$ phase voltage

$Vc = C -$ phase voltage

$Ia = A -$ phase current

$Ib = B -$ phase current

$Ic = C -$ phase current

$Io = Zero\ sequence\ current$

$$I_0 = (I_a + I_b + I_c) \qquad \text{………… (4.1)}$$

$$K_0 = (Z_0 - Z_1)/3 * Z_1 \qquad \text{………… (4.2)}$$

Where,

K_0= residual compensation factor

Z_0= zero sequence impedance

Z_1= positive sequence impedance

Impedance calculations for multiple faults can be created with the assistance of Fourier coefficients of the basic frequency element in terms of magnitude and phase angle.

The three stage fault (LLLG-fault), line-to-line fault (LLG) and single line-to-ground fault (LG) simulation models are shown below:

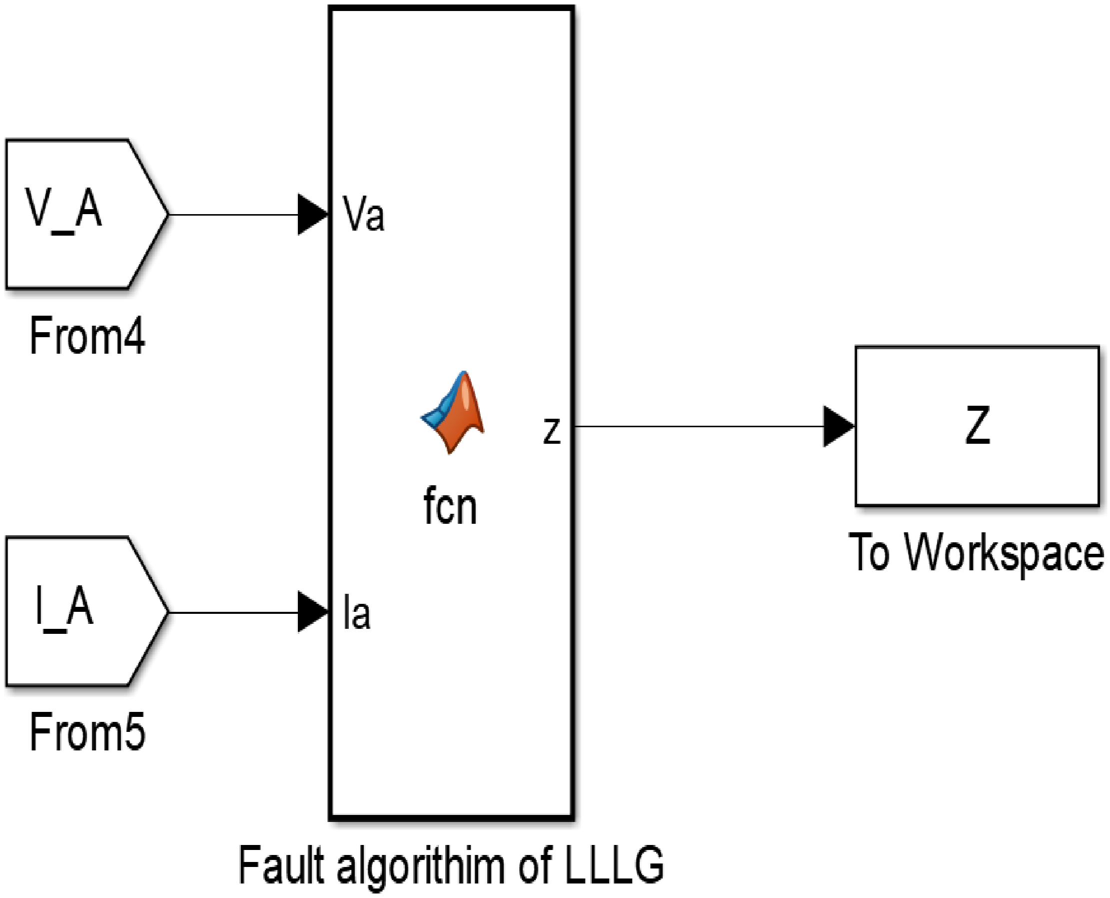


Figure 4.4 Fault algorithm of LLLG

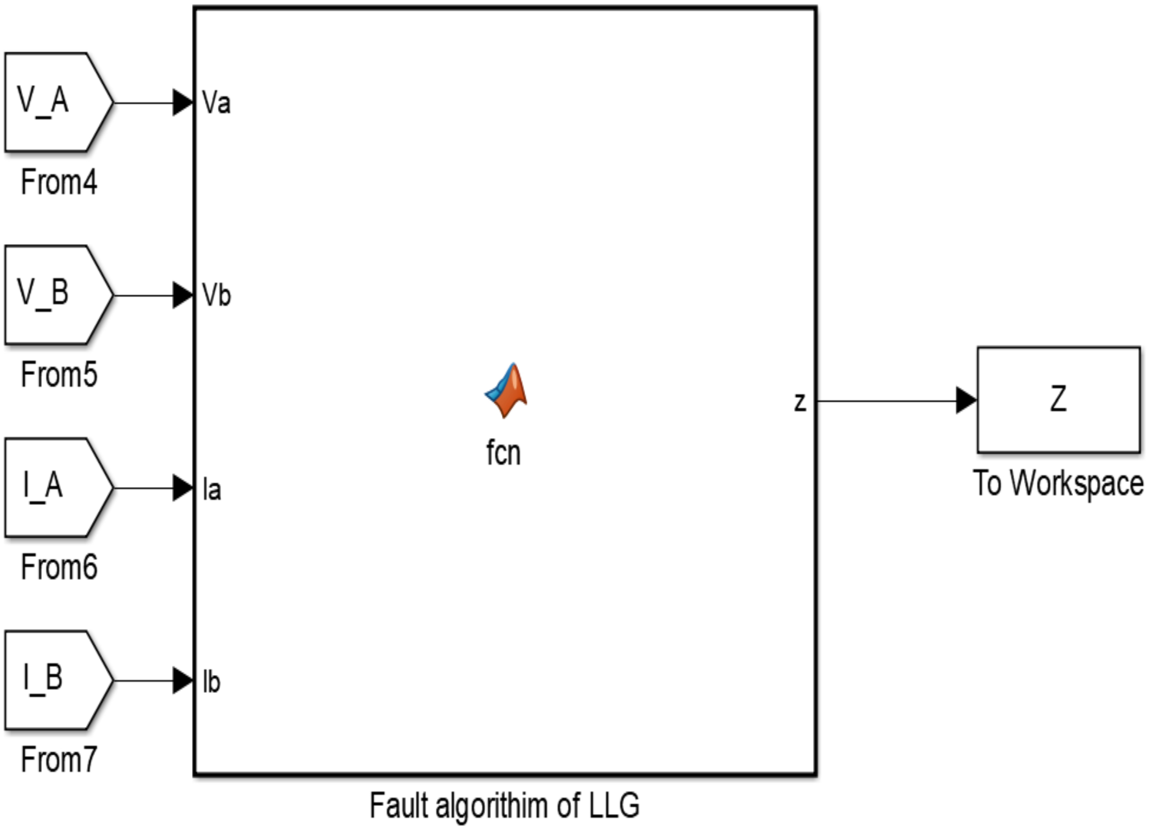


Figure 4.5 Fault algorithm of LLG

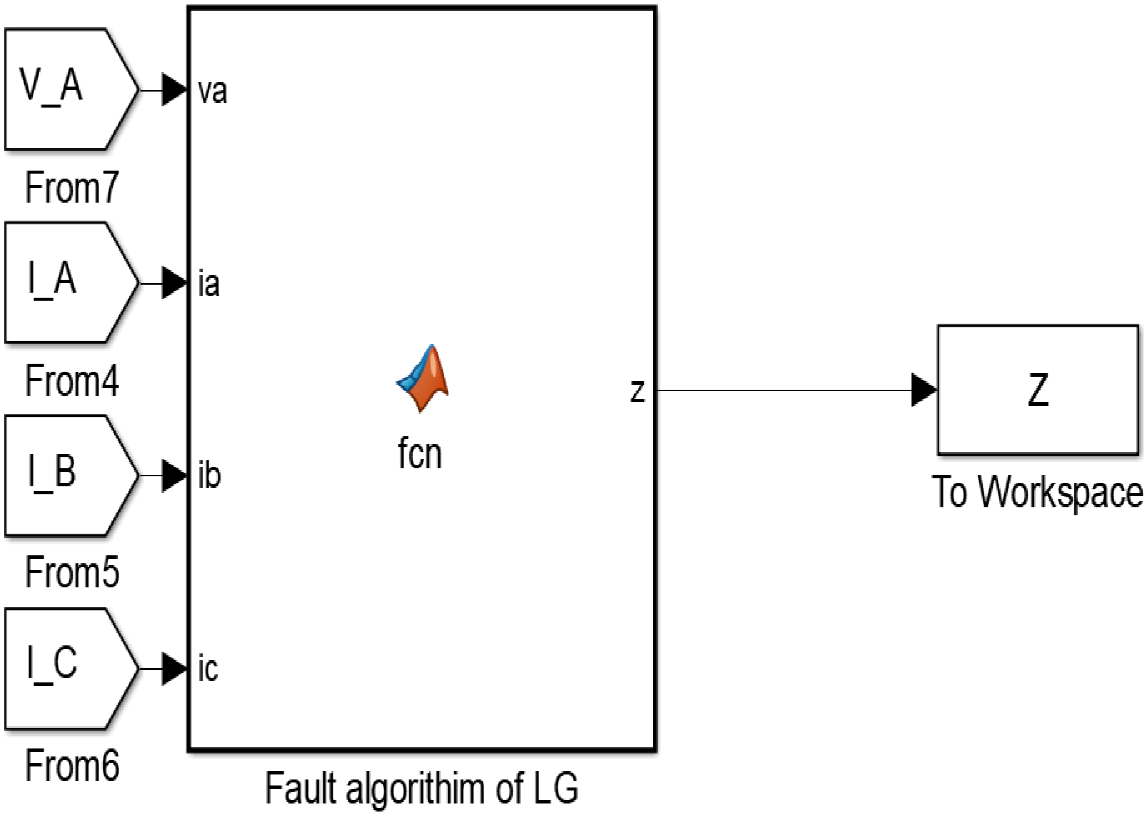


Figure 4.6 Fault algorithm of LG

The three-phase fault automatic fault detector (LLLG-fault), line-to-line fault (LLG) and single line-to-ground fault (LG) are shown below:

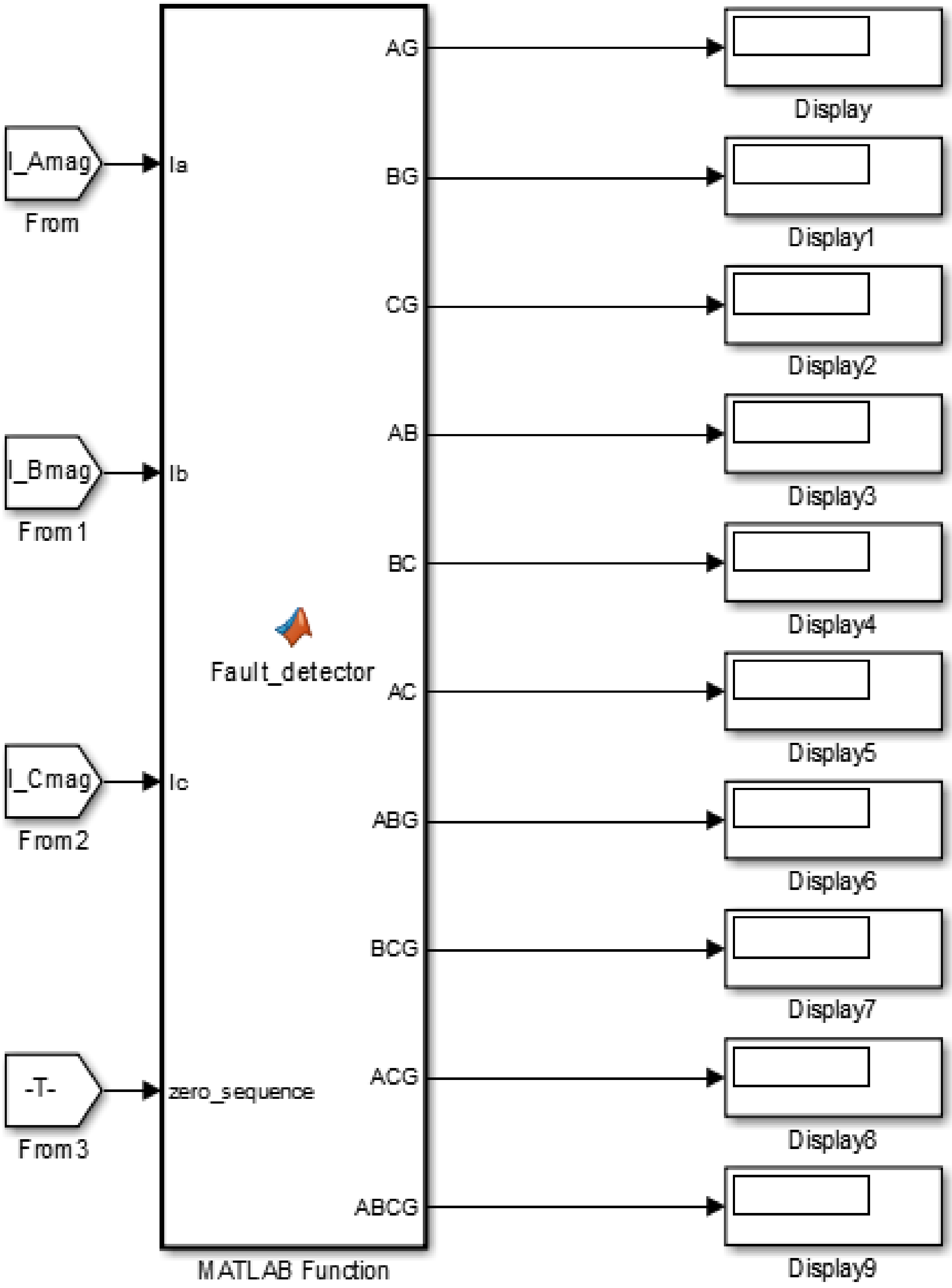


Figure 4.7 Fault detector

CHAPTER 5

RESULTS

5.1 SIMULATION RESULTS

The relay model created in the SIMULINK software is combined with the transmission line model and various working and fault circumstances are simulated as shown

5.1.1 THREE-PHASE FAULT:

ZONE 1st

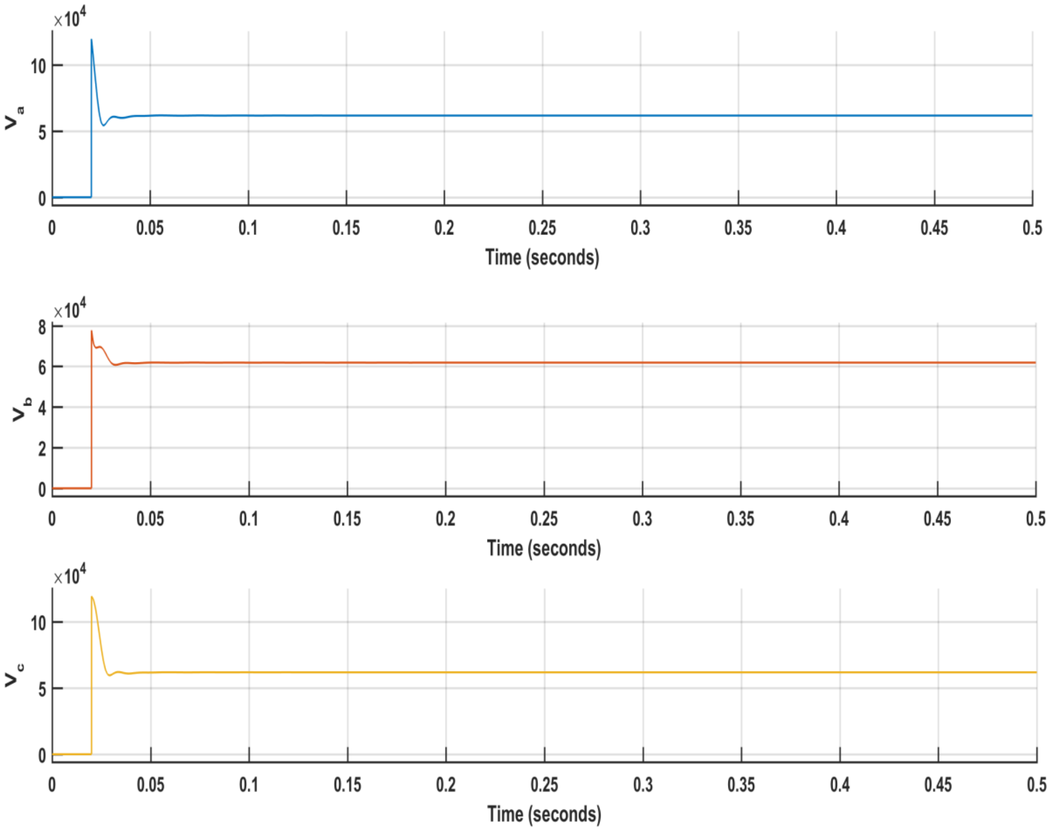


Figure 5.1 LLLG Fault voltage

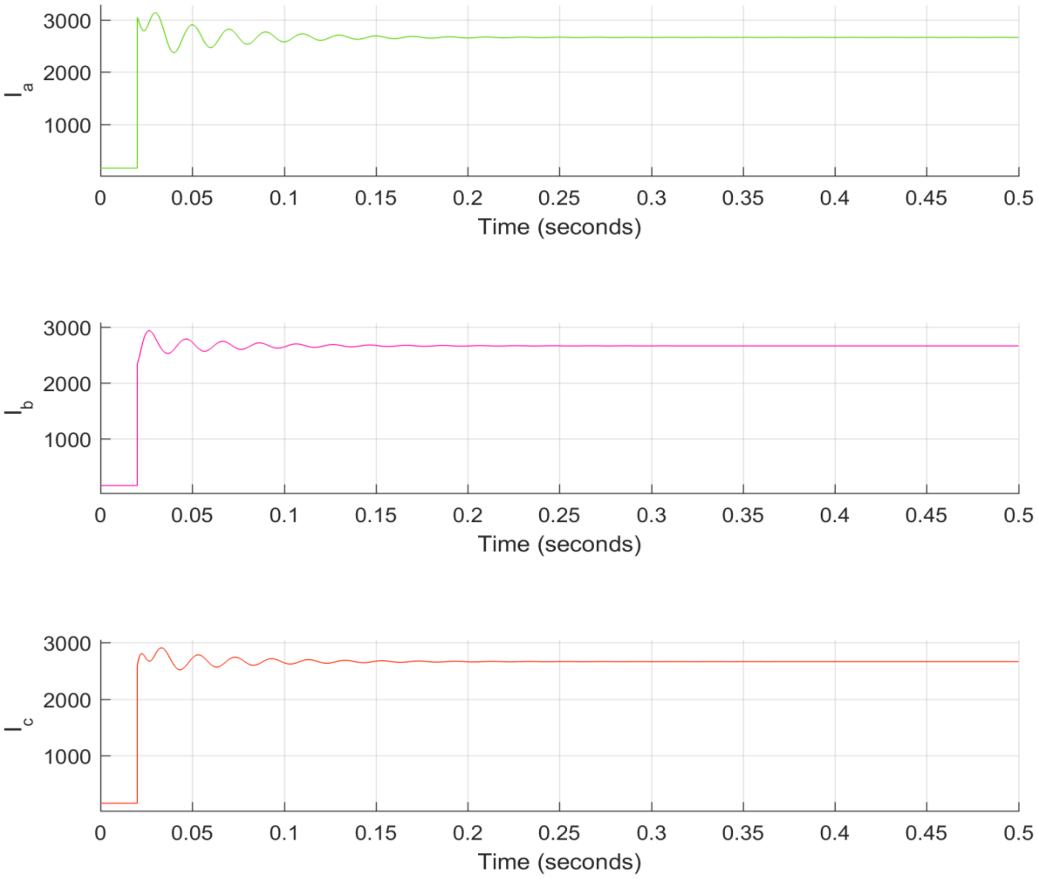


Figure 5.2 LLLG Fault current

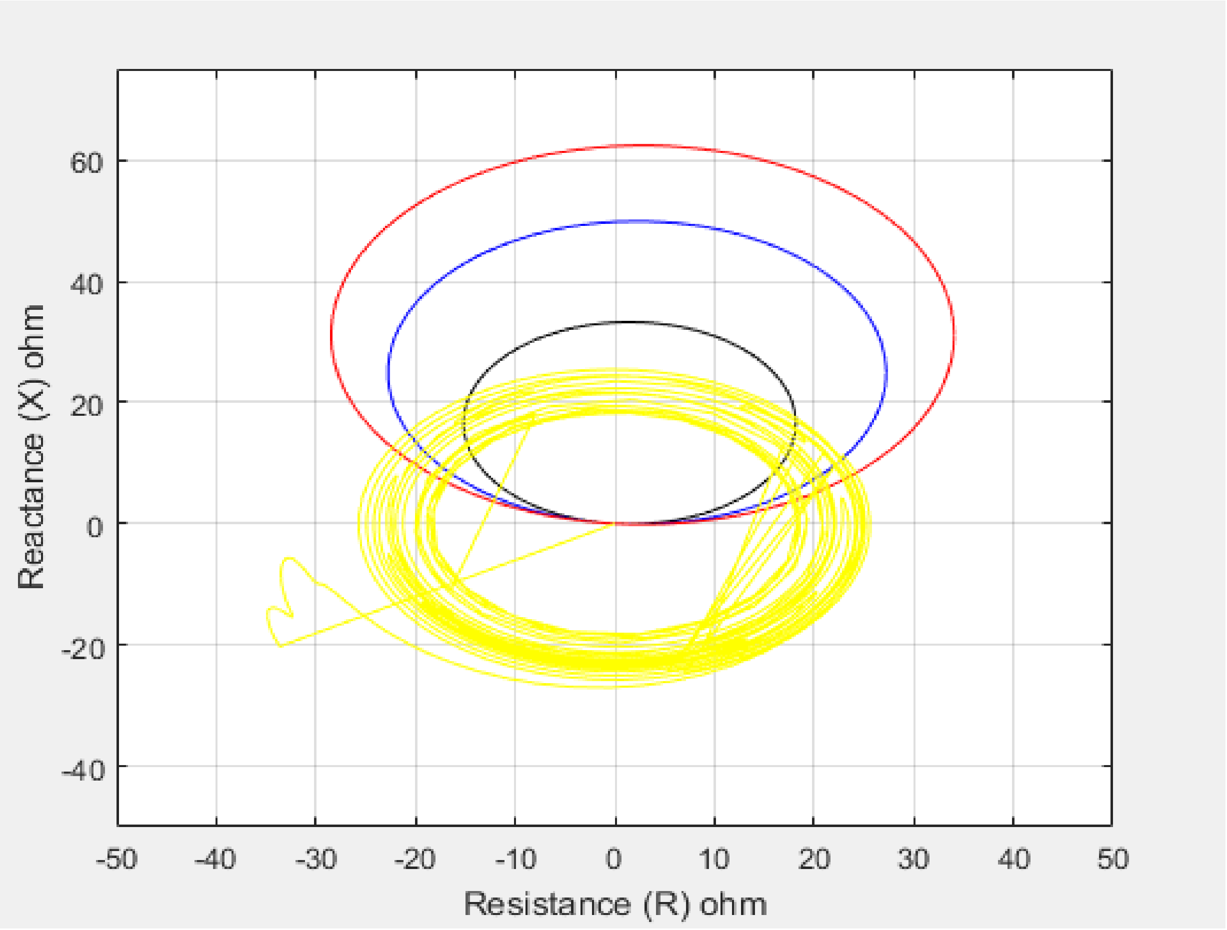


Figure 5.3 LLLG Fault impedance

ZONE 2nd

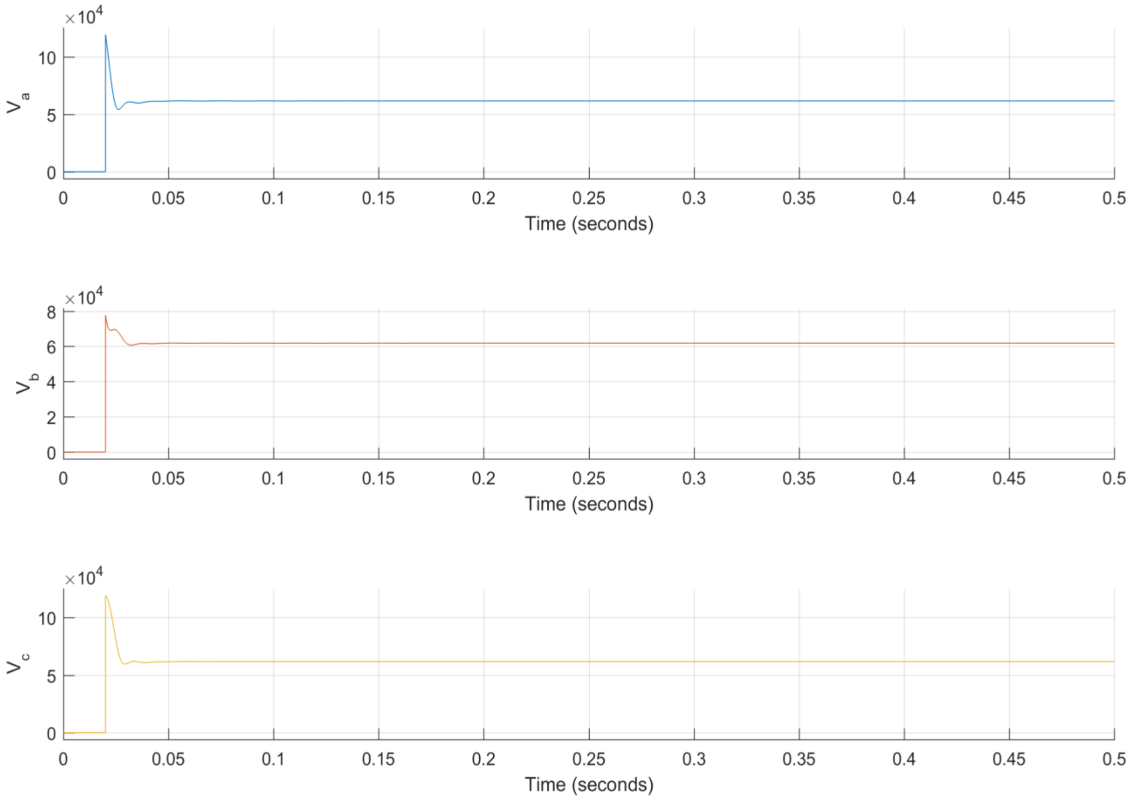


Figure 5.4 LLLG Fault voltage

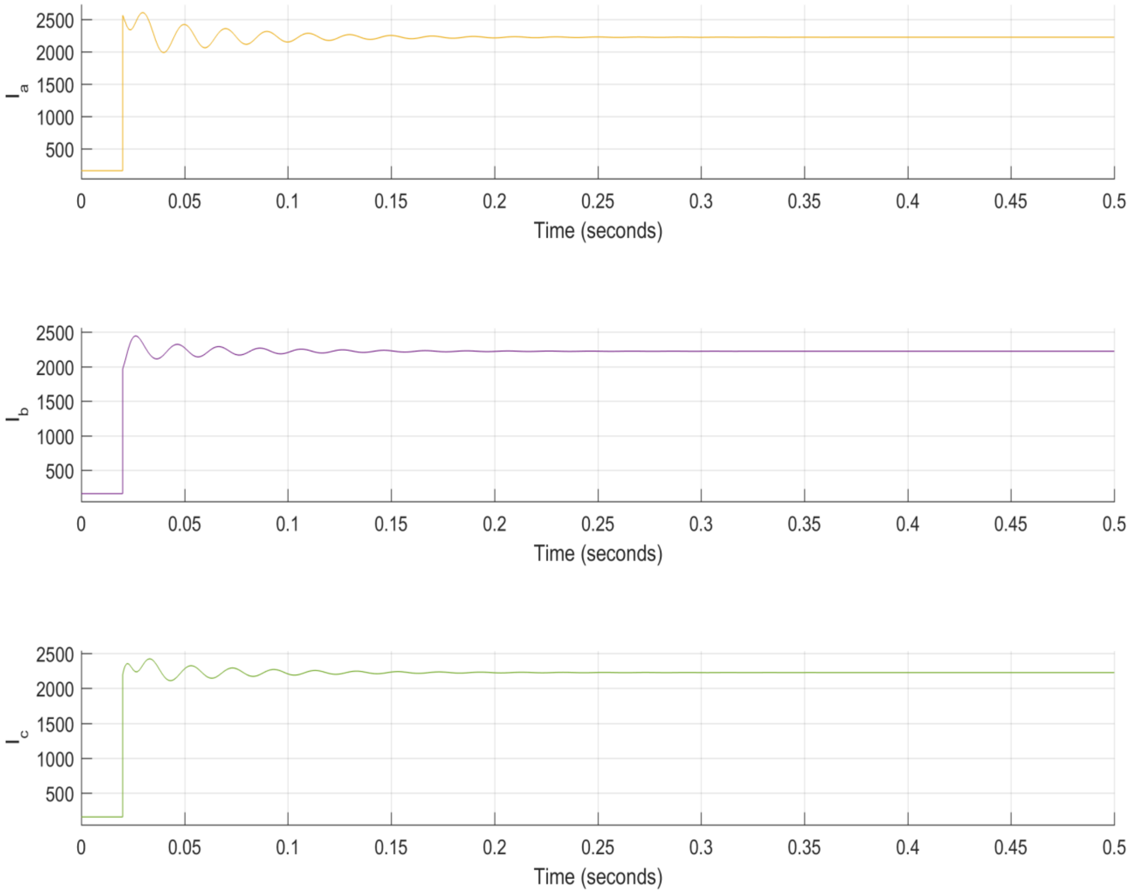


Figure 5.5 LLLG Fault current

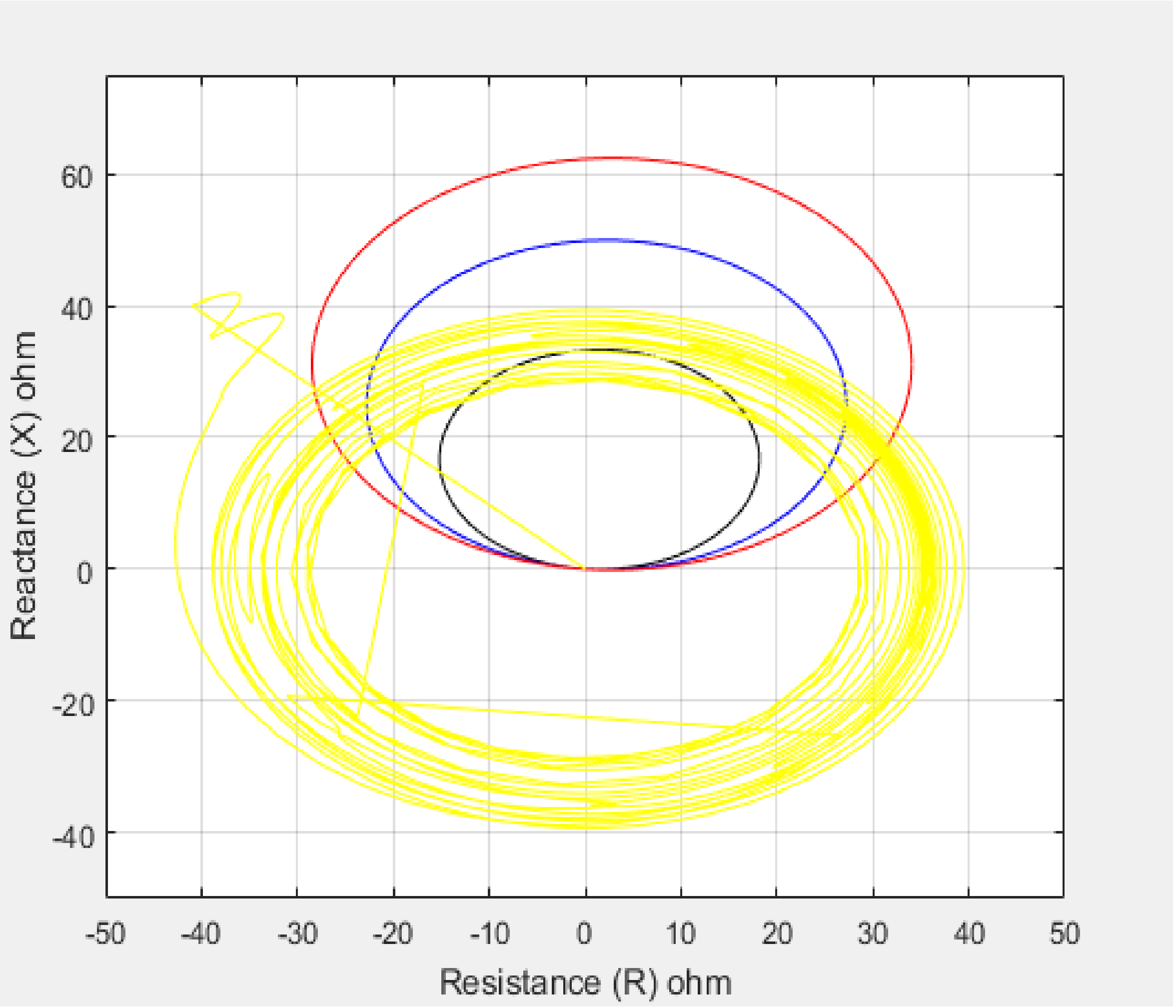


Figure 5.6 LLLG Fault impedance

ZONE 3rd

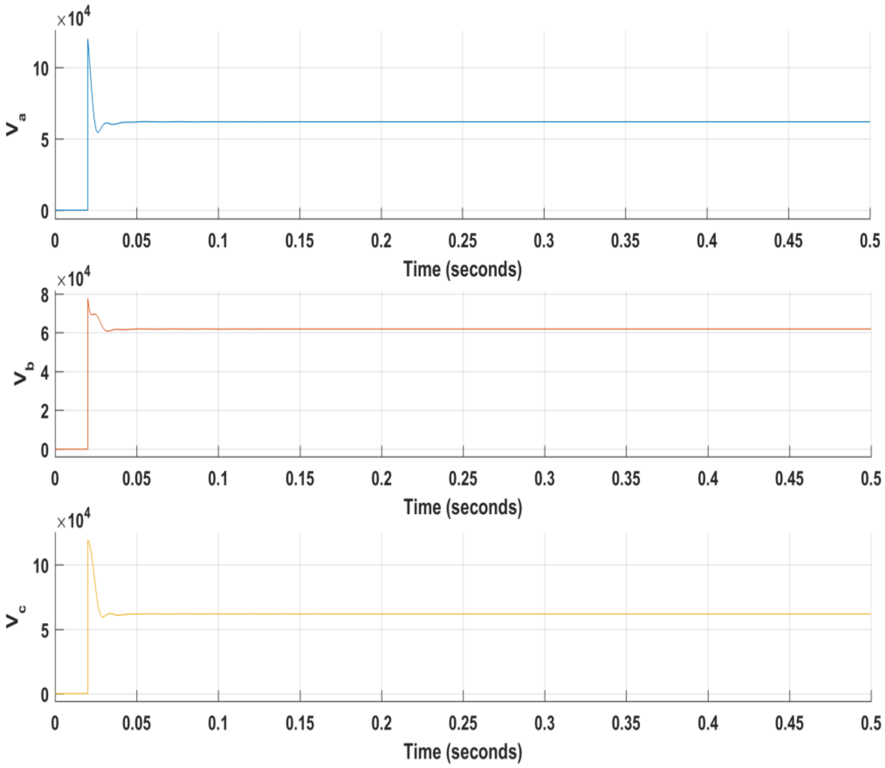


Figure 5.7 LLLG Fault voltage

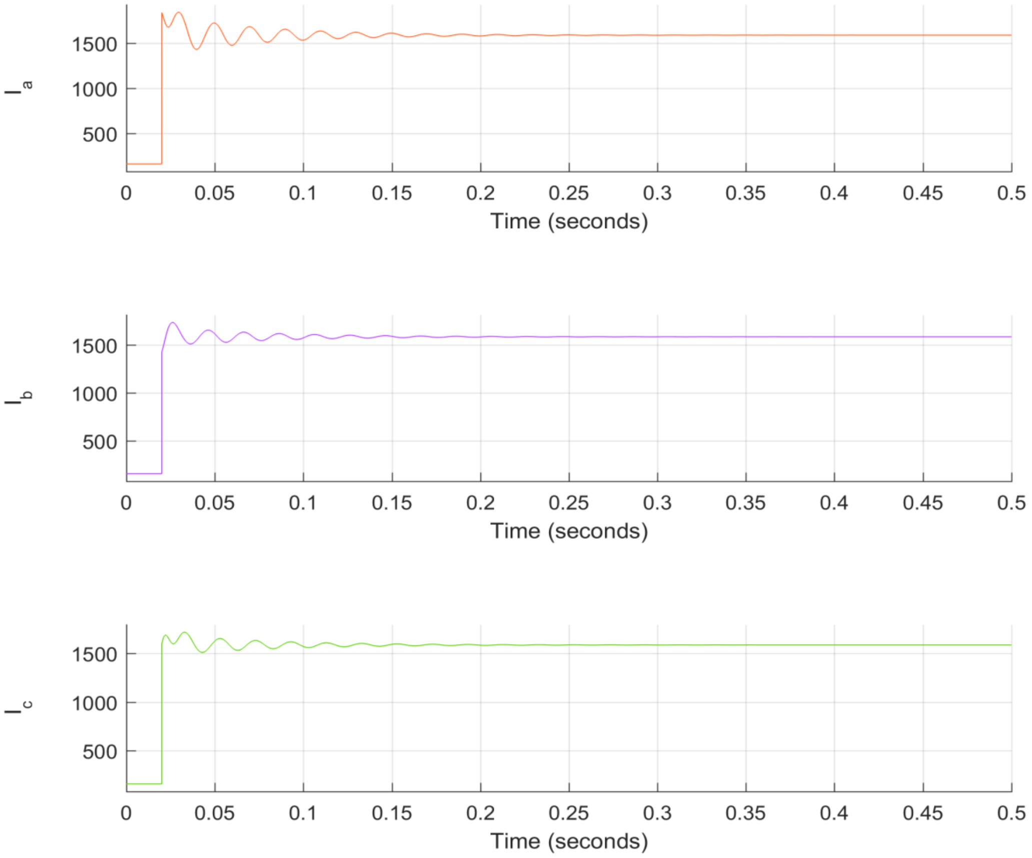


Figure 5.8 LLLG Fault current

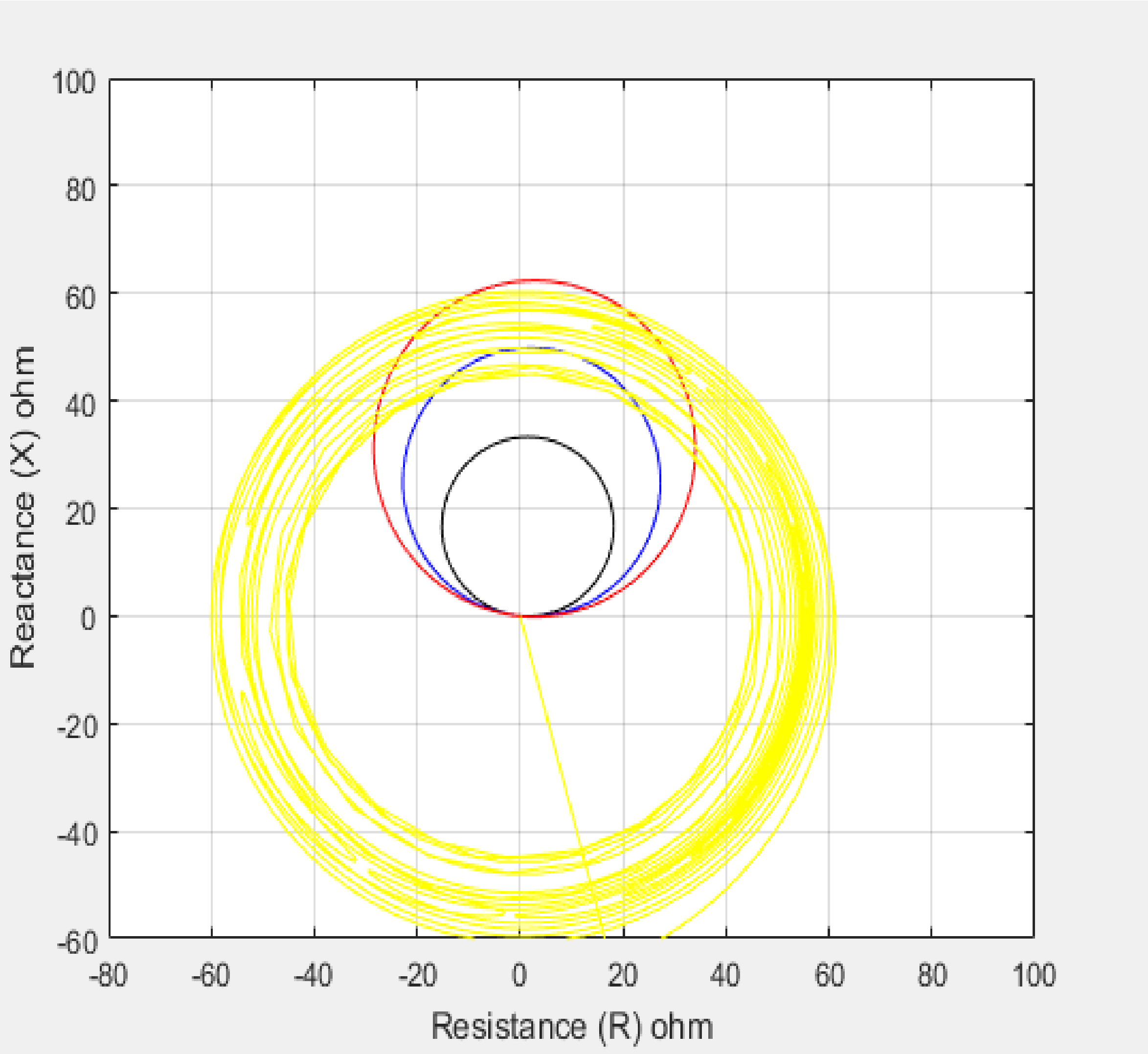


Figure 5.9 LLLG Fault impedance

The three-phase relays connected to a transmission line for phase failure detection are energized during three-phase faults by the differences in phase voltages and phase currents as shown in Table (II) and each evaluates the correct favourable sequence impedance to the fault. The relay of the stage range, which functions as a major area safety, will travel when a fault occurs in its region unless it fails. Security backup would operate in this scenario. We noted fault impedances in the above R-X parcels at a distance of 70 km, 100 km and 140 km from the sending terminal. Figure (5.3) indicates that the locus of fault impedance falls below area 1 characteristics, Figure (5.6) falls below area 2 characteristics, and Figure (5.9) falls below zone 3 characteristics.

5.1.2 DOUBLE-LINE TO GROUND FAULT:

ZONE 1st

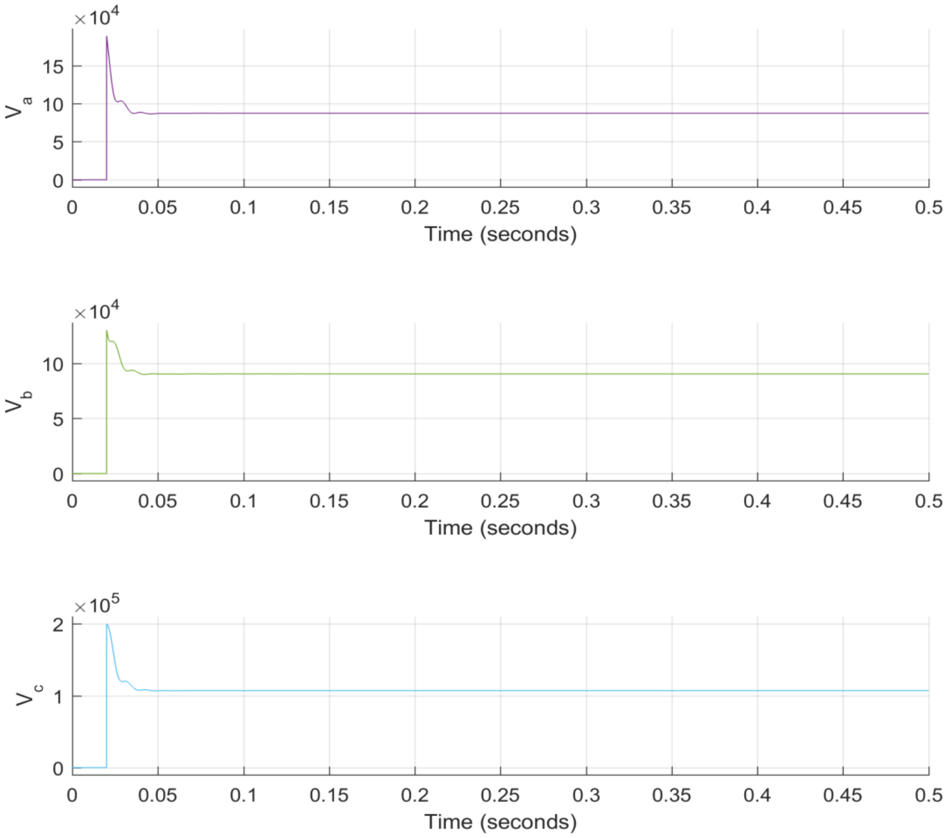


Figure 5.10 LLG Fault Voltage

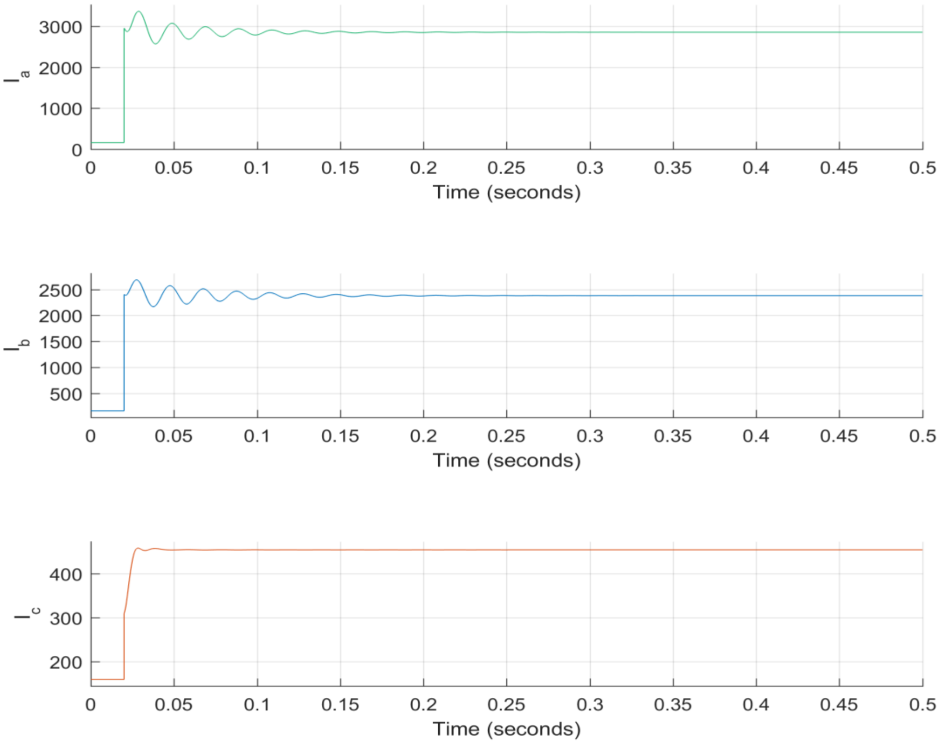


Figure 5.11 LLG Fault Current

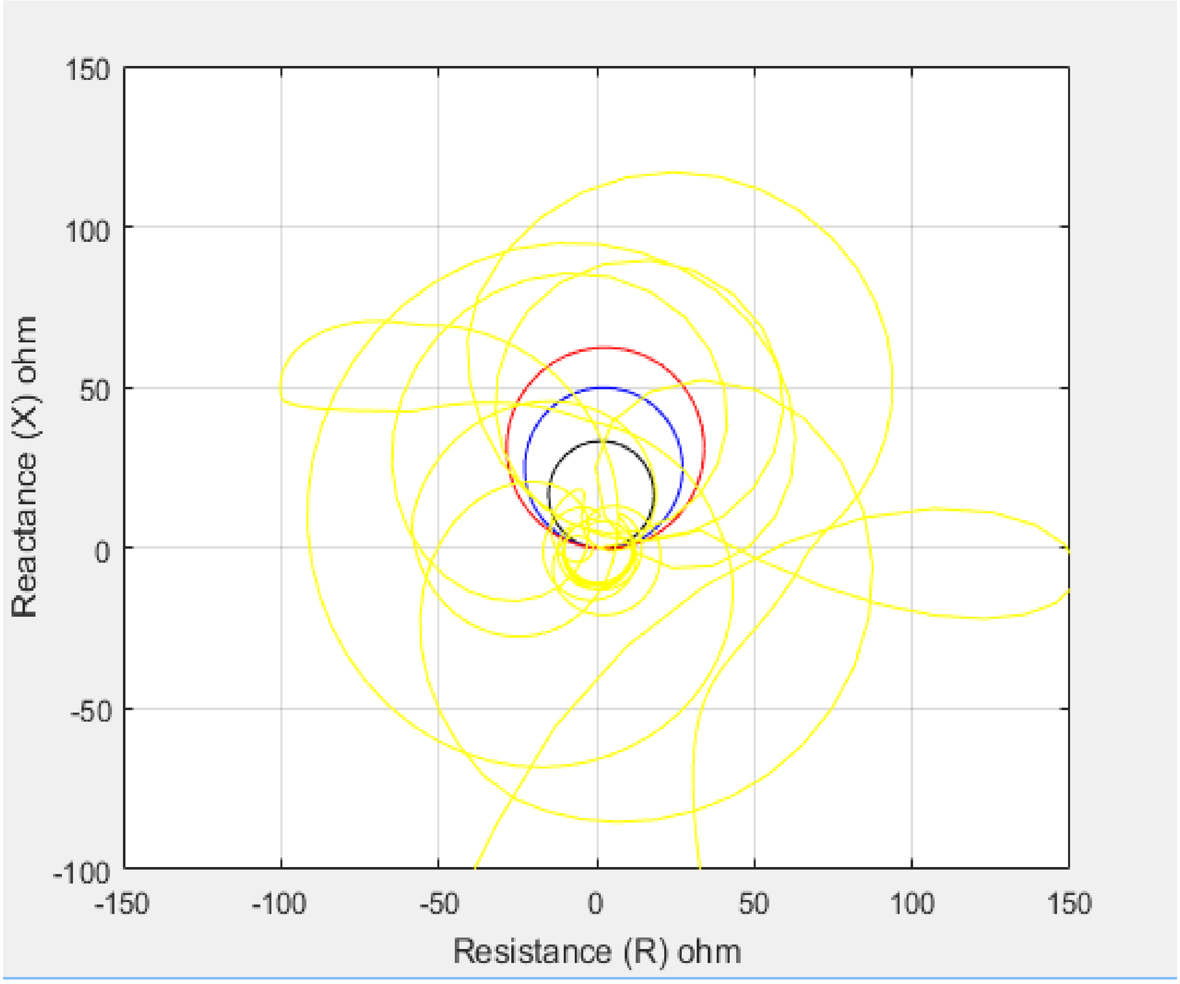


Figure 5.12 LLG Fault Impedance

ZONE 2nd

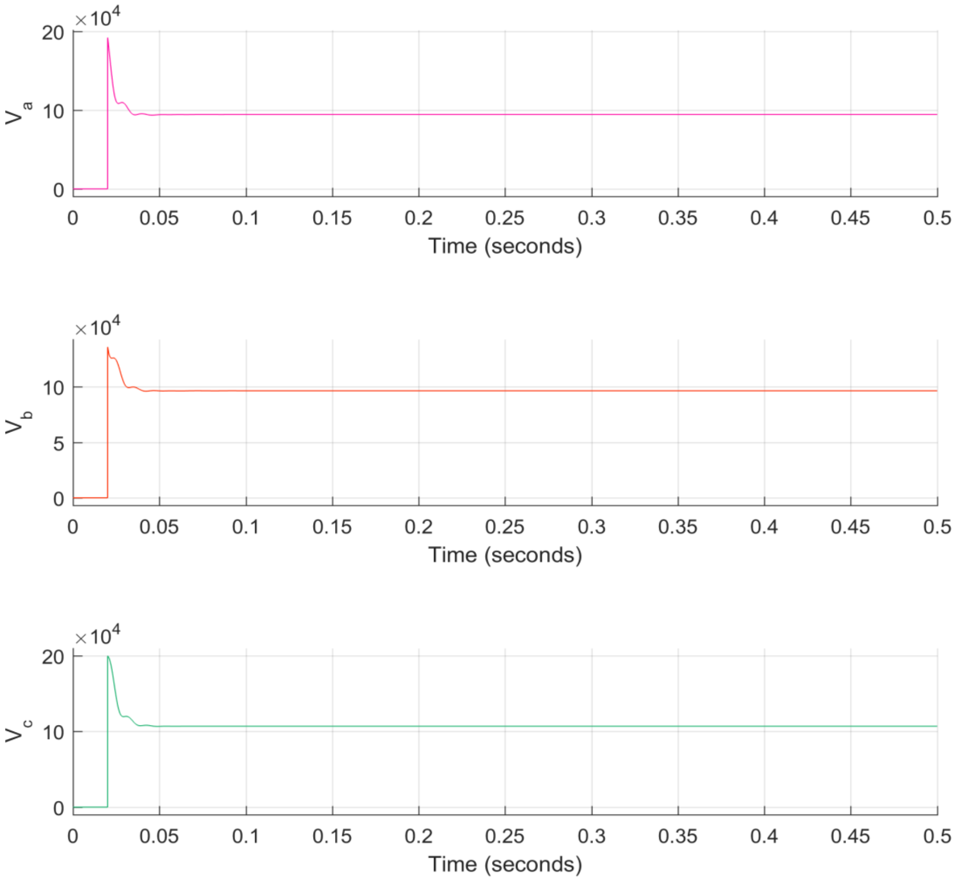


Figure 5.13 LLG Fault Voltage

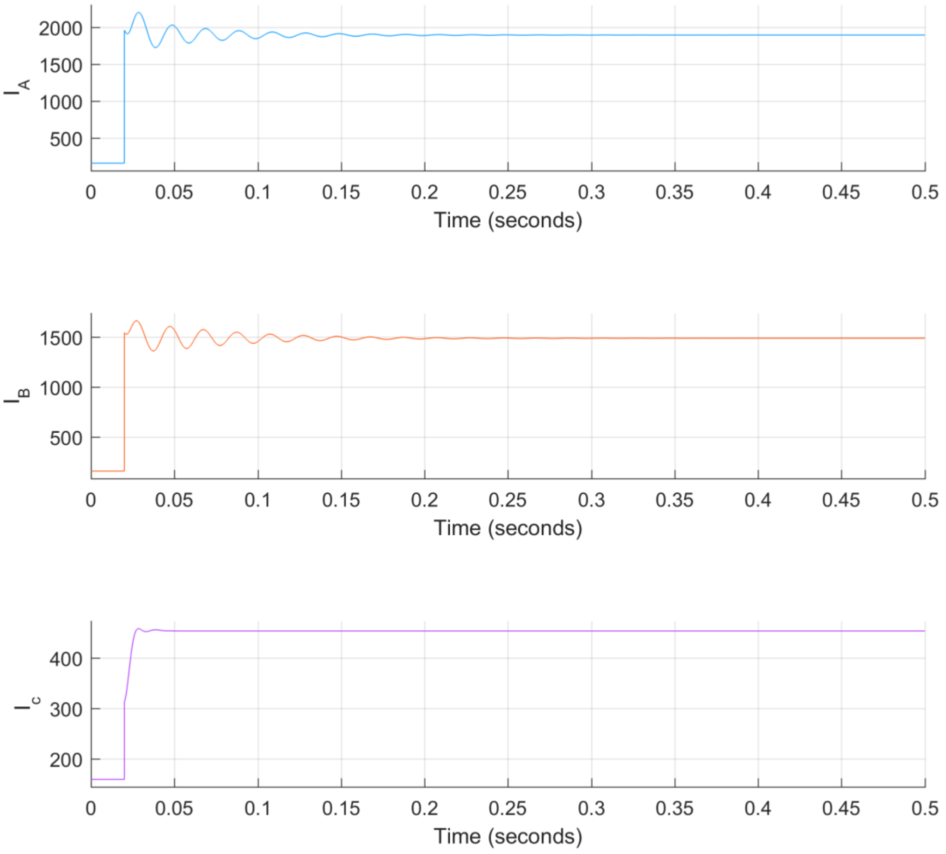


Figure 5.14 LLG Fault Current

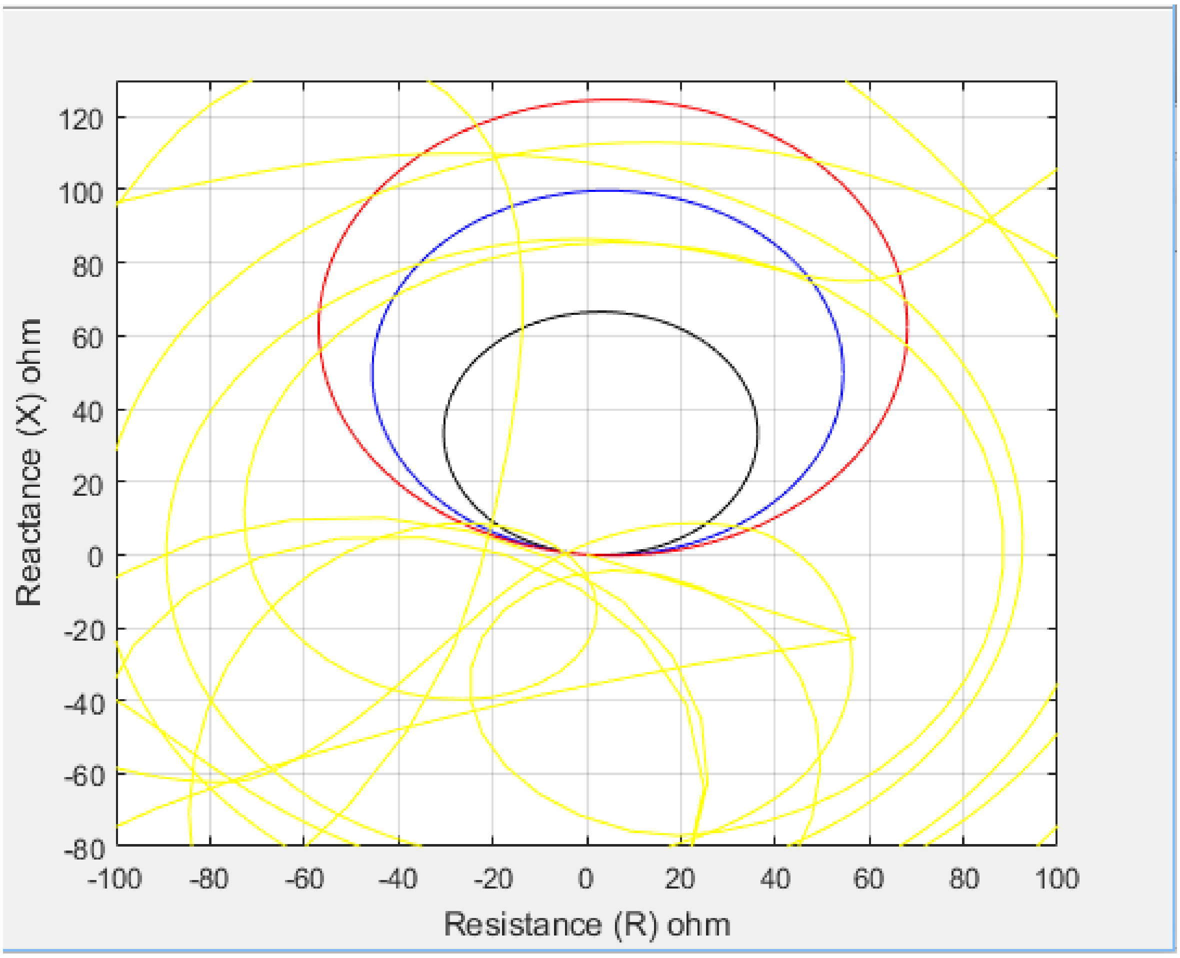


Figure 5.15 LLG Fault Impedance

ZONE 3^{rd}

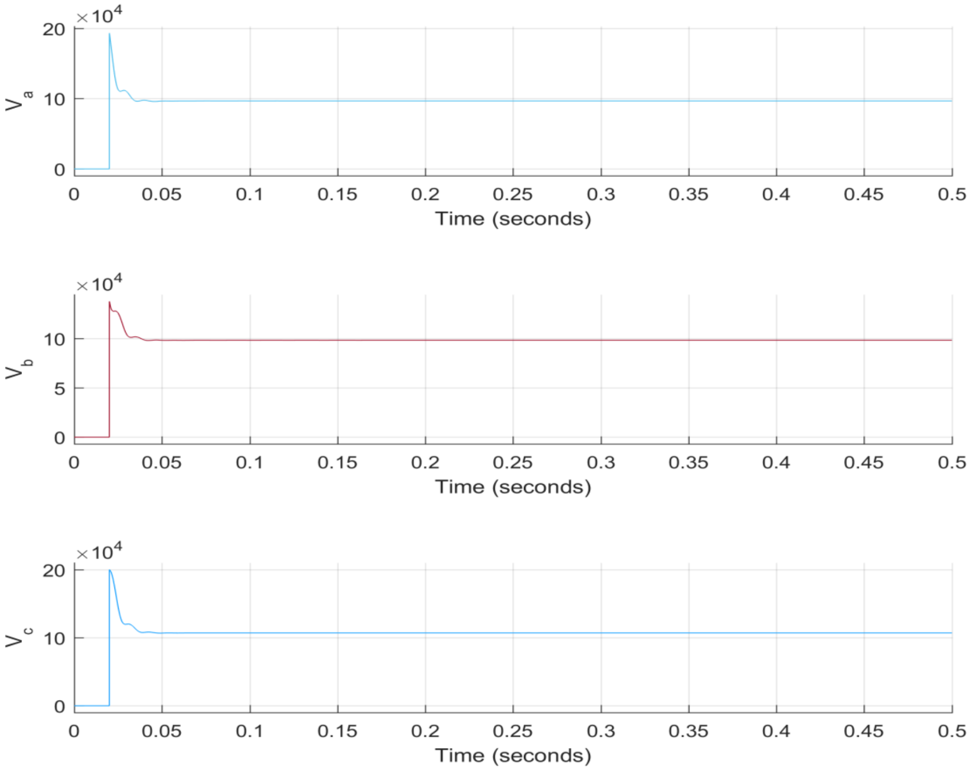


Figure 5.16 LLG Fault Voltage

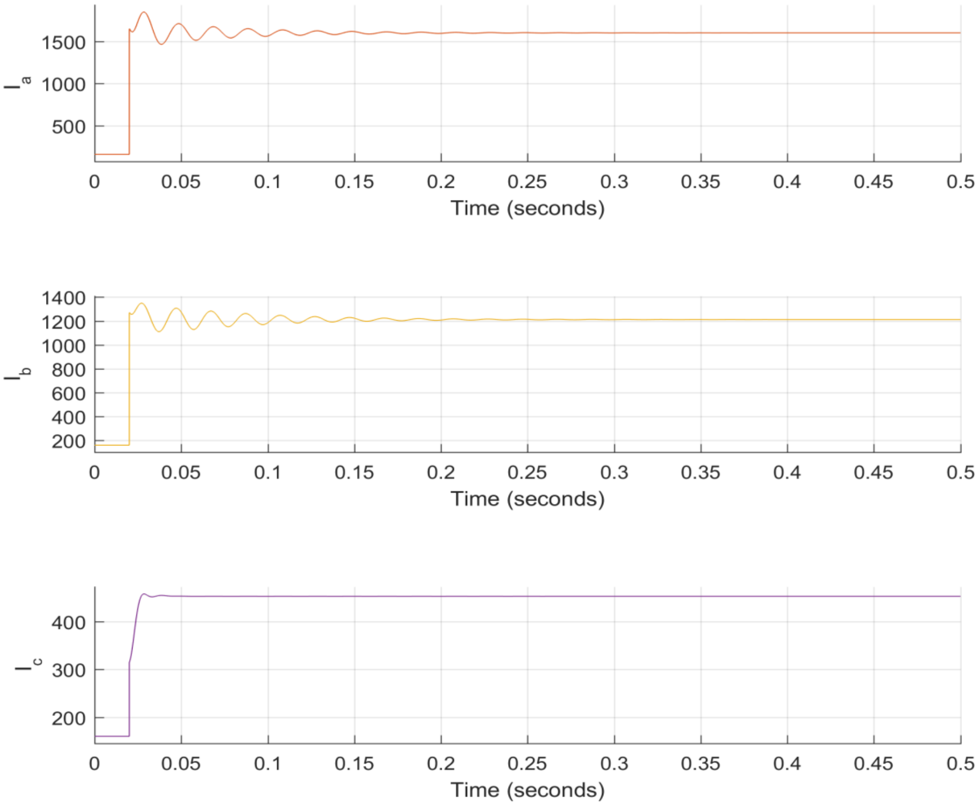


Figure 5.17 LLG Fault current

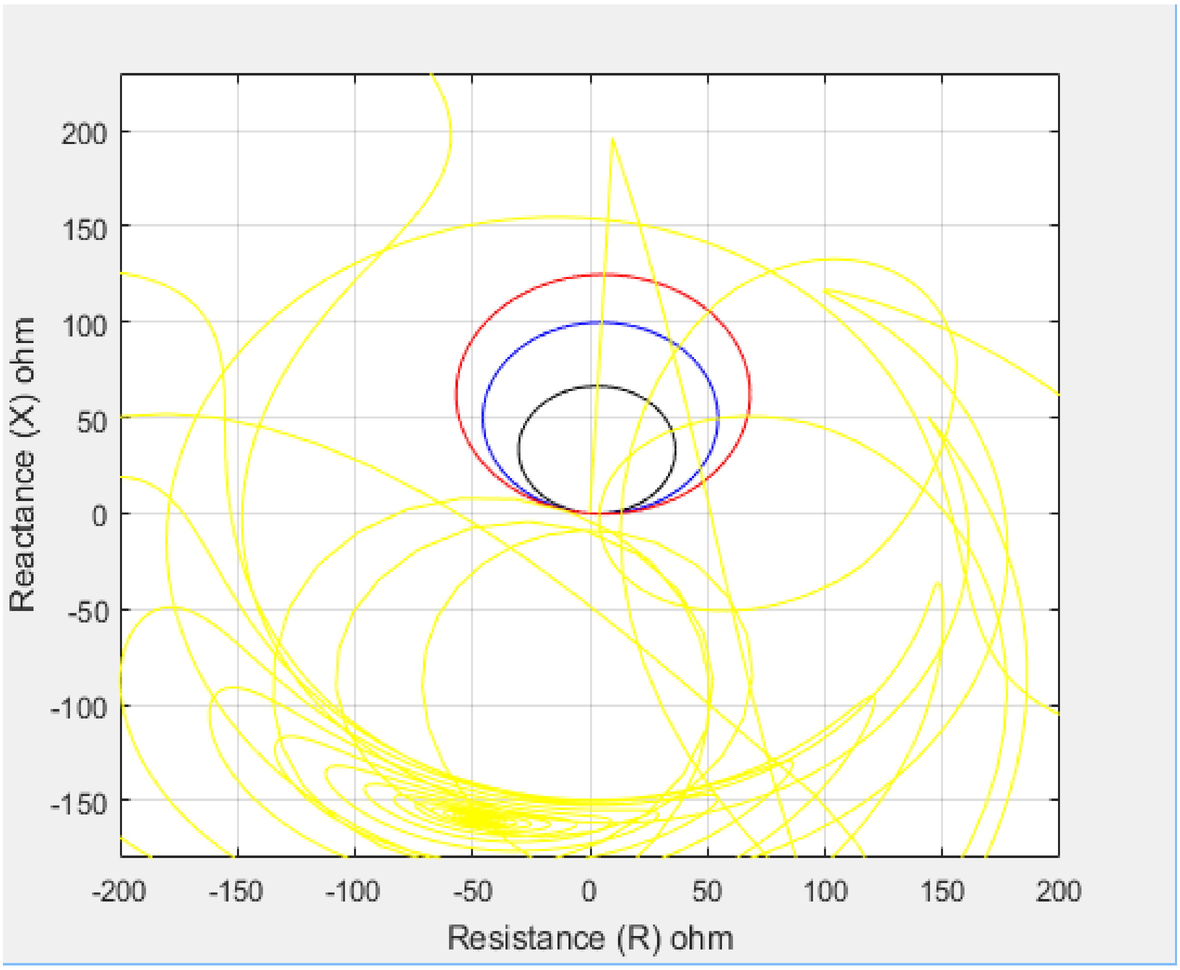


Figure 5.18 LLG Fault Impedance

In the above R-X range relay response plots for LLG faults, the measured fault impedance locus at 70 km, 100 km and 140 km from the sending terminal is situated. Figure (5.12) indicates that the locus of failure impedance falls below the region 1 feature, Figure (5.15) drops below the zone-2 characteristic and Figure (5.18) drops below the zone 3 feature. However, during such faults, only one of the three relay phases would assess the correct impedance or distance to the fault, and the remaining two would assess impedances greater than the impedance of the fault.

5.1.3 SINGLE-LINE TO GROUND FAULT:

ZONE 1st

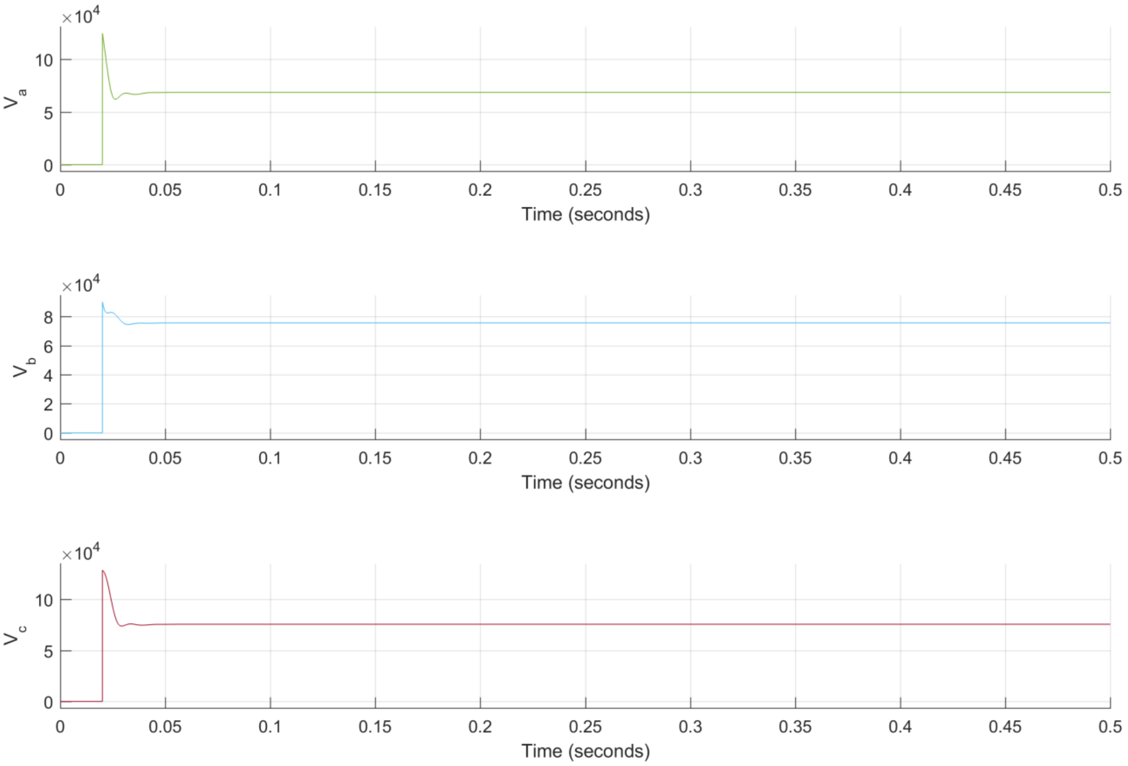


Figure 5.19 SLG Fault Voltage

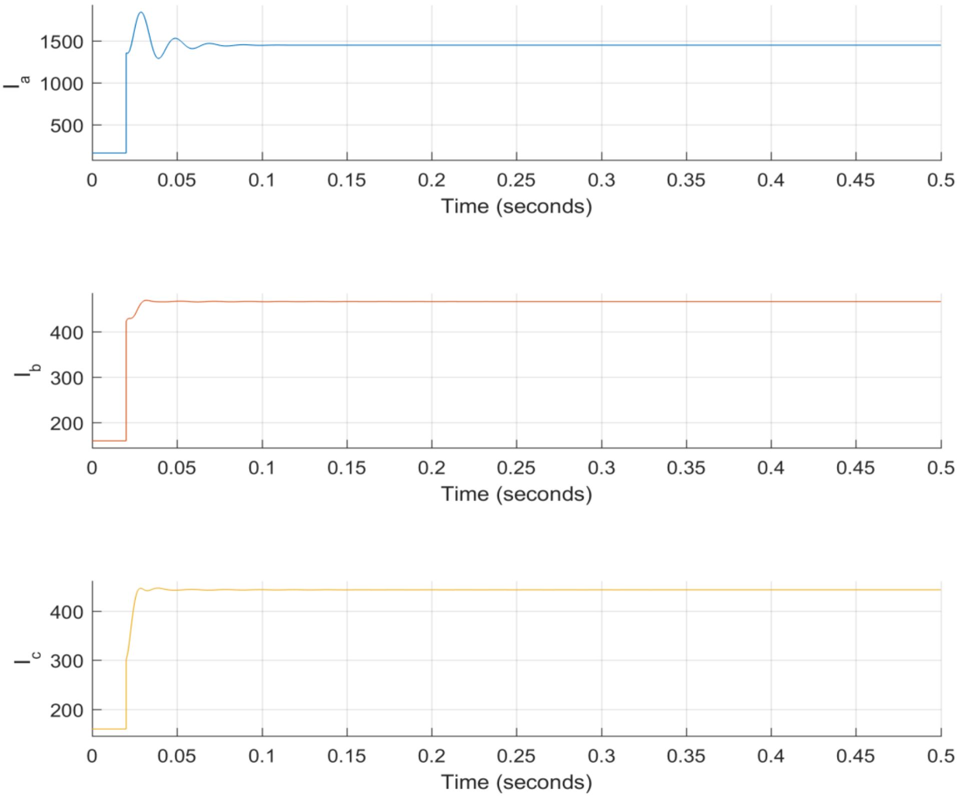


Figure 5.20 SLG Fault Current

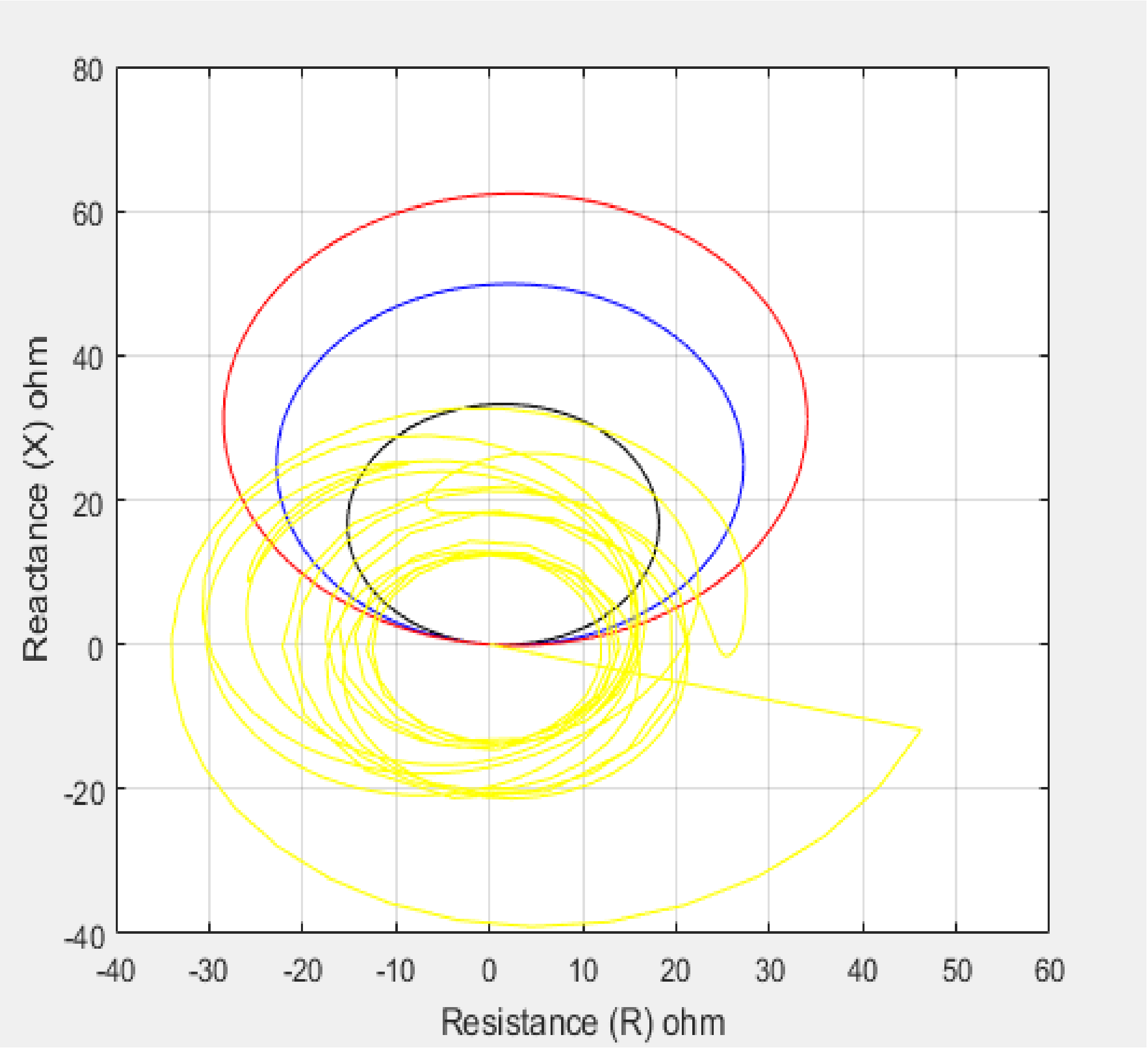


Figure 5.21 SLG Fault Impedance

ZONE 2nd

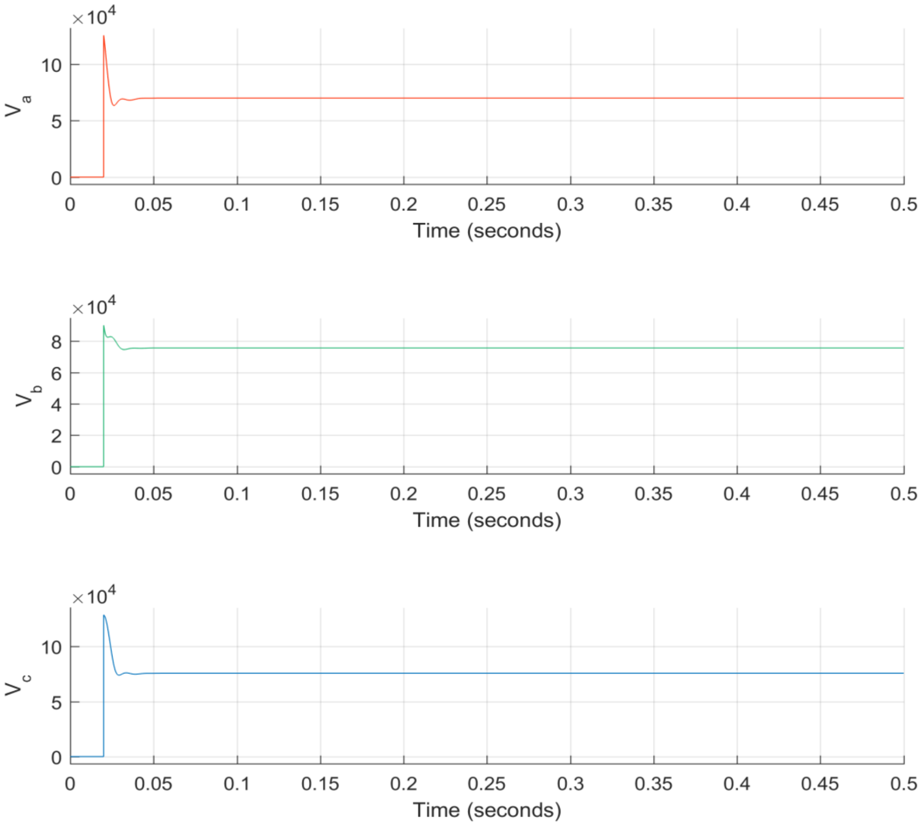
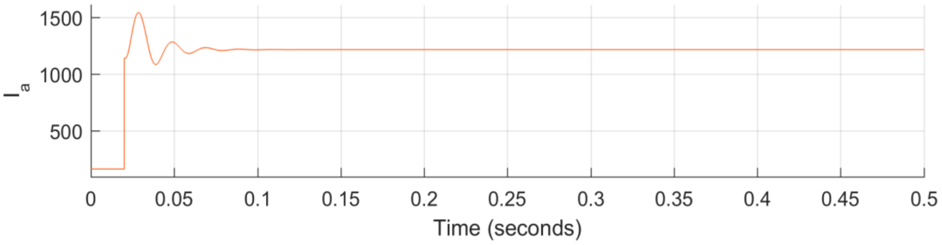
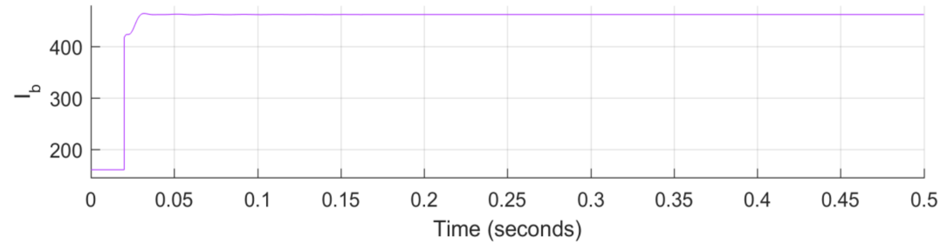


Figure 5.22 SLG Fault Voltage





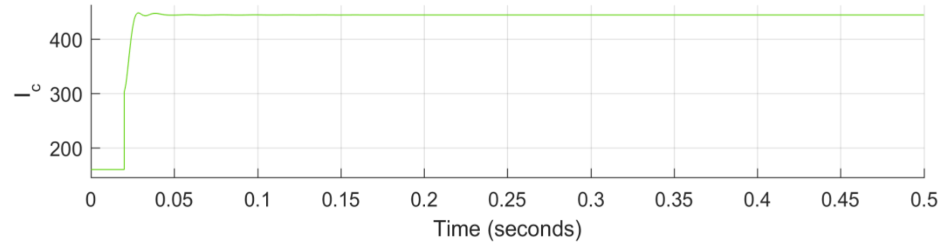


Figure 5.23 SLG Fault Current

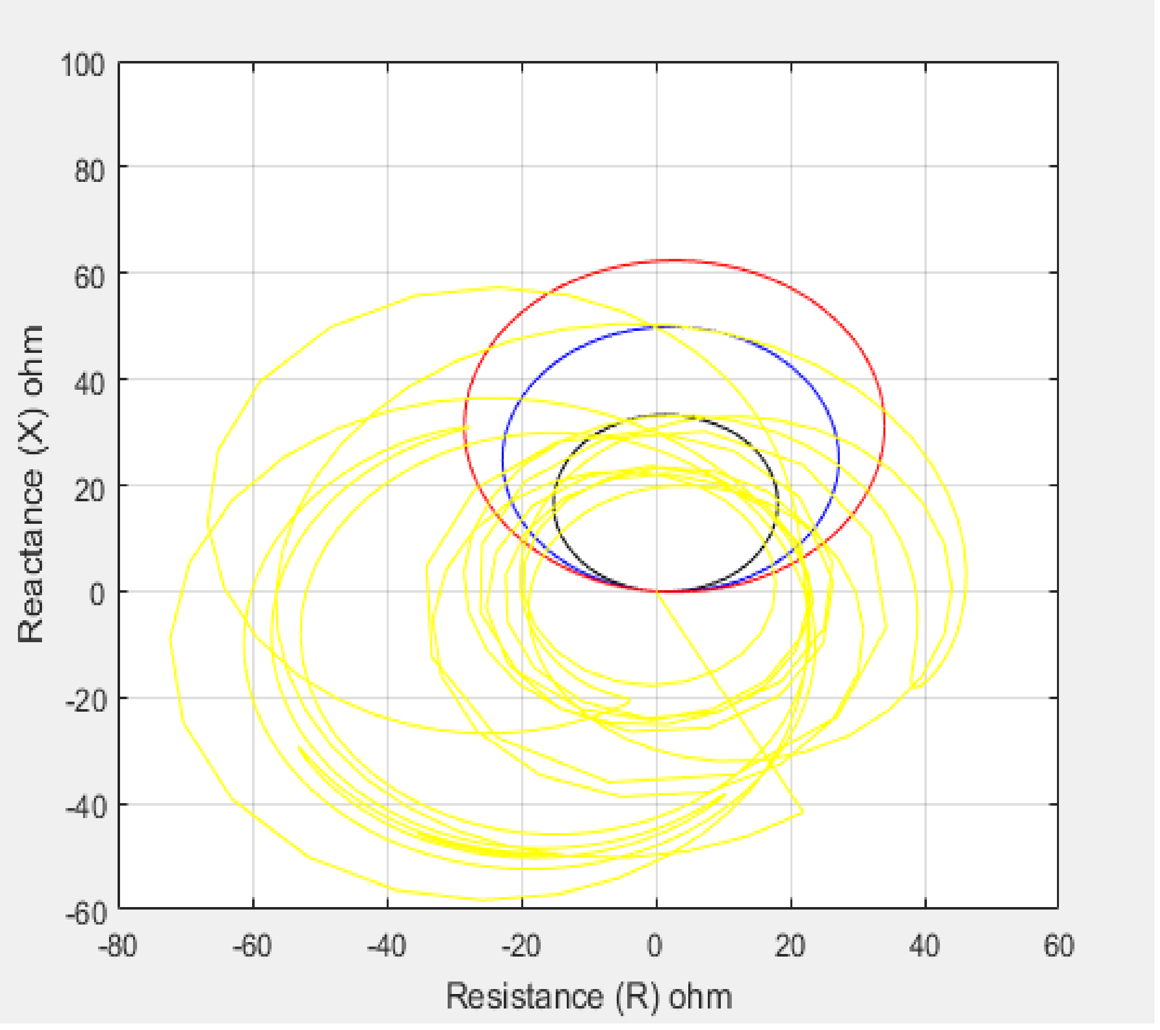


Figure 5.24 SLG Fault Impedance

ZONE 3rd

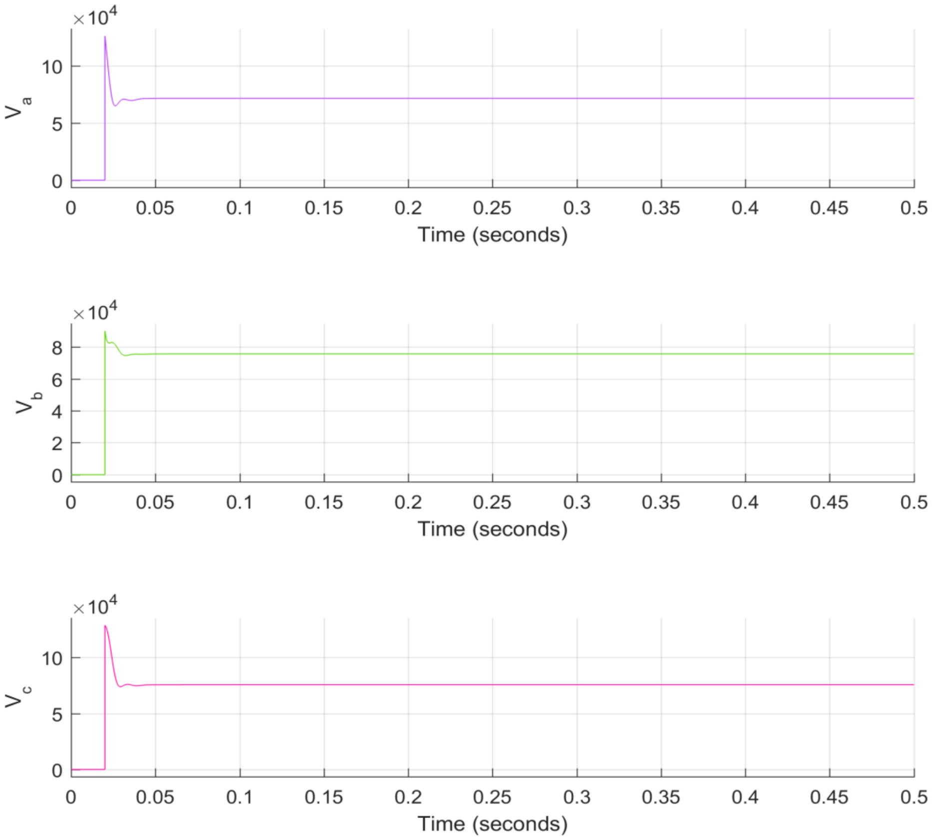


Figure 5.25 SLG Fault Voltage

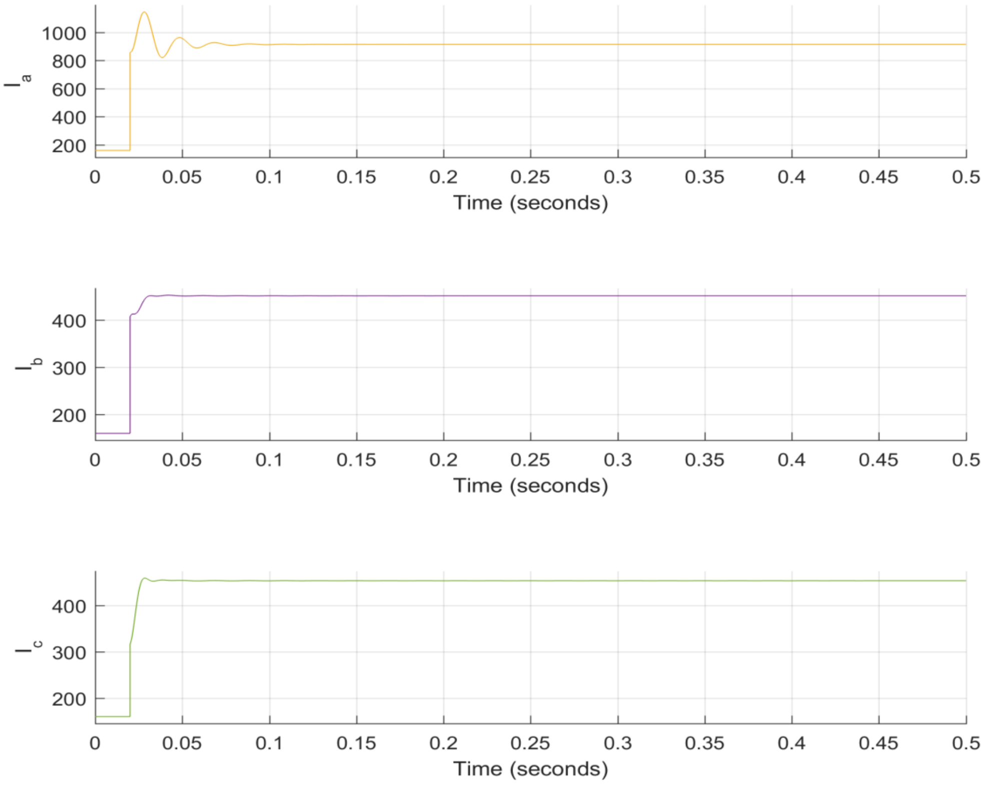


Figure 5.26 SLG Fault Current

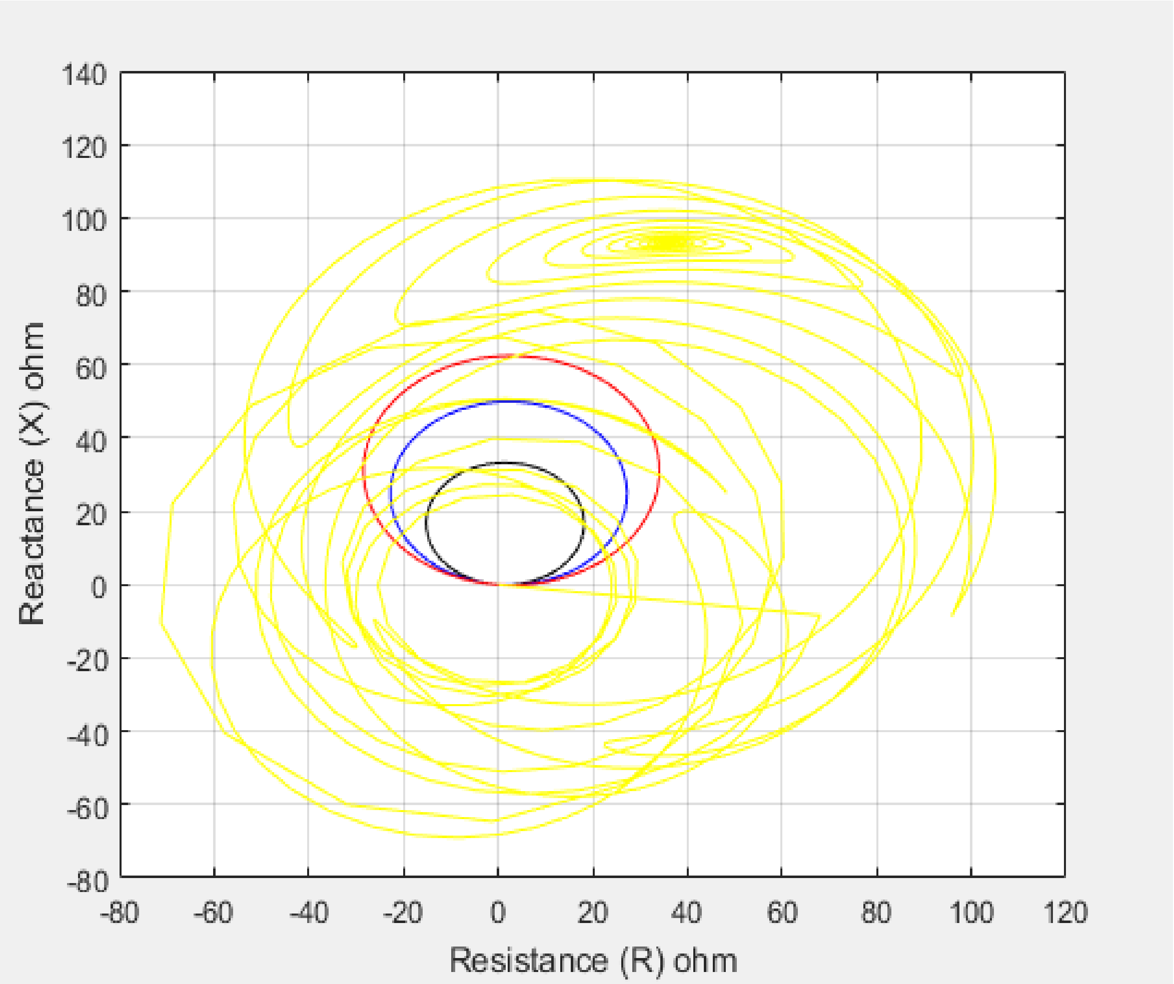


Figure 5.27 SLG Fault Impedance

For faults between stage and ground, the phase voltage and the adjusted phase currents energize ground range relays through mutual coupling. The statistics above show fault impedance measured from the original terminal at 70 km, 100 km and 170 km. In Figure (5.21), fault impedance locus is characteristic of area 1, Figure (5.24) is characteristic of area 2 and Figure (5.27) is characteristic of

5.2 CONCLUSION

For a long transmission line with defined parameters, namely, three-phase, double line to floor and single line to ground faults, we observed the voltage and current waveforms under separate fault conditions. The MHO relay characteristics were plotted in a three-step zone security system and the impedance (R-X) plots were plotted for separate faults and separate distances between the relay location and the fault incidence point (70 km, 110 km, and 140 km).

The plot helps to verify the increasing impedance as the fault location is further away from the relay location and helps to identify impedances measured in the energy system networks at strategic points during symmetrical and unsymmetrical faults.

5.3 FUTURE SCOPE OF WORK

With the implementation of advanced communication-based safety systems and distance relay digitization, digital specimens are often lost in the communication system. Despite the lost specimens, it is possible to create algorithms to evaluate the missing samples and attain the correct error paths. Further research can be performed in this area based on our work.

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