Adaptive Distance Relaying Scheme to Tackle the Under Reach Problem due Renewable Energy

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Abstract— Diminishing fossil fuels reserves is a big driver for more generation of electrical power from renewable energy sources. The power generated from the renewable energy resources is eco-friendly, eco-green and sustainable in nature. If the power generated from these energy sources is bulk and dispatchable then they are directly integrated in the power transmission networks. The transmission networks are conventional protected with the help of distance relays. The in-feed from the renewable energy source power may cause under reach operation of the existing distance relays in the power transmission networks. In this research paper the settings of distance relays are modified as per the level of in-feed from the renewable energy source in the transmission systems under study. The fuzzy set based protection scheme is proposed in this research paper which decides the settings of the distance relays as per in-feed for the renewable energy sources. The proposed adaptive fuzzy set based relaying scheme is implemented in two small sized transmission networks with single and multiple in-feeds scenarios. It is observed that the operation of distance relays in the test transmission systems are immune under integration of renewable energy sources using the proposed adaptive distance relaying scheme

Keywords-adaptive distance relaying; fuzzy set; transmission system; renewable energy source

I. INTRODUCTION

Integration of distributed renewable energy sources (*RES*) in power transmission systems has both merits and demerits. They can help the utilities to improve nodal voltage profile; system loss reduction; peak load sharing and enhancement in the power reliability [1]. One of the major challenges is protection and control of these sources in the power transmission networks. Distributed *RES* injection can jeopardizes the existing distance protection schemes in the power transmission networks. Distributed *RES* injection changes the topology of the power networks. Conventionally power network at transmission and sub transmission levels are protected with the help of distance relays. These relays are set for the predefined configuration of power transmission networks. *RES* are site specific and power output from these resources is highly unpredictable. Depending upon and availability and size of *RES*, they are connected in power transmission network for bulk transfer of electric power to the load centers.

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Presently very small portion of *RES* power contribution is in grid connected mode. But in the near future their contribution in the bulk power transfer through grid will be quite significant. Under those operational scenarios, the performance of existing distance relays will be quite unsatisfactory. They may mal- operate due to in-feed of fault currents from the connected *RES*. As the numbers of *RES* in the transmission system increases, the in-feed contribution from RES will increases and existing distance relays need new relay setting under these operational scenarios. Moreover, the contribution of in-feed from new *RES* is not similar to the in-feed due to connection of a conventional power generator. The in-feed in case of conventional generator is constant and distance relays can be easily set for new network configuration.

But in case of new *RES* connection with the transmission as states above, these sources are highly unpredictable and intermittent in nature which leads the variable in-feed fault currents to the distance relays. An adaptive distance relaying is discussed in the paper which changes the setting of distance relays as per the level of in-feed from the new connected *RES*. The proposed adaptive relaying protection scheme utilizes the fuzzy rule base sets for deciding the different zones of distance relays as per the location of *RES* in the power transmission networks. The proposed adaptive relaying scheme is implemented in two different test power networks with multiple in-feed from connected *RES* in the NEPLAN simulation software.

II. DISTANCE RELAY PROBLEM FORMULATION UNDER IN-FEED FROM *RES*

Distance protection is a non-unit type of protection scheme and has the ability to discriminate between faults occurring in different sections of the power transmission line, depending on the impedance measured by the distance relay. Essentially, this involves comparing the fault current as seen by the relay against the voltage at the relay location to determine the impedance down the line to the fault [2].

Normally, three protection zones in the direction of the fault are used in order to cover a section of line and to provide back-up protection to remote sections. In the majority of cases the setting of the reach of the three main protection zones is made in accordance with the following criteria [3].

Zone -1 (Z1): this is set to cover between 80 and 85 per cent of the length of the protected line;

Zone -2 (Z2): this is set to cover all the protected line plus 50 per cent of the shortest next line;

Zone -3 (Z3): this is set to cover all the protected line plus 100 per cent of the second longest line, plus 25 per cent of the shortest next line [4].

In addition to the unit for setting the reach, each zone unit has a timer unit. The operating time for zone-1 is denoted by t1, is normally set by the manufacturer to trip instantaneously of order 0.1 sec. Since any fault on the protected line detected by the zone- 1 unit should be cleared immediately without the need to wait for any other device to operate. The operating time for zone-2(t2) is 0.4 sec, and that of zone-3(t3) is 0.7 sec [5-6]. The Fig.1 shows the different zones of operation for a distance relay at bus A.

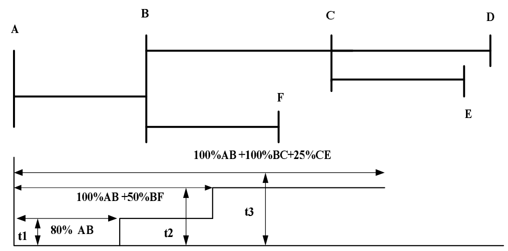

Fig.1. Three zones distance relaying scheme

The effect of in-feeds [7] is also taken into account when there are one or more generation sources within the protection zones of a distance relay, which can contribute to the fault currents without being seen by the distance relays. Fig.2 shows the *RES* in-feed at bus B, when main power source at bus A.

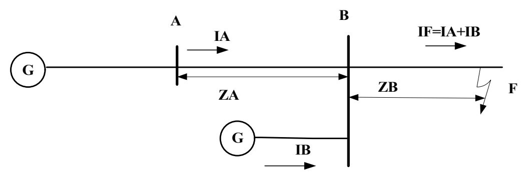

Fig.2 Effect of *RES* in-feed on the distance relaying scheme

Impedance seen by the distance relay at bus *A* for a fault beyond bus *B* is greater than actually value. In fact, if a solid earth-fault is present at F, the voltage at the relay at *A* would be expresses as per. (1) [8].

$$V_a = I_A * Z_A + (I_A + I_B) * Z_B \quad (1).$$

$$\frac{V_A}{I_A} = Z_A + (1 + \frac{I_B}{I_A}) * Z_B \quad (2).$$

The impendence seen by the distance relay at location *A* is expresses as per (3) below. From (3), it is clear that distance relay at *A*, is experiencing the under reach due to in-feed from bus B.

$$Z_z = Z_A + (1 + K) * Z_B \quad (3).$$

Where K is given in Eq. (4) below:

$$K = \frac{I_B}{I_A} = \frac{I_{\inf eed}}{I_{relay}} \quad (4).$$

The proposed adaptive distance relaying algorithm is explained in the Flow chat manner in Fig.3 below.

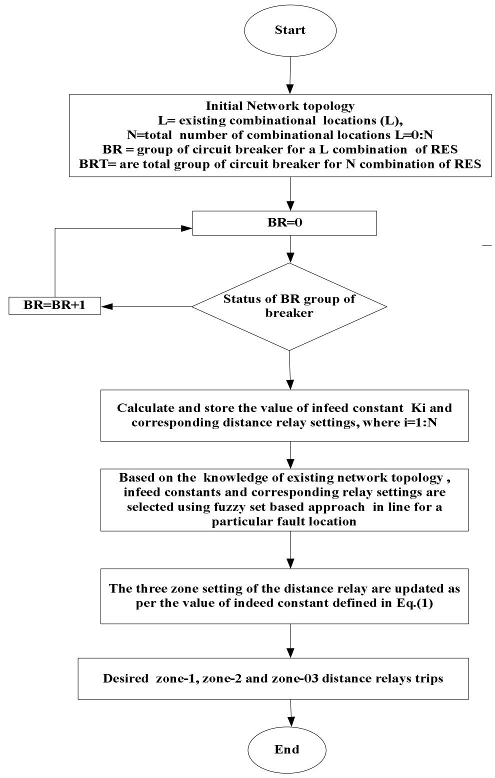

Fig.3.Adaptive distance relaying algorithm

Based upon the available site for *RES* connected in the power transmission network, all possible combination of *RES* are identified and stored in advance. Network topologies stored and all possible in-feed constants are also evaluated. Based upon the network topologies and in-feed constants, corresponding relay distance settings are calculated and a knowledge based is formulated in a lookup table form [9]. Then fuzzy rule base technique is utilised for the selection of desired distance relay settings based on the existing network topology. When a fault takes place in power network, the existing topology is identified with the help of circuit breaker status. Based on the topology, the in-feed constants are selected and desired relay settings for the different zones are transferred to corresponding distance relays [10].

In this way, based on the number of *RES* connected in the power network, desired relay settings are selected from the look up table using fuzzy based rule of the reliable operation of distance relays .

III. RESULT & DISCUSSUIN

The proposed adaptive distance relaying scheme is implemented in two different small sized transmission systems. The system description, result and subsequent discussion on the result are presented in the following sections.

A Test Transmission system with single in-feed

In this test transmission network single infeed is provided from a single *RES*. As per the Eq. (4) above, the infeed constant *K* in this case is 3.73. The distance relays are installed at each line ends in the forward directions as shown in Fig.4 below. The performance of forwards distance relays are checked without and with infeed conditions. Three zone settings of the distance relays in terms of impendences are given in Table 1 under infeed and without infeed operating conditions.

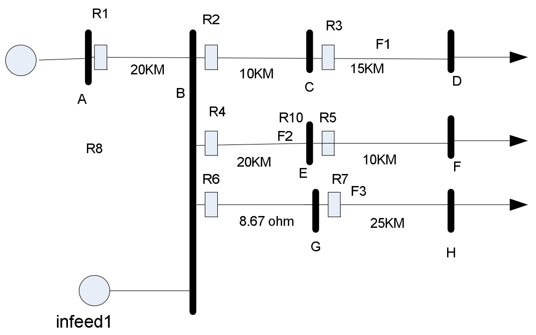

Fig.4 Single infeed transmission network

Table1. Distance relays settings with and without infeed

Relay	Zone settings					
	Zone 1		Zone 2		Zone 3	
	With out infeed	With infeed	With out infeed	With infeed	With out infeed	With infeed
	Z1	*Z1*	*Z2*	*Z2*	*Z3*	*Z3*
R1	5.05	5.05	7.90	12.61	19.67	52.11
R2	2.52	2.52	5.56	5.565	8.0	8.0
R3	3.79	3.79	4.75	4.75	-	-
R4	5.05	5.05	7.90	7.90	9.6	9.6
R5	2.52	2.52	3.17	3.17	-	-
R6	7.58	7.58	12.64	12.64	17.8	17.8
R7	6.32	6.32	8.0	8.0	-	-

Faults are conducted at different location in the system shown in Fig.4. When the faults are simulated at 50 % of CD (F1), 90% of BE (F2) and 10% of GH (F3), the summary of impendence seen by the distance relays for fault at F1 and F2 are given in Table 2 below.

Table.2. under Reach operation of relays under infeed

3 Phase Fault at	Relay name& zone	Relay setting with out infeed	Z seen by the relay		Remark	New zone setting for the relay
			With out infeed	With infeed		
F1	*R1* in zone-3	19.67	11.81	26.94	Under reach	52.11
F2	*R1* in zone-2	7.90	6.95	8.69	Under reach	12.61

From the Table 2, above it is seen that for a fault at location F1, *R1* distance relay should operate from the zone-3. *R1* is set at 19.67 ohm for zone-3 operation under without infeed operational scenario. For at fault at *F1, R1* senses 11.81 ohm and hence operates in 0.7 sec. (zone-3 operation time), when no infeed is in the network. However, during infeed at bus B, the zone-3 impendence for the relay *R1* increases to 26.96 ohm. Therefor relay *R1* faces the under reach relaying problem. In order to avoid the under reach problem of the *R1*, zone-3 setting of relay *R1* is redefined as per the adaptive relaying flowchart given in Fig.3 above. The new zone-3 setting for the R1 is selected which is 52.11 ohm. Similarly for a fault at *F2*, the *R1* have under reach problem for the zone-2 operation and its zone-2 settings are redefined for reliable operation of relays under infeed at bus B.

The settings of all the distance relays are updated as per the adaptive distance relaying algorithm discussed in Fig.3 above. Faults are once again simulated at *F1, F2* and *F3* for the system shown in Fig.4. Using the adaptive relaying algorithm as shown in Fig.3, the three zones settings of distance relays are calculated for infeed and without infeed operational conditions. The impendences seen by the different distance relays for the different zones with and without infeed ate tabled in Table.3 below. From the Table 3 below, it is seen that under reach relaying operation as seen in the Table 2 above are completely eliminated using the propose adaptive relaying algorithm as discussed in Fig.3 above.

Table.3.Adaptive setting of distance relays

3-phase Fault at	Operating relay		Z seen by the relay			
			Without infeed	Operating time	With infeed	Operating time
F1	Zone-1	*R3*	2.37	0.1	2.37	0.1
	Zone-2	*R2*	5.53	0.4	5.53	0.4
	Zone-3	*R1*	11.81	0.7	26.94	0.7
F2	Zone-1	*R4*	0.6322	0.1	0.632	0.1
	Zone-2	*R1*	6.956	0.4	8.69	0.7
	Zone-3	-	-	-	-	-
F3	Zone-1	*R7*	0.79	0.1	0.79	0.1
	Zone-2	*R6*	10.27	0.4	10.277	0.4
	Zone-3	*R1*	16.51	0.7	44.61	0.7

The impendence diagram of distance relays (*R3, R2* and *R1*) which are tripping under infeed for the fault location *F1* are given in the Fig.5 below.

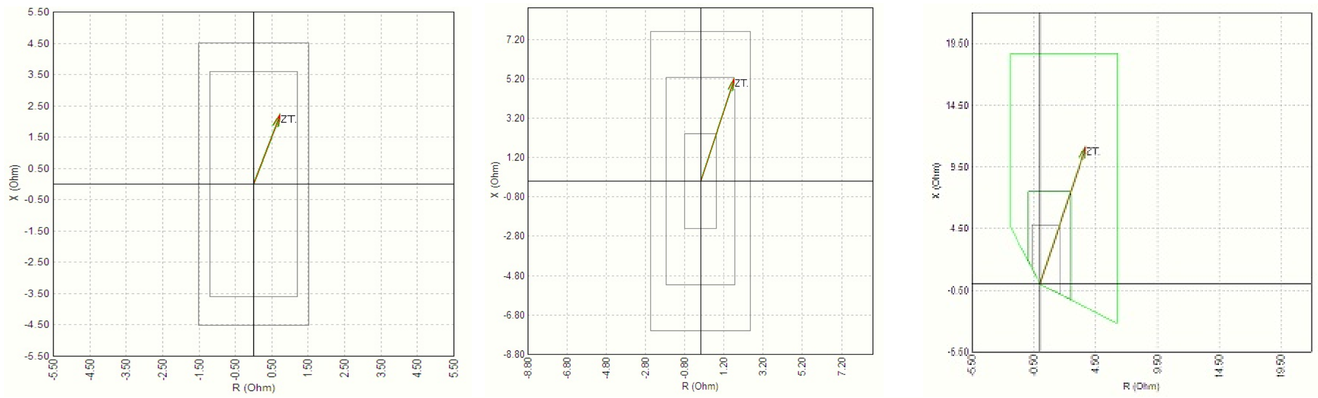

Fig.5 Impendence diagram for *R3, R2* and *R1* distance relays

B Transmission system with multiple in-feeds

The multiple infeed transmission system is shown in Fig 6 below. There four *RES* infeed at buses *C, D, G* and *F* on main system which have one main power sources at bus A. The distance relays are installed at the transmission lines ends which will clear the fault in the both backward and forward directions.

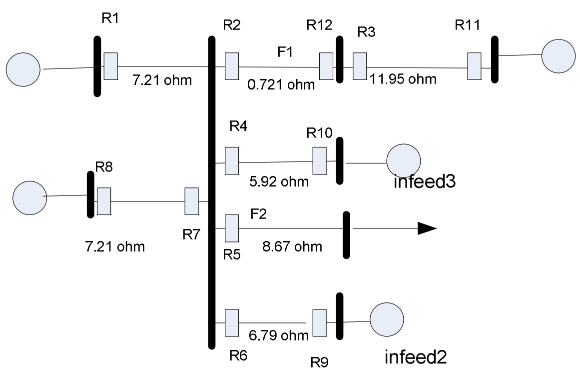

Fig.6 Multiple infeed transmission network

The distance relays which are experiencing the infeed fault currents from the connected *RES* are listed in the Table 4 below. The infeed constant values for the zone-2 and zone-3 operation of distance relays is also listed in the Table 4 below

Table.4 Infeed contents values for distance relays

Relay	Infeed constant	
	In zone-2	In zone-3
R1	3.37	4.44
R8	19.95	24.99
R9	0.72	1.14
R10	5.93	7.61
R11	6.49	8.82

The settings of distance relays for different combination of infeeds as listed in Table 5 below. These distance relays are set for different zones of operation.

Table5. Distance relays settings with and without infeed

Relays settings						
Relay		Without infeed	Infeed at bus 2	Infeed at bus 2&8	Infeed at bus 2,8&6	Infeed at bus 2,8,6&5
Zone -1		*Z1*	*Z1*	*Z1*	*Z1*	*Z1*
	R1	5.76	5.76	5.76	5.76	5.76
	R2	0.56	0.56	0.56	0.56	0.56
	R3	12.64	12.64	12.64	12.64	12.64
	R4	4.73	4.73	4.73	4.73	4.73
	R5	6.44	6.44	6.44	6.44	6.44
	R6	5.42	5.42	5.42	5.42	5.42
	R7	5.76	5.76	5.76	5.76	5.76
	R8	5.76	5.76	5.76	5.76	5.76
	R9	5.42	5.42	5.42	5.42	5.42
	R10	4.73	4.73	4.73	4.73	4.73
	R11	12.64	12.64	12.64	12.64	12.64
	R12	0.56	0.56	0.56	0.56	0.56
Zone-2		*Z2*	*Z2*	*Z2*	*Z2*	*Z2*
	R1	7.56	7.63	8.53	8.76	8.76
	R2	10.68	10.68	10.68	10.68	10.68
	R3	-	-	-	-	-
	R4	-	-	-	-	-
	R5	-	-	-	-	-
	R6		-	-	-	-
	R7	-	-	-	-	-
	R8	-	9.00	13.92	15.29	15.29
	R9	-	-	8.47	8.47	8.47
	R10	-	-	-	7.88	7.88
	R11	-	-	-	-	41.21
	R12	-	-	-	-	17.20
Zone -3		*Z3*	*Z3*	*Z3*	*Z3*	*Z3*
	R1	18.98	21.07	46.62	52.97	63.58
	R2	-	-	-	-	-
	R3	-	-	-	-	-
	R4	-	-	-	-	-
	R5	-	-	-	-	-

	R6	-	-	-	-	-
	R7	-	-	-	-	-
	R8	-	67.20	189.74	220.18	271.1
	R9	-	-	23.22	25.72	29.88
	R10	-	-	--	77.24	94.04
	R11	-	-	-	-	196.93
	R12	-	-	-	-	52.67

The distance relays which are experiencing the under reach due to *RES* penetration are identified and are listed in the Table.6 below. These relays are experiencing the under reach in zone-2 and zone-3 for faults at F1 (50% of line length) and F2 (at 90 % of line length). The new zone-2 and zone-3 settings of the distance relays are also provided in the Table.6 below as per the adaptive relaying algorithm for elimination of under reach operation of the distance relays.

Table.6. under Reach operation of relays under infeed

3-phase Fault	Relay name& zone	With out infeed relay settings	Z seen by the relay		Remark	New setting for the relay
			With out infeed	With all infeed		
F1	R1 zone-3	18.9	11.9	28.9	under reach	63.5
	R9 zone-3	-	-	15.3	under reach	29.8
	R10 zone-3	-	-	33.8	under reach	94.0
	R12 zone-3	-	-	21.4	under reach	52.6
F2	R9 zone-2	-	-	7.3	under reach	8.4
	R11 zone-3	-	-	59.1	under reach	196.9

Using the proposed adaptive distance relaying algorithm, distance relays settings are evaluated for different combination of infeed from the connected *RES*. These are selected using the adaptive fuzzy set based algorithm. Each distance relay which is expiring the under reach due to *RES* penetration are identified. Based upon the relay zone, number of infeed and distance relay a fuzzy rule is formulated as shown in Table 7 below.

Table.7 Fuzzy Rule base for distance relay settings

Relay	Relay Zone	No. of infeed	*K*
R8	2	0	0
R8	2	1	5.66
R8	2	2	16.69
R8	2	3	19.27
R8	2	4	19.95
R8	3	0	0
R8	3	1	5.79
R8	3	2	17.95
R8	3	3	20.95
R8	3	4	25.00

The new distance relay zone settings are calculated using the adaptive fuzzy algorithm as shown in the Fig.7.

In this algorithm, there are three inputs viz distance relay, zone of distance relay and number of infeed which decided the value of infeed constant (k).

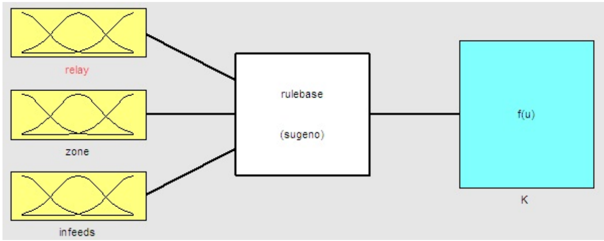

Fig.7 Adaptive fuzzy algorithm

In Fig.8 below, the membership function for a distance relay R8 are shown in which zone-3 settings are redefined for different combination of infeed. When all four infeed are in connection, the value of infeed constant K is 25 as shown in the Fig.8 below.

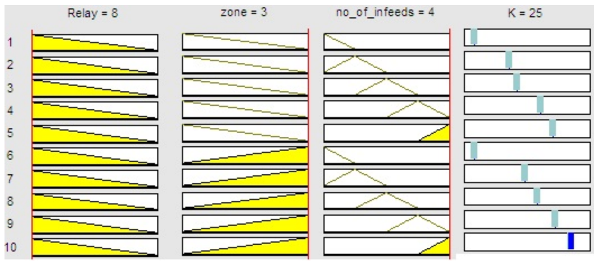

Fig.8. Membership function for relay R8

Based upon the value of infeed constants the new zone settings of the entire distance relays are calculated for elimination of under reach due to *RES* connections. These settings are given in Table 8 as per different *RES* infeed combination in the transmission system under study.

Table.8.Adaptive setting of distance relays

Fault Location	Operating Relay		Z seen by the relay				
			Without infeed	Infeed at bus 2	Infeed at bus 2&8	Infeed at bus 2,8&6	Infeed at bus 2,8,6&5
F1	Zone-1	*R5*	4.03	4.03	4.03	4.03	4.03
	Zone-2	-	--	-	-	-	-
	Zone-3	*R1* *R9* *R10* *R12*	11.1 - - -	12.01 - - -	22.2 12.6 - -	24.74 13.65 33.8 -	28.98 15.31 40.52 21.42
F2	Zone-1	*R2* *R12*	0.35 -	0.355 -	0.35 -	0.355 -	0.355 0.355
	Zone-2	*R1* *R9* *R11*	7.56 - -	7.63 - -	8.53 7.30 -	8.76 7.39 -	8.76 7.39 59.15
	Zone-3	*R8* *R10*	- -	9.25 -	13.5 -	14.65 8.38	14.65 8.38

In Fig.9, impendence diagram for different distance relays are shown for fault at location *F1* under infeed at buses 2, 5, 6 and 8.

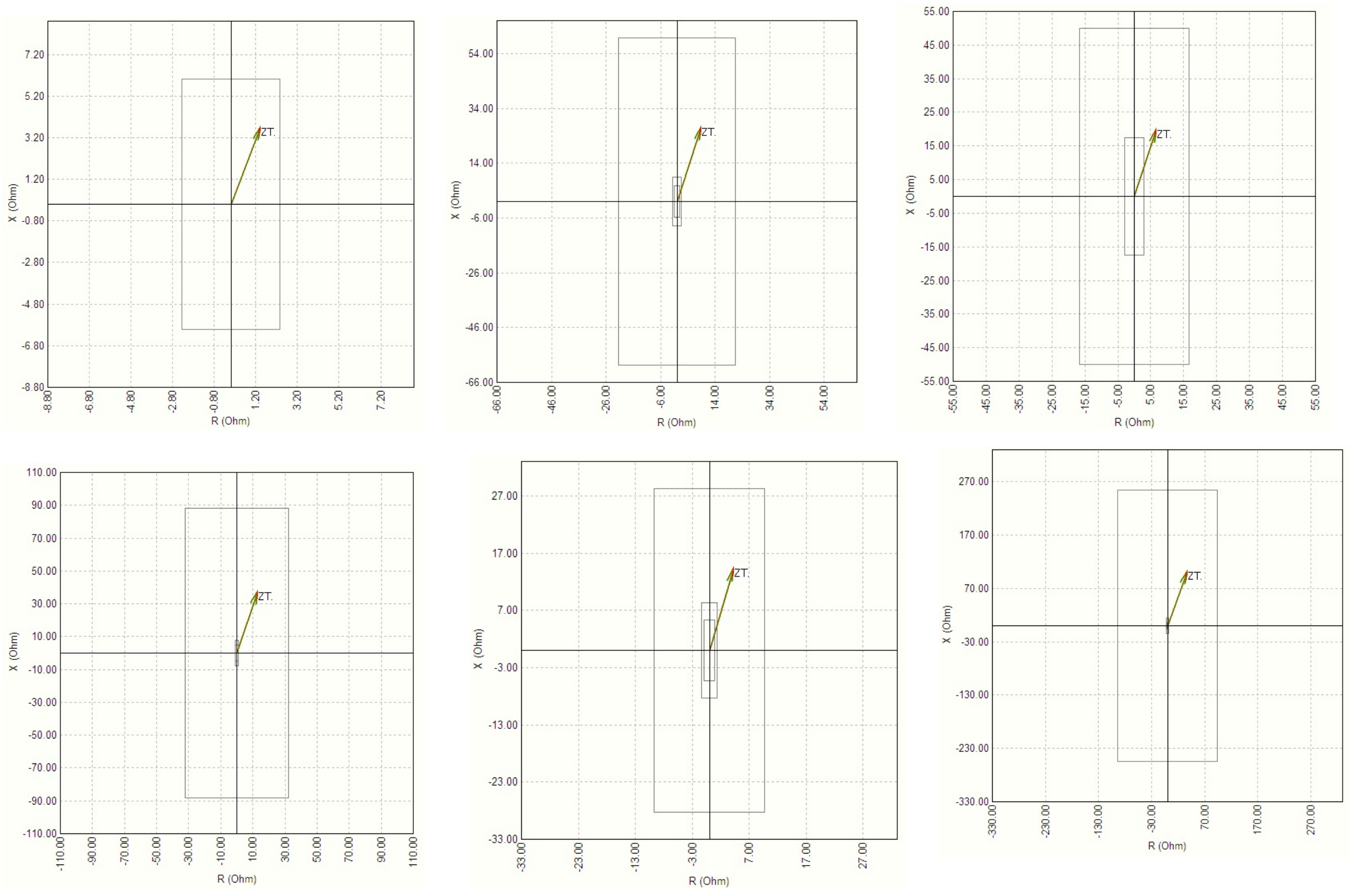

Fig.9 Impendence diagram for R5, R1, R12, R10, R9 and R8 distance relays

IV. CONCLUSION

The integration of unpredictable *RES* result in under reach operation of distance relays in a well-designed distance protection schemes of a transmission power network. This is due to in-feed of fault currents from the connected *RES* during fault conditions. In-feed from the *RES* is variable due to unpredictable nature of connected *RES* in the power networks. In this research paper, an adaptive distance relaying scheme is proposed which handle the variable in-feed from the connected *RES.* The presented research paper also proposes a suitable distance relay zone settings as per the network topology of the power system under *RES* connection. The proposed adaptive relaying algorithm is implemented for two different power networks with single and multiple in-feed from connected *RES*. Fuzzy rule based knowledge is applied for selection of zone settings of distance relays as per the in-feed from the *RES*. The proposed adaptive distance relaying algorithm is implemented with the help of NEPLAN simulation software. From the above presented results it is seen that the proposed adaptive distance relaying algorithm performs reliably under variable in-feed fault current contributions from different combination of connected *RES* in the test transmission network under study.

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