MODELING AND SIMULATION OF DISTANCE RELAY FOR POWER SYSTEM PROTECTION

DISSERTATION

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Submitted by:

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CERTIFICATE

I, **Ajit Kumar Singh**, Roll No. 2K12/PSY/02 student of **M. Tech. (Power System)**, hereby declare that the dissertation/project titled **"Modeling and Simulation of distance Relay for Power System Protection"** under the supervision of Mr. J. N. Rai, Associate Professor, Department 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.

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DECLARATION

I, hereby declare that the work being presented in this Project Report entitled **"Modeling and Simulation of Distance Relay for Power System Protection"** is an original piece of work and an authentic report of our own work carried out during the period of 4th Semester as a part of our major project.

The model developed and results presented in this report is an outcome of the work carried out during the above said period and is also compiled as thesis for my Major Project for completing the requirements of Master‘s Degree of Examination in Power System Engineering, as per Delhi Technological University curriculum.

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ABSTRACT

In the present thesis work 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.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOL AND ABBREBIATION

CT	Current Transformer
VT	Voltage Transformer
CB	Circuit Breaker
DSB	Digital Signal Processor
ADC	Analog to Digital Converter
S/H	Sample And Hold
DAS	Data Acquisition System
MOV	Metal Oxide Varistor
DFT	Discrete Fourier Transform
Z	Impedance
R	Resistance
X	Reactance
Y	Admittance
Θ	Impedance Angle

CHAPTER-1
INTRODUCTION

1.1 General:

In this thesis work a distance relay based on numerical technique has been developed and then the characteristic of that relay on various faults has been drawn. Numerical relays are the combination of microprocessor technique and digital signal processing.

1.2 Protective System:

A power system is a complex network of generators, transformers, transmission and distribution lines etc. Short circuits and other abnormalities often occurs in power system networks and due to this short circuit heavy current flows in the equipments working in the system causing damage to the equipment. Most of the equipments are very expensive in power system, and so the whole power system can be considered as a very large capital investment. For optimum utilization of the whole system, the system must be working under the applicable constraints of security and reliability of supply. More fundamental, however, is that the power system should response in a safe manner at all times. The power system may be very well designed but faults will always occur on a power system, and these faults may represent a risk to life and/or property. In power system terminology short circuits are commonly known as ‘Fault’. For protection of these equipments from such abnormalities we need protective arrangements. These arrangements consist of protective relays and circuit breakers. If a fault occurs in the system automatic protective device is required to isolate the faulty section and keep the healthy section in operation. If fault persist for long duration it may damage some important and costly equipment in the system. A high short circuit current may also cause fire which may damage a part of the system. During short circuit the system voltage reduces to a low level and generators may lose synchronism.

A protective system includes transducers, circuit breakers and protective relays for working of the protective system. Protective relays act as the brain of any protective system which with the help of the transducers senses the abnormalities in power system network and provide a command to the circuit breaker weather to trip or not. In this way the work of relay is to detect and locate a fault and provide a trip signal to the circuit breaker. During occurrence of fault there occur some changes in the system these changes are in terms of current, voltage, frequency and phase angle. Engineers always use relay models for selection of the relay types which is suitable for a particular application, and for the analysis of the performance of the relays which appear to either operate incorrectly or fail to operate when fault occur. Instead of using actual relay in the field for testing, manufacturers use software developed relay model designing to expedite and economize the process of developing new relays. Some important definition which are normally used in power system protection subject are as

1.2.1 Protection System (Definition):

An arrangement of protection equipment and other devices which is required to achieve a specified function based on a protection principle is known as protection system.

1.2.2 Protection Equipment:

It is a collection of protection devices (relays, fuses, etc.) excluding devices such as Current Transformers (CTs), Circuit Breakers (CBs) and contactors.

1.3 Protection Scheme:

A collection of protection equipment providing a defined function and including all equipment required to make the scheme work (i.e. relays, CTs, CBs, batteries, etc.)

To obtain the quicker speed for the various configurations of protection system, operating conditions and construction of power systems, it is important to develop different types of relay which respond to various functions of the power system quantities. For example, estimation of the fault current magnitude may be sufficient in some cases but we may require measurement of the power or impedance in other cases. Relays are capable of measurement of complex functions of the system quantities, which may only be represented by mathematical or graphical means.

1.4 Relay types based on Technology:

Relays may be classified according to the technology used:

- Electro-mechanical Relay
- Static Relay
- Digital Relay

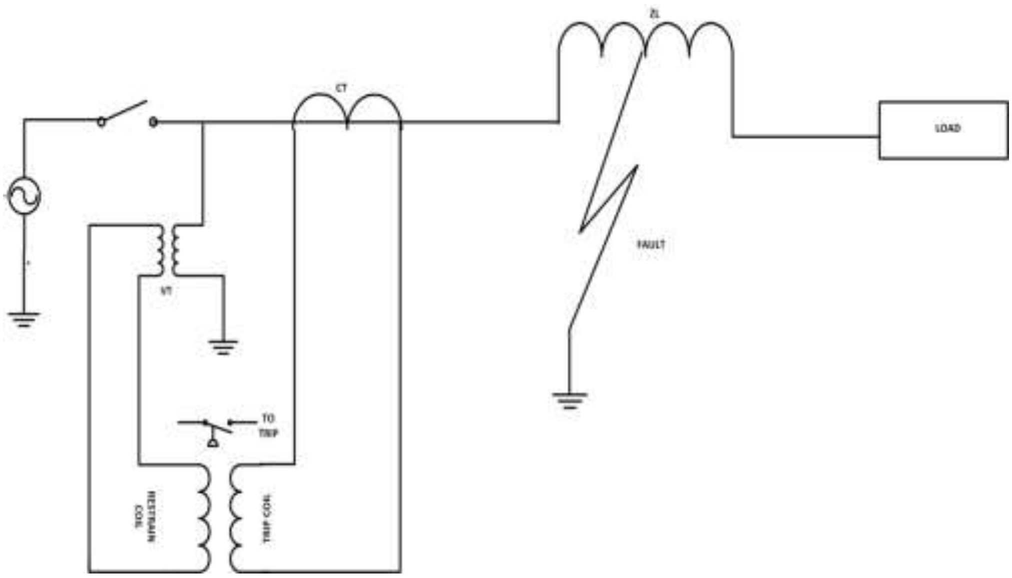


Figure (1.1): components of a protection system

1.4.1 Electromechanical relays:

The first relays employed in the electric industry were electromechanical devices. These relays worked based on creating a mechanical force to operate the relay contacts in response to a fault situation. The mechanical force was established by the flow of a current that reflected the fault current through windings mounted in magnetic cores. Due to the nature of its principle of operation, electromechanical relays are relatively heavier and bulkier than relays constructed with other technologies. Besides, the burden of these relays can be extremely high, affecting protection purposes. However, electromechanical relays were so largely employed, tested and known that even modern relays employ their principle of operation, and still represent a good choice for certain conditions of application.

1.4.2 Solid-state relays:

With the advances on electronics, the electromechanical technology presented in the relays of the first generation started to be replaced by static relays in the early 60's. Static relays defined the operating characteristic based in analog circuitry rather than in the action of windings and coils. The advantages that static relays showed over electromechanical relays were a reduced size, weight and electrical burden. However, static relays showed some disadvantages since analog circuitry is extremely affected by electromagnetic interference and the ranges of current and voltages values are strongly restricted in analog circuits, affecting the sensitivity of the relay.

1.4.3 Digital relays:

Incorporating microprocessor into the architecture of relay to implement relay and logic functions started happening in the 80's. Digital relays incorporated analog-to-digital converter (ADC) to sample the analog signals incoming from instrument transformers, and used microprocessor to define the logic of the relay. Digital relays presented an improvement in accuracy and control over incoming signals, and the use of more complexes relay algorithms, extra relay functions and complementary task.

1.4.4 Numerical relays:

The difference between numerical relays and digital relays lies in the kind of microprocessor used. Numerical relays use digital signal processors (DSP) cards, which contain dedicated microprocessors especially designed to perform digital signal processing.

1.5 Types of protective scheme:

Protection of equipments or a portion of a transmission line is done by using a protective scheme. In one protective scheme, one or more relays of same or different type can be used. The various protective schemes frequently used in protection are:

- Over current protection
- Distance protection
- Carrier current protection

- Differential protection

1.5.1 Over-current protection:

Over-current protection responds to the magnitude of fault current. When fault current exceeds a preset pickup level, a trip signal is issued after a coordination time delay. When the magnitude of a fault current greatly exceeds that of the load current, an instantaneous trip signal is typically issued. This is known as the high set or instantaneous setting value of the over-current relay. Over-current protection can be classified based on the operating characteristic, namely definite current, definite time, normal inverse, very inverse, and extreme inverse.

Over-current protection is used on radial transmission feeders to provide time-coordinated protection. However, modern transmission networks are not radial, but rather are meshed in nature. In such meshed topologies, simple over-current protection is difficult to apply where coordination, selectivity, speed, reliability, and stability are important.

In addition, over-current protection cannot discriminate load currents from fault currents, and it is therefore applicable only where the fault current exceeds the full load current. In meshed-topology networks, infeed currents and coordination are problematic too when using over-current protection. Finally any changes in transmission line configuration, network topology, and network upgrading require over-current protection settings to be completely redesigned.

1.6 Relay performance and relay technology:

The following characteristics are related with a good performance of a relay in a power system:

1.6.1 Reliability:

The reliability of a relay is directly in correspondence with the concepts of dependability and security. A relay is said to be dependable when it operates in the occurrence of a fault relevant to its protection zone. Security is reached either when the relay will not operate for a fault outside its operating zone, or when the system is in a healthy state.

1.6.2 Selectivity:

Selectivity is the ability that a relay has to only open those breakers that isolate the faulted element. Selectivity discrimination can be achieved by time grading or by unit protection. Selectivity by time grading means that different zones of operation are graded by time and that in the occurrence of a fault, although a number of protections equipment respond, only those relevant to the faulty zone complete the tripping function. Selectivity by unit protection means that the relay will only operate under certain fault conditions occurring within a clearly defined zone.

1.6.3 Speed:

In the occurrence of a fault, the greater the time in which the fault is affecting the power system, the greater is the risk that the power system falls into an unstable operation point. Relays are therefore required to clear the fault as quickly as possible.

1.6.4 Sensitivity:

The relay is said to be sensitive if the relay operates to the minimum value of faulted input signals.

1.7 Relay technology

The relay application for protection of power system date back nearly 100 years ago. Since then, the technology employed to construct relays have improved dramatically relay size, weight, cost and functionality. Based on the technology employed for their construction, relays can be chronologically classified as electromechanical, static or solid-state, digital and numerical.

CHAPTER-2

LITERATURE REVIEW

2.1 Introduction:

Since the evolution of the numerical relay technology a lot of work had been done for the development of numerical relay model. As the demand on the existing power system has increases then due to human nature we try to cop-up that demand, in that race we tried to modify the existing power system network and in doing so we had designed more complex and more capacitive power system network. Due to use of parallel transmission line the protection of the line has become more difficult. For the development of the numerical distance relay for my project work I have used MATLAB-SIMULINK software. Numerical relays were developed for the replacement of the classical electro-mechanical relays.

MuhdHafiziIdris, the modelling of Numerical distance relay is being designed by using MATLAB-SIMULINK platform. In the designed relay model discrete Fourier Filter has been used and then Discrete Fourier Transform (DFT) block from SIMULINK is used for the value of the magnitude and phase of the voltages and currents. And the developed model has been used for the simulation of the fault at various locations in modelled transmission line. And also the model is used for the calculation of the impedance up to the fault point from relay location [1].

Abdlmnam A. Abdlrahem, he had developed the numerical distance relay using MATLAB and Electro Magnetic Transient Program (EMTP). In this model the data for different faults has been generated by using EMTP. In this work they had used EMTP-ATP for collecting the voltage and current samples. This is a power system transient simulator which has been used for the simulation power system network [2].

Omar G. Mrehel, in this design he has used MATLAB SIMULINK blocks for the software realization of the digital relay. A user defined function known as s-function has been used for impedance calculation algorithm. By using signal processing block he has designed the signal conditioning model, analog to digital converter model. He has classified the designing of the relay in three categories namely fault detection, impedance measurement and zone protection co-ordination. He has developed phasors detection algorithm, fault detection algorithm and zone co-ordination algorithm [3].

Jyh-CherngGu, this paper describes the use and importance of the Discrete Fourier Transform. This is explained in this paper that the DFT can eliminate the harmonics from the voltage and currents samples. Along with the harmonics, the voltages and currents also contains dc offset during faults which is also removed by DFT effectively. In this paper it is shown that we require one cycle and two samples to completely remove the dc offset [4]

Li-Cheng Wu, This paper explains the modelling of digital distance relay using EMTP and MATLAB-SIMULINK. A protective relay algorithm has been developed for the calculation of the transmission line impedance up to fault location. Here also same mechanism has been used for the relay modelling of the digital distance relay. In this paper the formula for the impedance calculation has been given [5]

M.S. Sachdev, in this paper relatively a new method for the detection of the fault location has been explained, the formula mentioned here has been used for designing of the present model in hand. The proof of the formula used in the model has been given in this paper. This paper has described the use of fundamental component of voltage and current for measurement of impedance [6].

A. G. Phadke, a single equation has been designed which can be applied for any type of fault which may occur on a transmission line. This equation had been derived by using symmetrical components theory [7].

P.G. McLaren, has developed a software model for a digital distance relay which was fed with the same fault data as the actual relay and the trajectories of the impedance found were same as the actual relay [8].

T. S. Sidhu, has developed a technique for the designing of a software model he had used an interactive software package that can fetch the specification of the relay and can generate a software model for that particular relay [11].

CHAPTER-3

DISTANCE RELAY

3.1 General:

Distance protection is so called because it is based on an electrical measure of distance along a transmission line to a fault. The impedance of the transmission line is distributed uniformly along the transmission line length this provides the basis for the principle of the distance relay.

Distance relaying is considered where over current relay is so slow to adopt or is not selective. Distance protection provides an excellent way of obtaining discrimination, selectivity, and speed of operation by allowing trip operation up to a certain range of distance. Unlike an over-current protection scheme, which does not have built-in backup protection, in a distance protection scheme backup is provided by arranging three sets of distance protection zones operating in tandem. Normally distance protection is termed as a non-unit protection system. Unlike phase and neutral over-current protection, the main advantage of distance protection is that its fault coverage of the protected circuit is virtually independent of source impedance variations. Distance protection relays are comparatively very simple to implement and it is faster in operation in the fault location in protection zone. Distance relays can also be utilized in primary and remote back-up protection in a single protection scheme.

3.2 Working principle of Distance Relay:

This is a scheme widely used for protection of transmission and sub-transmission lines. In distance protection we use a number of distance relays which measure the impedance or some components of the line impedance at the relay location. The measured quantity is proportional to the line length between the location of relay and the point where fault has occurred. A distance protection scheme is a non-unit system of protection. A single unit provides both primary and backup protection.

Distance relays are of following types:

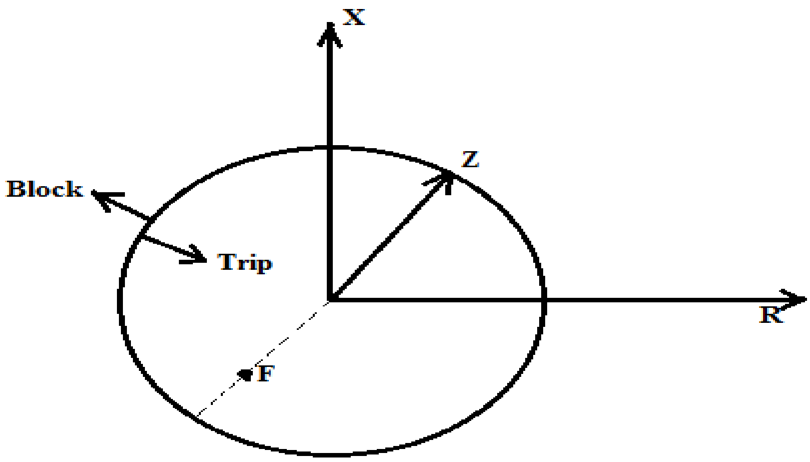
- Impedance relays
- Reactance relays
- Mho relays
- Quadrilateral relays

3.3 Impedance Relays:

An impedance relay measures the impedance of the line at the relay location. When a fault occurs on the protected line section, the measured impedance is the impedance of the section of the line between the relay location and the fault point. It is proportional to the length of the line and hence to the distance along the line.

3.3.1 Impedance Relay Characteristic:

The impedance relay characteristic has been shown in figure(3.1) below which is drawn on R-X diagram. Where Z=K represent a circle and Z<K indicates the area within the circle. Thus it is understood that the area within the circle is operating zone of the relay. Its radius is Z=K is the setting of the relay. K is equal to the impedance of the line which is to be protected. If the fault is on the protected section of the line, it will lie within the circle. For this condition, the relay will operate send a trip signal to the circuit breaker. The region outside the circle is the blocking zone.



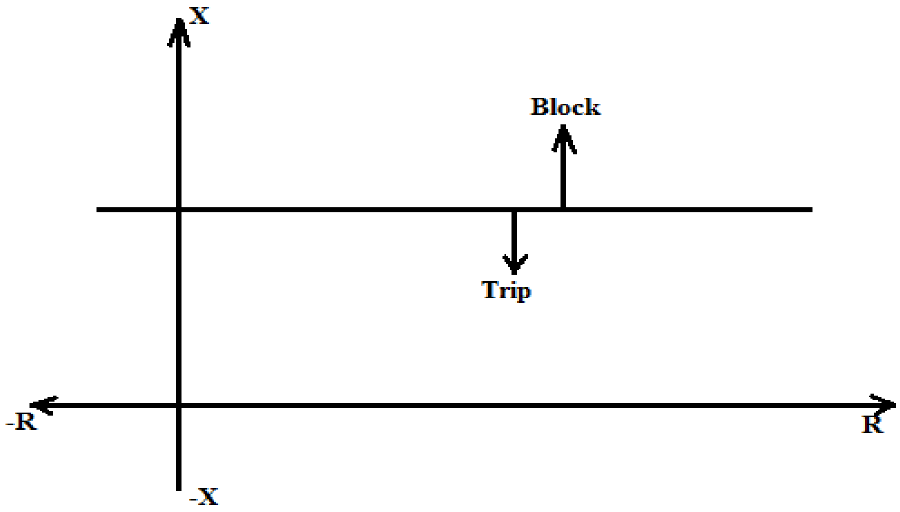
Figure(3.1): Operating Characteristic of an Impedance Relay on R-X diagram

3.4 Reactance Relay:

A reactance relay measures the reactance of the line at the relay location, and is not affected by variation in resistance. Hence its performance remains unaffected by arc resistance during the occurrence of the fault. In case a fault on protected line, the measured reactance is the reactance of the line between the relay location and the fault point.

3.4.1 Reactance Relay Characteristics:

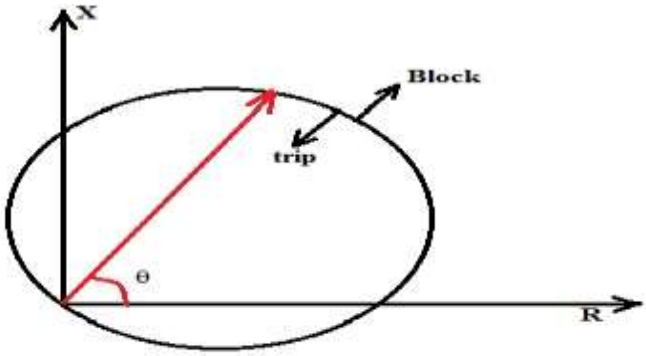
Its characteristic on the R-X diagram is a straight line, parallel to R axis as shown in figure(3.2).



Figure(3.2): Operating Characteristic of a reactance relay

3.5 MHO Relay (Admittance Relay):

A MHO relay measures a component of admittance relay $|Y| \angle\theta$. But its characteristic, when plotted on impedance diagram (R-X diagram) is a circle passing through origin. It is inherently a directional relay as it detect the fault only in forward direction. As it is clear from its circular characteristic passing through the origin, as shown in the figure(3.3)



Figure(3.3): Characteristic of MHO relay

3.6 Zones of Protection:

Non-pilot application of distance relaying is called step distance protection. The first zone is conventionally set to cover 80%, the second zone is set to cover 120%, and the third zone is set to cover 180% of the transmission line length.

The first zone uses high-speed tripping without intentional time delay, followed by the second and third zones with coordinated time delays. The first and second zones provide 20% margin of safety to avoid incorrect protection operation due to uncertainties in the line parameters, and the measurements obtained from the current and voltage transformers. These two zones provide primary protection, while the third zone provides backup protection.

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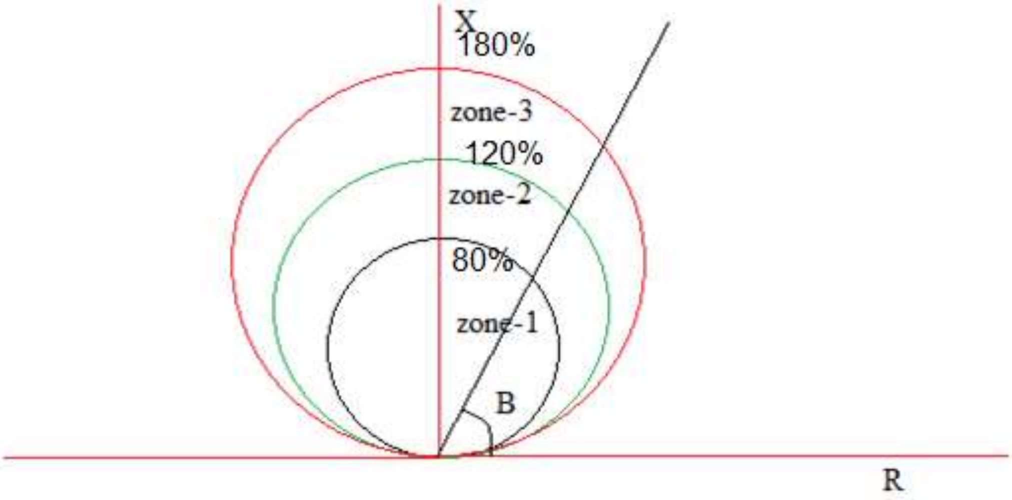
3.6.1 Zone 1 Setting:

The zone-1 of the transmission line is adjusted to 80-90% of the total length of the transmission line, it is also known as high-speed protection zone as no time-delay adjustment is provided for this unit.



Figure(3.4): Three zone protection of transmission line

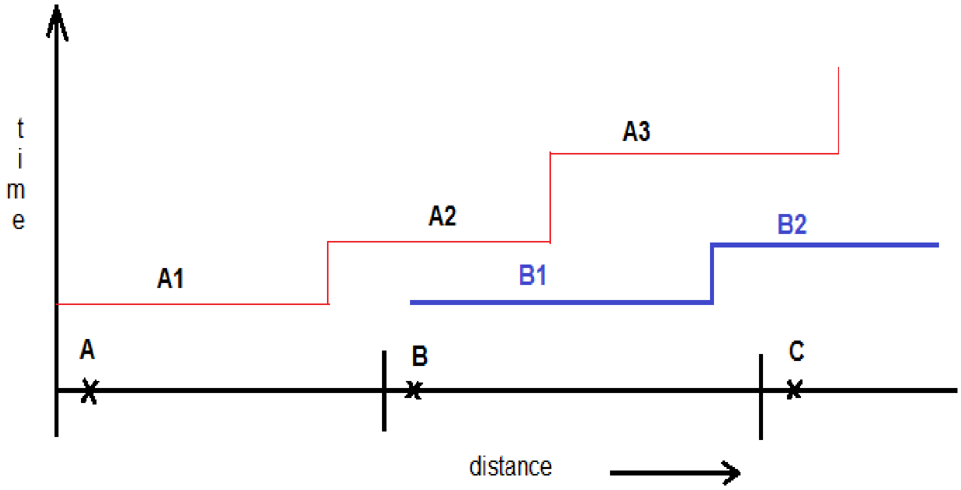
Electromechanical or static relays are generally having a setting of up to 80% of the whole length of the transmission line for Zone 1 protection. In digital or numerical distance relays, setting is provided for 85% of the total length of the transmission without much compromise in safety. As a consequence, we will loss the discrimination property of relay in fast operating protection zone that is zone 1of the protected line section.

3.6.2 Zone 2 Setting:

The remaining 15-20% of the transmission line length is covered in Zone 2 of the distance protection scheme. The main purpose of providing the second-zone unit in the transmission line is to protect the rest of the line beyond the set point of the first-zone protection unit of the distance relay. The setting of zone 2 should be adjusted in such a way that it will be able to sense the arcing faults occur at the other end of the transmission line. For achieving this quality, the zone 2 protection unit must be provided the reach beyond the end of the line. The section which falls under second unit of protection zone, is known as second zone of protection. The second zone unit operates after a certain time delay. Its operating time is usually 0.2 s to 0.5 s.

2.6.3 Zone-3 Setting:

Zone-3 protection covers the whole length of line in zone-1 plus length of section of zone-2 and 25% of the third line. And the whole section is known as zone-3.



Figure(3.5): Stepped time distance characteristic of impedance relay

The above figure (3.5) shows the operating time of impedance relays and is known as stepped time distance characteristic. A1, A2 and A3 are operating times for the zone-1, zone-2 and zone-3 relays placed at A respectively. Similarly B1, B2 and B3 for relays at point B.

CHAPTER-4
NUMERICAL RELAY

4.1 GENERAL:

The different between digital and numerical relays is particularly implied for Protection. Numerical relays are immerged form of digital relays because of advancement in technology. Here we use mathematical algorithms for the protection functions. With the developments in VLSI and computer hardware technology, microprocessor that appears in late seventies have evolved and made remarkable progress in recent years. Fast microprocessors, microcontrollers, and digital signal processors (DSPs) are available today at low prices. Their application to power system protection have resulted in the availability of compact, faster, more accurate flexible and reliable protective relays, as compared to the conventional relay.

Numerical relays which are based on numerical devices like microcontroller, microprocessors, DSPs etc. are the latest development in the power system protection technology. In these relays, the current and voltage signal which are monitored with the help of primary transducers (current and voltage transformers) are conditioned and sampled at specified instant of time and converted to digital form for numerical manipulation, display and recording.

Numerical relay, receives the data from data acquisition system, and process the data numerically using an algorithm to calculate the fault discriminates and make trip decision. At present numerical relays are widely used. Numerical relays have become an alternative to conventional relaying system employing electro-mechanical and static relays.

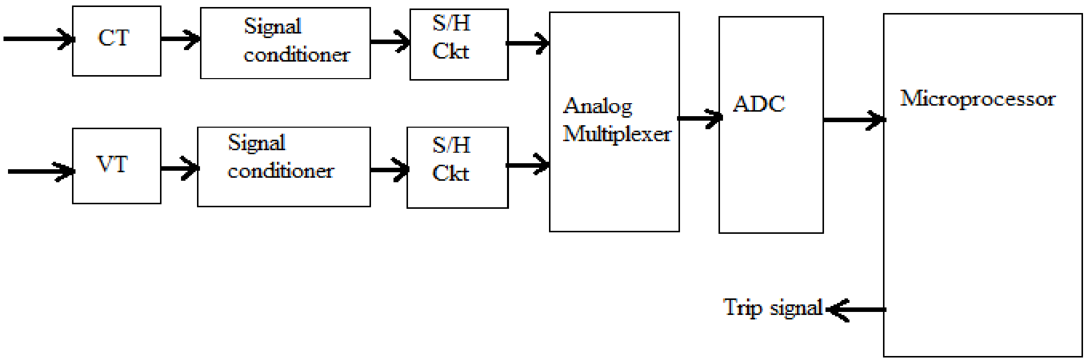


Figure (4.1): block diagram of typical numerical relay

4.2 Data Acquisition System:

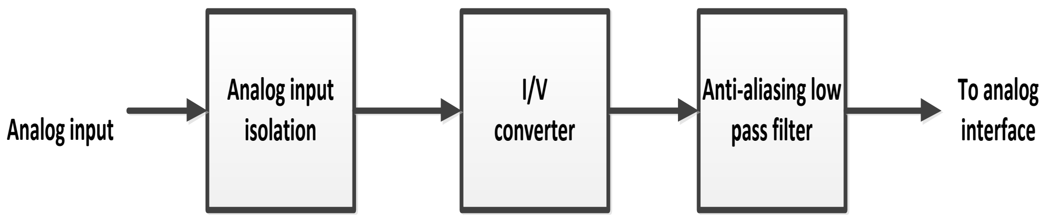
It is the process of sampling of real world analog signals and conversion of resulting sample in to digital numeric values that can be manipulated by a computer. DAS involves the conversion of analog signals in to digital values for processing. For numerical relays the DAS takes the sequential samples of analog ac quantities and converts them in to digital numeric values. The output of the transducers that is VT's and CT's are applied to DAS. DAS consists of various signal conditioning techniques to modify different electrical signal in to voltage that can be digitized using an analog to digital converter (ADC).

4.3 Signal conditioner:

Signal conditioner also known as analog input subsystem is necessary to make the signals from transducers compatible with the analog interface. Its circuitry converts analog input signals in to a form that can be converted to digital values. The general methods for conditioning analog signals consist of following:

- Analog input isolation and scaling
- Current to voltage conversion
- Filtering

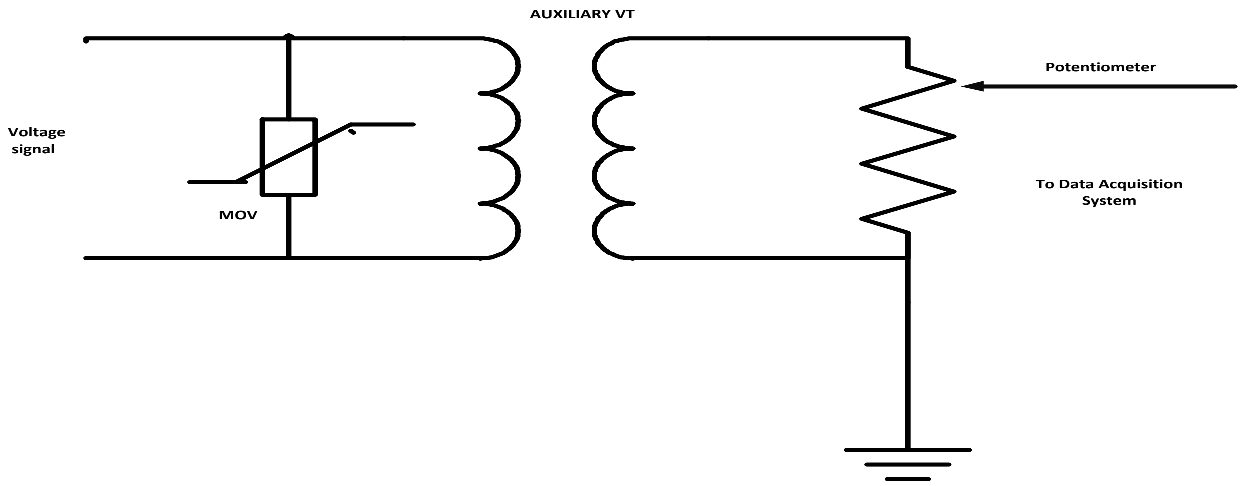
The relays are electrically isolated from power system by using auxiliary transformers which receive analog signal from the transducers and reduce their levels to make them suitable for use in relay. Metal oxide varistor (MOV) which has a high resistance at low voltage and low resistance at high voltage due highly nonlinear current voltage characteristic is used to protect circuit against excessive transient voltages figure(3.2 & 3.4). The phenomenon of appearance of a high frequency signal as a low frequency signal is called aliasing. To prevent aliasing from affecting the relaying functions, anti-aliasing filters are used along with analog input isolation box.



Figure(4.2): block diagram of a typical signal conditioner

4.3.1 Isolation and analog signal scaling module:

The isolation and analog signal scaling module acquires the voltage and current signals from the transducers of the power system. This module provides electrical isolation from the power system and scales down the acquired inputs to levels suitable for use by the data acquisition system. Since analog-to-digital converters accept only voltage signals, this module also converts currents to equivalent voltages. In Figure (4.2) is shown a schematic diagram of the circuit for isolation and analog scaling of a voltage signal. The output of a voltage transformer is applied to an auxiliary transformer that reduces the voltage level and provides electrical isolation to the rest of the relay equipment. After the auxiliary voltage transformer, the voltage is further reduced by a potentiometer to a level suitable for use by the data acquisition system. A metal oxide varistor (MOV) is used at the input of the auxiliary transformer to protect the data acquisition system from transients in the input signals.



Figure(4.3): isolation and scaling of voltages

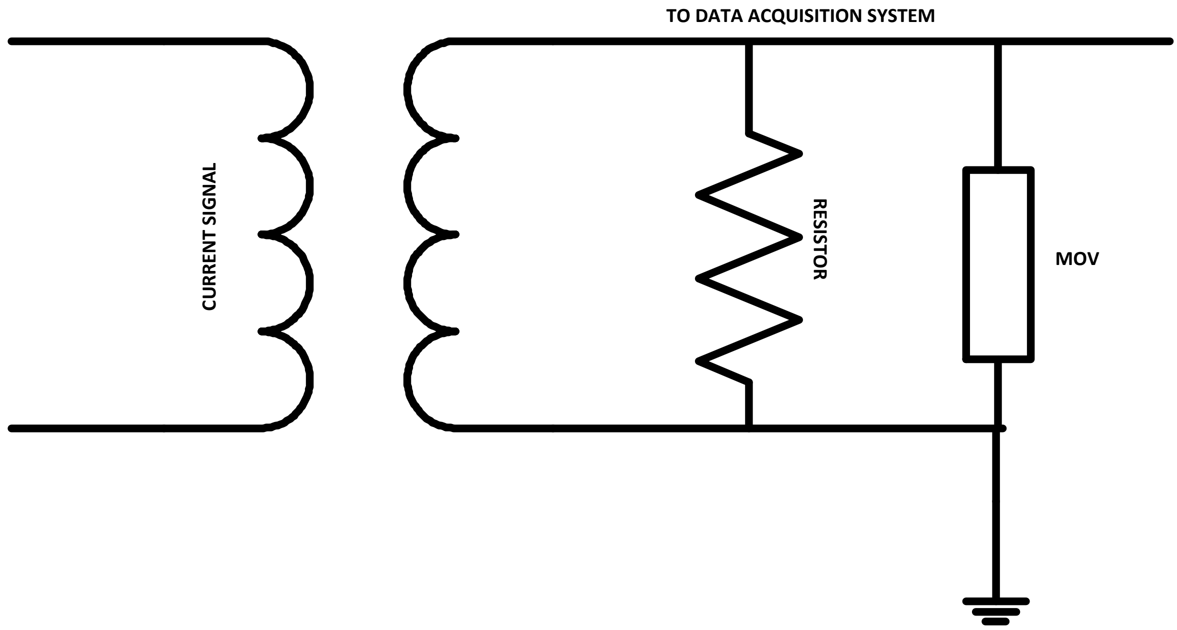


Figure (4.4): isolation and scaling of currents.

4.3.2 Analog Anti-aliasing filtering:

Post fault power system signals contain dc offset and harmonic components, in addition to the major fundamental frequency component. For conversion of analog signal to a sequence of numbers a suitable sampling rate must be used, because high frequency components which might be present in the signal could be incorrectly taken as components of lower frequencies. The mechanism of a high frequency component in an input signal representing itself as low frequency signal is called “aliasing”. It is appearance of a high frequency signal as a lower frequency signal that distorts the desired signal.

Since it is not possible to select a sampling frequency that would prevent the appearance of all high frequency components of frequency of interest, the analog signals are applied to a low pass filter. This process of band limiting of input by using low pass filter removes most of the high frequency components. Thus the effect of aliasing is removed.

4.3.3 Sampling:

Sampling is the process of converting a continuous signal, to a discrete time signal. The sampling rate should be selected by taking analog and digital converter into consideration. In order that the samples represent the analog signal uniquely and contains enough information to recreate the original waveform, a continuous signal sampled properly. With the unique collection of numerical values of samples the original waveform can be easily recreated.

4.4 Analog Interface:

For interaction of analog world with the microprocessor analog signal must be converted in to digital signal. The outputs of signal conditioner are applied to analog interface which include sample and hold (S/H) circuit, analog multiplexer and analog to digital converters.

4.4.1 Sample and hold circuit:

A sample and hold circuit is used to acquire the samples of the time varying analog signal and keep the instantaneous sampled values constant during the conversion period of ADC. An S/H circuit has two modes of operation namely sample mode and hold mode. When the logic input is high it is in sample mode, and the output follows the input with unity gain. When the logic input is low it is the hold mode and the output of the S/H circuit retains the last value it had until the command switches for the sample mode. The S/H circuit, is actually an operational amplifier which charges a capacitor during the sample mode and retain the value of the change of the capacitor during the hold mode.

4.4.2 Multiplexer:

A multiplexer has many input channels and only one output. It selects one out of multiple inputs and transfers it to a common output. Any input channel can be selected by sending proper commands to the multiplexer through the microprocessor. The analog multiplexer consists of an array of analog switches controlled with digital logic. The analog multiplexer uses the digital control logic to select a specific analog input and direct it to its output. In the generalized relay model of Figure 3.1, the analog multiplexer is applied to select one sample-and-hold output channel at a time for subsequent analog scaling and analog-to-digital conversion. During a sampling interval, the multiplexer brings all the sampled-and-held signals one at a time for analog-to digital conversion. The multiplexer is not relevant for modeling of numerical relays, because the multiplexer does not affect the analog inputs. For the purposes of this thesis, it is assumed that the multiplexing process is accomplished seamlessly.

4.4.3 Analog to digital converter:

Analog to digital (A/D) converters takes the instantaneous values (sampled) of the continuous time signal (analog).convert them to equivalent numerical values and provide the number as binary outputs that represent the analog signal at the instants of sampling. Thus, after quantization by the A/D converter, analog electrical signals are represented by discrete value of the samples taken at specified instant of time. The signals in the form of discrete numbers are processed by a relaying algorithm using numerical method.

4.5 Discrete Fourier Transform:

This is the technique for extracting the fundamental frequency components from the complex post fault relaying signals. The Discrete Fourier Transform (DFT) of a data sequence is used to evaluate the Fourier coefficients. In this technique, the fundamental Fourier sine and cosine coefficients are obtained by correlating the incoming data samples with the stored samples of reference fundamental sine and cosine waves respectively. The fundamental Fourier sine and cosine coefficients are respectively equal to the real and imaginary parts of the fundamental frequencies component. Using the DFT, the real and imaginary components of the fundamental frequency voltage and current phasors are calculated.

4.5.1 Mathematical expression:

The Discrete Fourier Transform (DFT) is used to evaluate the Fourier coefficients of N samples of x(t) taken at time t= 0, Ts, 2Ts, …..(N-1)Ts, where Ts= T/N is sampling interval. The DFT may be regarded as a discrete time signal processing technique for the evaluation of the Fourier coefficients. If a periodic function x(t) is sampled N times per period at the sampling interval of Ts. Then the N samples of x(t) from the data sequence xm, m= 0, 1, 2,…..(N-1).

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

$$C_{fk}=\frac{1}{N}\sum_{m=0}^{(N-1)} Xm * e^{\frac{-j2\pi km}{N}},\ k=0,\ 1,\ 2,...(N-1)\ldots\ldots(4.1)$$

The Fourier series of equation (3.1) allows k to be any integer.

The computation of Fourier coefficient by eq. (3.1) involves complex arithmetic which makes the computation difficult with a microprocessor. Therefore for microprocessor implementation of DFT, separate equations for real and imaginary parts are used, instead of using DFT equation in complex form.

Equation (3.1) can be written as follows.

$$C_{fk}= \frac{1}{N}\sum_{m=0}^{(N-1)} Xm(\cos\frac{2\pi km}{N} - j\sin\frac{2\pi km}{N})\text{.............}(4.2)$$

or $$\frac{1}{2}(a_k\text{-}jb_k)= \frac{1}{N}\sum_{m=0}^{(N-1)} Xm(\cos\frac{2\pi km}{N} - \sin\frac{2\pi km}{N}), \quad k= 0, 1, 2,\ldots.(N\text{-}1)$$

therefore

$$a_k = \frac{2}{N}\sum_{m=0}^{(N-1)} Xm\cos\frac{2\pi km}{N}, \qquad \text{....................}(4.3)$$

$$b_k= \frac{2}{N}\sum_{m=0}^{N-1} Xm\sin\frac{2\pi km}{N},\text{.................}(4.4)$$

where

k= 0, 1, 2,……….(N-1)

The DFT equation (3.3) and (3.4) can easily be implemented on microprocessors in order to obtain the Fourier coefficient corresponding to any frequency component.

4.6 Impedance calculation Algorithm:

The formula used in the relay for the calculation of the impedance of the line impedance has been given in the table and the proof for the formula has been given there after.

FAULT TYPE	FORMULA
AB	$\frac{Va - Vb}{Ia - Ib}$
BC	$\frac{Vb - Vc}{Ib - Ic}$

AC	$\frac{Va - Vc}{Ia - Ic}$
AG	$\frac{Va}{Ia + 3 * K0 * I0}$
BG	$\frac{Vb}{Ib + 3 * K0 * I0}$
CG	$\frac{Vc}{Ic + 3 * K0 * I0}$
ABC	$\frac{Va}{Ia}=\frac{Vb}{Ib}=\frac{Vc}{Ic}$

Table (4.1): formulas for calculation of impedance for various faults

Here A,B and C represent the three phases of the system

Where,

Va = phase-A voltage,

Vb = phase-B voltage,

Vc = phase-C voltage,

Ia = phase-A current,

Ib = phase-B current,

Ic = phase-C current,

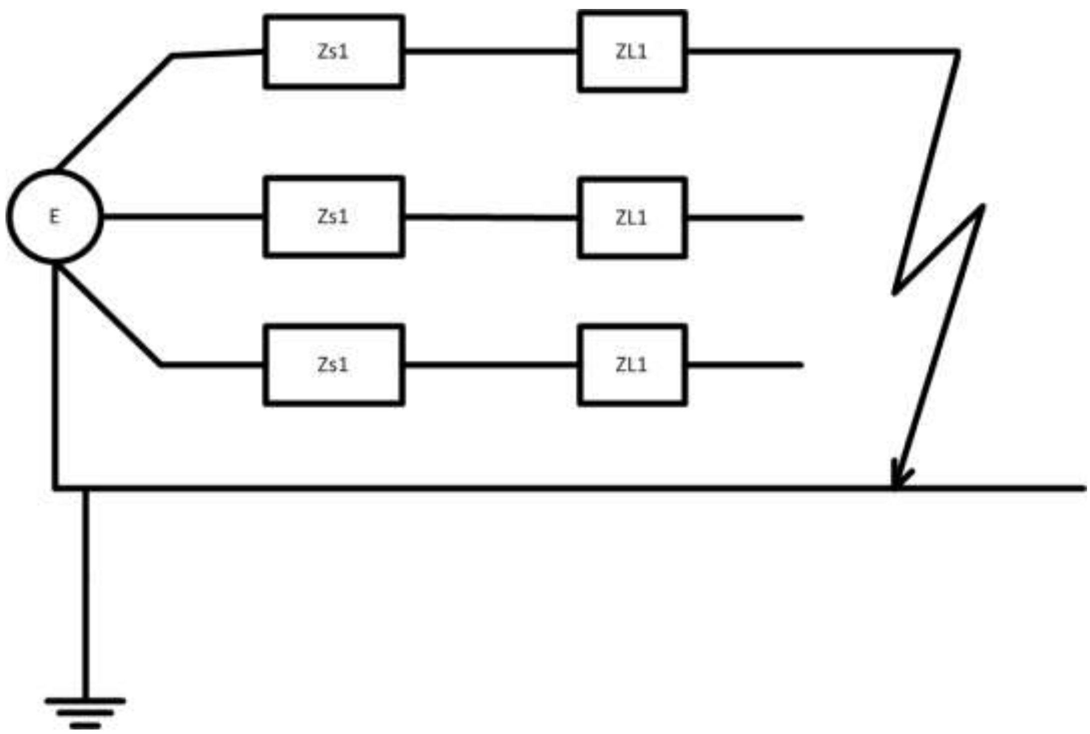
I0 = zero sequence current

$=\frac{Ia+Ib+Ic}{3}$,

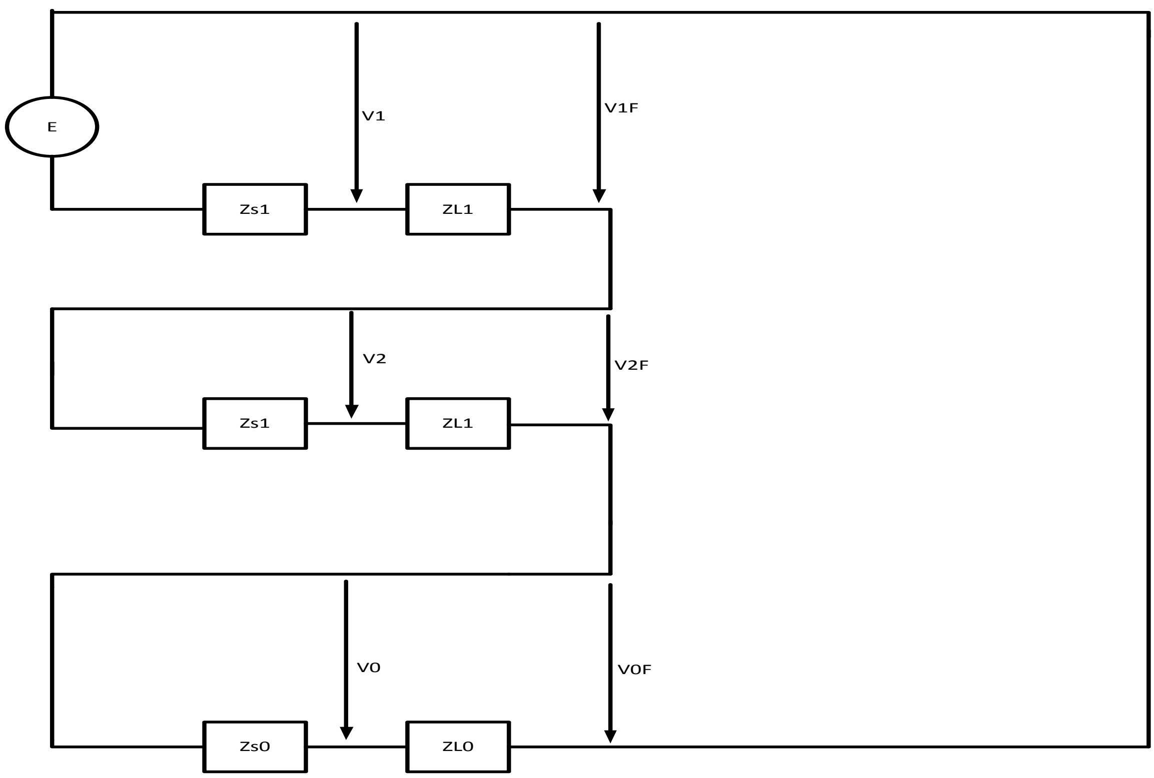
K0 = $\frac{Z1+Z0}{3*Z1}$,

Z0= zero sequence impedance,

Z1= positive sequence impedance,



Figure(a): single phase to ground fault



(b) Sequence network

Figure(4.5):Sequence-networks connection for a phase A-to-ground fault in a transmission line

From Figure 2.1(b), the voltage at the relay location *V*a can be calculated as follows:

$Va = V1 + V2 + V0$……………………… (2)

where,

V1 is the positive-sequence voltage at the relay location

V2 is the negative-sequence voltage at the relay location

V0 is the zero-sequence voltage at the relay location

The sequence voltages are equal to

$$V_1 = I_1 * Z_{L1} + V_{1F}$$
$$V_2 = I_{2*} Z_{L1} + V_{2F}$$
$$V_0 = I_0 * Z_{L0} + V_{0F}$$

Where

$I_1$is the positive-sequence current at the relay location

$I_2$is the negative-sequence current at the relay location

$I_0$is the zero-sequence current at the relay location

$Z_{L1}$is the positive-sequence impedance from the fault to the relay location

$Z_{L0}$is the zero-sequence impedance from the fault to the relay location

$V_{1F}$is the positive-sequence voltage at the fault location

$V_{2F}$is the negative-sequence voltage at the fault location

$V_{0F}$is the zero-sequence voltage at the fault location

Therefore,

$$V_a = I_1 Z_{L1} + I_2 Z_{L1} + I_0 Z_{L0} + (V_{1F} + V_{2F} + V_{0F})$$

But

$$V_{1F} + V_{2F} + V_{0F} = 0$$

Therefore

$$V_a = (I_1 + I_2) * Z_{L1} + I_0 Z_{L0}$$

$$= (I_1 + I_2 + I_0) Z_{L1} + (Z_{L0} - Z_{L1}) I_0$$

$$= (I_1 + I_2 + I_0) Z_{L1} + 3 I_{0*} \left(\frac{ZL0 - ZL1}{3} \right)$$

$$V_a = I_a Z_{L1} + 3 I_0 \left(\frac{ZL0 - ZL1}{3ZL1} \right) Z_{L1}$$

$$= I_a Z_{L1} + K_0 3 I_0 Z_{L1}$$

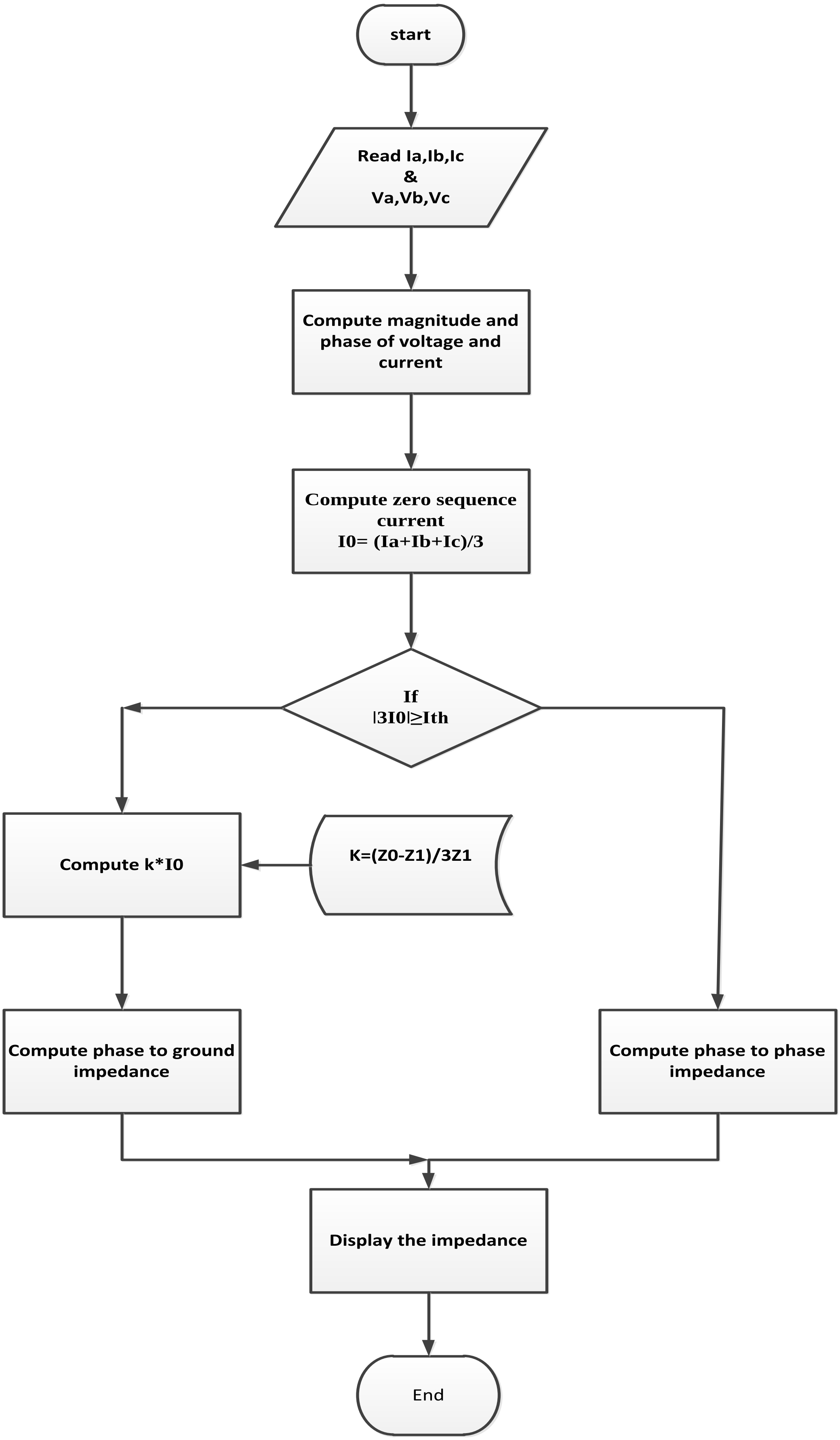
The compensated current $I_{a(comp)}$ can be defined as

$$I_{a(comp)} = I_a + K_0 3I_0$$

$$\frac{Va}{Ia(comp)} = Z_{L1}$$

Depending on the manner I_0 is provided to the relay, the K_0 factor may be expressed as

$$K_0 = \frac{ZL0 - ZL1}{3ZL1}$$



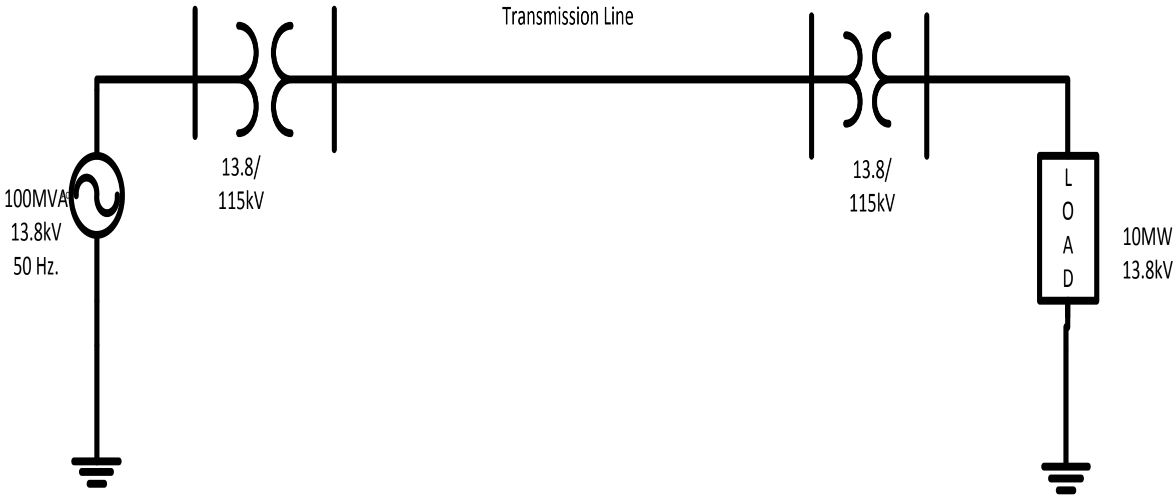
Figure(4.6): Flow chart for the impedance calculation

CHAPTER-5

SIMULATION AND RESULTS OF PROPOSED WORK

5.1 TRANSMISSION LINE MODEL SIMULATION:

The single line diagram of the developed power system is shown below



Figure(5.1): single line diagram of transmission line

The developed power system is designed by a 13.8 kV three phase generator, a 15 MVA transformer to increase the voltage level up to 115kV and a 100 km. transmission line. Again at load end a step down transformer of 15 MVA 115/13.8kV is used to reduce the voltage level back to 13.8kV to feed the 10MW load connected to the system. Measurement unit is provided at both end of the transmission line for sensing the current and the voltage. First we observe the changes in the voltage and the current wave form during fault condition and then we utilize the same knowledge for the formation of the relay model. Transformer used in this model is star/star connected.

Magnitude of various parameters in the simulation model:

Component	Parameter
Generator	V= 13.8 kV; f=50 Hz
Transformer	Voltage ratio=13.8/115 kV; S=15MVA
Line	Length =2*50 km; R=0.01273Ω/km ; L=0.9337e-3 H/km C= 12.74e-9 F/km
Load	10 MW

Table (5.1): values of transmission line parameter

From the parameters of the power system transmission line as given in the table (5.1) of this chapter the values of positive sequence resistance and positive sequence inductance are respectively-

$$R_1=0.01273\ \Omega/\text{Km}.$$

$$\text{And}\quad L_1= 0.9337\times10^{-3}\ \text{H/Km}.$$

Now, for 100 Km long Transmission Line the value of positive sequence reactance and resistance can be calculate as follow:

$$R_1' = .01273\times100$$

$$= 1.273\ \Omega$$

$$X_1= 2\pi\times502\pi\times50\times.9337\times10^{-3}\times100$$

$$= 29.33\ \Omega$$

Therefore the positive sequence impedance will be

$$Z_1= 1.273+j*29.33\ \Omega$$

$$Z_1= 29.36\angle 87.51^{O}\ \Omega$$

By using the values of zero sequence resistance and the zero sequence induction

$$R_0= 0.3868\ \Omega/\text{Km}$$

$$L_0= 4.1264\times10^{-3}\text{H/m}$$

Now

$$R_0= 0.3868\times100$$

$$R_0= 38.68\Omega$$

$$X_0= 2\pi\times50\times4.1264\times10^{-3}\times100$$

$$X_0= 129.63\ \Omega$$

So the zero sequence impedance would be

$$Z_0 = 38.68 + j*129.63\ \Omega$$

$$Z_0 = 135\angle 73.386^{O}\ \Omega$$

S. No.	**Transmission line parameter**	**Values**
1.	Length of transmission line	100 Km.
2.	Nominal frequency	50 Hz
3.	Line Resistance (R_1=R_2)	0.01273 Ω/Km.
4.	Line Inductance (L_1=L_2)	0.9337×10^{-3} H/Km.
5.	Line Capacitance (C_1=C_2)	12.74×10^{-9} F/km.
6.	Zero Sequence Resistance (R_0)	0.3868 Ω/km.
7.	Zero Sequence Inductance (L_0)	4.1264×10^{-3} H/km
8.	Zero Sequence Capacitance (C_0)	7.751×10^{-9} F/km.
9.	Total Positive Sequence Impedance (Z_1)	$29.36\angle 87.51^{O}$ Ω
10.	Total Zero Sequence Impedance (Z_0)	$135\angle 73.386^{O}$ Ω

Table (5.2): Transmission line parameter

The developed model of the above power system network has been shown below.

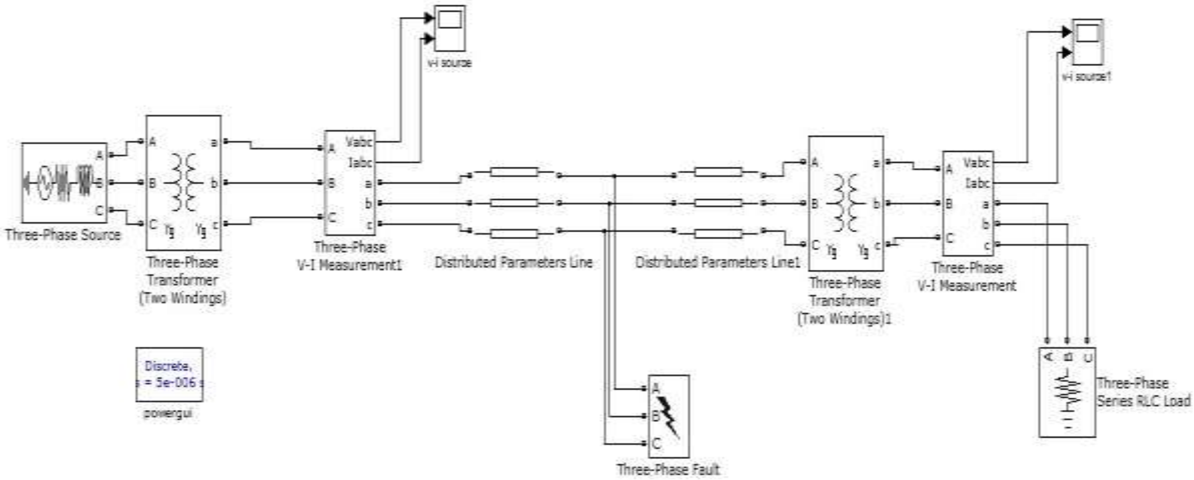


Figure (5.2): Model of transmission line developed in MATLAB-SIMULINK

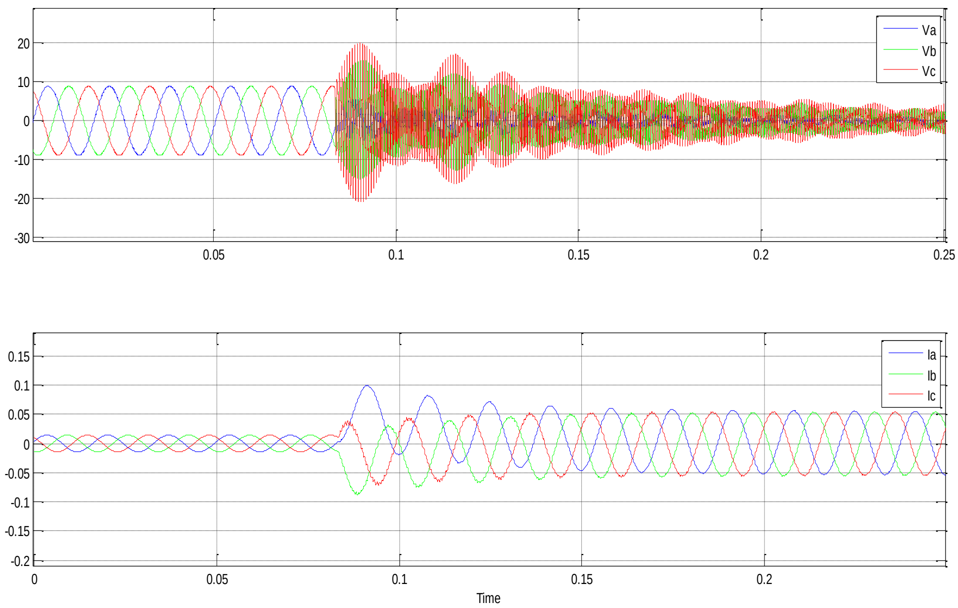


Figure (5.3): voltage and current wave form during 3-phase fault for fault resistance is equal to zero

From the simulation result it observed that during fault on the transmission line at a distance 50km. from sending end the voltage of the faulty phase will drop drastically and the current on the other hand will increase very high. The same concept will be used for the fault detection and fault calculation algorithm. Here fault resistance has been taken as zero.

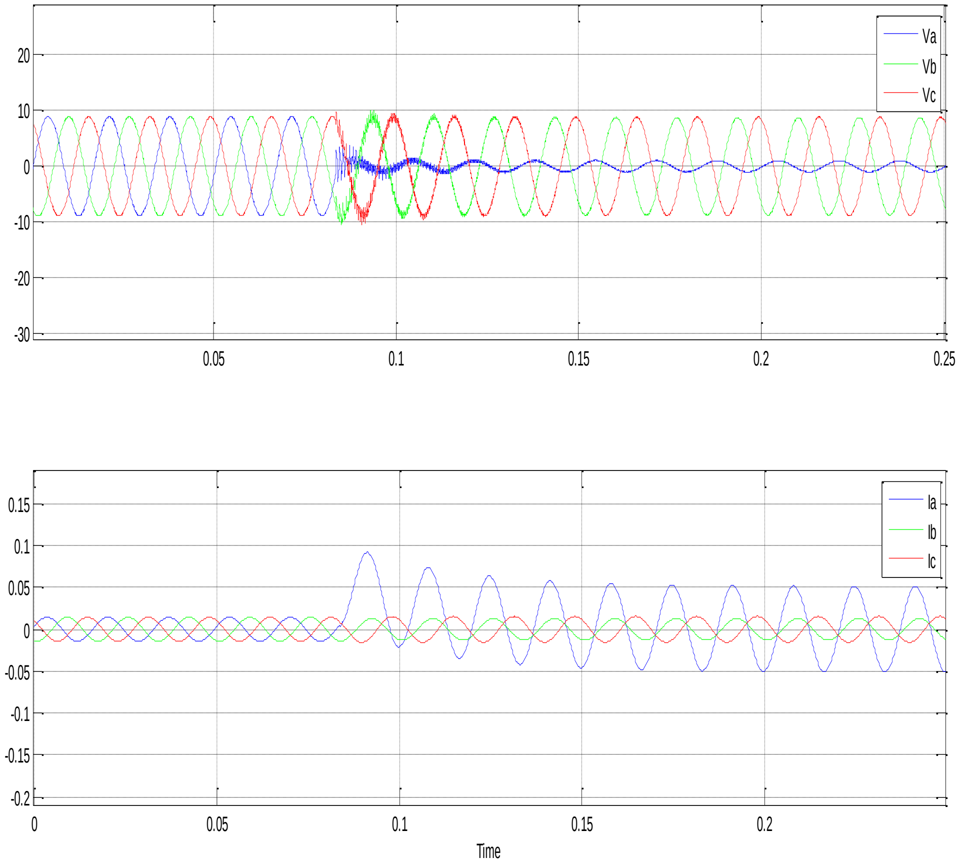


Figure (5.4): single phase fault and voltage and current wave-form for fault resistance equal to zero

From the wave diagram of voltage it is clear that it will contain harmonics and dc offset. For relay design we need to get rid of these unwanted quantities.

5.2 Relay Model:

The simulation model of relay has been designed by using discrete filter and discrete Fourier transform block available in the SIMULINK library. From the measurement block we provide the three phase voltage and current signal to the multiplexer to split the voltage and current signals in to three single phase voltages and currents. Then these quantities are passed through the discrete filter to avoid the higher order harmonics figure (5.5).

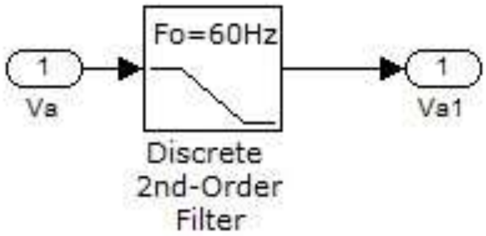


Figure (5.5): discrete second order filter cut-off frequency is set to 60 Hz.

Only fundamental frequency component of the signal are passed to the next block which is discrete Fourier transform block figure (5.6). Discrete Fourier transform due to its property eliminate the dc off-set from the signal.

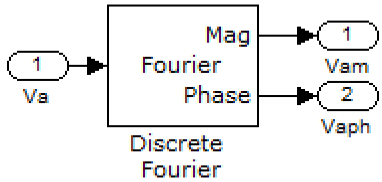
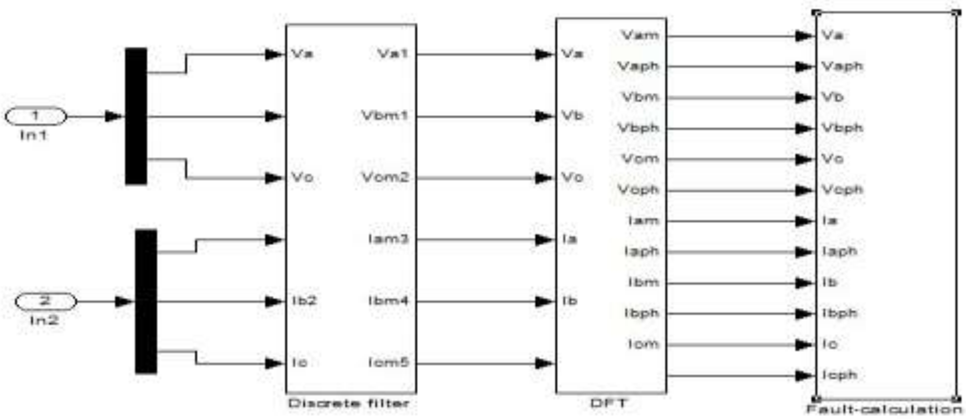


Figure (5.6): Discrete Fourier Transform block

From the output of the DFT block we get the magnitude and phase angle of the voltages and the currents. Once the magnitudes and phase of the currents and the voltages is known, now mathematical calculation model for various fault conditions has been developed. The overall developed model of the whole relay is shown in the figure (5.7).



Figure(5.7): Relay model designed in SIMULINK

5.2.1 Mathematical simulation model for impedance calculation in three phase fault (LLLG-fault):

The mathematical model for the calculation of impedance during three phase fault uses the mathematical formula given in the table in previous chapter. The designed model is shown below in figure (5.8). Here fault resistance Rf=10 ohm has been taken.

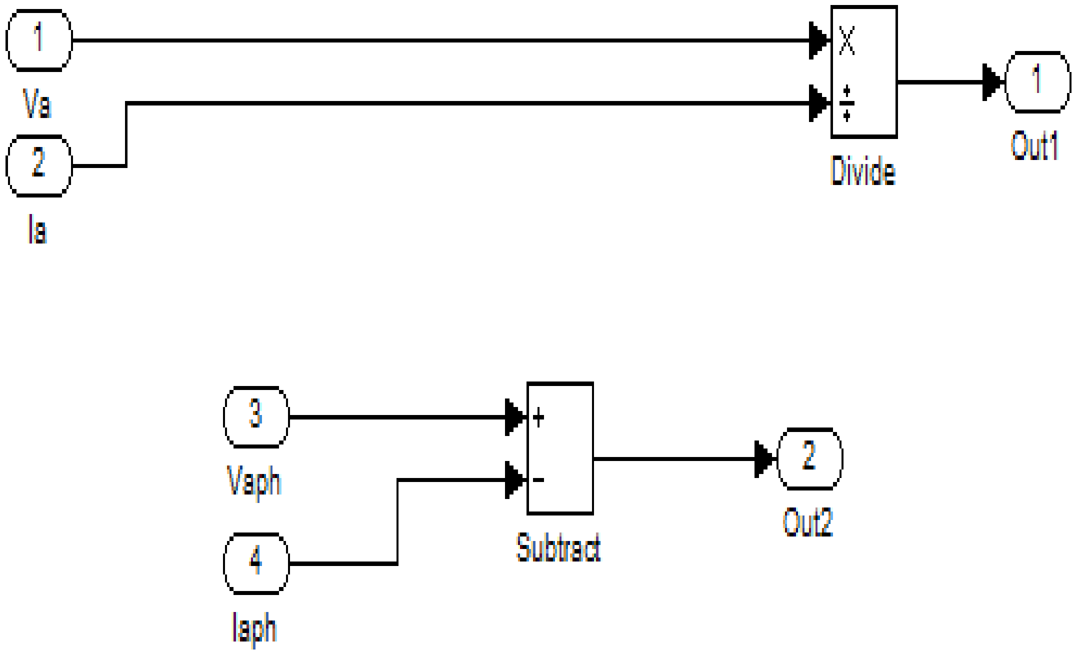


Figure (5.8): impedance calculation model for three phase fault

5.2.2 Result and R-X characteristic of relay for 3-phase fault

Faults in the system have been created in the model and the impedances for the various location of fault on the transmission line have been simulated and the result has been shown in the table below. Fault resistance is taken as 10 ohm.

S.No.	Distance of fault from relay location (Km.)	Measured impedance in polar form		Measured impedance in rectangular form in ohm.
		Magnitude of Z	Phase angle of Z in degree	
1.	10	10.46	16.1	10.05+j*2.9
2.	15	11.02	23.35	10.11+j*4.3677
3.	20	11.74	29.81	10.1865+j*5.836
4.	25	13.0	35.47	10.5874+j*7.5436
5.	30	13.54	40.36	10.317+j*8.7683
6.	35	14.58	44.59	10.3831+j*10.2356
7.	40	15.7	48.40	10.4564+j*11.7112
8.	45	16.86	51.39	10.5209+j*13.174
9.	50	18.08	54.13	10.5939+j*14.6511
10.	55	19.33	56.52	10.6634+j*16.1227
11.	60	20.61	58.61	10.7349+j*17.5936
12.	65	21.91	60.46	10.80+j*19.0619
13.	70	23.24	62.09	10.878+j*20.5368
14.	75	24.59	63.55	10.9528+j*22.016
15.	80	25.95	64.86	11.0243+j*23.4918
16.	85	27.32	66.03	11.0989+j*24.9638
17.	90	28.71	67.1	11.1717+j*26.4472
18.	95	30.11	68.06	11.2502+j*27.9293

Table (5.3): measured impedance by relay for different fault locations.

Now from the above calculated values of the transmission line impedance, R-X plot has been developed shown in the figure below.

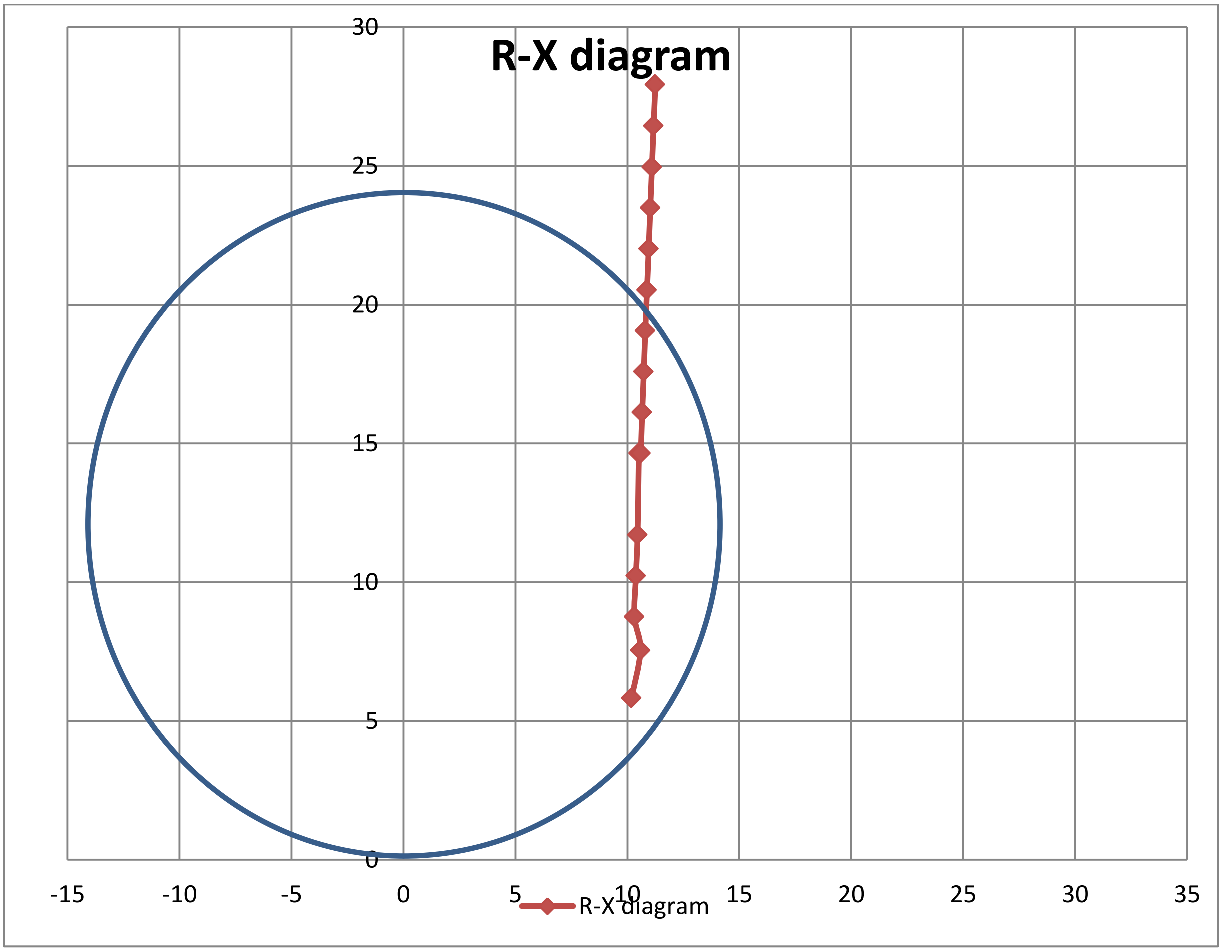


Figure (5.9): locus of impedance during three phase fault

5.2.3 Mathematical simulation model for impedance calculation in Line to Line fault (LL-fault):

The mathematical model for the calculation of impedance during line to line fault uses the mathematical formula given in the table in previous chapter. The designed model is shown below in figure (5.10).

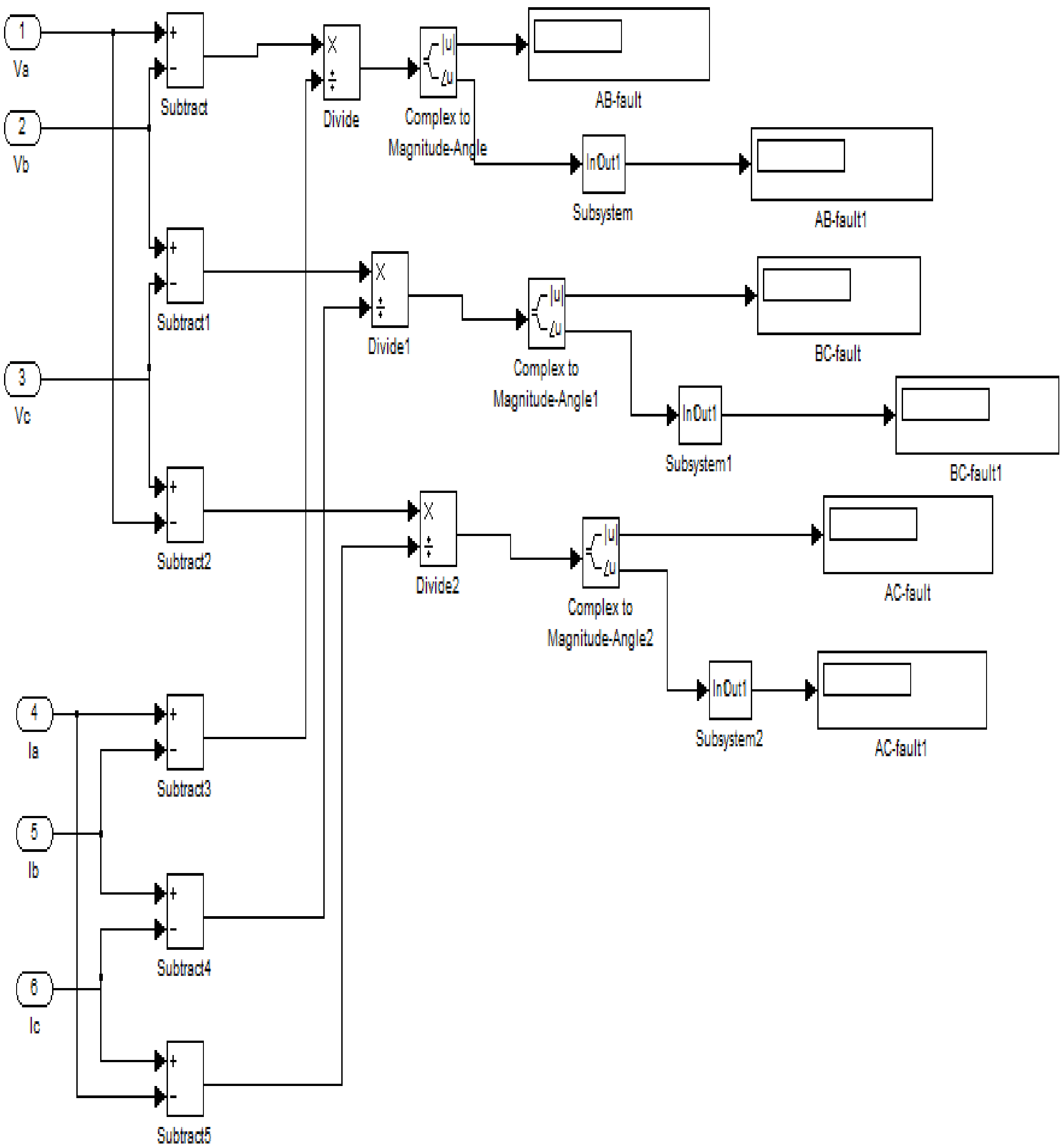


Figure (5.10): Mathematical simulated model for impedance calculation in Phase to Phase fault

5.2.4 Results and R-X characteristic of relay for phase to phase fault

As the model for the calculation of line impedance for phase to phase fault has been developed. Now we simulate the fault at various locations in the transmission line. And the relay will give the value of the impedance at all the condition.

S. No.	Distance of Fault From the relay location (Km.)	Measured impedance in rectangular form
1.	30	0.3765+j*8.8
2.	35	0.448+j*10.27
3.	40	0.5+j*11.74
4.	45	0.56+j*13.21
5.	50	0.6228+j*14.67
6.	55	0.6823+j*16.15
7.	60	0.7444+j*17.61
8.	65	0.807+j*19.092
9.	70	0.8689+j*20.56
10.	75	0.9315+j*22.04
11.	80	0.994+j*23.52
12.	85	1.0521+j*24.997
13.	90	1.114+j*26.47
14.	95	1.176+j*27.98

Table (5.4): Measured impedance by relay for different fault location

Now from the above data of the transmission line impedance, R-X plot has been developed shown in the figure (5.11) below.

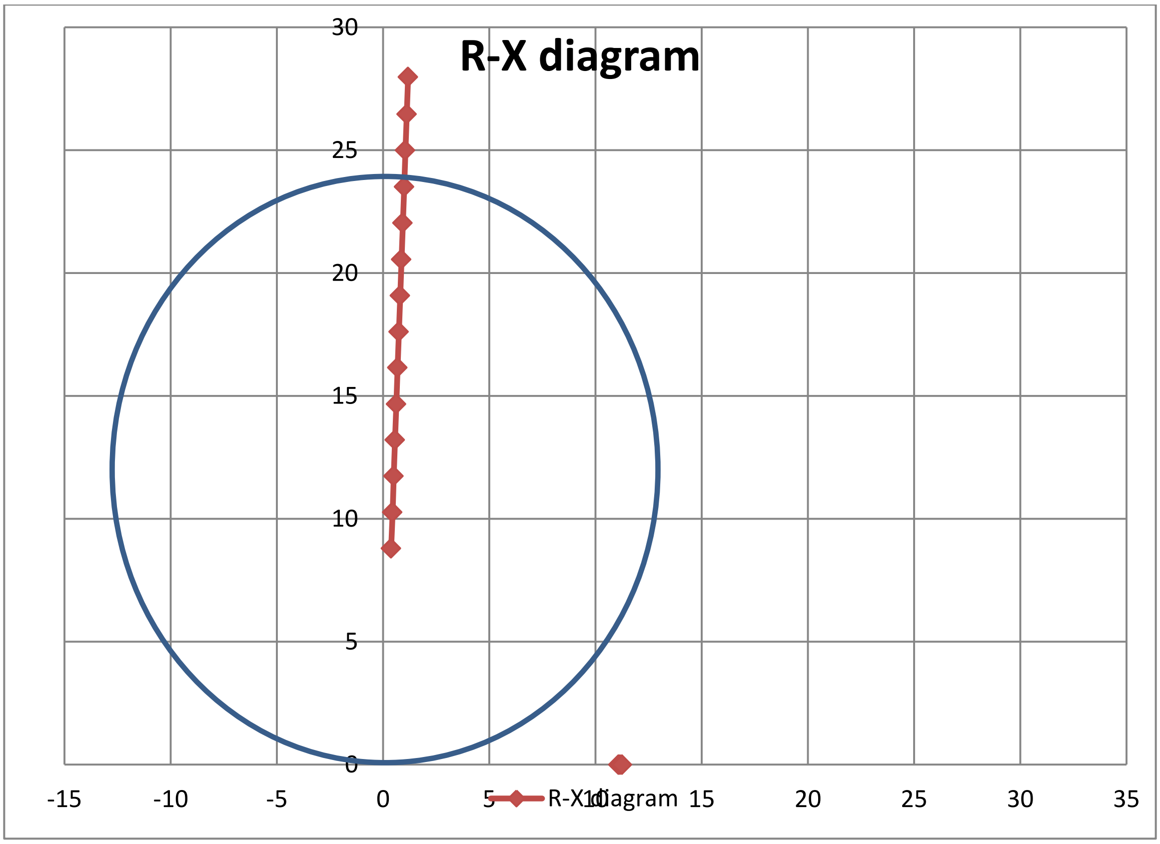


Figure (5.11): Locus of the impedance for phase to phase fault

From the above R-X characteristic of the relay the locus of the impedance for different fault location has been drawn and the characteristic of impedance relay verified.

5.2.5 Mathematical simulation model for impedance calculation in Line to ground fault (LG-fault):

For the completion this thesis work a mathematical calculation model for calculation of impedance for phase to ground fault have been developed as shown in the figure (5.12) below. The mathematical expression given in the table in previous section has been used for the modeling of the calculation block. For better working of the model an extra factor has been added. The designed model has been shown in the figure (5.12) below

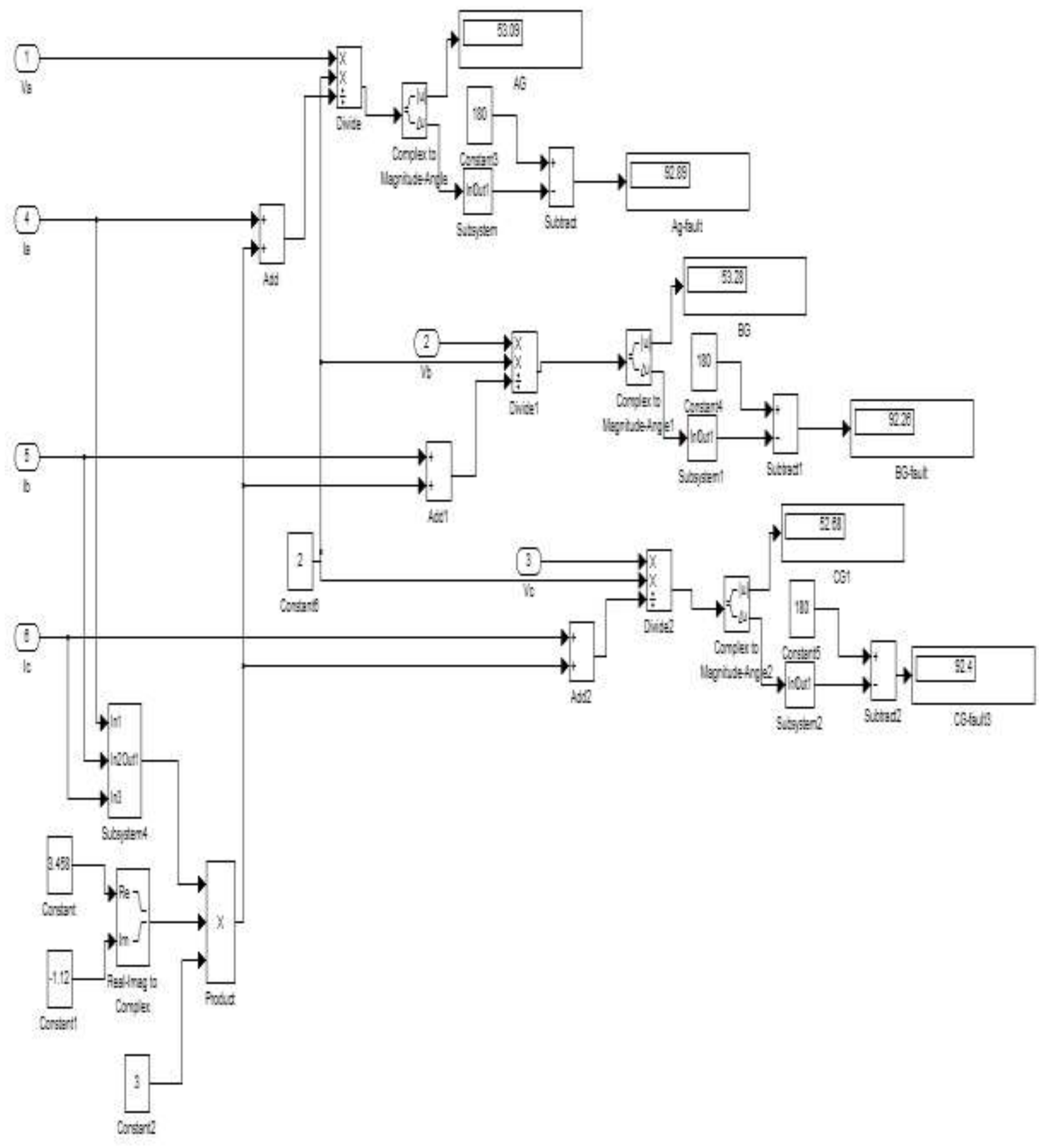


Figure (5.12): Mathematical model for impedance calculation in phase to ground fault

5.2.6 Results and R-X Characteristic of Relay for LG fault:

As the model for the calculation of line impedance for phase to ground fault has been developed. Now we simulate the fault at various locations in the transmission line. And the relay will give the value of the impedance at all the condition.

S. No.	Distance of Fault From the relay location (Km.)	Measured impedance in rectangular form
1.	15	0.3516+j*4.135
2.	20	0.479+j*5.51
3.	25	0.6237+j*6.879
4.	30	0.7477+j*8.248
5.	35	0.8885+j*9.615
6.	40	1.032+j*10.979
7.	45	1.182+j*12.34
8.	50	1.336+j*13.7
9.	55	1.5+j*15.06
10.	60	1.6588+j*16.416
11.	65	1.827+j*17.768
12.	70	1.999+j*19.122
13.	75	2.176+j*20.465
14.	80	2.362+j*21.81
15.	85	2.5487+j*23.16
16.	90	2.736+j*24.51

Table (5.5):Values of impedances for different fault locations

As we have got the values of impedances for various fault location we can now draw the R-X characteristic of the relay,Which has been shown below in figure (5.13)

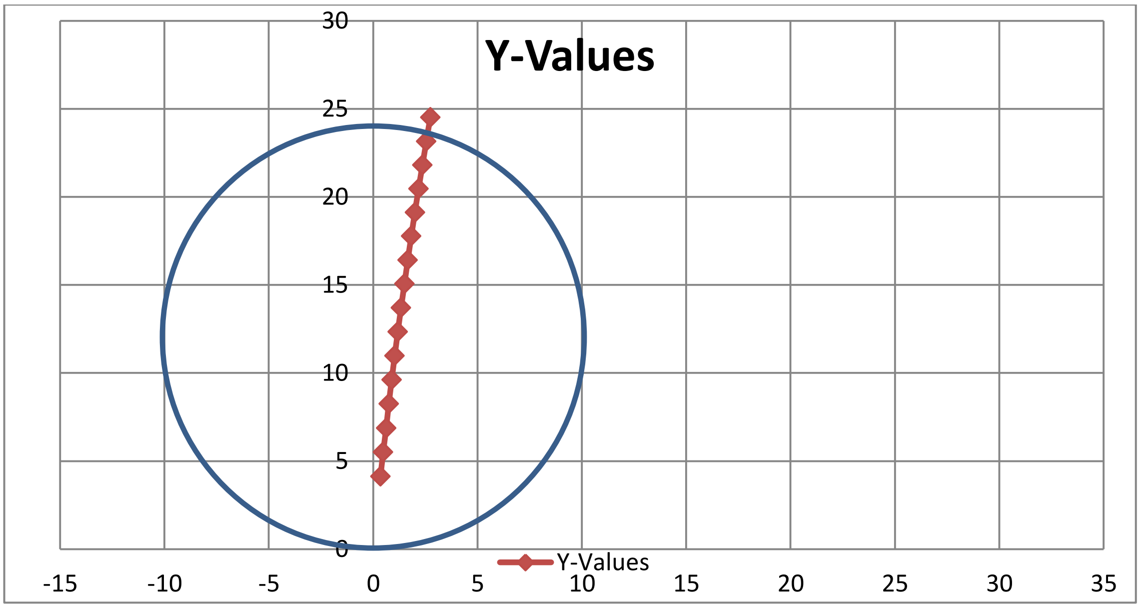


Figure (5.13): locus of impedance at various fault location

From the above R-X characteristic of the relay the locus of the impedance for different fault location has been drawn and the characteristic of impedance relay verified.

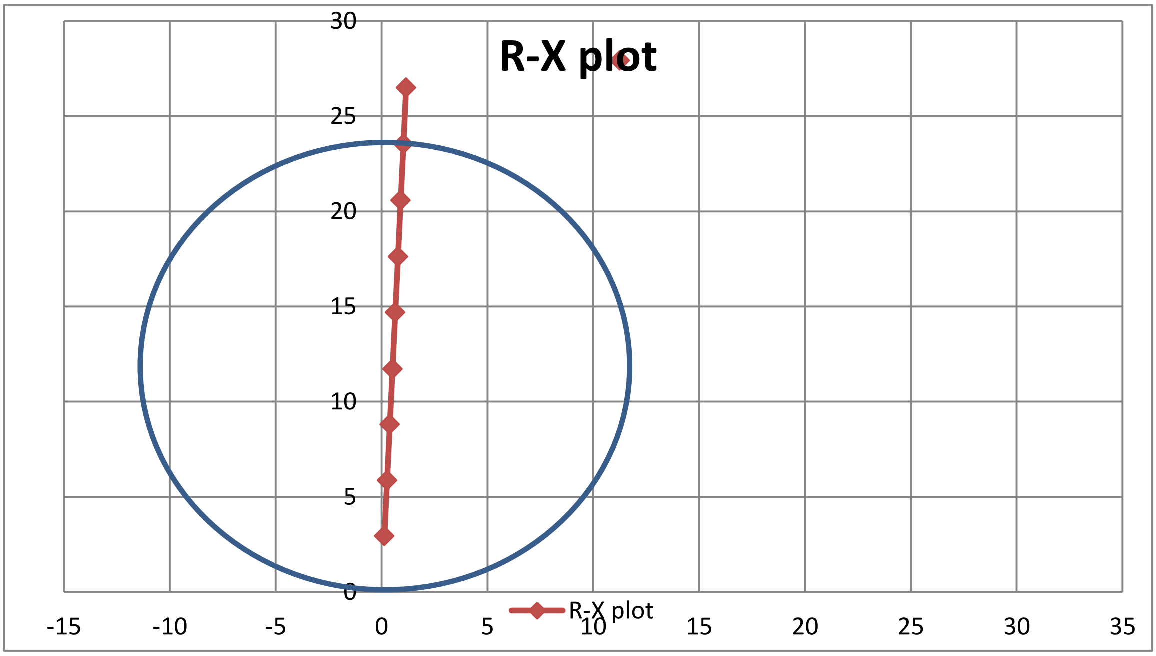
5.2.7 Results for Three phase fault with zero fault impedance:

In the designed model now I changed the fault setting with zero fault resistance and the impedance of the line has been calculated by the relay for the various location of three phase fault on the transmission line. For this condition also we use same mathematical model for impedance calculation. And the values of the impedance for various fault locations have been given in form of table given below.

S. No.	Distance of Fault From Relay Location(Km.)	Measured impedance in rectangular
1.	10	0.1373+j*2.9338

2.	20	0.264+j*5.867
3.	30	0.392+j*8.8033
4.	40	0.5207+j*11.73
5.	50	0.6488+j*14.6856
6.	60	0.7786+j*17.6228
7.	70	0.9053+j*20.57
8.	80	1.0354+j*23.527
9.	90	1.16+j*26.4945

Table (5.5): values of impedance for different fault locations



Figure(5.14): locus of impedance on R-X plot

5.2.8 Results and discussion:

From the transmission line parameter the magnitude of positive sequence impedance of the line is 29.36 Ω. For the 80% length of the transmission line is 23.488 Ω so for first zone a circle of diameter 23.488 unit passing through origin has been drawn on R-X diagram. Now if we observe the table of the measured impedances for three phase fault in table (5.4) and plot these points on R-X diagram, we can see that the locus of the impedance has just crossed the marginal value of set impedance at the circle itself. This can be observe in any of the fault discussed in the results and the compiled data and the R-X diagram that the locus of the impedance crosses the circle approximately at the fault located at 80 Km from the fault location.

Chapter-6

BRIEF CONCLUSION AND FUTURE SCOPE OF WORK

6.1 General

In this dissertation a distance relay has been designed in MATLAB-SIMULINK. And the results are obtained from the relay model by manually selecting fault type and the respective calculation algorithm, after the compilation of data for various faults the R-X diagram has been plotted and it has been observed that the relay is working properly.

6.2 Conclusion

In this thesis work the design and modeling of distance relay has been done, and a manual prototype has been developed using MATLAB-SIMULINK software package. From the data obtained from the various faults the R-X diagram for all types of faults have been drawn and it has been observed that the measurement of the impedance by the has been done properly. And the trajectories of the impedance data collected from the relay cuts the set impedance value circle at the fault produced at 80% length of the line from relay location on R-X diagram. From the R-X diagram it has been shown that the characteristic of the relay is as per the theoretical characteristic. When we observe the R-X diagram of the relay for various faults it is clear that when the fault is at 80 km. from the relay location the impedance calculation.

6.3 Future Scope of Work

The model designed here is intended for the calculation of the impedance of the line from relay location by manually selecting the proper algorithm for the fault on the hand which is already known to us. For further improvement of the relay a model can be develop with the designing of fault detection algorithm block, which can be design in such a way that not only it can detect the fault in the transmission line but also discriminate the type of fault existing in the system and accordingly it will select the suitable impedance calculation model for the calculation of the distance of the fault from the relay. Apart from that after the calculation of the impedance a decision making model can be developed using ‘if-else’ block-set available in the MATLAB-SIULINK library. Once the decision making block will be designed the relay can now be able to work automatically, which can detect the fault and discriminate the type of fault and after the calculation of impedance of line to the fault point from the relay location it will make sure that whether the fault occurred is within its reach or not and if the fault is in its protection range it will provide a trip signal for the circuit breaker.

REFERENCES

[1] MuhdHafiziIdris, Surya Hardi, Mohd. ZamriHasan, “Teaching Distance Relay Using MATLAB/SIMULINK Graphical User Interface”.

[2] Eng. Abdlmnam A. Abdlrahem, Dr. Hamid H Sherwali, “Modelling of Numerical Distance Relays using MATLAB”, IEEE Symposium on Industrial Electronics and Applications (ISIEA 2009), October 4-6, 2009.

[3] Omar G. Mrehel, Hassan B. Elfetori,AbdAllah O. Hawal, “Implementation and Evaluation a SIMULINK Model of a Distance Relay in MATLAB/SIMULINK”.

[4] Jyh-CherngGu, Sun-Li Yu, “Removal of DC Offset in Current and Voltage SignalsUsing a Novel Fourier Filter Algorithm”, IEEE Transactions on Power Delivery, Vol. 15, no. 1, January 2000.

[5]Li-Cheng Wu, Chih-Wen Liu, “Modeling and Testing of a Digital Distance Relay Using MATLAB/SIMULINK”.

[6] M.S. sachdev, R. Agarwal, “A Technique For Estimating Transmission Line Fault locations from digital impedance relay measurements”, IEEE Transactions on Power Delivery, Vol. 3, No. 1, pp. 121-129, 1988

[7] A.G. Phadke, M. Ibrahim, T. Hlibka, “Fundamental Basis For Distance Relaying With Symmetrical Components”, IEEE Transaction on Power Apparatus and System, Vol. PAS-96, no. 2, pp. 635-646, 1997

[8] P.G. McLaren, E.N. Dirks, R.P. Jayasinghe, I. Fernando, G.W. Swift, Z. Zhang, “An Accurate Software Model for Off-line Assessment of a Digital Relay” IEEE WESCANEX '95 PROCEEDINGS.

[9] M. Sreeram, P. Raja,“Implementation of DSP Based Numerical Three-Step Distance Protection Scheme for Transmission Lines”, 2013 Annual IEEE India Conference (INDICON).

[10] Sham M V, Dr. K P Vittal, “Development of DSP Based High Speed Numerical Distance Relay and its Evaluation Using Hardware in Loop Power System Simulator”, 2011 IEEE PES Innovative Smart Grid Technologies.

[11] T.S. Sidhu, M. Hfuda, M.S. Sachdev, “A Technique For Generating Software Models Of Microprocessor-Based Relay”.

[12] Tarlocha S. Sidhu, Mohamed. Hfuda, Mohindar S. Sachdev, “Generating Relay Model For Protection Studies”.

[13] M. H. Idris, M. W. Mustafa, Y. Yatim, “Effective Two-Terminal Single Line to Ground Fault Location Algorithm”. 2012 IEEE international Power Energy And Optimization Confrence.

[14] Christos A. Apostolopoulos, George N. Korres, “Real-time implementation of digital relay models using MATLAB/SIMULINK and RTDS”, EUROPEAN TRANSACTIONS ON ELECTRICAL POWER(2008).

[15]P. G. McLaren, K. Mustaphi, M. S. Sachdev, V. Skendzic, T. S. Sidhu, “Software Models for Relays” IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 16, NO. 2, 2001.

[16]Rashesh Mehta, BhuvaneshOza, Nirmal Kumar C Nair, and Manish Kumar, “Simulation of Numerical Distance Protection Through Senior Design Project”.

[17]P.G. McLaren SM, G.W. Swift SM, Z. Zhang, E. Dirks, R.P. Jayasinghe, I. Fernando, “A New Directional Element for Numerical Distance Relays”, IEEE Transactions on Power Delivery, Vol. 10, No. 2, pp. 666-675, 1995.

[18] Badri Ram, D. N. Vishwakarma, “Power System Protection and Switchgear” ISBN 0-07-107774-3 McGraw Hill, 2011

[19] “Network Protection & Automation Guide” - NEW Edition ALSTOM.

Appendices

The parameter of transmission line parameter which has been used for the modeling is

S. No.	**Transmission line parameter**	**values**
1.	Length of transmission line	100 Km.
2.	Nominal frequency	50 Hz
3.	Line Resistance (R_1=R_2)	0.01273 Ω/Km.
4.	Line Inductance (L_1=L_2)	0.9337×10^{-3} H/Km.
5.	Line Capacitance (C_1=C_2)	12.74×10^{-9} F/km.
6.	Zero Sequence Resistance (R_0)	0.3868 Ω/km.
7.	Zero Sequence Inductance (L_0)	4.1264×10^{-3} H/km
8.	Zero Sequence Capacitance (C_0)	7.751×10^{-9} F/km.
9.	Total Positive Sequence Impedance (Z_1)	$29.36\angle 87.51^{O}$ Ω
10.	Total Zero Sequence Impedance (Z_0)	$135\angle 73.386^{O}$ Ω

The value of K_0 factor from the transmission line parameter is given by ($3.636\angle -17.97^{O}$).