Three zone detection and distance relay co-ordination of power system protection

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ABSTRACT

To secure the transmission lines against power system faults, the distance relays are mostly used. Distance relay has its own resistance (R)-reactance (X)-characteristics. Co-ordination of different distance relays is necessary for the fast operation of circuit breaker. Various distance relays which are being tripped with respect to circuit breakers which are attached at individual buses faraway from each other. These relays will be operated with respect to the distance between the occurred fault and relay location. In this paper, detection of three zones using relay characteristics, co-ordination of distance relays and circuit breakers are shown with the faults placed at different locations of an IEEE 9 bus system using MATLAB/Simulink GUI environment. A comparison also made between the relays performance and circuit breaker tripping operation with respect to severe faults at different locations on IEEE 9 bus system.

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1. INTRODUCTION

With day by day increase in power demand, results the power system to be more stressed. Due to these sudden increase in power demand where the power generation remains constant for a short period of time, the power system experiencing major disturbances like heavily loaded, cascaded outage of lines which may allow to grids blackout [1]. Inorder to prevent darkness due to blackout, it is essential to block the multiple outages of lines [2, 3]. Distance Relays are mostly used protection system for transmission lines, which are also play a crucial role in preserve the security as well as reliability of supply [4, 5]. Distance Relays will provide three zone schemes of protection. Compared to the first and second zones, third zone is vulnerable and will have a wide area of protection [5]. Due to any disturbance, the impedance identified by relay will go in for the third zone of mho relay characteristics, the relay will consider as a fault and relay operates which it should not. This maloperation of relay under stressed conditions can cause blackout [6-8]. So, it is necessary to detect the zones of the relay before blocking of the relay maloperation. By using conventinal relays, the circuit breakers will trip the supply to the nearby fault whch is required and inaddition the circuit breakers connected faraway from severe fault may also trip the supply which is not required [9]. This interrupted power supply from the source to the loadends may effect the consumer side products [10-12]. Inorder to reduce this effect, the relays and circuit breakers should be in co-ordination. The distance relay and respective circuit breaker should respond only if the fault is near to the relay, called as primary relay but not to be operated if the fault is faraway from the relay, it should need to operate only if the required circuit breaker not responded, called as backup realy [13]. To acomplish the relay co-operation, mho type relays are used, the operation is done with reference to the admittance evaluated at the specific node [14]. The power system having used numbers of transmission lines and needs to protect all these transmission lines by using fast responding relay [15].

An elementary mho relay [16] ahead with a 2-bus test network shall be observed in Figure 1. The vectors from Figure 1 are set off by current I through the line with a change of resistsnce R, reactance X and impedance Z values. The resistance R value and the X is considered to be the real and imaginary values respectively. The impedance (R-X) characteritics is the marked by using the measured current and voltage at a particular tarnsmission line. Impedance angle is determined by comparing the angles between V, said to be polarizing quantity and IZ said to be conducting quantity. Considered E is Grid or supply and fault occurred on line. The circle diagram also presented in Figure 1 for more clarity on representation of system parameters used in grid system. Morevore, the relay can able to measure the current flowing through line continuously to work accordingly occurance of fault on the system [17].

Impedance charactersitics or R-X plot always fluctuate with variation in the diameter of the respective zone, if a transient state [18] happen on the line such as severe fault at both the ends of the respective line. When the current and impedance relation changes which are generally inverse to each other, the performance of the relay also varies. During steadystate conditions, the impedance Z value is high because the V is greater than the current I. So, the impedance measured by relay will never enter into the R-X characteristics in result relay will not respond. But during abnormal such as fault conditions, the value of V falldown to a low value whereas the I value suddenly raises which makes the Z value to falldown [19, 20], results the relay will respond immediately. The circuit breakers which are attached to the power carrying lines are operated with variation in Z value with reference to the faults, either at source or at load ends. To view mho relay co-ordination, this paper considers an IEEE 9 bus system. The severe faults are taking place at various placements and observed the switching operation of the breakers with reference to the fault distance from the relay placement [21].

An IEEE 9 bus system [22] which actually consists of 3 PV generating sources at respective buses 1, 2 and 3. Three PQ load buses at buses 5, 6 and 8 respectively. The six 230 kV operating lines which are medium lines. The total power system network is a ring main system where 3 PV sources out of one generating source acts as a slack bus and three PQ loads are connected with respect to each other by allocating the active and reactive power from all the sources. IEEE 9 bus system single line diagram is shown in Figure 2. PV source each generates active power at various voltages [23] and dissimilar capacity of step up transformers are interconnected to each other. Individual transformer secondaries are maintained at 230 kV.

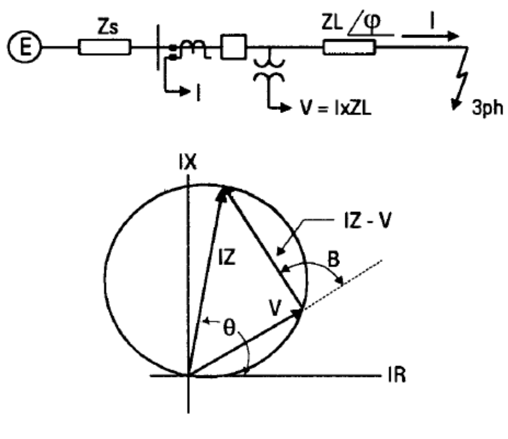


Figure 1. Mho relay function

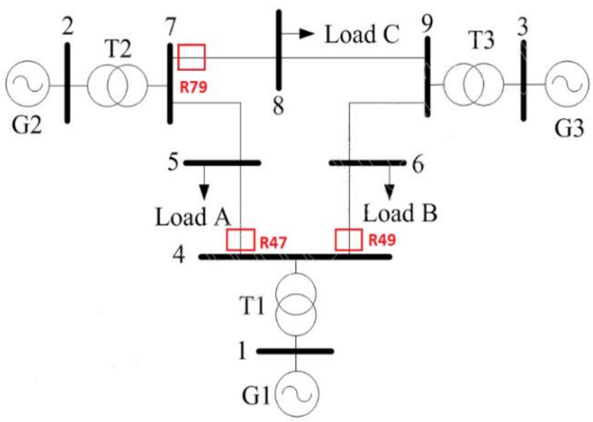


Figure 2. Placement of distance relays R79, R47 and R49 of IEEE 9 bus system

Impedance is generally considered with resistance R and reactance X, as given below

$$Z = R + jX \tag{1}$$

Now the complex impedance signal is converted to polar form inorder to fing the angles of each parameter, given as

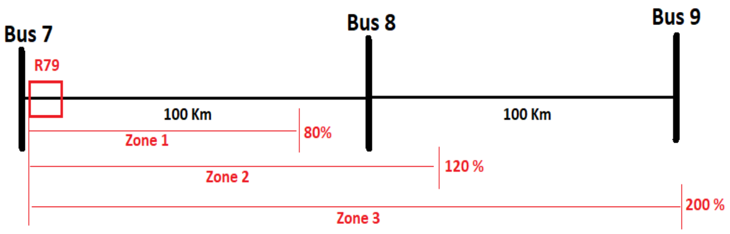
$$Z| = (|V|)/(|I|) \quad (2)$$

$$\angle Z = \angle V - \angle I \quad (3)$$

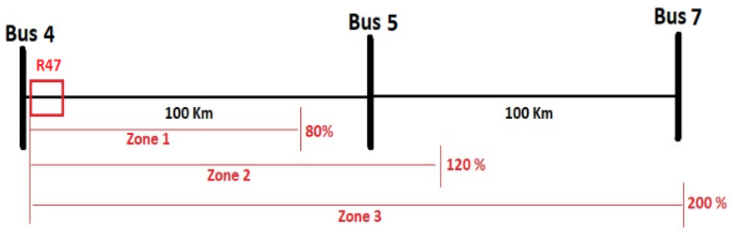
Consider a most severe fault is created for sudden change in current in the transmission lines. Modelling of IEEE 9 bus system with three distance relays are: i) Distance relay R79: R79 is placed at bus 7-9 which ensures three zone protection of power carrying lines connecting from bus 7 to bus 8 and bus 8 to bus 9; ii) Distance relay R47: R47 is placed at bus 4-7 which ensures three zone protection of power carrying lines connecting from bus 4 to bus 5 and bus 5 to bus 7; iii) Distance relay R49: R49 is placed at bus 4-9 which ensures three zone protection of power carrying lines connecting from bus 4 to bus 6 and bus 6 to bus 9. R79, R47 and R49 relays are used to ensure three zone protection of the power system which are placed at different places also shown in Figure 2. These distance relays will sense the fault and make the circuit breakers to operate if necessary. Three circuit breakers are: i) Circuit Breaker CB1: Operates when signals sent by the distance relay R79; ii) Circuit Breaker CB2: Operates when signals sent by the distance relay R47; iii) Circuit Breaker CB3: Operates when signals sent by the distance relay R49 connected at system. A three-phase fault is applied at respective buses at 0.3 secs and fault cleared at 0.5 secs. Simulation run for 0.7 secs.

2. ZONAL SCHEME OF PROTECTION

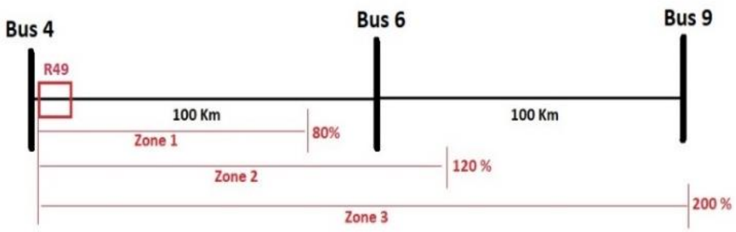
To ensure complete protection of a power system, it requires to operate a distance relay for three zones. Zone-1 operates for 80% of first line, Zone 2 operates for 100% of first line plus 20% of second line and Zone 3 operates for 100% of first line plus 100% of second line. So that a distance relay provides protection for two transmission lines. Zone 2 and Zone 3 also acts as a backup relays with a time delay [24, 25]. The three-zone protection scheme of IEEE 9 bus system is shown in the Figure 3. Figure 3(a) shows three zone protection of relay R79. Figure 3(b) shows three zone protection of relay R47. Figure 3(c) shows three zone protection of relay R49.



(a)



(b)



(c)

Figure 3. Three zone scheme of protection, (a) R79 three zone scheme, (b) R47 three zone scheme, (c) R49 three zone scheme

The design of distance relays shown in Figure 4 which detects the zone of the relay. The zone detection is designed as shown in Figure 4 is based on if and else programming. If the impedance evaluated by distance relay is less than the impedance setting of the respective relay, then this design shows at which zone the relay is going to operate.

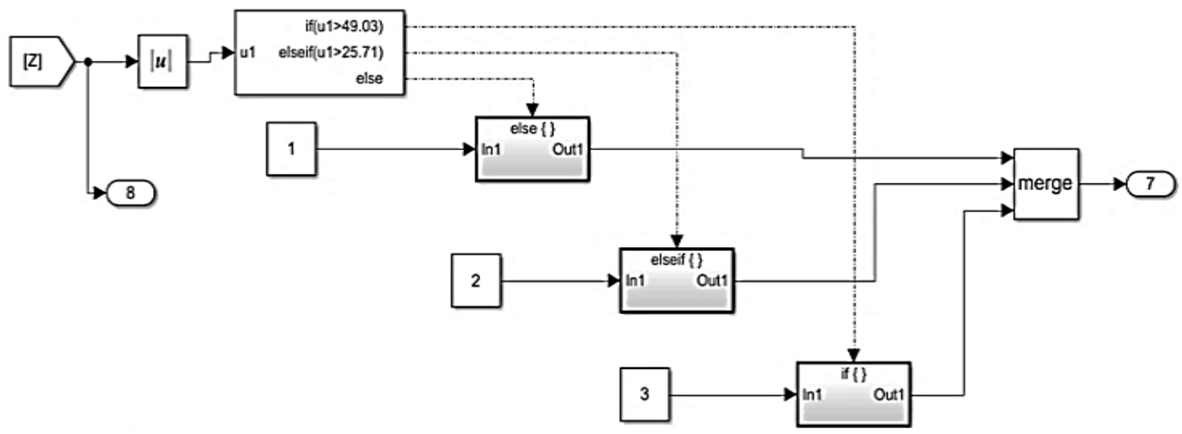


Figure 4. Zone detection simulink design

3. RESULTS AND ANALYSIS

3.1. Distance relay characteristics

To protect the transmission lines of IEEE 9 bus system, the distance relays R79, R47 and R49 are placed. To understand the relay operation, the three phases to ground fault is applied at 0.3 secs and cleared at 0.5 secs at different distances far from the relay position. The simulation has run for the following different fault occurable cases:

- Fault at 60 km far from bus 7-9;
- Fault at 110 km far from bus 7-9;
- Fault at 160 km far from bus 7-9;
- Fault at 60 km far from bus 4-7;
- Fault at 110 km far from bus 4-7;
- Fault at 160 km far from bus 4-7;
- Fault at 60 km far from bus 4-9;
- Fault at 110 km far from bus 4-9;
- Fault at 160 km far from bus 4-9;

3.1.1. Distance relay R79

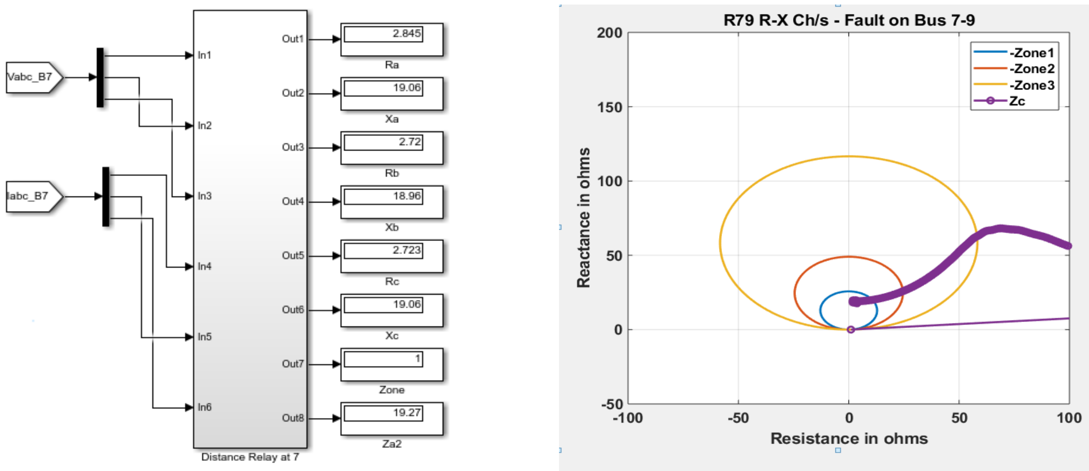
The settings of the distance relay R79 placed at bus 7-9 is shown in the Table 1.

Table 1. R79 settings

Protective Zones	Zonal Percentage	Z (Ohms)
Zone-1	80% of Bus 7-Bus 8	25.80
Zone-2	100% of Bus 7-Bus 8 + 20% of Bus 8-Bus 9	49.00
Zone-3	100% of Bus 7-8 + 100% Bus 8-Bus 9	116.80

- Fault at 60 km far from bus 7-9

  A three-phase fault is placed at 60 km, 110 km and 160 km far from R79 relay and the design of distance relay is shown in the Figure 5(a), reveals the variations of resistance and reactance values due to fault for all the three phases. The impedance variation due to fault is entering into the zone 1 characteristics as shown in Figure 5(b), zone 2 characteristics as shown in Figure 6 and zone 3 characteristics as shown in Figure 7. So, the relay R79 operates and makes the CB1 to trip.
- Fault at 110 km far from bus 7-9 as shown in Figure 6
- Fault at 160 km far from bus 7-9 as shown in Figure 7



(a) (b)

Figure 5. (a) Design of distance relay R79, (b) R79 R-X characteristics

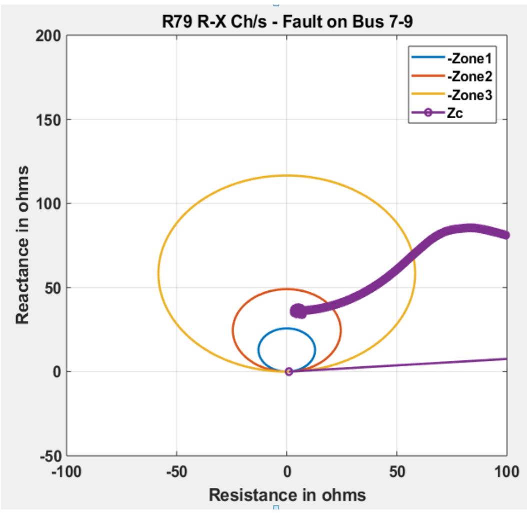


Figure 6. R79 R-X characteristics

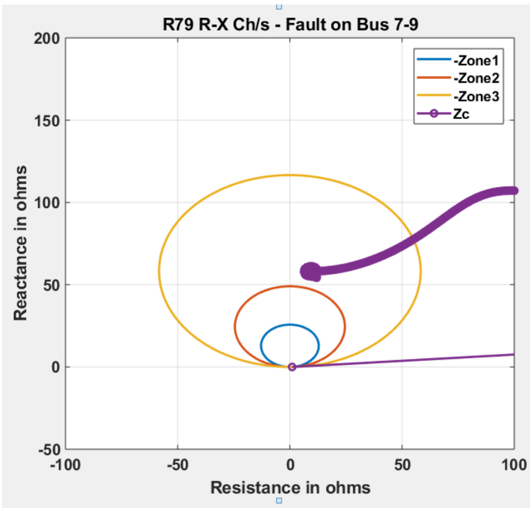


Figure 7. R79 R-X characteristics

3.1.2. Distance relay R47

The settings of the distance relay R47 placed at bus 4-7 is indicated in the Table 2.

Table 2. R47 settings

Protective Zones	Zonal Percentage	Z (Ohms)
Zone-1	80% of Bus 4-Bus 5	30.40
Zone-2	100% of Bus 4-Bus 5 + 20% of Bus 5-Bus 7	61.50
Zone-3	100% of Bus 4-Bus 5 + 100 % Bus 5-Bus 7	155.80

– Fault at 60 km far from bus 4-7

  A three-phase fault is applied at 60 km, 110 km and 160 km far from R47 relay and the design of distance relay is same as shown in the Figure 5(a), reveals the variations of resistance and reactance values due to fault for all the three phases. The impedance variation due to fault is entering into the zone 1 characteristics as shown in Figure 8, zone 2 characteristics as shown in Figure 9 and zone 3 characteristics as shown in Figure 10. So, the relay R47 operates and makes the CB2 to trip.
– Fault at 110 km far from bus 4-7 as shown in Figure 9
– Fault at 160 km far from bus 4-7 as shown in Figure 10

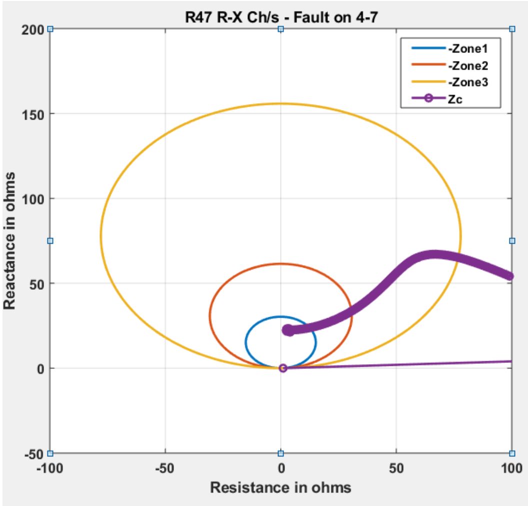


Figure 8. R47 R-X characteristics

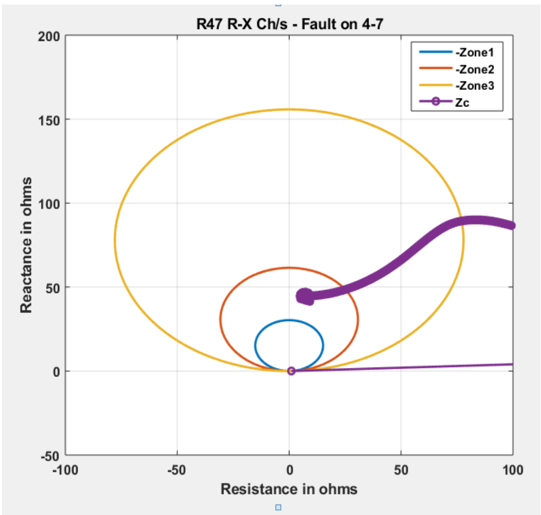


Figure 9. R47 R-X characteristics

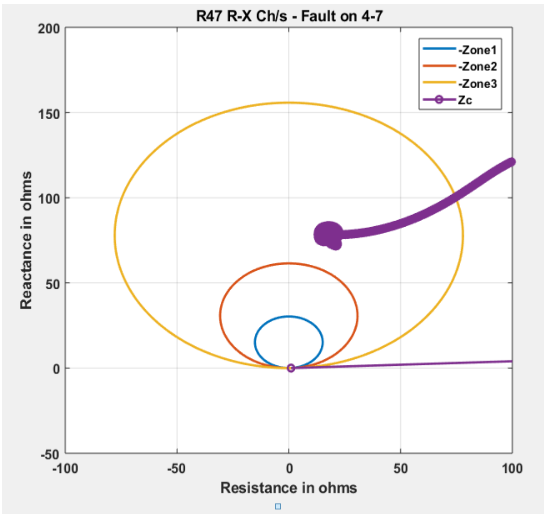


Figure 10. R47 R-X characteristics

3.1.3. Distance relay R49

The settings of the distance relay R49 placed at bus 4-9 is indicated in the Table 3. A three-phase fault is applied at 60 km, 110 km and 160 km far from R49 relay and the design of distance relay is same as shown in the Figure 5(a). Reveals the variations of resistance and reactance values due to fault for all the three phases. The impedance variation due to fault is entering into the zone 1 characteristics as shown in Figure 11, zone 2 characteristics as shown in Figure 12 and zone 3 characteristics as shown in Figure 13. So, the relay R49 operates and makes the CB3 to trip.

– Fault at 60 km far from bus 4-9
– Fault at 110 km far from bus 4-9 as shown in Figure 12
– Fault at 160 km far from bus 4-9 as shown in Figure 13

Table 3. R49 settings

Protective Zones	Line Zonal Percentage	Z (Ohms)
Zone-1	80 % of Bus 4-Bus 6	33.40
Zone-2	100% of Bus 4-Bus 6 + 20% of Bus 6-Bus 9	67.00
Zone-3	100% of Bus 4-6 + 100 % Bus 6-9	168.30

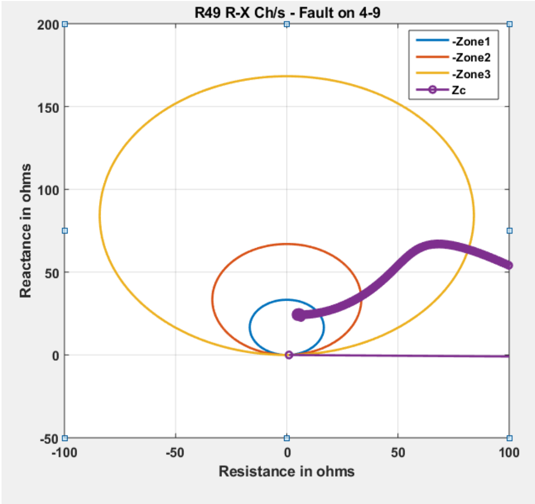


Figure 11. R49 R-X characteristics

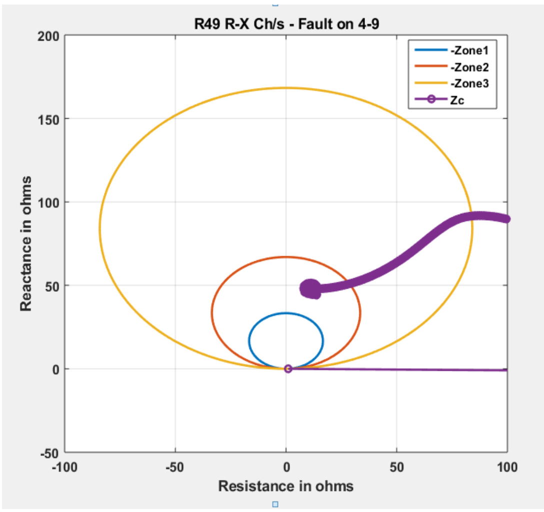


Figure 12. R49 R-X characteristics

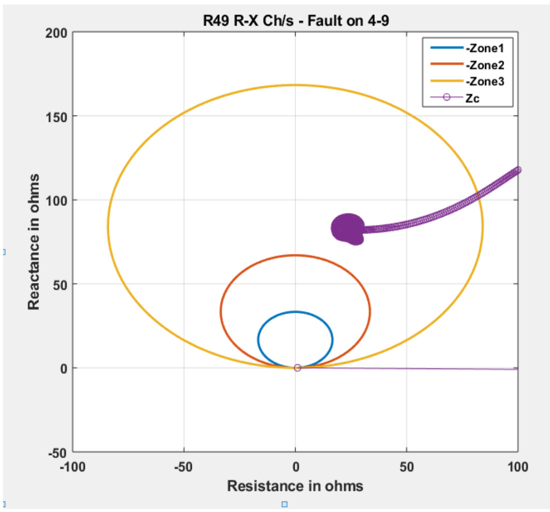


Figure 13. R49 R-X characteristics

3.1.4. Operation of circuit breakers CB1, CB2, CB3

The circuit breakers are tripped using relays R79, R47 and R49 where the impedance is evaluated by examining current and voltageof individual line. From the above section, it is observed that the distance relays R79, R47 and R49 are responding to the three-phase fault and are operating with respect to measured impedance seen between the locations of fault and relay. When the relays sense the fault, it sends tripping signals to the respective circuit breakers CB1, CB2 and CB3. It is observed that all the three single phase individual circuit breakers trip to logic '0' when the fault takes place at 0.3 secs and opens the transmission line. When the fault is cleared at 0.5 secs the circuit breakers CB1, CB2 and CB3 of all three phases will increase to logic '1' which is implemented in this simulation with the help of [8-14].

3.2. Relay co-ordination

Characteristics of R47 and R49: Consider when R79 operates due to three-phase to ground fault 160 km far from bus 7-9, the relay which is placed near to the fault location should operate i.e. R79 operates. Where as the other relays R47 and R49 should not operate which means there should be the co-ordination between the relays. The impedance measured by the R79 will enter into the R-X characteristics and the relay R79 operates as observed in Figure 5(b). But the impedance measured by other relays R47 and R49 will not enter into the R-X characteristics as shown in Figure 14 and Figure 15.

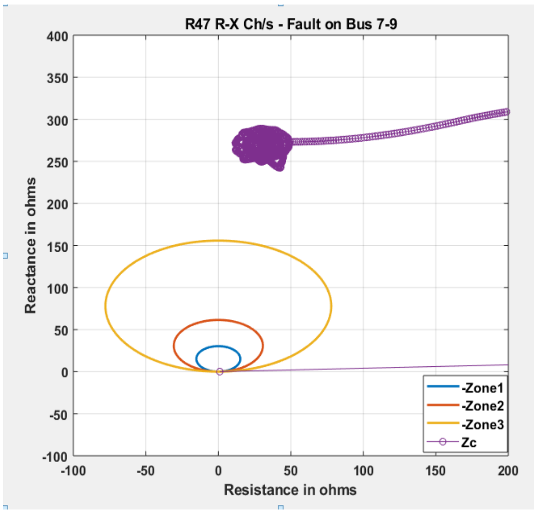


Figure 14. R47 R-X characteristics

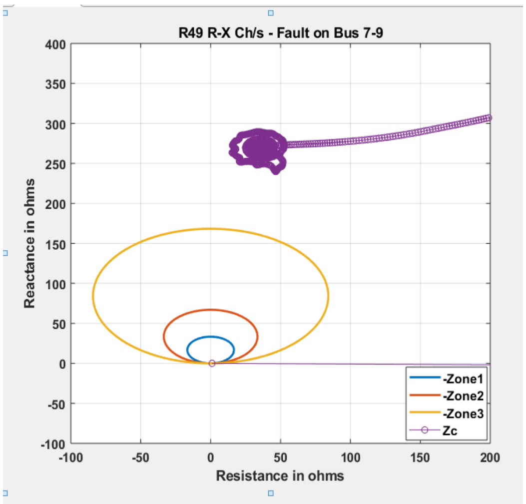


Figure 15. R49 R-X characteristics

3.3. Circuit breaker co-ordination

It is clearly observed that the breaker CB1 trips which near to the fault at bus 7-9 rather the other circuit breakers CB2 and CB3 are very far from location of fault is not operated as there is no much variation in line impedance which means circuit breaker co-ordination can be observed in Figure 16 and Figure 17. The relay co-ordination and the circuit breaker co-ordination for the above cases are indicated in Table 4, Table 5 where NT indicates as No Trip, Z1, Z2, Z3 indicates as Zones 1, 2 and 3.

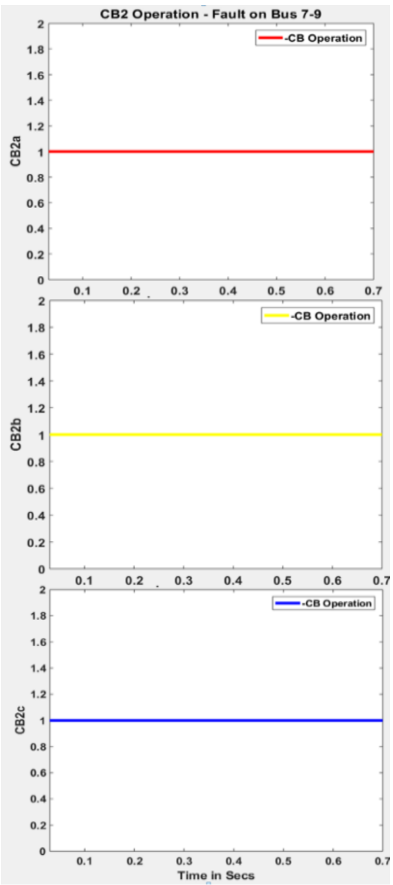


Figure 16. CB2 non-tripping signals

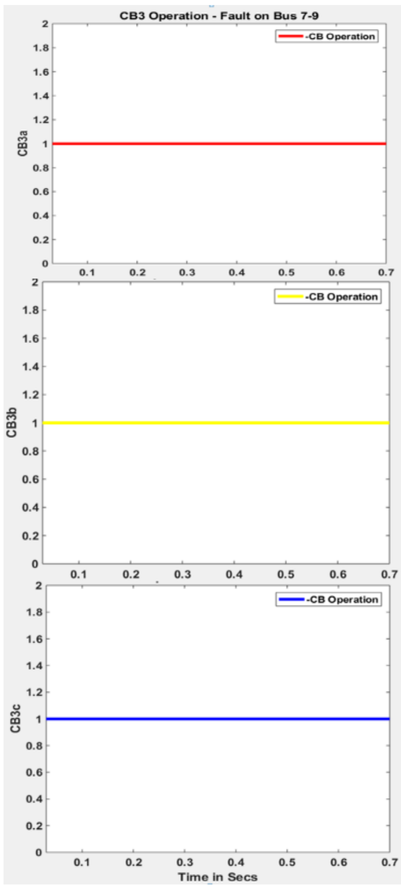


Figure 17. CB3 non-tripping signals

Table 4. Relay co-ordination

Fault/Relay	Fault on Bus 7-9			Fault on Bus 4-7			Fault on Bus 4-9		
	60 km	110 km	160 km	60 km	110 km	160 km	60 km	110 km	160 km
R79	**Z1 Trips**	**Z2 Trips**	**Z3 Trips**	NT	NT	NT	NT	NT	NT
R47	NT	NT	NT	**Z1 Trips**	**Z2 Trips**	**Z3 Trips**	NT	NT	NT
R49	NT	NT	NT	NT	NT	NT	**Z1 Trips**	**Z2 Trips**	**Z3 Trips**

Table 5. Circuit breaker co-ordination

Fault/CB	Fault on Bus 7-9			Fault on Bus 4-7			Fault on Bus 4-9		
	60 km	110 km	160 km	60 km	110 km	160 km	60 km	110 km	160 km
CB1	**Trips**	**Trips**	**Trips**	NT	NT	NT	NT	NT	NT
CB2	NT	NT	NT	**Trips**	**Trips**	**Trips**	NT	NT	NT
CB3	NT	NT	NT	NT	NT	NT	**Trips**	**Trips**	**Trips**

4. CONCLUSION

The above simulation results, reveals that the distance relays R79, R47 and R49 will operate whenever three phase faults is taking place at any distance and also ensures the three-zone protection of relay. The circuit breakers CB1, CB2 and CB3 are tripped with respect to the signals sent by the relays. When the relay operates which is close to the fault location, the other relays should not operate means relay co-ordination is done. Similarly, the circuit breakers which are linked near to the fault is immediately tripped where as the circuit breakers linked faraway from the fault are untripped. The impedances evaluated at buses 7-9, bus 4-7 and bus 4-9 are different in values when the location of fault is different and the respective relays will trip only when the measured impedance falls less than the setting value.

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