Implementation of Multifunction Relay for Three Zone Protection of Transmission Line

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CERTIFICATE

Certified that the dissertation entitled, **"IMPLEMENTATION OF MULTI FUNCTION RELAY FOR THREE ZONE PROTECTION OF TRANSMISSION LINE"**, which is being submitted by Manish Verma in fulfillment of the requirements for the award of the **Master of Engineering in Power Systems**, to Thapar University, Patiala, is a bona-fide record of the candidate's own work carried out by him under my supervision and guidance. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other university or institute for award of any degree.

Place: Patiala
Date: 15/07/16.

(Dr. Amrita Sinha)
Supervisor

DECLARATION

I hereby certify that the work which is presented in dissertation entitled, "**IMPLEMENTATION OF MULTI FUNCTION RELAY FOR THREE ZONE PROTECTION OF TRANSMISSION LINE**", in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Power Systems, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of **Dr. AMRITA SINHA**. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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ABBREVIATIONS

L-L	Line to Line
L-G	Line to Ground
L-L-G	Line to Line to ground
CT	Current Transformer
PT	Potential Transformer
ELD	Extra Long Distance

ABSTRACT

The multifunction relay includes quadrilateral relay, overcurrent relay, under/over voltage relay and under/over frequency relay and has been implemented at the generating end of a 5 bus system in Simulink. The three phase voltage and current signals have been sampled at 20 kHz for L-G, LL and LLG faults with varying distance, fault resistance and inception angle. The DC offset has been filtered from the current signal using full cycle window. The fundamental component of voltage and current signals has been extracted using FFT algorithm full cycle window. The fault resistance (R) and reactance (X) have been calculated using sine and cosine coefficients of voltages and currents for LG, LL and LLG faults. These values of R and X have been used for implementation of three zone protection scheme of transmission line. The effect of arc resistance and power swing on the quadrilateral relay has also been analyzed. The impedance seen by the relay has been calculated for location of the fault after its classification.

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OVERVIEW

1.1 Introduction

An electrical power system mainly consists of three parts namely generation, transmission and distribution. Generally power is generated at lower voltages which is further increased using a transformer and is fed into grid. A transmission grid can have different voltage levels in its path. Also the loads can be far away from the generation unit. Hence the power has to be transmitted along long distances. One of the key features of power system is that during steady state the whole system works at the same frequency irrespective of area.

The power system has different voltage levels at different locations which can be from 415V to 415kV and above. Various electrical devices can be enclosed like motors or placed in open e.g., transmission lines. While in operation any equipment can suffer from abnormalities. For example, a motor can get overloaded due to wear and tear of bearing. The transmission line can get short circuited due to falling of a tree, insulation failure can take place due to lightning, performance of transmission lines can degrade due to pollution causing breakdown. The system frequency may rise beyond the nominal value for which it is designed during which the alternator should be tripped to prevent any mechanical damage. Similarly, low frequency can be equally damaging for turbine.

In the light of above factors, it becomes necessary to install protection system not only for the safety of the equipment but also for human lives. On encountering any danger, the protection system must isolate the faulty equipment from the system in minimum time.

With the increasing flow of capital investment in power system for increasing power generation it becomes immensely important that proper precautions are taken for the safe operation along with good efficiency. Normally the electric current flows from generator to load via transmission lines and is confined to this path by insulation provided by various equipments. But sometimes this insulation might break due to various reasons highlighted above thus causing the current to flow through an abnormal path known as fault. During such conditions, the energy of the system gets consumed in destructive processes causing revenue losses, drop in voltage, current surges, damage to equipment, potential loss of lives. Although with good designing and high tech equipment most faults can be prevented but still nature can play havoc and lead to equipment failure. Table 1.1 shows the probability of different types of fault.

Table 1.1 Probability of different types of fault occurrence

Fault	Probability of occurrence.
Single line to ground fault	0.70
Line to line fault	0.15
Double line to ground fault	0.10
Line to line to line fault	0.02-0.03
Three line to ground fault	0.02-0.03

One of the most important equipment in protective system is the relay. The primary function of the relaying system is to select the proper circuit breaker that can isolate the faulted equipment from the system with minimum damage and time. One of the ideal cases would be that system could anticipate the fault and prevent it from happening but that is impossible unless the system generate some kind of signals which can operate the relaying system. Only a single type of relay comes under this category and that is gas detector relay which is used in transformer protection. For all other equipment the only possibility lays in isolating the equipment in minimum time and preventing the harmful effects on system.

A protective system consists of various equipments like relays, circuit breakers, transducers, CT, PT, etc. Relays make use various input parameters to take a decision about fault and send a trip signal to circuit breaker if it concludes that a fault has taken place. A Circuit Breaker on the other hand after receiving the activation signal from the relay immediately isolates the faulted section from the healthy system so that the remaining system continues to function normally. It is worth mentioning here that there is a proper organization of circuit breakers and it is the relaying system which identifies the fault zone and the sends a trip signal to the required circuit breaker [16]. Backup protection schemes are also applied in case the main relay fails to clear the unhealthy zone. But the backup protection relay isolates not only the unhealthy zone but also the healthy system connected to that unhealthy zone. Thus it is in the best interest that the primary relay acts correctly.

1.2 Essential qualities of Protection

The main requirements of a protection system are given below :

1. **Selectivity or Discrimination**

It is the quality of a relay to be able to distinguish between:-

1. a faulted and a healthy system
2. a fault and a transient condition occurring in power system like power surges, inrush current from transformer. Such transient conditions are often confused by the relaying system as a fault.

2. **Reliability**

It signifies the probability of relay not performing its function in its zone of protection during fault. The failure of the protective system can take place due to failure of various equipments like CT, PT, Circuit breaker, Battery, wiring, etc. For reliability, more attention must be given to the design, maintenance, installation and testing of different equipments of protective system. Robustness and Simplicity are another important factors contributing to reliability. Few other noticeable factors include proper contact pressure, prevention of contact contamination, and the contact material used with the relay.

3. **Sensitivity**

Every relay has a preset value of current above which it is supposed to operate. This preset current is also known as pick-up current. The relay must be sensitive enough to operate as soon as the current exceeds the pick-up current. The lowest and highest preset value should lie within the sensitivity of the relay.

4. **Stability**

The property of stability is concerned with relaying system's ability to stand against disturbances of high intensity and yet distinguishing them from faults. The relay should operate only for faults occurring within the zone of protection.

5. **Fast operation**

The operating time of a relay is the time taken by the relay from the time when the input signals to the relays exceed the pickup value to the moment when it sends signal to the circuit breaker. The time of operation for the protective system must not be more than the critical clearing time which could result in loss of synchronism.

1.3 Fundamental principles of protective relaying

Mainly there are two types of protective relaying that is “primary” relays which act immediately when the load occurs and the “backup” protection which acts in case the “primary” relay fails. Hence to avoid the long term damage to equipment and other property “backup” comes into play.

Further there various reasons for the failure of primary protection scheme which prevents it from isolating the faulted system. Some of failure which further effects primary protection is as follow:-

1. Current or voltage supply to the relaying system
2. Protective Relay
3. Circuit Breaker
4. Tripping mechanism
5. DC tripping

1.4 How protective Relays operate?

All relays works using the current and voltage data supplied to them by the current transformer and the voltage transformer which are connected to the equipment to be protected. Any change in the signals of current and voltage helps to determine the type of fault, its location and magnitude. The different types of fault have its own unique characteristics which may vary with the distance. In order to detect this distinctive behavior there are different relaying equipments available which catches that differences and acts accordingly [6].

Various parameters that shows differences to determine the characteristics of the fault are as follows:

1. Magnitude
2. Phase Difference

3. Duration
4. Frequency
5. Wave Shape
6. Rate of Change
7. Changed direction

1.5 Terminology of protective relay

1. Pick up value: This is the value of voltage or current above which the relay comes into action and commands the corresponding circuit breaker to isolate the faulted section. Hence the value acts like a threshold quantity which when exceeded brings relay into action.
2. Reset Level: Whenever the current or voltage level goes below the reset level, the relay opens its contact and resets itself.
3. Operating time of relay : This is the time taken by the relay from the instant when the voltage or current exceeds the pickup value to the point of time when the relay contacts are closed. For the protection purpose the operating time of relay should be minimum.
4. Reset time of relay: The time taken by the relay from the instant when the actuating quantity has fallen below pick up value to the instant when the relay resets itself to original position .
5. Reach of relay: This term often pronounced in distance relay protection where impedance is a function of distance between the relay and the fault point. This with the variation in fault distance the impedance varies and hence the impedance acts as the actuating quantity. Whenever the impedance calculated by the relay is than the pre specified distance the relay trips.

1.6 Protective Relays

Protective Relays have evolved a lot from ancient times. With advancement in technology and development of compact, precise, fast and accurate electronic products highly sophisticated protection system are being developed. The most ancient relays are the Electromechanical relays. They served the purpose of protection reliably well. But with more advancement, solid relays have taken over the electromechanical relays. One of the most pronounced inventions in the field of electronics is that of microprocessors. It has been employed in relays to perform all protective action. Such type of relays are known as numerical/adaptive relays .

1. Electromechanical Relays

Electromechanical Relays belongs to the earliest generation in the history of relays. They have been used in industry for many years owing to their reliability, accuracy and dependability. Two types of operating mechanisms of electromechanical relays include electromagnetic-attraction and electromagnetic-induction. The electromechanical relays work by using the principle of electromagnetic induction. In normal state the two types of forces that is controlling and actuating forces are balanced. Now when a fault occurs the actuating quantity becomes greater resulting in more electromagnetic forces which exceed controlling forces resulting in operation of relay. Such forces are pressing against the spring system inside relay. The electromechanical relays don't carry any intentional delay system within although it can be given if desired. Although electromechanical relays possess many advantages they also have several disadvantages which are mainly because of moving parts. Few of them are: low speed, ageing effect, bulky, chemical reaction with environment, high power consumption for various mechanisms, friction etc.

2. Static Relays

The static relays belong to the immediate next generation after electromechanical relays. They were made in an attempt to achieve better performance to that of electromechanical relays. In fact, they were successful to a great extant because of faster operating speed, more life time, low noise, more accurate. The major disadvantage lies in its lesser robustness.

3. Numerical Relay

Numerical relays are widely used these days. They acquire sampled data from the power system the data acquisition system. Then different algorithm are used to for the processing of data to determine the kind of fault that has occurred and send a trip signals. The numerical relays have become possible because of the technological development in the field of electronics especially VLSI, microcontrollers/microprocessors. The signals are send to the microcontroller. The microcontroller has all the required algorithm within itself to reach to some decision.

The main advantages of numerical relays include faster in operation, light in weight, precise, highly sensitive, and selective.

1.7 Literature Review

L. Mathew, *et al.* [1] analyzed one of the reason for black out in northern region of India in 2008 have been the improper setting of relay for zone 3 protection of transmission line. The third zone protection works as backup for the primary zones and if the limits not defined relay operation gets cascaded for present day power system structure.

In the report by PSRC WG D6 [2] analyzed power swing and out-of-step condition affects on protective relays. The method of islanding the power system into various self sufficient units has taken up by using PSB and OST technique. Also detailed study of the Power Swing Block (PSB) and Out of Step Trip(OST) has been done for its setting.

Bogdan KasztennY, Dale Finney [3] has discussed the basics of computing distance from one end of the system to fault and the method of comparing amplitude and phase for implementation of distance relay. Many critical issues concerned with the distance relays has been studied that includes determining the characteristics of a relay, fault resistance impact during a fault, effect of compensation of transmission line.

Kamalesh Kumar Sharma [4] proposed two filtering techniques. The post fault voltage/current signals for transmission line contain DC offset and harmonic components along with the fundamental component. Two filtering techniques for removing DC offset and sub synchronous resonance terms from the voltage/current signals have been shown. The second technique using samples taken from random positions have been concluded to be faster.

In [5] the sampled values of current and voltage signals have been used to evaluate the real and imaginary elements of fundamental frequency phasor. Many techniques have been proposed for computing Fundamental components that includes FFT full wave and half wave, Walsh Hadamard transform, Fourier Walsh technique.

Abderrahamane Ouadiand Hamid Bentarzi [6] proposed the algorithm for quadrilateral distance protection function implementation into DSP Kit in [6]. The relay so developed has been tested for various conditions in MATLAB/Simulink. The outcome of the implementation meets the expectation and satisfies the principles of working of distance relay protection.

Harikrishna M. [7] proposed the Quadrilateral relay design and implementation on Bergeron model type transmission line using PSCAD software for different fault resistances. The suitability of quadrilateral relay has been highlighted [7]. The protection of transmission line during L-G fault has been shown using quadrilateral relay. The setting of quadrilateral relay can be done easily which makes it highly suitable for faults involving high resistance and also minimizes the over/under reach trouble.

Kiran Shrivastava, D. N. Vishwakarma [8] proposed the implementation of quadrilateral relay using the 8097 microcontroller. The technique used for evaluating the fundamental components of voltage and current fro the post fault is block pulse method. The fundamental components are used to compute to the apparent impedance which is used to check whether the fault lies within the protection zone or outside it. If the fault is within the zone , tripping signal is given.

Jyh-Cherng Gu, Sun-Li Yu [9] proposed a novel method of extracting fundamental frequency components after removal of DC offset. The DFT method is good for getting fundamental components but there are many other elements in the post fault signal DC offset, subsynchronous resonance. These elements generate errors in evaluating fundamental components. The novel technique with full cycle consumes a cycle and two samples for computation while half cycle technique requires half cycle and two samples for computation..

Jyh-Cherng Gu, Kun-Yuan Shen *et al* [10] suggested the computation of fundamental components of voltage and current using the Fourier filter technique. The method is found to be highly accurate and converging. Before applying this elimination of dc offset from post fault signal is done but the novelty of the technique propsed here is that it can remove all such components.

Hector J. Altuve F., *et al* [11] analyzed various techniques of filtering the post fault signal and made a comparative study of those methods. The paper provides ample information about various methods used in distance relay protection. The main focus lies on the Fourier and Walsh transform method. The paper also evaluates the recent sine-cosine technique.

lsaksson [12] proposed the least squares digital protection technique. The RLS method has been used for the inference of current ad voltage. The RLS is found to be very reliable technique for the implementation of protective scheme.

Gabriel Benmouyal [13] studied the performance various filtering techniques for DC offset removal. The mimic filtering method successfully suppressed the DC offsets in the post fault waveform for a large array of time constants. The least square technique of filtering was evaluated to be poor in performance.The performance of filtering techniques improve when DC offset is modeled as a constant along with a decaying ramp rather than as a exponentially decaying function. Kalman filters of third order could be concluded to be highly responsive to DC offset.

S.A. Soliman, R.A. Alammari, *et al* [14] proposed the application of Park's transformation for computing the fundamental components from the post fault signals. For its application, the sampling frequency and and the signal frequency should be well-known in advance. The technique was successfully tested with various degree of distortion.

Kuo-Hsiung Tseng, Wen-Shiow Kao, *et al* [15] studied the load model effects by taking a taipower transmission model for the distance relays. The variation of impedance value against three zones of protection along with its effect on the impedance angle was described. The power swing on distance relays has also been studied. The blocking time in case of power swings was also analyzed. The paper proposes a new load model for better accuracy in distance relay.

Li-Cheng Wu, Chih-Wen Liu, *et al* [16] proposed the method of implementing the distance relays on transmission line using MATLAB/SIMULINK. The modeling and testing of relay was also done in MATLAB. The algorithm of the digital distance relay was mainly tested on a 345 kV, 100km transmission line in MATLAB. The paper also describes the principle of working of the distance relays.

Z. Y. Xu *et al* [17] suggested a new model for the implementation of the distance relay and measurement of impedance. The system used for the implementation is 1000kV, 645 km UHV line by taking various elements into consideration like shunt reactors. The whole model was tested in Real Time dynamic System which showed improved performance of distance relay.

Muhd Hafizi Idris *et al* [18] proposed making a simple model of distance relay using MATLAB/SIMULINK for the teaching purpose. With this model distance relays can be vividly explained in the class.

D.L. Waikar , S. Elangovan *et al* [19] described a real time distance relay protection using INTEL 8097 microcontroller. The system works using the fault distance estimation algorithm for the symmetrical faults. The designed system worked well for the first zone of protection of the transmission line under protection.

Zhijun Gan, S. Elangovan, *et al* [20] designed overcurrent (directional and non-directional) relay for ground faults for the three phase system using INTEL 8096BH. The sampling rate was kept around 12 samples per cycle. The fundamental frequency was extracted using the Fast Fourier Transform.

G. Gangadharan,P, Anbalagan [21] designed quadrilateral relay using the microcontroller. The fundamental frequency element of voltage and current was extracted using the fast fourier transform technique. The designed quadrilateral relay was successfully tested for three zone protection. 16- Bit have been recommended for faster processing.

M. Vichitchot, Adel A. Ghandakly [22] designed an impedance relay using five INTEL MCS-96 which is a 16bit microcontroller. The developed model isolated the faulted region within 20 ms thus displaying the desired speed and accuracy. A practical example of co-generating plant has also been discussed.

A. Rafa, S. Mahmod, *et al* [23] proposed implementation of microcontroller for the protection of transformer. The system successfully discriminates between an actual internal fault and the magnetizing inrush current. The system also implemented protection from over current, over voltage, and under voltage.

G. Ramarao, Sateesh K Telagamsetti *et al* [24] proposed implementation of multi functional relay using ATMega328 microcontroller. The simulations were carried out in Proteus eight and testing was done in microcontroller. The relaying system could protect the system from the over current and over voltage.

S. Jamali, and H. Shateri [25] studied the variation of earth fault resistance for distance relay. The paper concluded the maximum variation that a distance relay could bear. The boundary value of fault resistance has been used to determine the robustness of the quadrilateral relay.

S.G. Srivani, Panduranga Vittal K, *et al* [26] proposed the protection of parallel transmission lines considered with mutual coupling through adaptive distance relay. The three zone directional quadrilateral characteristics have been developed as the distance relaying system. The zero sequence current have been used to compensate the mutual coupling effect.

Junyu Han, Peter A Crossley [27] proposed a hybrid relay method which added the features of a quadrilateral relay to a travelling wave fault locator. The new technology is useful for overhead and underground transmission line. When a fault occurs at the junction of transmission line and underground cable, the quadrilateral is not able to function properly. This is where travelling wave fault locator comes into picture and isolates the faulty section.

1.8 Scope of Work

The nature of work on relays has wide range of scope in power system protection. The relays can be designed with different algorithms and implementation can be done in many ways. For the protection of transmission line, distance relays are quite pronounced. Out of many distance relays, the focus has been on quadrilateral relay. Also overcurrent relay, over/under frequency relay has been implemented. In fact once voltage and current data is received most of the relays can be implemented.

1.9 Aim and Objectives of Thesis

The three main objectives of this work are

- Fault Simulation of transmission line and acquisition of three phase voltage and current.
- Removal of dc offset and extracting of fundamental component of for effect of power swing and arc resistance.
- Implementation of quadrilateral relay for 3 zone protection of transmission line faults identification, classification and its location.
- Multi function relay implementation for overcurrent, over/under frequency, protection of transmission line using voltage and current signals.

1.10 Organization of Thesis

This thesis is subdivided into 6 chapters

Chapter 1: Overview of protection system and literature review

Chapter 2: Discussion about Protection schemes of transmission line

Chapter 3: Implementation of Multi Function Relay has been done

Chapter 4: Modeling of 5-bus test system and simulation of different types of faults in the transmission line, power swing and frequency changes have been done.

Chapter 5 : Implementation of Multifunction Relay including Quadrilateral relay, overcurrent relay, under/over frequency relay, under/over voltage relay.

Chapter 6: Conclusion and future scope of work has been discussed.

CHAPTER-2

PROTECTION OF TRANSMISSION LINES

2.1 Distance Relays

The transmission lines are generally protected by the distance relays whether they are medium or long lines. Distance protective system is a non unit system with many advantages on technical side as well as economically. The overcurrent protection suffers from problems with the variation in impedance of source. On the other hand distance relays' performance does not hamper due to such factors hence they are preferred. Distance relays are easier to apply in comparing to other relays and the operating time is lesser for the faults occurring on the line under protection. A single unit of distance relays is sufficient to provide the primary as well back up protection. The most important feature of distance is that the location of fault can be determined on transmission line. Thus it is one of the most preferred relay for transmission lines under critical condition.

There are many different algorithms used in these relays, but commonly used one is to measure the positive sequence impedance from the relay to the fault. When full fault protection is provided by the distance relaying, six elements are required, phase element A-B, B-C, C-A and ground elements A-G, B-G, C-G.

The system backup protection is generally done by a phase distance relay and by ground distance. In order to limit the impact of ground fault, the generators are generally grounded. On grounding a generator solidly and connecting to a distribution system directly or through a Y-Y transformer, superior fault sensitivity and economy is given by overcurrent ground relays when compared to ground distance relays. Overcurrent ground relaying is applicable because generator ground faults do not decay to values less than full load current and ground overcurrent relays are not subject to setting limitations due to load current.

Similarly, when connecting a generator to the system through a Δ-Y grounded transformer, backup ground protection is required by a time overcurrent ground relay which is connected in the neutral of transformer.

2.2 Working of distance relays

The impedance of a line transmitting power is directly proportional to its length. This fact is used by the distance relays which measure the impedance of the line from relay point to the desired point on the line. The distance relays are relays are good in making discrimination for the faults. The faults occurring between the relay point and the reach point are only taken into purview of distance relay. Any fault occurring outside the reach point is neglected.

The working principle of the distance relays involves getting the measured values of voltage and current and dividing voltage by current. This results in computation of the apparent impedance which is compared with the actual impedance of the reach point from the relay point. In case the apparent impedance is less than the actual impedance, it can be concluded that a fault has fault within the region to be protected and a trip signal is given to the circuit breaker.

The point along the transmission line whose impedance is intersected by the boundary condition of relay is known as the reach point of the distance of the distance relay. The reach point can be easily plotted on the R-X axis as it depends on the values of the voltage and current and the phase angle between the two. The loci of the apparent impedance can be drawn on R-X diagram and the fault effects can be analyzed. Also other effects can be studied like power swings, sudden removal or addition of loads.

2.3 Relay performance

The two main parameters for analyzing the performance of relay are accuracy of reach point and the speed of operation. The accuracy of reach point signifies the difference between the apparent impedance and the actual impedance from the relay point to the reach point. The lesser the difference, the better is the accuracy. It depends on several factors like the voltage measured by the system after occurrence of the fault, the techniques used for the calculation of the apparent impedance and the actual impedance.

The time of operation depends on many factors which includes the current after fault occurrence, the position of the fault from the relay location, the point of time on the voltage wave where the fault occurs and the algorithm applied for the apparent impedance calculation. The algorithm used can get affected by the errors occurring due to saturation of CTs, faults occurring near the reach point. But the digital relays popular these days show least affect due to above variations.

2.4 Characteristics of Distance Relay

The distance relays measure the fault impedance and compare it with the boundary condition to make a decision for tripping. The traditional relays either compared phase angle or magnitude of the signals. Thus they could only have straight line or circular characteristics on R-X axis. But with development of more sophisticated technology and challenges of cost, numerical relays are fast replacing the traditional relays. There are many different techniques for phase distance measurement. The self polarized distance elements technique is mentioned below. It is so called because the polarizing voltage is taken from the same phases as the current.

Table 2.1 Impedance Calculation

Fault	***Equation***
A-G	Va/Ia
B-G	Vb/Ib
C-G	Vc/Ic
A-B	[Va-Vb]/[Ia-Ib]
B-C	[Vb-Vc]/[Ib-Ic]
C-A	[Vc-Va]/[Ic-Ia]

2.5 Comparison of amplitude and phase

The two parameters that used to be compared by the relays were phase and amplitude. Even these days such traditional relays are at some parts of the power system. But they are fast losing to numerical relays. The impedance relays, the measured data of voltage and current is made use of. Several methods are available for making the comparison. For the electromagnetic relays, amplitude comparison is made using the balanced beam method and for the comparison of the phase induction cup method is used. In static distance relays op-amps are used along with diodes. For digital relays sequence comparators are used while for the numerical relays several algorithms have been proposed.

2.6 Plain type impedance characteristic

This type of impedance characteristics are called plain because the phase angle between the two main quantities is not used in relay. As a result, when plain impedance characteristics are plotted on a R-X diagram it comes out to be a circle with its centre at the origin and radius of circle equal to the pre defined impedance. For any point lying within the circle after the fault occurrence, the relays treats it as a fault and send the tripping signal. Such relays can be directional as well as non- directional. The non- directional relays looks for fault in both the directions of the circle that is positive as well as negative direction while the directional relays can be set as per the requirement or as a default they watch out for fault point only in the positive direction.

Some of the characteristics of the non directional relay :

1) Looks for fault in both the directions of the relay
2) Irregular fault resistance
3) It is inclined to be affected by the sudden changes in the power system like removal or addition of heavy load, power swings due to large coverage area.

Due to above reason it can be concluded that the directional property should be given to the relays to make a accurate and fast decision about the faults. This becomes possible with the addition of directional elements. The characteristics of directional relays are a semi circle.

2.7 Problems with distance relays

Distance relays suffer from many different problems. But with the digitization of relays most of these have been eradicated.

1. **Relay terminal voltage**

The distance relays provides erroneous reach point if in case it is not using voltage memory method and thus needs to maintain a minimum voltage. If this required voltage is not maintained, the accuracy of relays decreases.

2. **Minimum length of line**

Before bringing distance relay into it must be ensured that the minimum voltage which the relay might touch during fault must be within its sensitivity range. Also the line impedance must be within the range of the zone1 as programmed for the relay. Earlier these two problems were common with the distance relays especially for the short transmission lines where the ohmic impedance of line is very low due to short length. But with the advancement of numerical relays, all kinds of line can be protected because of high ranges.

3. **Under reach**

It is condition in distance which happens when the apparent impedance computed by the relay is more than the actual than that of actual impedance. The reason behind this phenomenon is the in feed of the current taking place at bus bars which are remotely present.

Thus under reach can be stated as :

$$\frac{R_S - R_A}{R_S} \times 100\%$$

where :

R_S = Relay setting reach point

R_A = Actual reach point as calculated

4. **Over reach**

Over reach is a condition in distance relays which occurs when apparent impedance computed by the relay is less than that of actual impedance. This phenomenon occurs when the relay is deployed on parallel lines with one of the many line getting isolated due to various reasons.

$$\frac{R_A - R_S}{R_S} \times 100\%$$

where :

R_S = Relay setting reach point

R_A = Actual reach point as calculated

5. **Forward reach limits**

Strict limits needs to be implemented on the maximum impedance reach settings of the different zones. If they are not accurately implemented the impedance from one zone may enter into zone 2 which can result in erroneous operation. But again with advancement in numerical relays such problems have considerably declined.

6. **Power swing blocking**

One of the major problems with the relays is that of power swings. The power swings occur when sudden change in internal voltage of the alternators takes place. In fact the system experiences swings even after a fault and immediate isolation of the faulted region.

The power swings bring changes in the apparent impedance seen by the relay. This change is often misinterpreted as a fault and tripping signal is sent to the circuit breaker. As a result of that, unnecessary discontinuity in power supply takes place. To avoid such situation the relays are often associated with the power swing blocking facility. The system should be tripped fro only those swings which are that are heavy in nature as explained earlier. The quadrilateral relay are one of the best in among distance relays as it is least affected by the power swings.

2.8 Zones of protection

The three zone protection scheme is used for the primary and backup protection of the transmission lines. It is because for the transmission little delay in clearing is tolerable and immediate high speed isolation is not required to maintain stability. Distance relays are least affected by the power swings due variation in generation of power or sudden removal of load. Hence distance relays are preferred over other types of relays for operation in transmission lines.
One of the primary advantages of the distance relays is that the reach point can be easily modified which implies that the fault between the relay and the reach point will only be taken into consideration. The faults beyond the reach are not taken into consideration. The distance relay calculates impedance of the transmission lines from the relay to the reach point. This forms the major reason for their use in the transmission lines for most of the times.

The voltages and currents are measured by the phase and ground distance relays at one end where relay is planted and impedance is computed between the two points. The zone scheme of protection is discussed below:

Zone 1

Generally there are three zones of protection in step distance protection method. This scheme of protection becomes possible mainly due to convenient setting of the reach point and the tripping time setting for the three zones. Zone 1 covers 80-85 % of the line to be protected. It carries no intentional delay to act instantaneously. The 15-20 % of the transmission line left kept out of the first zone of protection to avoid overreaching for faults beyond the protected line which could disturb the protective system on the adjacent line. Such overreaching can occur due to errors in the instrument transformer, fallacies in transmission line impedance data. The remaining portion of the line is covered by the zone 2 protection scheme.

Zone 2

The zone 2 comes into play after some time delay. The main role of zone 2 is to provide protection to the region in protected line where zone 1 did not reach. Zone 2 also provides protection to the line 1 if in case directional properties have been embedded into the relay. The reach point and delay setting are done bases on the adjacent line protection and requisite back-up. The zone 2 protection covers 50 % of the shortest adjacent line along with the coverage of the remaining line after zone 1 protection. The time delay for zone 2 is set in such a way so as To avoid any overlap between zone 1 and zone 2. The delay time is around 20-30 cycles of system frequency.

Zone 3

The zone 3 protection comes into play if zone 1 and zone 2 has failed to isolate the system. It covers all the zone 1 and zone 2 of transmission line. Over reaching and under reaching should me minimized in the distance relays. The zone 3 covers 225% of the line.

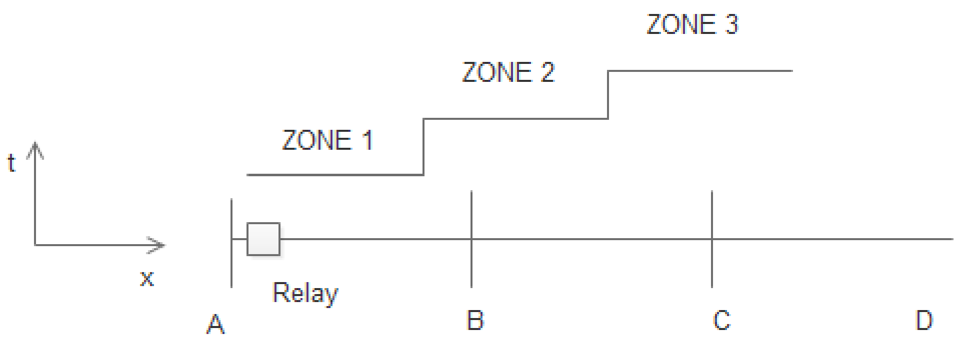

Fig 2.1 Three zone protection scheme

CHAPTER-3

QUADRILATERAL RELAY

3.1 Introduction

The distance relay with circular and straight line characteristics were developed initially because only electromechanical techniques were available. The circular characteristics of such relays were an obvious result from such technology. A straight is an extension of circle with radius tending to be infinite. With the development in the field of electronics, other shapes of characteristics became a reality. One of the leading developments in this process was that of quadrilateral relay. There are two major ways of developing such relays. The first way for the development of quadrilateral relay is to build equations corresponding to the quadrilateral and apply them. The second method is to develop four blocking characteristics base on analog electronics especially using operational amplifiers. Some of the advantages linked to the quadrilateral relays include: the relay characteristics can be easily controlled in R and X directions.

The figure shows that both types of setting that is forward and resistive can be done and adjusted as per requirement. This feature makes it better than mho relay as it provides better resistive coverage. The quadrilateral relay characteristics become particularly useful for the measurement of impedance for faults involving ground as the earth fault resistance contributes to errors. This problem is avoided in quadrilateral relay by applying maximum impedance limits to keep the reach of relay within requirement.

The quadrilateral relay suffers from reach point errors particularly for the case of plain reactance type characteristics. Such errors occur because of the difference between the phase angle difference between that of total current and the current value provided by the relay measurement system. For reactance type relay, this problem can be solved by polarizing it. The quadrilateral relay shows flexibility for the faults involving ground. As a result the quadrilateral relay characteristics are gaining popularity among digital and numerical relays. Also there is minimal cost for the operation of these characteristics.

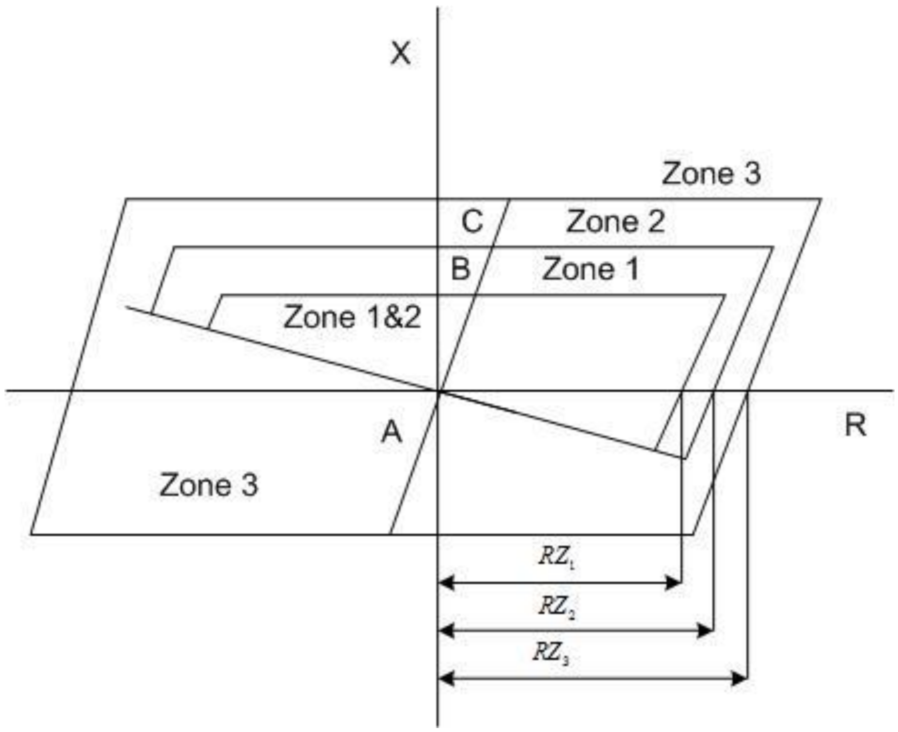

Fig. 3.1 Three zone protection system

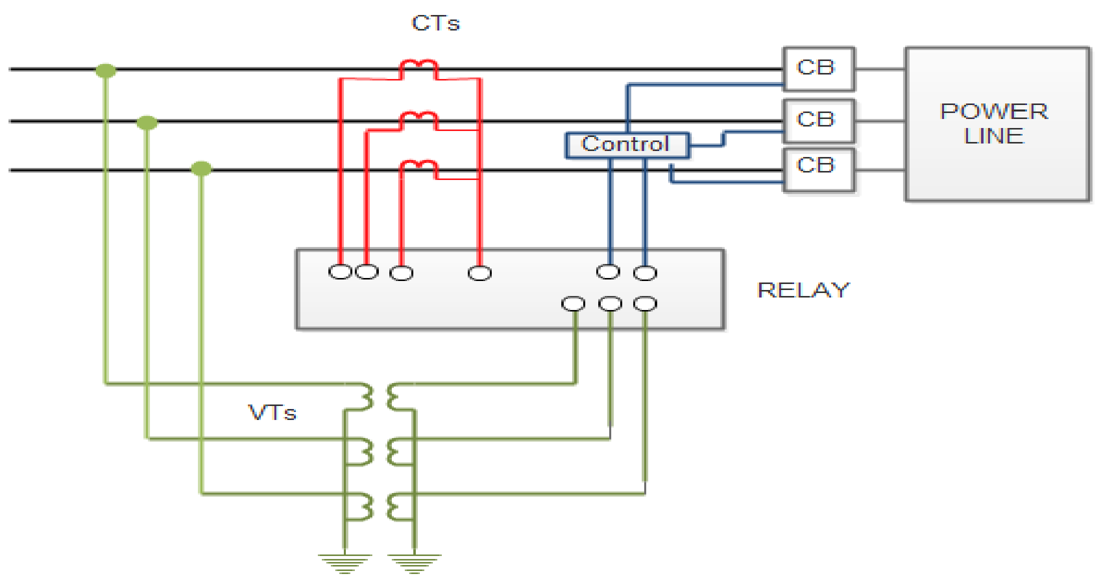

Fig. 3.2 Three phase protective system

3.2 Realization of quadrilateral relay

The characteristics of the quadrilateral relay are one of the best among all distance relays. It is so because the designing of boundary impedance condition can be done in such a way that it encloses a very small area. Such a small area makes it highly selective and yet accurate relay because it will show minimal effect due to power swings, sudden variation in loads and arc resistance. Beyond ELD lines quadrilateral relay is also appropriate for the short and medium length transmission lines. It has already been stated that electromagnetic relay face many problems for implementing characteristics other than a straight line or circle thus static numerical relays are the best.

For the implementation of distance relay including quadrilateral relay multi input comparators are required for phase and amplitude comparison. It is better to use many comparators of two input type rather than a single comparator with many inputs. This makes the overall system faster. The only problem in this case is that of synchronization between the relays. This problem can be solved by extending the output of comparator for some time.

The figure shown below shows the realization of quadrilateral relay by using multi input comparators for phase comparison. The input signals are compared with each other. The consequential output from comparison leads to certain characteristics which can be bounded by straight lines or a circle.

When phase of IX_r and V are compared the output comes out to be a straight line. Other comparison has also been shown in the figure given below. The quadrilateral characteristics are shown in fig. (g). The undesired characteristics of MHO have been eliminated by giving pulse to $(IZ_r - V)$ or V . The characteristic in fig h has been given a shift of 10° by setting the value of IX_r and IR_R .

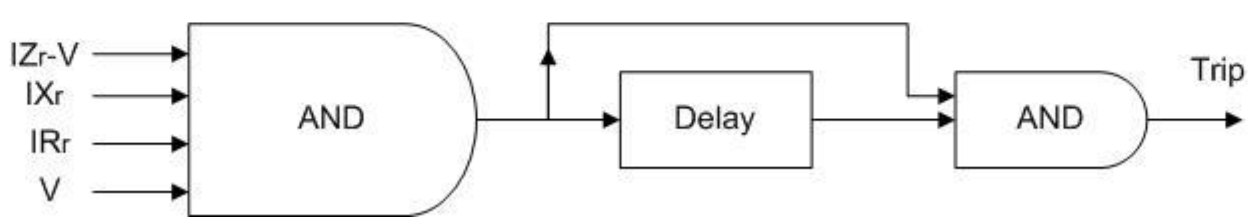

Fig. 3.3 Realization method of quadrilateral relay

3.3 Extraction of fundamental frequency

Many techniques have been suggested for the removal of DC offset and extraction of fundamental frequency. In paper [13] novel techniques were proposed which can perform both the functions. The least square method was proposed in [10]. The walsh-hadamarad techniques has been used in [14]. Most of the techniques used for extraction of fundamental component are orthogonal in nature. Here FFT technique has been implemented for extraction of fundamental frequency due to high sampling rate.

3.4 Effect of power surges

The current flowing in the transmission line depends on the value of phase difference between the voltages at either end .The rotor angle equals phase angle difference. Now when a load is suddenly varied or some faulted region is isolated from the system, many disturbances are created. These disturbances tend to change the rotor angle which tries to attain a new steady state. In order to achieve the steady state, the rotor angle starts swinging around the steady state value. With changes in rotor angle, the current flowing through the transmission line also changes. In case there is abrupt change in current, the equipments might get damaged. The distance relay measuring elements receive the fluctuating current. This results in variation of apparent impedance calculated by relay leading to an impression that a fault has occurred.

The diagram elaborates the effect of power swing on the various relays. The relay having largest area on the R-X plot is most susceptible to the power swings. The reactance relay has the largest area hence it is most vulnerable to be affected by the power swings. The relay with characteristic area lesser than reactance is impedance relay. Hence it is less susceptible to the swing fluctuation but still more than MHO relay. MHO relay has minimum area and so least susceptible. The setting of quadrilateral can be easily done to enclose a small area which makes it one of the best relay distances showing least affect of power swings.

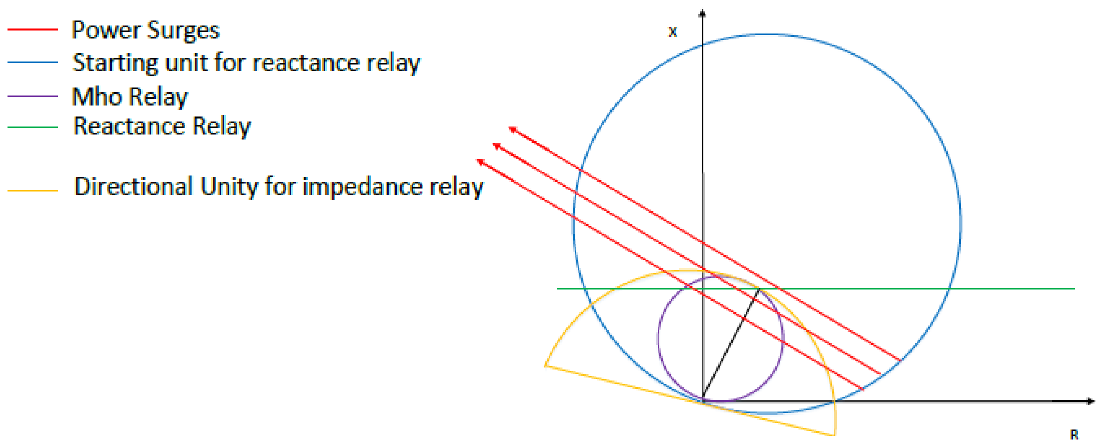

Fig 3.4 Effects of power swings

3.5 Power swing protection

In case power swings of high intensity occur in the power system, it can destabilize the whole system. To bring it back to the normal state the only method is to isolate the source from which such swings were produced. The splitting of the system is one of the methods to minimize the damage. But it should be noted that system on both side of the split have same frequency and load matching is properly done.

Such disturbances are not easy to detect accurately even by distance relays. But it is desirable that the distance should be able to distinguish well between an fault and a disturbance. But still in case the disturbance is strong enough to destabilize the whole system, an ohm impedance scheme can be employed to split the power system.

The characteristics for ohm impedance are shown below. It is employed for the forward as well reverse impedance axis on R-X plot. Its operating characteristics are set parallel to the impedance vector of the line protection. As it is shown in the Fig. 3.1, the R-X plot of ohm impedance characteristics is divided into three parts i.e., A, B and C. When a power swing occurs in the system, the impedance value changes and results in movement of impedance point on the R-X plot. This results in out of step tripping of relay. When the impedance vector comes into the zone 3 the sequence is completed for the tripping signal to be given for interrupting arc to minimize risk.

It is important to note that only an unstable power swing would make the impedance vector to go consecutively through all the three zones. Hence the tripping would occur exclusively for the unstable swings and all other kind of disturbances gets neglected.

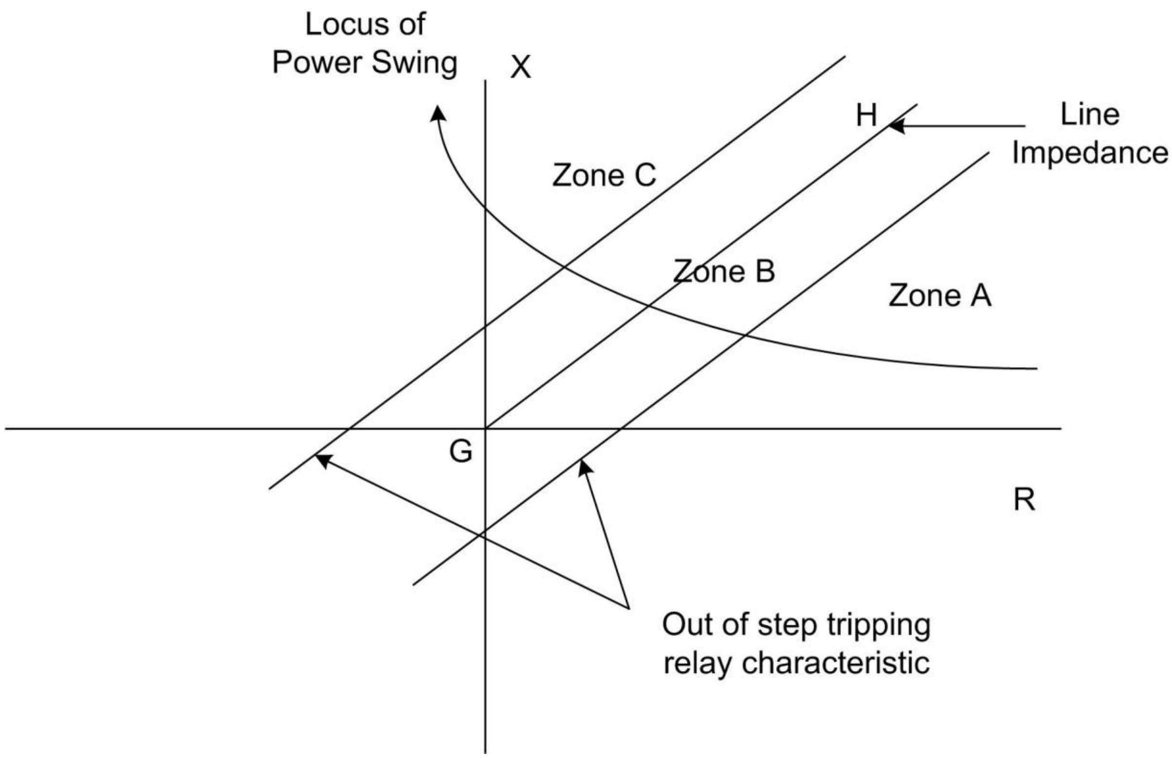

Fig 3.5 Swing Protection Scheme

3.6 Effect of arc resistance

The faults occurring from line to line and from line to ground an additional resistance called arc resistance is involved. As the voltage of the system gets higher, the arc resistance gets more pronounced. It adds to the total impedance seen by the distance relay. There is earth resistance for ground faults. The earth resistance is the sum total of tower resistance, resistance of the foot of tower and resistance of the earth return course. These two types of resistance add up to be called as earth resistance.

The Warrington formula for the calculation of arc resistance is as follows:

$$R_{arc} = \frac{29 \times 10^3 . l}{I^{1.4}} \Omega$$

where l = arc length (m)

I=post fault current (amperes)

The effect of arc resistance on various distance relays is clearly demonstrated in the figure shown below. Suppose a fault occurs at the point F with an arc resistance of R_1 , the total impedance after addition of R_1 moves out of the protective area of MHO relay. Thus MHO relay fails to act against the fault. All other relays would send tripping signals in a timely manner. Now suppose the arc resistance is R_2. The total impedance moves of out the protective region of MHO and impedance relays. Thus only reactance is able to respond to the fault. The reactance takes only reactance into consideration thus it is one of the best relay to avoid arc resistance problem.

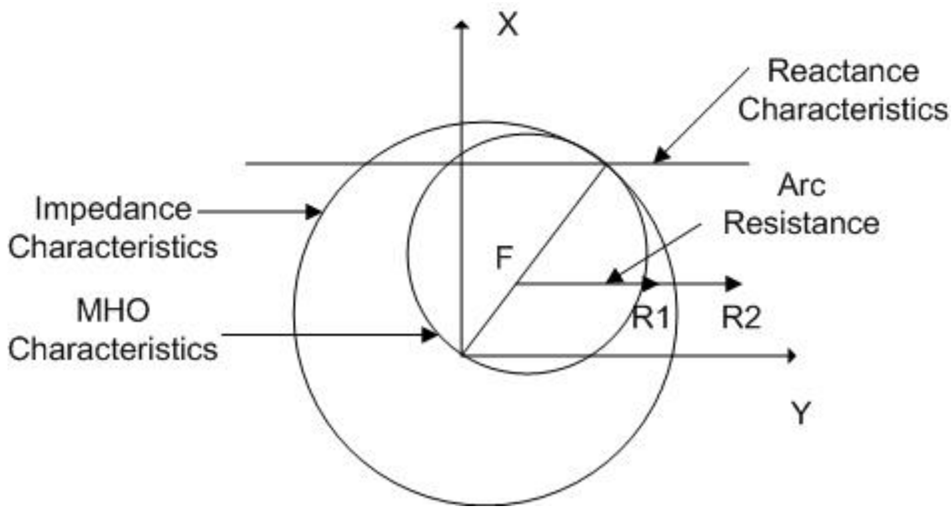

Fig 3.6 Effect of arc resistance

3.7 Various comparators for the quadrilateral relays

Various arrangements are possible for the appropriate output. Most of them demands either two or four input comparators.

TYPE 1 – This type of comparator is associated with directional units with at least one unit being offset from the origin with replica impedance. When the impedance comes within the area between two characteristics, tripping takes place.

TYPE 2 – The advantage of comparator with many inputs over comparator with single input as in type 1 is that all ouptput occur at the same time. The equation for type 2 comarators are shown below:

$$S_1 = Z_{R1} I_L \angle \theta_1 - \phi - K_1 \angle \alpha_1 V_L$$

$$S_1 = Z_{R1} I_L \angle \theta_1 - \phi$$

$$S_3 = Z_{R3} I_L \angle \theta_3 - \phi$$

$$S_4 = K_4 \angle \alpha_4 V$$

For enclosing the fault area:

$$Z_{R2} = X_R$$

$$Z_{R3} = R_R$$

$$Z_{R1} = R_R + jX_R = Z_R$$

Type 3 – In order to eliminate the mho circle from the case studied above the input signal $I_L Z_R$ or $I_L Z_R - V_L$ should me made a pulse. The quadrilateral relay characteristics can be obtained using the equation given below for multi input comparator for phase.

$$S_1 = I_L Z_R \text{(pulse)}$$

$$S_2 = V_L \angle -90^o \text{(control input)}$$

$$S_3 = V_L \angle -90^o$$

$$S_4 = I_L R_R - V_L$$

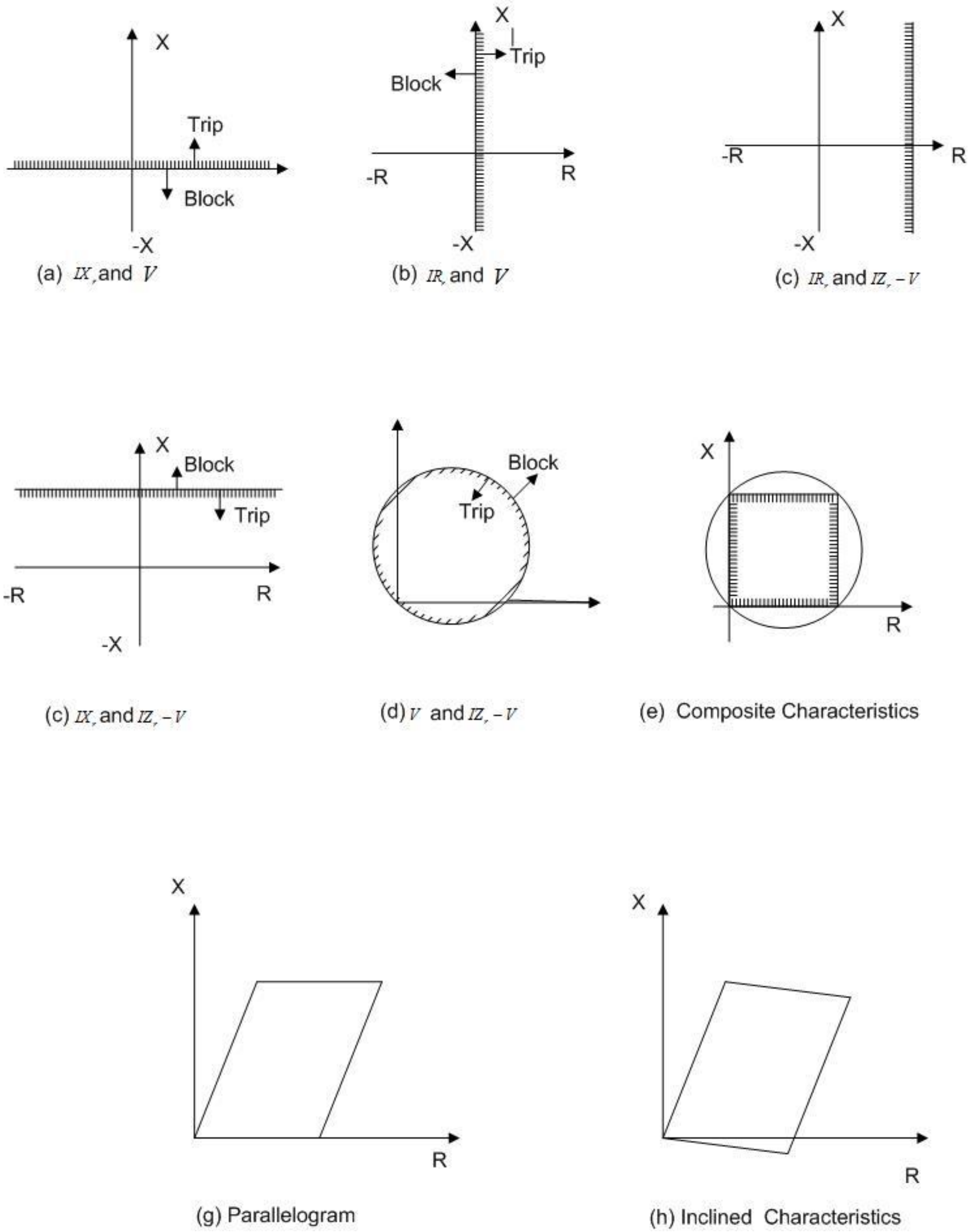

Fig 3.7 Different characteristics of distance relay after comparison of phase

3.8 Overcurrent Relay

An overcurrent relay is the one which acts as the current goes beyond a predetermined value which is usually 10% above normal current. There are overcurrent relays present across the feeder. It is suitable for faults occurring in phases, earth faults and winding faults. However one precaution has to be taken while implementing overcurrent relay. The current during starting is generally high so that some delay needs to be provided to the relay.

3.9 Over/Under Frequency Relay

The over/under frequency relay is required to keep frequency deviations in check. Allowed frequency variation is just 5%. Frequency variations can damage the equipments connected to the system like motors, generators, power electronics devices, etc..It is because there is a range of frequency for which the devices are designed for. Also the frequency deviation becomes particularly important to determine the Unscheduled Interchange (UI) in the power market. Through frequency reading, the amount of load on the system can be determined and according the price of power units can be set.

3.10 Over/under voltage Relay

The voltage variation is normal phenomenon in the power system. Although to some extent, it does not cause any harm but beyond a certain point care has to be taken. The voltage surges can occur due to switching impulses, lightning strokes, insulation failure, etc. Thus the over/under voltage protection relay performs the function of isolating the system if voltage beyond ± 10 %.

CHAPTER-4

SIMULATION RESULTS

A 735 kV, 50 Hz, 5 bus system with a generator and exciter control has been simulated using Simulink as shown in fig. 4.1. The generator rating is 6*350 MVA, 13.8 kV which is attached to the step up transformer of rating 13.8/735 kV. The subsystem samples the current and voltage signals at 20 kHz frequency for the implementation of multi-function relay. The designed quadrilateral relays function provides zone I protection to the transmission line connected to the transformer of length 300 km. The voltage sink of 30 MVA, 735 kV has been connected at the other end. Different loads are connected at different buses.

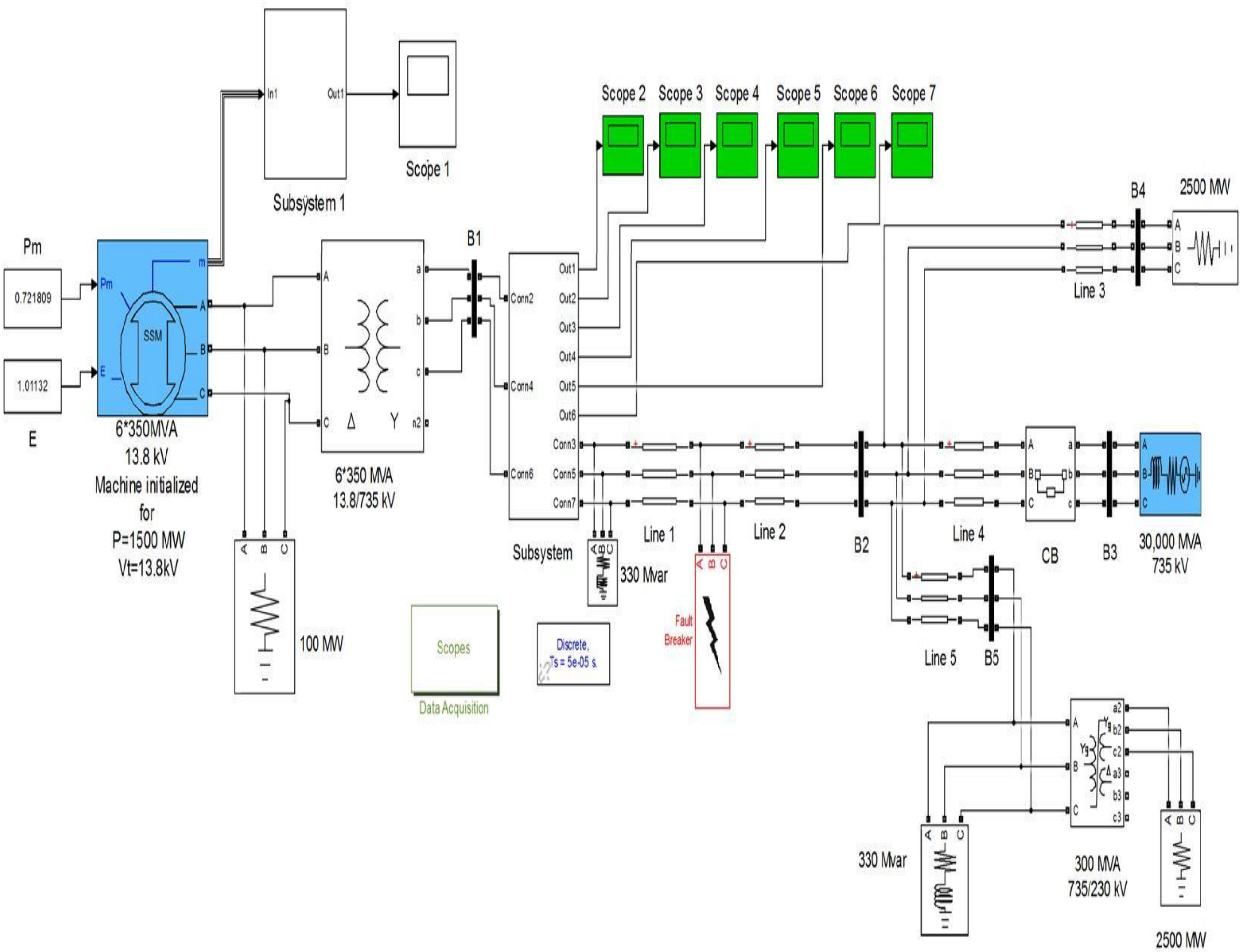

Fig 4.1 5 Bus system

The Fig. 4.2 (a) and (b) shows three phase voltages and currents signal for phase A-G fault at 20 km from the generating end with Rf = 0.001Ω and inception angle = 1.43°respectively. Fig. 4.3 (a) and (b) shows three phase voltages and currents signal for A-B fault at 20 km from the generating end with Rf = 0.001Ω and inception angle = 1.43. Fig 4.4 shows frequency variation due to L-G fault at a distance of 280 km from the generator.

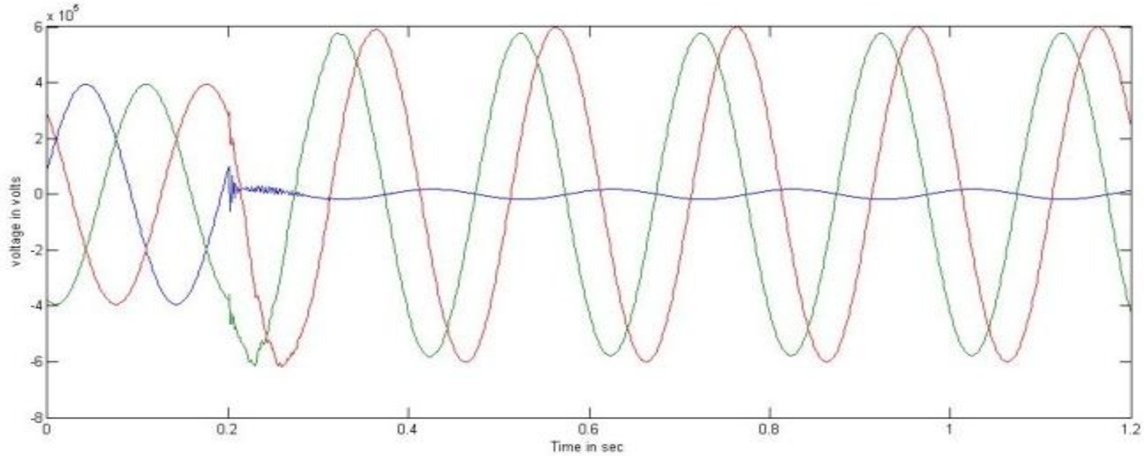

Fig. 4.2 (a)

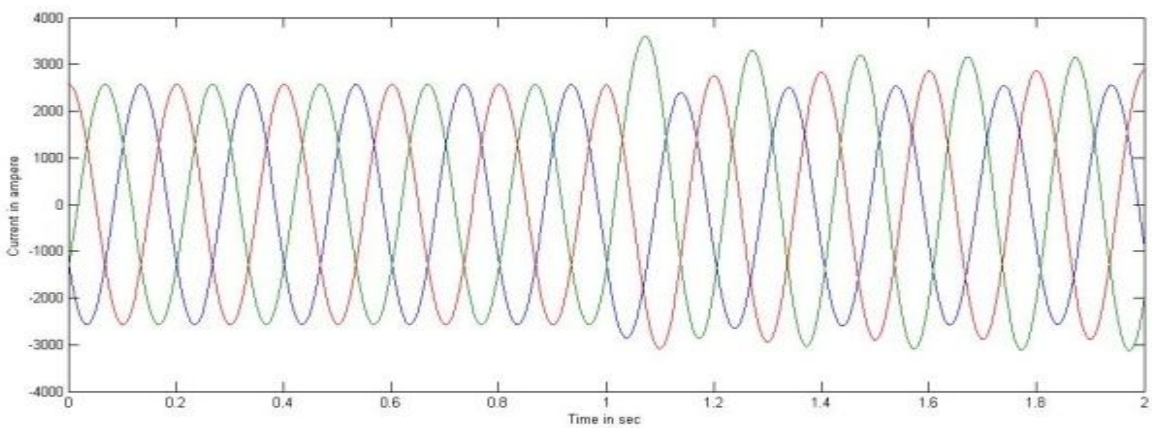

Fig. 4.2(b)

Fig. 4.2 Three phase voltages(a) and currents(b) signal for phase A-G fault at 20 km from the generating end with Rf = 0.001Ω and inception angle = 1.43°.

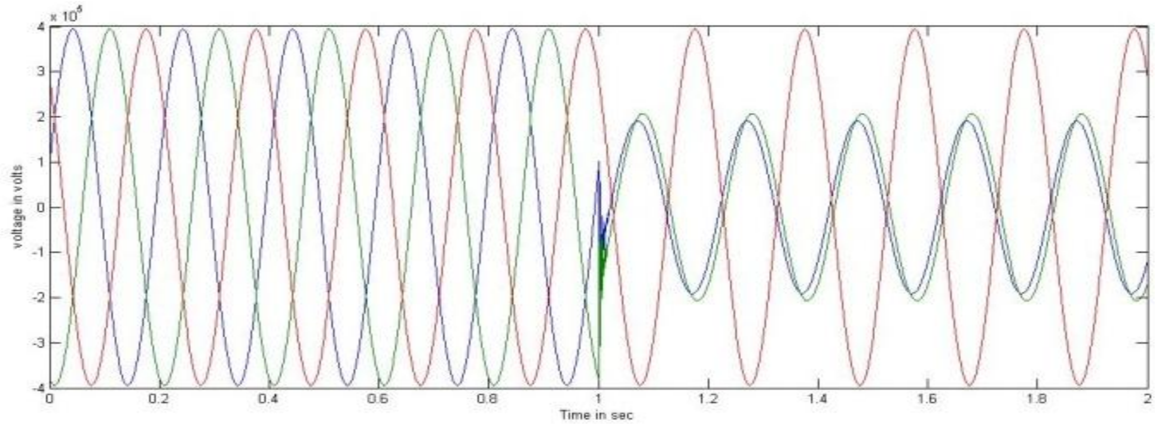

Fig. 4.3 (a)

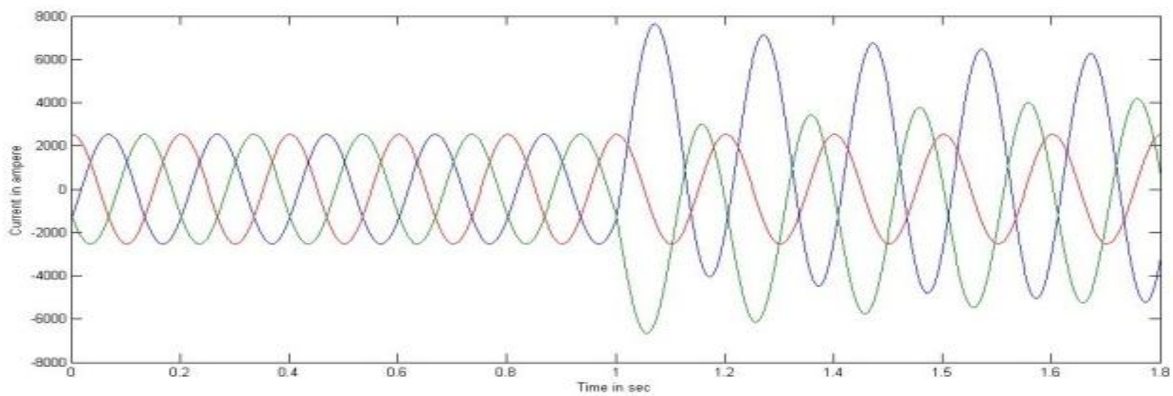

Fig. 4.3 (b)

Fig. 4.3 Three phase voltages(a) and currents (b) signal for A-B fault at 20 km from the generating end with Rf = 0.001Ω and inception angle = 1.43°

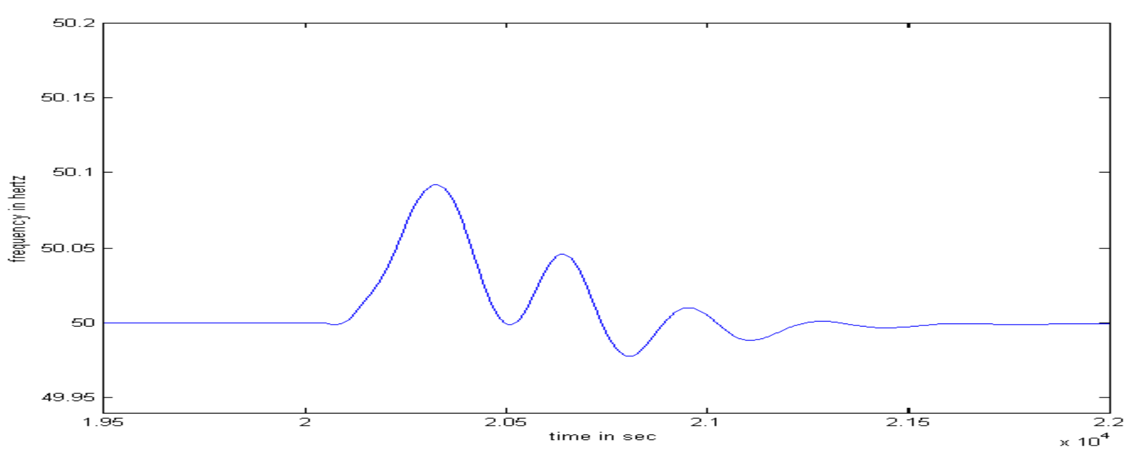

Fig. 4.4 Frequency variation do to fault L-G when line distance is 280 km from the generator

Table 4.1 Data of 5 bus test case

Parameter	***Value***
Resistance r1(per unit length)	0.01273 Ohms/Km
Resistance r0(per unit length)	0.3864 Ohms/Km
Inductance (per unit length)	0.9337e-3 H/Km
Capacitance(per unit length)	12.74e-9 (F/Km)
Generator rating	6*250 MVA,13.8 kV, 50 Hz

CHAPTER-5

IMPLEMENTATION OF MULTIFUNCTION RELAY

5.1 Introduction

The voltage and current signals have been simulated and saved for different faults by varying the fault resistance, inception angle and its location. With the occurrence of a fault, the voltage level suddenly dips while the current level rises abruptly. The simulated data of voltage and current for L-G and L-L fault has been shown in fig. 4 & 5 respectively. The three phase current and voltage signals are sampled at 10 kHz sampling frequency at the generating end

The DC components have been removed using the algorithm mentioned above from the current signals. The fundamental components of voltage and current signals have been extracted using FFT full cycle window. The resistance and reactance has been calculated using sine and cosine components of processed voltage and current signals (11) & (12) and compared with the three zone values of the quadrilateral characteristics. The trip signal has been issued as per the zone classification. The first zone tripping is instantaneous while zone 2 and zone 3 trip signals is send after 100 ms and 1 s delay respectively. The fault location has been calculated using table 1 after its classification.

The resistance and reactance values have been tabulated in table 2 for L-G fault in phase A for faults at different locations and fault resistances. After fault classification the impedance has been calculated using rms values of voltage and current and compared with the actual value of the impedance up to fault location. The Pre-fault value of R has been around 106.41 ohm and X has been around 153 ohm. The resistance, reactance and impedance have been tabulated in table 2 for phase A to ground fault at different locations and inception angles. The R, X and Z values for L-L fault between phase A and B has been tabulated in table 3. The effect of power swing on quadrilateral relay has been studied by sudden removal of another source and load. The values of R and X are significantly more in case of power swing as compared to the fault occurrence in the transmission line as tabulated in table 5.

The effect of fault resistance and power swing on quadrilateral relay has been studied and the results show that the values of R and X are within its zone limit and chances of mal-operation are minimal. The error in fault location for L-G and L-L fault is more for faults with high arc resistance near to the generating end. The fault location error reduces with increase in distance from generating end and decrease in arc resistance.

5.2 DC components due to short circuit current

The occurrence of DC current in AC power system seems completely illogical at first glance. At the one of the important phenomenon in electrical engineering is that in an inductive circuit, the current lags the voltage by 90°. In case a fault occurs when the voltage is zero, the current is either a positive maximum or a negative maximum. Also, the generator is a large inductor and that the current in an inductor cannot change instantaneously.

Assuming that the generator is carrying no load before the fault occurrence. Also it is assumed that voltage is zero when the fault occurs. The generator was not carrying any current before the fault so that just after the fault occurrence also the current must be zero in the inductive circuit. But at same when the voltage is zero, the current must be maximum as per the inductive circuit phasing. It can be pointed out that both the rules are in contradiction to each other.

The above puzzled is solved with the DC component in the circuit post fault. These components are generated due to fault in the circuit. Initially the magnitude of DC components is same as AC current components but of opposite polarity at t=0. Thus the total fault current in the circuit remains zero. This results in maintenance of overall current equivalency in the circuit before and after the fault occurrence.

The actual magnitude of DC component current depends when the fault occurrence on the voltage waveform and also on the circuit angle (X/R). For the analysis purpose the fault occurrence is assumed when the voltage is at its peak thus generating the largest DC component. The DC components start decaying immediately, but tens cycles are generally required for complete dissipation because of high X/R ratio of the ratio. But in protection system, the faulted circuit should be isolated as soon as possible. Thus for the functioning of relaying system, the voltage, and current signals have to be extracted. There are many unwanted components present in the signals apart from like harmonic terms and sub-synchronous resonance terms which should be removed before signal processing [9-14]. A signal $Z_A(t)$ is extracted from power system with 'N' harmonics where $N = (N_0 - 2)$. The fundamental frequency $\omega_0 = 2\pi f_0 = 2\pi / T_0$ where the value of f_0 is 50Hz or 60Hz in most of the countries.

$$Z_a = A_0 + \sum_{n=1}^{N_0-2} A_n \cos(n\Omega_0 t + \theta_n) + Ae^{-t/\tau} \text{ …. (5.1)}$$

Where

A_0 = DC offset value

A_n = Amplitude value of nth harmonic component

θ_n = Phase value of the nth harmonic component

τ = Time constant (Overall)

$\Delta T = T_0 / N$ Where ΔT is the time difference after which the signal is sampled

N represents the entire discrete samples of a signal taken over its period

Now the signal Z_a can be represented as follows:-

$$Z(k) = A_0 + \sum_{n=1}^{N_0-2} A_n \cos(nk\pi / M + \theta_n) + Ae^{-k\Delta T/\tau} \text{ , for all } k \in N \qquad \text{…. (5.2)}$$

Where M = N/2. Also $\cos(n\pi / M) = \cos(n\pi(N+1)/M)$, thus it can be concluded:

$$Z(N+1) - z(1) = A(e^{-N\Delta T/\tau} - 1)e^{-\Delta T/\tau} \text{ ,\&}$$

$$Z(N+2) - Z(2) = A(e^{-N\Delta T/\tau} - 1)e^{-2\Delta T/\tau} \text{ …. (5.3)}$$

Using (3) it can be concluded:

$$e^{-\Delta T/\tau} = \frac{Z(N+2) - Z(2)}{Z(N+1) - Z(1)} = U \qquad \text{…. (5.4)}$$

Using (3) & (4) the value of A can be obtained

$$A = \frac{z(N+1) - z(1)}{U(U^N - 1)} = \frac{z(N+2) - z(2)}{U^2(U^N - 1)} \quad \text{…. (5.5)}$$

Also, $\sum_{k=0}^{N-1} \cos(nk\pi / M + \theta_n) = 0$ for n= 1, 2,…, $N_0 - 2$ …. (5.6)

Therefore, for k>N+2, the value of x(k) can be easily obtained as $x(k) = Z(k) - A_0 - Ae^{-k\Delta T/\tau}$. The term x (k) provides the signal after removal of DC components.

Though DC components has been removed using the above mentioned method, the harmonic components are still present in the signals. In order to obtain the basic frequency component, FFT technique is used.

5.3 Extraction of Fundamental Frequency Phasor

Full cycle data window FFT algorithm

The current and voltage waveforms have been sampled to get N samples. The DC offset have been removed from the sampled signals using the process explained above. But for the application of algorithm of quadrilateral relay, fundamental components of frequency are required. The FFT algorithm [5] is used to achieve that purpose which is shown below:

$$F_{1(v)} = V_S = \frac{\sqrt{2}}{N} \sum_{m=0}^{N-1} V_m \sin \frac{2\pi m}{N} \quad \text{…. (5.7)}$$

$$F_{2(v)} = V_C = \frac{\sqrt{2}}{N} \sum_{m=0}^{N-1} V_m \cos \frac{2\pi m}{N} \quad \text{…. (5.8)}$$

$$F_{1(i)} = I_S = \frac{\sqrt{2}}{N} \sum_{m=0}^{N-1} I_m \sin \frac{2\pi m}{N} \quad \text{…. (5.9)}$$

$$F_{1(v)} = I_C = \frac{\sqrt{2}}{N} \sum_{m=0}^{N-1} I_m \sin \frac{2\pi m}{N} \quad \text{…. (5.10)}$$

where V_S , I_S represents the sine component of voltage and current signal

where V_C , I_C represents the cosine component of voltage and current signal

The fundamental voltage and current can be determined as:

$$V = \sqrt{V_S^2 + V_C^2} \text{ and } I = \sqrt{I_S^2 + I_C^2} \quad \text{…... (5.11)}$$

Using the above sine and cosine components the entire waveform can be constructed.

5.4 Calculation of Apparent Impedance

After obtaining the fundamental frequency components, the resistance and reactance can be

Calculated [5] as shown below:

$$z = \frac{V_S + jV_C}{I_S + jI_C} = R + jX \quad \text{…. (5.12)}$$

where $R = \frac{V_S I_S + V_C I_C}{I_S^2 + I_C^2}$ … (5.13)

and $X = \frac{V_C I_S - V_S I_C}{I_S^2 + I_C^2}$ …. (5.14)

In the above equation R and X represents the real and imaginary parts of the impedance. After evaluating the impedance, the Quadrilateral relay algorithm has been applied for the protection of the transmission lines.

5.5 Classification and location of Fault

In balanced condition, $I_1 + I_2 + I_3$ is equal to zero. If $I_1 + I_2 + I_3$ is not equal to zero, it implies that a fault has occurred. Let $I_1 + I_2 + I_3$ be equal to x. If x>0.01, then ground is involved.

The type of fault has been detected by analyzing the voltage and current readings. The location of fault has been predicted by computing the value of impedance.

Z_{cal} = V/I Apparent Impedance Equation as shown in table 2.1.

5.6 Results

The Z_{act} is computed directly from the 5 bus system. The Table 5.1 and 5.2 shows the tabulation of resistance, reactance and impedance for L-G faults with variation in length, fault resistance and inception angle for zone I protection. The resistance and reactance have been also calculated for the same transmission line having 40% series compensation with varying length of fault occurrence. The zone and location of the fault in terms of impedance has been calculated and can be compared with the actual values. Fig. 5.1 shows the comparison of impedance calculated and its actual value graphically. Table 5.3 and 5.4 shows the tabulation of resistance, reactance and impedance with variation in length and fault resistance for L-L fault and L-L-G respectively. Fig 5.2 and Fig. 5.3 shows the calculated impedance variation with actual impedance for location of fault for LL and LLG fault respectively. The zone 1 protects 80% of the line, zone 2 protects 120% of the line and zone protects 225% of the line.

The Table 5.5, 5.6 and 5.7 shows the tabulation of resistance, reactance and impedance with variation in length and fault resistance for L-G, L-L and L-L-G faults respectively and zone II protection. Table 5.8, 5.9 and 5.10 shows zone III protection for L-G, L-L and L-L-G faults respectively and the value of resistance, reactance and impedance has been tabulated with variation in length and fault resistance.

Table 5.11 shows the tabulated result of occurrence of power swing due to sudden removal of source and loads in the connected system. The tabulated values of resistance and reactance are differentiable with respect to faulty conditions. Therefore the designed quadrilateral relay is suitable for the system under consideration.

Table 5.12 shows the tabulated values for the operation of the relay in case of overcurrent, under voltage and under/over frequency. The overcurrent relay tripping has been done for current greater than 20% of normal rated current. The under voltage relay sends a trip signal for a dip of more than 15%. The under frequency and over frequency is below the 5% limit for isolation, hence it needs no tripping signal. Similarly for various faults occurring in the system, the current has surged and hence the tripping signal issued by the relay.

Table 5.1 Tabulated values of R, X, Zcal, Z_{act} for R_f = 0.001, 1, 10 ohms during L-G fault

		R_f = 0.001					***R_f = 1***					***R_f = 10***				
Dist.	***Z_{act}***	***R***	***R_c***	***X***	***X_c***	***Z_{cal}***	***R***	***R_c***	***X***	***Xc***	***Z_{cal}***	***R***	***R_c***	***X***	***X_c***	***Z_{cal}***
20	5.86	0.71	0.73	1.80	1.40	5.79	1.20	1.20	2.60	2.60	5.86	5.58	5.69	6.67	6.69	7.43
60	17.6	0.94	1.0	3.42	3.42	17.4	1.44	1.44	6.21	6.21	17.60	5.94	6.11	10.33	10.14	17.43
100	29.34	0.92	1.08	5.8	5.8	29.01	1.39	1.45	10.30	10.30	29.34	6.16	6.48	14.36	14.09	28.54
140	41.07	0.95	1.06	8.73	8.71	40.73	1.46	1.40	15.08	15.08	41.07	6.29	6.7	18.96	18.75	39.88
180	52.81	1.05	0.87	12.48	12.48	52.52	1.49	1.00	20.82	20.82	52.81	6.44	7.04	24.56	24.36	51.48
220	64.54	1.06	0.73	17.46	17.48	64.91	1.52	1.23	27.92	27.17	64.85	6.57	7.58	30.97	31.3	63.32
260	76.28	1.44	0.91	24.29	24.29	77.46	1.52	1.31	36.94	36.14	76.28	7.05	8.56	39.31	40.07	75.85

Table 5.2 Tabulated values of Z_{act}, R, X, Z_{cal} for inception angles $0^\circ, 30^\circ, 60^\circ$

		Angle = 0°			***Angle =*** 30°			***Angle =*** 60°		
Distance	***Z_{act}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***
20	5.86	.71	1.80	5.79	0.71	3.83	5.77	0.71	5.68	5.79
60	17.6	.94	3.42	17.4	0.93	12.11	17.35	0.93	16.88	17.39
100	29.34	.92	5.8	29.01	0.93	20.13	29.07	0.91	28.16	29.47
140	41.07	.95	8.73	40.73	0.94	27.83	40.77	0.9	39.67	40.69
180	52.81	1.05	12.48	52.52	0.98	35.11	52.68	0.93	51.56	53.05
220	64.54	1.06	17.46	64.91	0..9	41.68	64.92	0.96	63.94	64.89
260	76.28	1.44	24.29	77.46	0.89	47.10	77.86	0.92	76.94	77.06

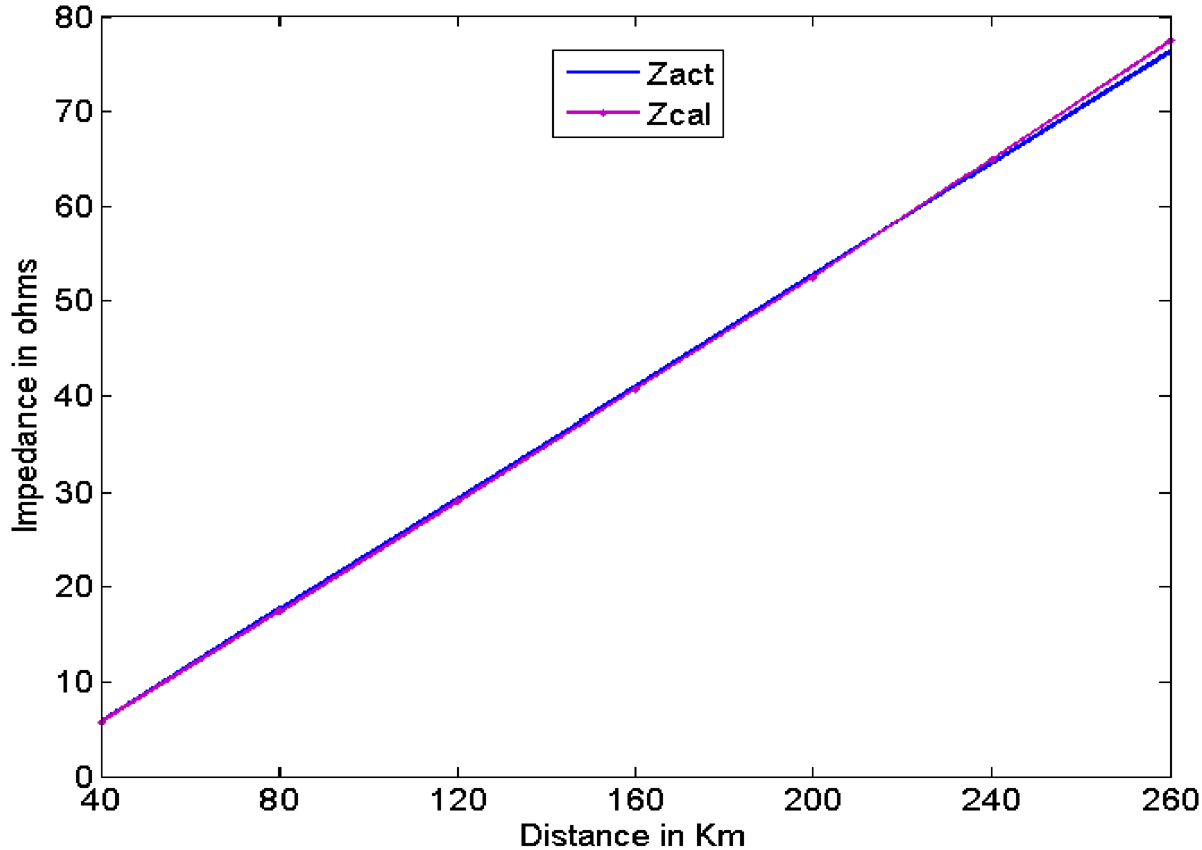

Fig. 5.1 The actual impedance(Z_{act}) and calculated impedance(Z_{cal}) for L-G fault for zone 1 for fault resistances as R_f = 0.001 ohms.

Table 5.3 Tabulated values of R, X, Zcal, Z_{act} for R_f = 0.001, 1, 10 ohms during L-L fault

		$R_f = 0.001$			$R_f = 1$			$R_f = 10$		
Distance	Z_{act}	***R***	***X***	Z_{cal}	***R***	***X***	Z_{cal}	***R***	***X***	Z_{cal}
20	5.86	.25	5.8	7.26	34.33	32.20	7.26	42	41.71	10.34
60	17.6	.77	17.4	33.14	35.53	35.26	33.23	43.18	44.5	17.27
100	29.34	1.28	29.10	52.91	36.55	40.65	50.28	43.95	47.84	26.76
140	41.07	1.8	40.91	67.02	37.16	44.87	87.33	44.34	51.62	35.7
180	52.81	2.35	52.88	71.46	37.38	48.55	55.34	44.37	55.77	51.26
220	64.54	2.9	65.06	80.34	37.8	52.86	76.67	44.07	60.23	62.30
260	76.28	3.48	77.50	83.7	37.7	57.41	79.45	44.17	64.98	69.16

Table 5.4 Tabulated values of R, X ,Z_{cal}, Z_{act} for R_f = 0.001, 1, 10 ohms during L-L-G fault

		R_f = 0.001			R_f = 1			R_f = 10		
Distance	Z_{act}	R	X	Z_{cal}	R	X	Z_{cal}	R	X	Z_{cal}
20	5.86	0.30	1.6	5.73	1.19	2.4	5.9	8.82	8.3	7.32
60	17.6	0.72	5.52	17.54	1.60	6.15	17.72	9.05	11.71	21.16
100	29.34	1.06	10.32	29.49	1.93	10.83	29.66	9.27	15.31	32.42
140	41.07	1.24	16.21	41.64	2.30	19.61	47.97	9.45	20.07	44.19
180	52.81	1.55	22.72	54.06	2.41	23.03	54.21	9.62	25.93	56.30
220	64.54	1.75	30.43	66.83	2.63	30.67	66.95	9.84	32.94	68.72
260	76.28	2.01	39.35	79.97	2.90	39.52	80.07	10.20	41.23	81.43

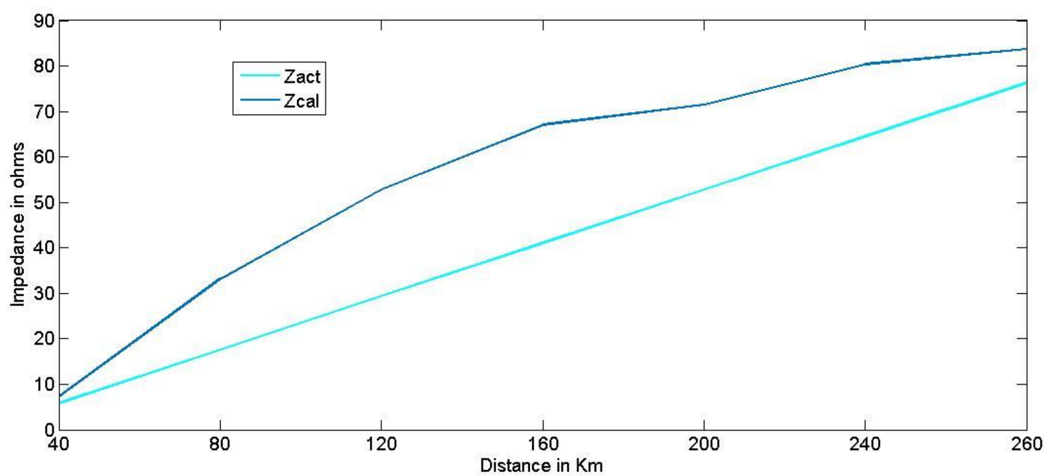

Fig 5.2 The actual impedance (Z_{act}) and calculated impedance (Z_{cal}) for L-L fault for zone 1 with R_f = 0.001

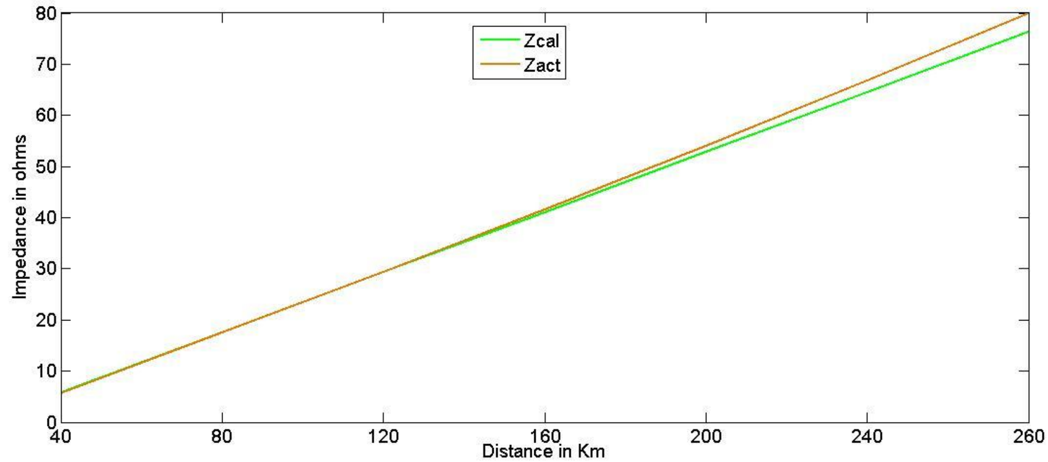

Fig. 5.3 The actual impedance (Z_{act}) and calculated impedance (Z_{cal}) for L-L-G fault for zone 1 with R_f = 0.001

Table 5.5 Tabulated values of R, X ,Z_{cal}, Z_{act} for R_f = 0.001, 1, 10 ohms during L-G fault for Zone 2 protection of transmission line

		R_f = 0.001			***R_f = 1***			***R_f = 10***		
Distance	***Z_{act}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***
20	93.88	2.11	49.12	98.04	3.07	46.69	98.25	11.09	49.55	96.98
40	99.75	4.47	52.77	105.87	5.44	53.08	105.73	13.5	55.48	104.54
60	105.62	6.77	59.03	112.64	7.76	59.24	112.8	18.25	61.36	11.82

Table 5.6 : Tabulated values of R, X ,Z_{cal}, Z_{act} for R_f = 0.001, 1, 10 ohms during L-L fault for Zone 2

		R_f = 0.001			***R_f = 1***			***R_f = 10***		
Distance	***Z_{act}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***
20	93.88	4.54	96.78	86.7	5.65	96.81	86.03	14.68	97.59	93.88
40	99.75	5.09	103.30	87.96	6.21	103.3	87.68	15.21	103.81	99.75
60	105.62	5.78	109.82	89.15	6.89	109.79	89.97	15.89	110.27	105.62

Table 5.7 : Tabulated values of R, X ,Z_{cal}, Z_{act} for R_f = 0.001, 1, 10 ohms during L-L-G fault for Zone 2

		R_f = 0.001			***R_f = 1***			***R_f = 10***		
Distance	***Z_{act}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***
20	93.88	2.11	46.39	98.54	3.07	46.69	98.3	11.09	49.55	96.97
40	99.75	4.47	52.77	105.93	5.44	53.03	105.71	13.5	55.48	104.52
60	105.62	6.77	59.03	112.96	7.76	59.24	112.78	15.9	61.36	111.86

Table 5.8 : Tabulated values of R, X ,Z_{cal}, Z_{act} for R_f = 0.001, 1, 10 ohms during L-G fault for Zone 3

		R_f = 0.001			***R_f = 1***			***R_f = 10***		
Distance	***Z_{act}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***
20	93.88	6.51	47.29	100.96	7.06	47.51	100.65	13.41	51.04	101.57
40	99.75	13.48	53.52	109.06	13.8	53.65	108.74	19.06	55.07	106.33
60	105.62	19.9	58.76	115.58	20.37	58.83	115.26	24.55	59.64	112.88
80	111.49	26.53	63.15	120.83	26.55	63.18	120.53	29.85	63.65	118.18
100	116.36	31.92	66.84	125.11	32.21	66.85	124.83	34.84	67.08	122.57
120	123.22	37.12	69.98	128.63	37.34	69.98	128.36	39.83	70.05	126.22

Table 5.9 : Tabulated values of R, X ,Z_{cal}, Z_{act} for R_f = 0.001, 1, 10 ohms during L-L fault for Zone 3

		R_f = 0.001			***R_f = 1***			***R_f = 10***		
Distance	***Z_{act}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***
20	93.88	4.8	96.59	86.47	5.88	96.52	85.79	14.57	96.53	79.69
40	99.75	6.19	102.59	87.22	7.18	102.4	86.64	15.04	101.52	81.37
60	105.62	8.13	108.17	87.71	9.05	107.91	87.21	16.71	106.28	82.62
80	111.49	10.55	113.31	88.07	11.38	112.62	87.64	18.41	110.76	83.6
100	116.36	13.07	118	88.38	14.05	117.62	87.99	20.43	114.94	84.39
120	123.22	16.32	122.23	88.67	16.98	121.82	88.32	22.71	118.8	85.06

Table 5.10 : Tabulated values of R, X ,Z_{cal}, Z_{act} for R_f = 0.001, 1, 10 ohms during L-L-G fault for Zone 3

		R_f = 0.001			***R_f = 1***			***R_f = 10***		
Distance	***Z_{act}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***	***R***	***X***	***Z_{cal}***
20	93.88	6.95	56.32	98.08	7.81	56.35	98.09	14.88	56.94	98.58
40	99.75	10.84	61.66	102.1	11.64	61.64	102.07	18.25	61.78	102.25
60	105.62	14.35	66.18	105.77	15.09	66.15	105.73	21.25	65.9	105.57
80	111.49	17.62	70.08	109.17	18.3	69.99	109.07	24	69.48	108.64
100	116.36	20.7	73.49	112.32	21.32	73.37	112.19	26.59	72.62	111.5
120	123.22	23.67	76.49	115.25	24.23	76.36	115.1	29.07	75.43	114.18

Table 5.11: Variation R and X as perceived by quadrilateral relay due to power swings in the system

Fluctuations due to Power Swing	
Due to removal of voltage source at B3	
R(Pre-Swing) = 106.41	X(Pre-swing) = 126.2
R(Post-swing) = 105.83	X (Post-swing) = 122.04
Due to removal of load at B4	
R(Pre-Swing) = 107.21	X(Pre-swing) = 147.6
R(Post-swing) = 639.31	X (Post-swing) = 247.39
Due to removal of load at bus 5	
R(Pre-Swing) = 107.21	X(Pre-swing) = 147.6
R(Post-swing) = 131.29	X (Post-swing) = 99.36

Table 5.12 Multifunction relay implementation

Distance	Over current	Under freq	Over freq	Under vol
20	3.5824e+03	49.97	50.038	1.8e+4
60	3.545	49.96	50.038	5.346e+4
80	3.526e+03	49.96	50.04	7.07e+4
100	3.503+03	49.96	50.04	8.89e+4

Chapter-6

CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusions

The 5 bus test system has been simulated in MATLAB/Simulink for L-G, L-L, L-L-G faults. The dc offset has been removed from the post faults signals. The FFT technique has been used for extraction of fundamental frequency of voltage and current signals. The power swings and arc resistances have shown minimal effect on the working of quadrilateral relay. Using the R and X values three zones of protection have been implemented. The fault distance has been calculated using the Z_{cal}. The rms values of voltage and current have been calculated for the implementation of overcurrent relay and under/over voltage relay. The frequency of voltage has been used for under/over frequency relay. A multifunction relay has been implemented for three zone identification, classification and location of transmission line faults alongwith overcurrent, under/over voltage, under/over frequency.

6.2 Future Scope

- Negative sequence relay, reverse power flow, and power factor relay can be implemented in the multifunction relay.
- The relay can be implemented on a larger bus system for the analysis of power swing.
- The multifunction relay can be designed for double line compensated transmission lines also.

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