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Three Zone Protection By Using Distance Relays in SIMULINK/MATLAB

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Abstract - This project describes modeling of distance relay and zone protection scheme using Matlab/Simulink package. SimPowerSystem toolbox was used for detailed modeling of distance relay, transmission line and fault simulation. In the modeling, single line to ground (SLG) fault was chosen to be the fault type and impedance type distance characteristic was choose to be as the protection scheme. A graphical user interface (GUI) was created using GUI package inside Matlab for the developed model.

In this project fault (L-G) is applied only for a particular amount of time externally by using a block called 'three phase fault'. Fault is applied only for phase A in this paper. It is simulated only upto opening of the circuit breaker when there is a fault in the line but not upto the reclosing of the circuit breaker. It is also observed the waveforms of voltages and currents by simulating the transmission line with and without faults also.

Key Words— **Switch gear protection, distance relay, line protection, MATLAB/SIMULINK, Impedance.**

1. Introduction

It is necessary for the for electrical engineering graduates who takes switchgear and protection subject understanding the protection schemes are very important. They must be prepared with sufficient knowledge and understands before being ready to work in power systems or power related fields. Protection relays are among main components in power systems which can give very high impact on power system's stability and reliability. One of the protection relays used in power system is distance or impedance relay which is mainly used in transmission system These relays can be used as Primary or backup protection. Distance relays can be used to protect the transmission lines or power transformers[7]. Now a days, numerical distance relays have been used widely replacing the electromechanical and static distance relays.

Distance relay will be designed to protect the power system by using some logic from the observed waveforms. Some of the logics obtained from the waveforms to implement the zone protection scheme.

The goal of this paper is to explain the building process of Simulink model for distance relay, inside the modeling, fault detection, apparent impedance calculation for all types of faults, zone coordination were designed and implemented, a Impedance type distance characteristic was chosen to be the protection scheme for this relay is the developed model can be included in one block set only by creating the subsystem for the developed model. The created subsystem block set also can be copied and pasted at any space or file thus eliminates the multiple building of the model.

1.1 Principle of Operation

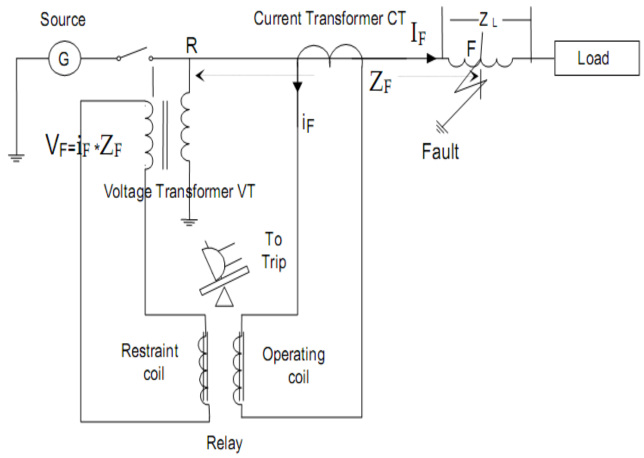

Fig 1: Principle operation of a Distance Relay

The basic principle involved in the above figure explains the division of the voltage at the relay by the measured current. The absolute impedance is compared with the reach point impedance If the measured impedance is less than the reach point impedance, it is assumed that a fault exists on the line between the relay and the reach point. The reach point of the relay is the point along the line impedance locus that is intersected by the boundary characteristics of the relay. Distance relay is the broader name of the different types of impedance relay. The relay is connected at position , R and receives a secondary current iF, equivalent to a primary fault current , IF. The secondary voltage , VF, is equivalent to the product of the fault current "IF" and impedance of the line up to the point of fault, ZF. The operating torque o f this relay is proportional to the fault current "IF", and its restraining torque is proportional to the voltage "VF". Taking into account the number of turns of each coil, there will be a definite ratio of V/I at which the torque will be equal. This is the reach point setting of the relay. The relay will operate whe n the operating torque is greater than the restraining torque .Thus any increases in current coil ampere - turn s , without a corresponding increase in the voltage coil ampere - turns , will unbalance the relay. This means the V/ I ratio has fallen below the reach point. Alternatively if the restrain torque is greater than the operating torque , the relay will restrain and its contacts will remain open[8] . In this case the V/I ratio is above the reach point. The reach of a relay is the distance from the relaying point to the point of fault. Voltage on the primary voltage transformer , VT , is :

$$V = \frac{EZ_F}{Z_S + Z_F} \qquad \text{------------(1)}$$

And Fault current is given as

$$I_F = \frac{Z_F}{Z_S + Z_F} \qquad \text{--------------(2)}$$

The Relay compare the secondary values of V and I as to measure their ratio which is called measured impedance Zm

$$Z_m = \frac{Z_F * C.T.Ratio}{P.T.Ratio} \qquad \text{----------------(3)}$$

2. Algorithm for Fault Calculation:

The different types of faults in the power system may be classified as symmetrical and unsymmetrical faults. The line to ground(LG), line to line (LL) fault and double line to ground (DLG) fault are classified as unsymmetrical faults [5]. Three phases fault is the only symmetrical fault where all phases are in contact with each other. Basically, when a fault occurs at a transmission line, distance relay measures the impedance between the faulty phases in case of LL fault or between faulty phases and neutral conductor in case of ground faults. Table 1 show the different algorithm used to measure the fault impedance for different types of fault [1]. Distance relay will first determined the fault type by using internal phase selection feature and then determine which impedance measurement algorithm must be used.

Fault Type	Algorithm
RG	$V_R/ (I_R+3K_0I_0)$
YG	$V_Y/ (I_Y+3K_0I_0)$
BG	$V_B/ (I_B+3K_0I_0)$
RY or RYG	$(V_R - V_Y)/(I_R - I_Y)$
BR or BRG	$(V_B - V_R)/(I_B - I_R)$
YB or YBG	$(V_Y - V_B)/(I_Y - I_B)$
RYB or RYBG	(V_R/ I_R) or (V_Y/ I_Y) or (V_B/ I_B)

Table 1. Fault Impedance Algorithm For Different Fault Types

Where; R, Y and B indicates faulty phases.
G indicates ground fault.
V_R, V_B, V_Y indicate voltage phasors
I_R, I_Y, I_B indicate current phasors
Z_0 = line zero-sequence impedance
Z_1 = line positive-sequence impedance
k_0 = residual compensation factor
where $k_0 = (Z_0 - Z_1)/k Z_1$,
k can be 1 or 3 depend on the relay design

3. Modeling of Transmission Line and Impedance Relays.

Matrix laboratory is powerful analysis software which has the capability of modeling power system components using Sim Power Systems toolbox inside Simulink package. In this toolbox, many power systems components are available such as three-phase transformer, three-phase load, distributed parameters , three-phase source, circuit breaker etc can be utilized for DC or AC applications [4]. All these components are ready to use where the users should only drag the components into model file and enter the parameter values.

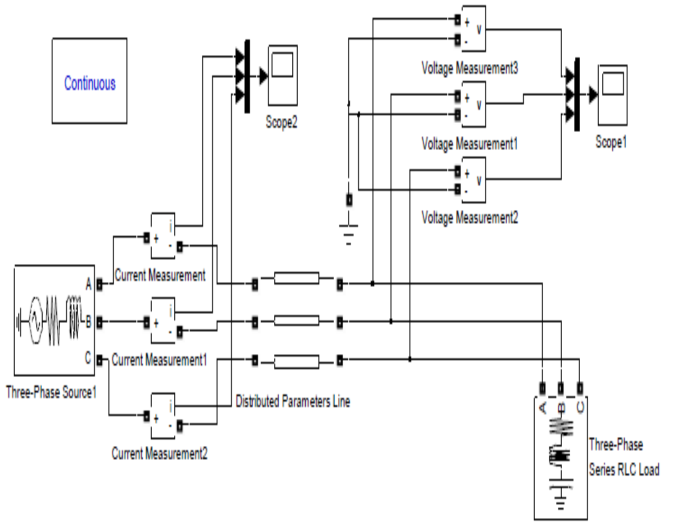

Fig. 2. Simulation of transmission line without fault:

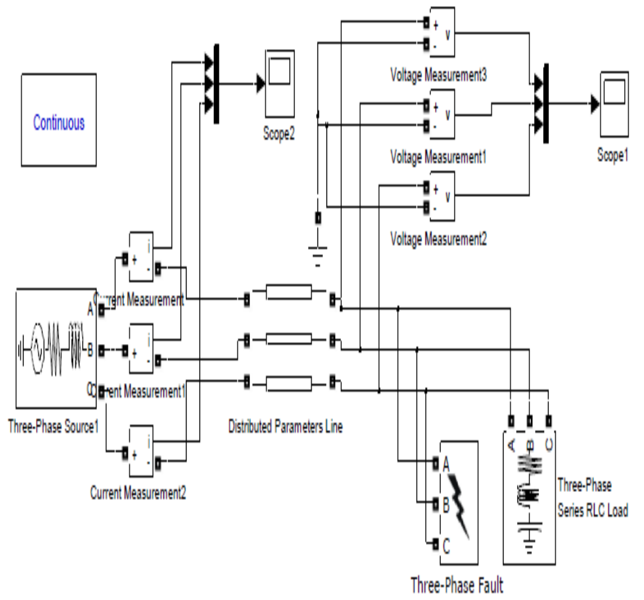

Fig.3 Simulation Of Transmission Line With Fault

In the following two plots the fault voltage and fault currents are shown when the fault is applied in phase A.

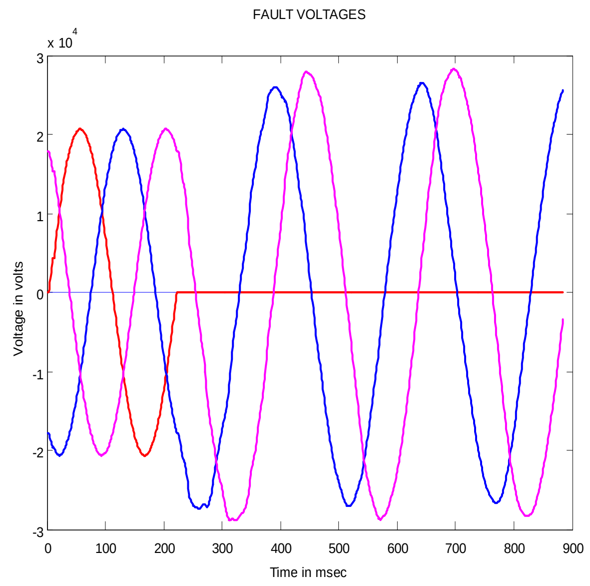

Fig.4 Fault Voltages

From the above waveform it can observe that the circuit will be operated under normal conditions up to 0.22 seconds. When the single line to ground fault occurs the phase A voltage becomes zero and the voltages of remaining phases slightly increased.

When the fault is applied, it is observed that the fault currents in the transmission line as shown in the below figure.

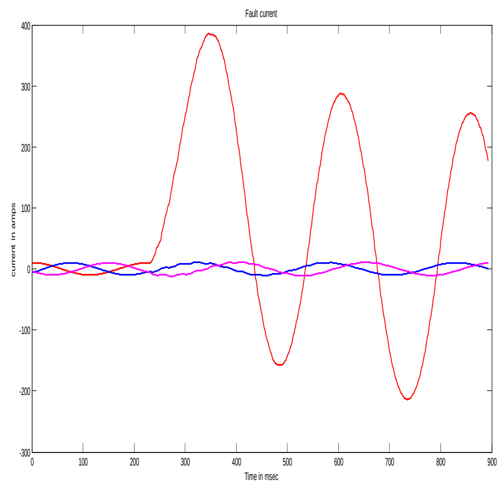

Fig.5 Fault Current

3.1 Modeling Of Impedance Relay:

In this we will discuss about the circuit model of both impedance relay and zone protection scheme The following simulink model shows the impedance relay.

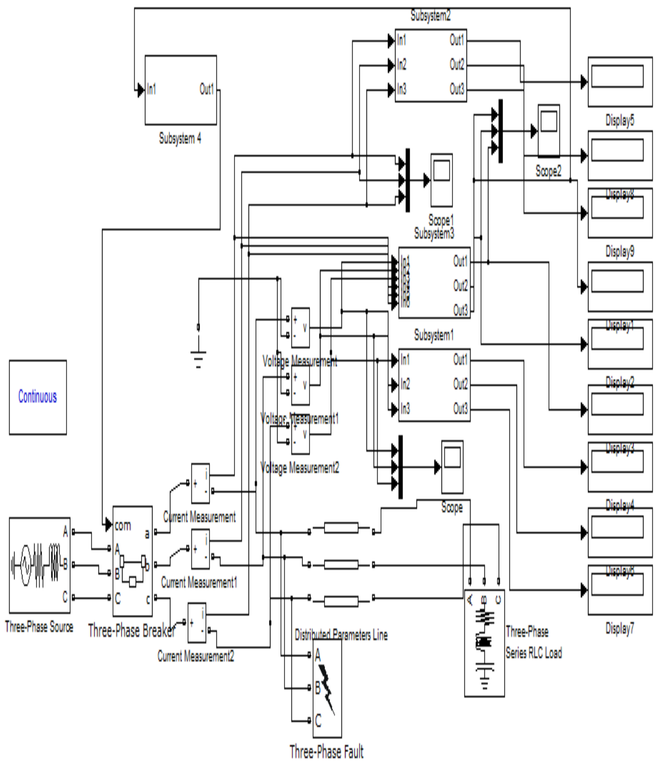

Fig.5 Simulation Of Transmission Line With impedance Relay

There are four subsystems in this circuit model. In the first subsystem average value of voltage is measured. In the second subsystem average value of current is measured. Similarly, in the third subsystem average value of impedance is measured. In the fourth subsystem relay circuit is designed so that whenever relay senses that the impedance is less than a pre-specified value(here 20).The average values of these quantities can be measured by using RMS and MEAN VALUE blocks.

In the third subsystem the mean value of impedance is obtained by dividing the mean value of voltage by mean value of current in the respective phases. In the fourth subsystem a relay is designed so that whenever the impedance of the fault line is decreased below a pre-specified value the relay circuit senses the fault and gives a signal to the circuit breaker to open the line.

3.2 CIRCUIT MODEL OF ZONE PROTECTION SCHEME

The following simulink model shows the zone protection scheme.

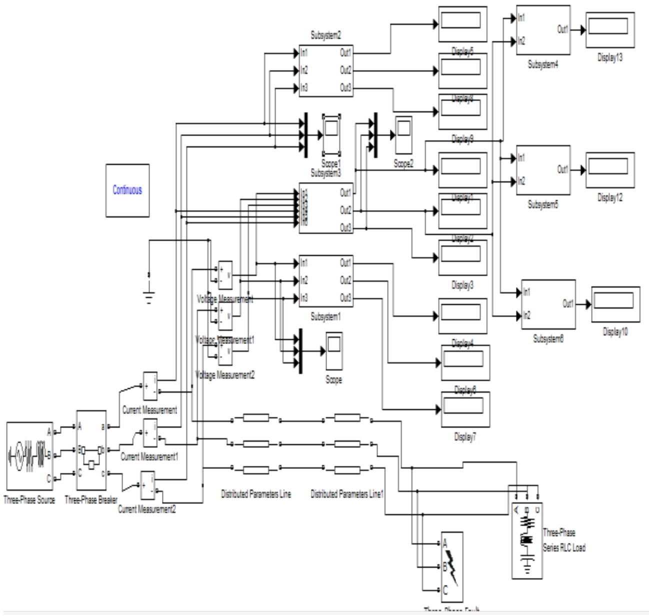

Fig6 Simulation Of Transmission Line With Zone Protection

In this circuit model there are six subsystems. The following six circuits show the six subsystems. In the first subsystem average value of voltage, in the second subsystem average value of current, in the third subsystem average value of impedance is measured. In the fourth subsystem a relay circuit is designed for the protection of zone 'A' by using the output wave forms of impedance of zone 'A' simulation. In the fifth subsystem a relay circuit is designed for the protection of zone 'B' by using the output wave forms of impedance of zone 'B' simulation. . In the sixth subsystem a relay circuit is designed for the protection of zone 'C' by using the output wave forms of impedance of zone 'C' simulation.

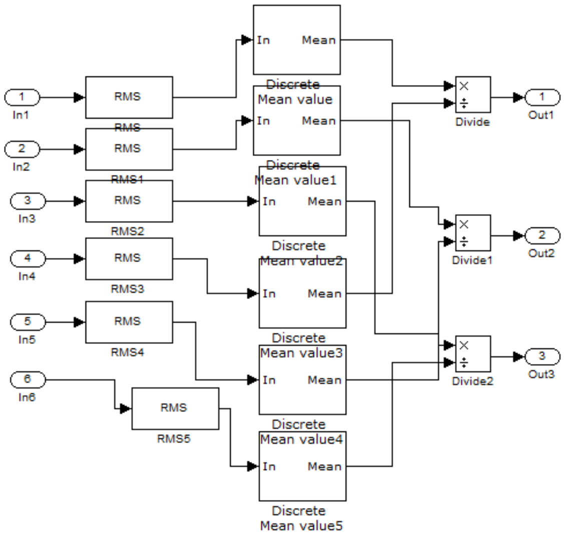

Fig.7 Logic for Impedance Calculation.

In the subsystem 3, mean values of impedances of three phases are calculated.

3.3 Modeling Of Zone Protection Scheme:

From the impedance wave forms we can observe that impedance of phase A will be decreased to zero and the impedances of the remaining phases are above 3000 ohms. By using this relation the relay is designed. When impedance of phase A is less than 3000 ohms and impedances of phase B or C (healthy lines) are greater than 3000 ohms the display will show logic '1'. If only first display shows logic high, it means that the fault is at zone A. i.e. near to the generating station.

From the impedance wave forms we can observe that impedance of phase A will be decreased to a lowest point of 17 ohms and the impedances of the remaining phases are above 1350 ohms. By using this relation the relay is designed. When impedance of phase A is less than 1350 ohms and impedance phase B or C (healthy lines) are greater than 1350 ohms the first and second displays will show logic '1'. If only first and second displays show logic high, it means that the fault is at zone B. i.e. the fault is at a point 30 kilometers ahead from the generating system.

From the impedance wave forms we can observe that impedance of phase A will be decreased to a lowest point of 34 ohms and the impedances of the remaining phases are above 1840 ohms. By using this relation the relay is designed. When impedance of phase A is less than 1840 ohms and impedance phase B or C (healthy lines) are greater than 1840 ohms, then all the displays will show logic '1'. If all the three displays show logic high, it means that the fault is at zone C. i.e. the fault is at a point near to the load centre. In this relay design we have to take care about the coincidence of the logic with the other two relay circuits.

4. Operation Of Impedance Relay

Impedance relay is nothing but the change in impedance will be recognized by the relay and give a signal to the circuit breaker to open the line. The following figure will show the impedance relay when the fault is not applied.

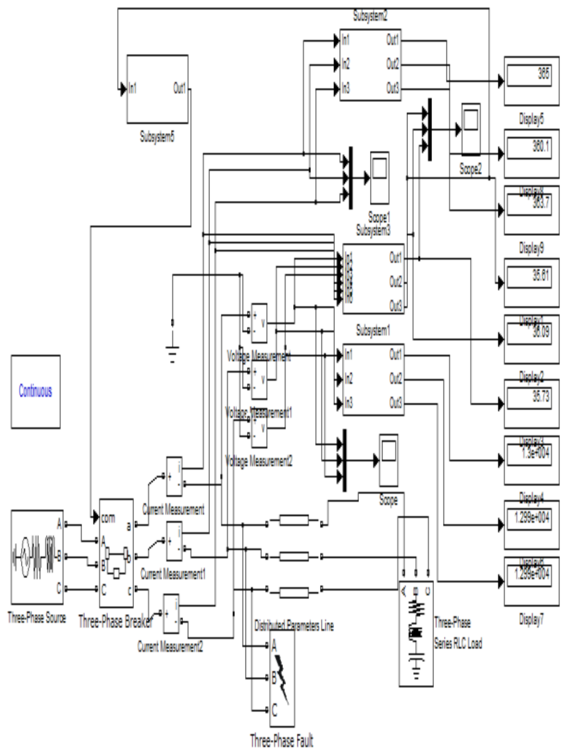

Fig. 8 Impedance relay when fault is not applied

Initially before applying the fault normal voltages, currents and impedances will present in the transmission line. The average values of voltages, currents and impedances are shown in the above figure.

The following waveforms show voltages in the transmission line before the fault.

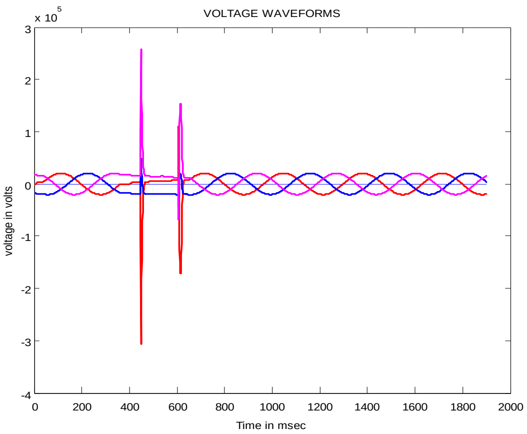

Fig. 9 voltages in the transmission line

From the above figure it is clear that before applying the fault the voltages in transmission line are normal.

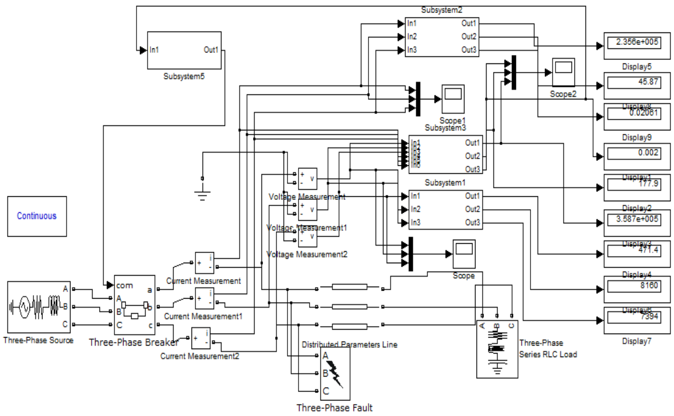

Fig.10 Impedance relay immediately after the fault has applied

In the above figure immediately after the fault is applied, we can observe that fault current (phase A) is increased enormously and fault voltage, impedance are decreased enormously. The operation of relay when the fault is applied can be explained as When the fault is recognized i.e. the impedance is reduced the relay circuit in the subsystem4 will generate a signal and send it to the circuit breaker so that it will open the line. It can be observe that the currents of the transmission line are zero after opening of the line by the circuit breaker.

The following wave forms explain us that as the relay sense the fault, immediately the circuit breaker opened the transmission line.

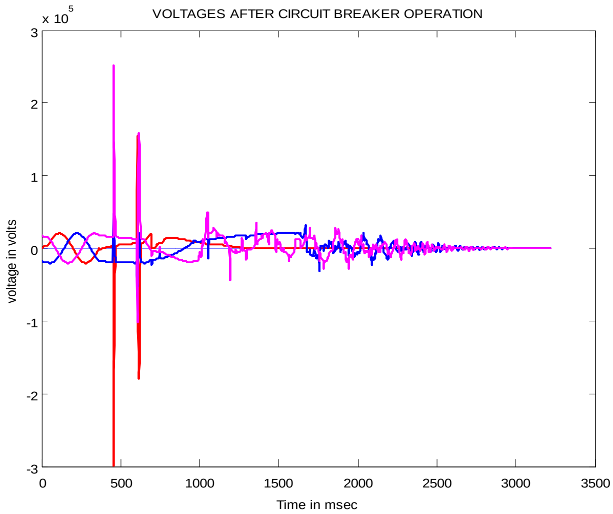

Fig.11 Voltage waveforms after the circuit breaker is opened.

From the above figure it is concluded that as the circuit breaker is opened all the voltages of three phases decreased to zero.

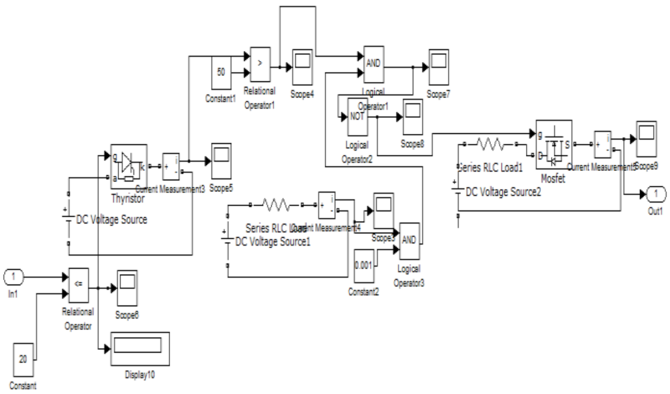

Fig.12 Operation of relay circuit

From the input1 impedance of phase A will be carried. Whenever a fault occurs in phase A, the impedance will be decreased enormously near to zero. So we compared impedance of phase A with a constant say 20 using a relational operator. When a fault occurs the relational operator will give its output as '1' or signal high. This will trigger the thyristor in the next circuit so that a current will start to flow in the closed circuit. This current will be measured by a current transformer and the measured value will be compared with a low constant by using a relational operator so that it will give an output logic high or '1' . This logic high signal and a constant high signal are given to an AND gate so that the AND gate give its output as logic high. This logic high is connected to NOT gate so that the NOT gate give its output as logic low or '0'.

From the above explanation as long as there is no fault in the line the NOT gate give logic high or '1' to mosfet so that it closes circuit and carries some current through it. This current will be measured by the current transformer and give measured value to circuit breaker so that the circuit breaker keeps closing the line.

Whenever there is a fault the NOT gate give logic '0' as its output so that the mosfet stops conducting. So the current transformer won't give any current value to circuit breaker so that the circuit breaker opens the three phase transmission line.

In this way the impedance relay operate when there is a fault.

4.2 Operation Of Zone Protection Scheme

Zone protection is nothing but the protection of power system zone wise.

The following circuit will show the zone A protection scheme.

:

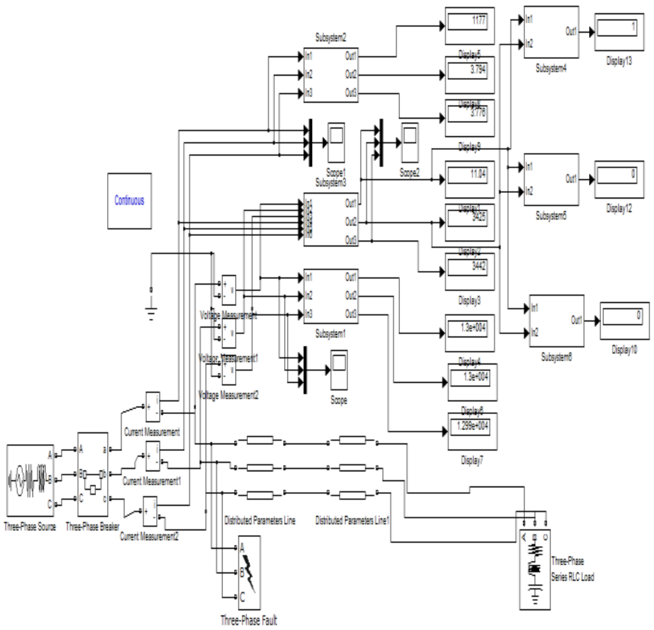

Fig.13 Zone 'A' Protection

When the fault is applied at the generating side i.e. at zone 'A' only the relay circuit designed inside the subsystem4 will activate so that only the first display will show '1'. Whenever only the first display shows '1', it means that the fault is occurred at zone 'A'.

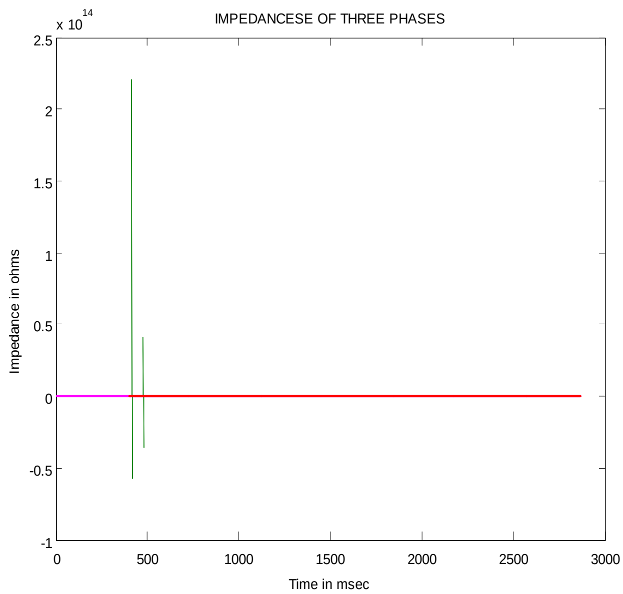

Fig 14. Impedance waveforms of the three phases when fault is at zone 'A':

The following figure will show the zone 'B' protection scheme.

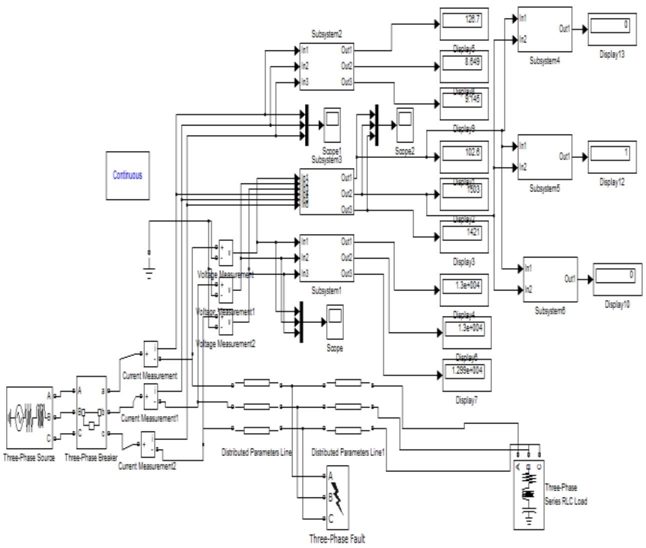

Fig. 15 Zone 'B' Protection:

When the fault is applied at a point near to the middle point i.e. at zone 'B', the relay circuit designed inside both subsystem4 and subsystem5 will activate so that only first and second displays will show '1'. Whenever first display and second display shows '1', it means that the fault is occurred at zone 'C'.

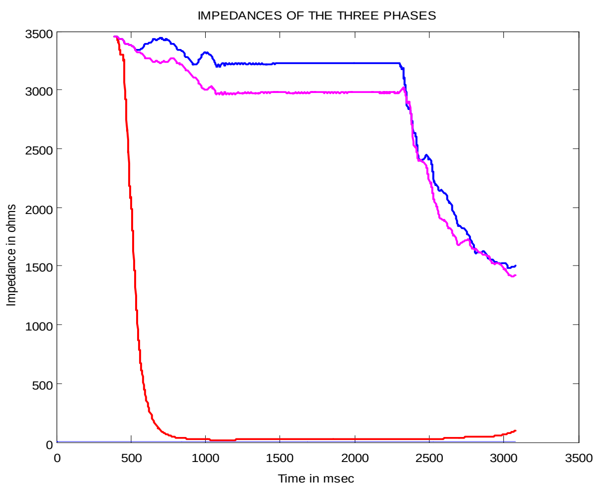

Fig.16 Impedance wave forms of the three phases when fault is at zone 'B':

From the above impedance wave forms we can observe (by zooming) that impedance of phase A will be decreased to a lowest point of 17 ohms and the impedances of the remaining phases are above 1350 ohms. By using this relation the relay is designed. When impedance of phase A is less than 1350 ohms and impedance phase B or C (healthy lines) are greater than 1350 ohms the first and second displays will show logic '1'. If only first and second displays show logic high, it means that the fault is at zone B. i.e. the fault is at a point 30 kilometers ahead from the generating system.

The following figure will show the zone c protection scheme.

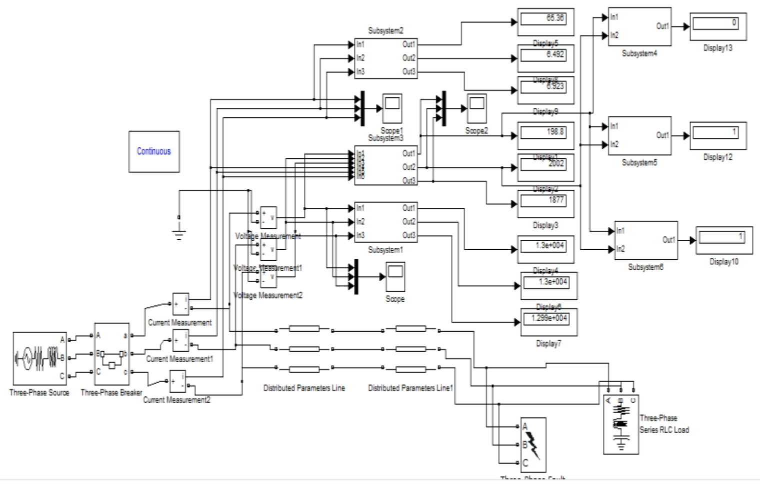

Fig.17 Zone Protection 'C':

When the fault is applied at a point near to load point i.e. at zone 'C', the relay circuit designed inside subsystem4, subsystem5 and subsystem6 will activate so that all the three displays will show '1'. Whenever all the displays show '1', it means that the fault is occurred at zone 'C'.

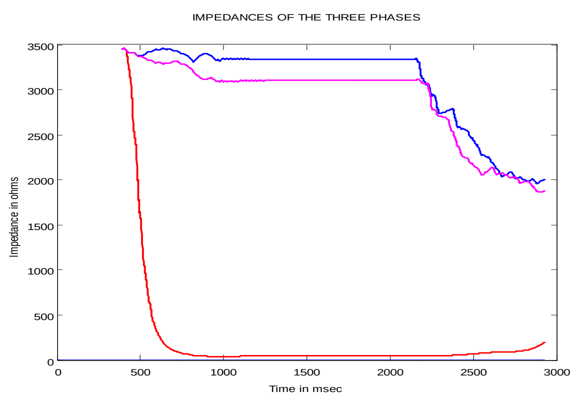

Fig. 18 Impedance wave forms of the three phases when fault is at zone 'C':

From the impedance wave forms we can observe (by zooming) that impedance of phase A will be decreased to a lowest point of 34 ohms and the impedances of the remaining phases are above 1840 ohms. By using this relation the relay is designed. When impedance of phase A is less than 1840 ohms and impedance phase B or C (healthy lines) are greater than 1840 ohms, then all the displays will show logic '1'. If all the three displays show logic high, it means that the fault is at zone C. i.e. the fault is at a point near to the load centre. In this relay design we have to take care about the coincidence of the logic with the other two relay circuits.

5. CONCLUSION

A 25kv transmission line is taken into consideration and a simulink model is designed for the line. A single line to ground fault is considered and the line is simulated with and without fault. Current and voltage waveforms under normal and fault conditions are observed. From the waveforms it is concluded that the voltage becomes zero and high currents in the order of 500 amps flow in the line.

A relay circuit is designed and a circuit breaker is incorporated in the transmission to isolate the line against the fault. Impedance values are measured at different instances like before fault occurrence, at the instant of fault, and after isolation of line. It is concluded that under fault conditions the circuit breaker gets opened and impedance values are less.

A simulink model is designed for the distance zone protection scheme. Logic circuit for relay operation is developed from the observed impedance waveforms. From this model it is concluded that the zone at which the fault occurs can be identified.

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