

# A New Fault Resistance Compensation Scheme for Distance Relaying Application

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**Abstract**--- Protective distance relays, which make use of impedance measurements in order to determine the presence and location of faults. The resistance introduces an error in the fault distance estimate, and hence may create an unreliable operation of a distance relay. A new compensation method based on fault resistance calculation is presented. The fault resistance calculation is based on monitoring the active power at the relay point. The compensated fault impedance measures accurately the impedance between the relay location and the fault point. This new compensation method avoids the under-reach problem in ground distance relays. MATLAB/SIMULINK'S Power System Block set (PSB) is used for detailed modeling of a power system network and fault simulation. A 400 KV, 300 km transmission line is selected as example for fault simulation and suggested approach is tested using different fault types and proven successful identification for the type of fault.

**Keywords:** Fault Resistance, Protection, Distance Relays.

## I. INTRODUCTION (Heading 1)

Protection of an important transmission line is most frequently performed using phase and ground distance relaying techniques. Distance relaying is considered for protection of transmission lines where the time-lag cannot be permitted and selectivity cannot be obtained by overcurrent relaying. Distance protection is used for secondary lines and main lines. Distance relays effectively measures the impedance between the relay location and the fault. If the resistance of the fault is low, the impedance is proportional to the distance from the relay to the fault. A distance relay is designed to only operate for faults occurring between the relay location and the selected reach point and remain stable for all faults outside this region or zone [1]. Hence It protects a certain length of line

Consider a simple radial system, which is fed from a single source. Let us measure the apparent impedance ( $V/I$ ) at the sending end. For the unloaded system, ( $I=0$ ), and the apparent impedance seen by the relay is infinite. As the system is loaded, the apparent impedance reduces to some finite value. In presence of a fault at a per-unit distance 'x', the impedance seen by the relay drops to an  $xZ_{line}$ . The basic principle of distance relay is that the apparent impedance seen by the relay, which is defined as the ratio of phase voltage to line current of a transmission line ( $Z_{app}$ ), Impedance is reduced drastically in the presence of fault. A distance relay compares this ratio with the positive sequence Impedance ( $Z_1$ ) of the transmission line. If the fraction of  $Z_{app}/Z_1$  is less than unity, it indicates a fault. This ratio also indicates the distance of the fault from the relay. Because, impedance is a complex number, the distance protection is

inherently directional. However, if only magnitude information is used, non-direction impedance relay results. Figure 1 shows a characteristic of an impedance relay and Fig. 2 presents 'mho relay' both belonging to this class. The impedance relay trips if the magnitude of the impedance is within the circular region. Since, the circle all the quadrants, it leads to non-directional protection scheme. In contrast the mho relay which covers primarily the first quadrant is direction in nature.

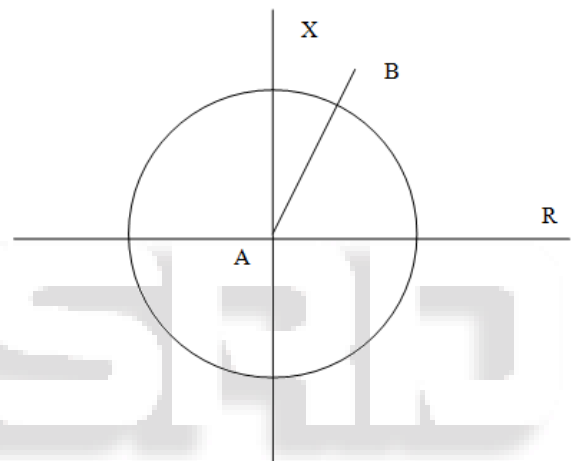


Fig. 1 Characteristics of Impedance Relay

In developing distance relay equations, the fault under consideration is assumed to be an ideal (i.e., zero resistance) [2]-[8]. In reality, the fault resistance will be between two high-voltage conductors, whereas for ground faults, the fault path may consist of an electrical arc between the high-voltage conductor and a grounded object. The fault resistance introduces an error in the fault distance estimate and hence, may create unreliable operation of a distance relay [9].

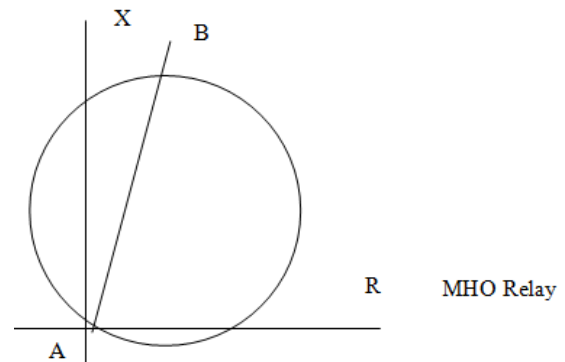


Fig. 2: Characteristics of MHO relay

The impedance seen by the relay is not proportional to the distance between the relay and the fault in general, because of presence of resistance at the fault location. There are some

techniques for arcing faults detection and fault distance estimation [10]-[11]. The techniques are based on the voltage and current at one terminal in the time domain. The overhead line parameters and arc voltage amplitude during the fault are given. The techniques have optimal application in the medium voltage networks and symmetrical faults.

## II. PROBLEM IN DISTANCE PROTECTION

### A. Over/under reach in distance relay

A distance relay is set to operate up to a particular value of impedance; for impedance greater than this set value the relay should not operate. This impedance, or the corresponding distance is known as the reach of the relay. A distance relay may under-reach because of the introduction of fault resistance as illustrated in Fig. 4. Relay at O is set for protection up to Z. If a fault at Z occurs such that fault resistance R is high and by adding this resistance the impedance seen by the relay OZ' such that Z' lies outside the operating region of the relay, then the relay does not operate. Fig. 4 shows the tripping polygonally characteristic in case of high fault resistance. In [12]-[17], different techniques are

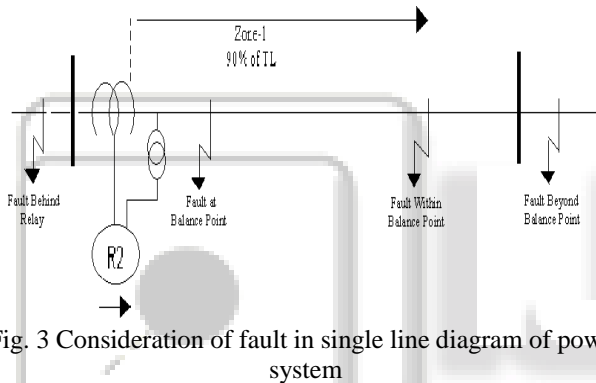


Fig. 3 Consideration of fault in single line diagram of power system

Suggested for enhancing the high fault resistance problem. These techniques accommodate this problem by shaping the trip zone of the distance relay to ensure the apparent impedance is included inside the trip zone.

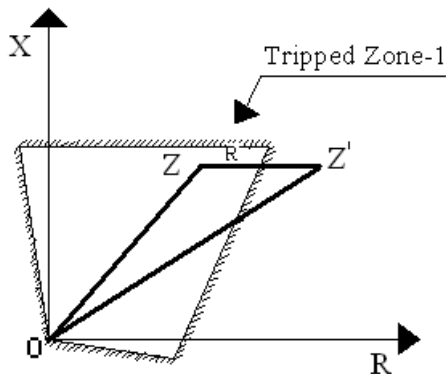


Fig. 4: Under reach in Distance relays

In this paper, a new fault impedance compensation method based on fault resistance calculation is given. The fault resistance is calculated using the active power at the sending end. The relay uses a Fourier filter to derive the voltage and current phasor. The problem of under reach in ground distance relay is solved. The ground distance relay with this new compensated is solved. The ground distance relay with this compensated method will be demonstrated. The results

will show that the fault impedance with the fault impedance with high fault resistance is accurately zoned.

### B. Double-End-Fed Earth Faults

Fig. 5 shows the phase current  $I_{g2}$  lags the phase current  $I_{g1}$  by the angle  $\delta$  because of the transfer of power from  $E_{g1}$  to  $E_{g2}$ . Since the fault resistance can normally be neglected in the case of phase-to-phase faults, it is sufficient to consider it only in the case of earth faults particularly since the tower-to-earth resistance, which under difficult ground conditions and the absence of a continuous earth wire, can reach significant values.

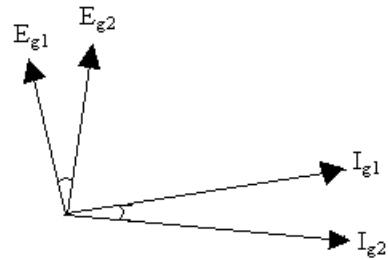


Fig. 5: Relation between phase voltage and phase current

Consider a single unbalanced fault from line-to-neutral on a system supplied through a grounded generator with positive, negative-, and zero-sequence impedances of  $Z_1$ ,  $Z_2$ , and  $Z_0$ , respectively, and with a generated positive sequence line-to-neutral voltage of  $E_{g1}$  and  $E_{g2}$ , respectively. Assume that this system is supplying a fault resistance on phase A whose impedance is  $Z_f$  as illustrated in Fig. 6 and Fig.7.

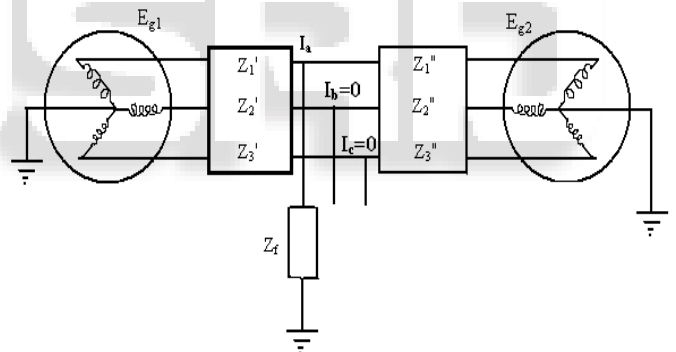


Fig. 6: Diagram for illustrating flow of power quantity For a fault between phase A and ground, the symmetrical component connection diagram is shown in Fig. 7. The phase A voltage and current can be expressed in terms of the symmetrical components and the voltage of phase A at the fault point can be set as

$$E_f = E_1 + E_2 + E_0 = (I_{g1} + I_{g2})R_f \quad (1)$$

$$E_{g1} = Z_1' I_{g1} + (Z_0' - Z_1') I_0' + R_f(I_{g1} + I_{g2}) \quad (2)$$

where  $I_{g1}$  has been substituted for the sum  $I_1' + I_2' + I_0'$  and  $I_{g2}$  has been substituted for the sum  $I_1'' + I_2'' + I_0''$ .

$$I_{g1} = I_0' (Z_0' - Z_1') / Z_1' + I_{g1} \quad (3)$$

So the uncompensated fault impedance is

$$Z_{1UN} = Z_1' = E_{g1} / I_{g1} \quad (4)$$

$(R_f (I_{g1} + I_{g2}) / I_{g1})$  is a source of error in distance relays, so the actual fault impedance is

$$Z_1' = E_{g1} / I_{g1} - R_f (I_{g1} + I_{g2}) / I_{g1} \quad (5)$$

In the same manner and for a three-line-to-ground fault and symmetrical component circuit, the compensated fault impedance for the distance relays is

$$Z_{1UN} = Z_1' = E_{g1} / I_{g1} \quad (6)$$

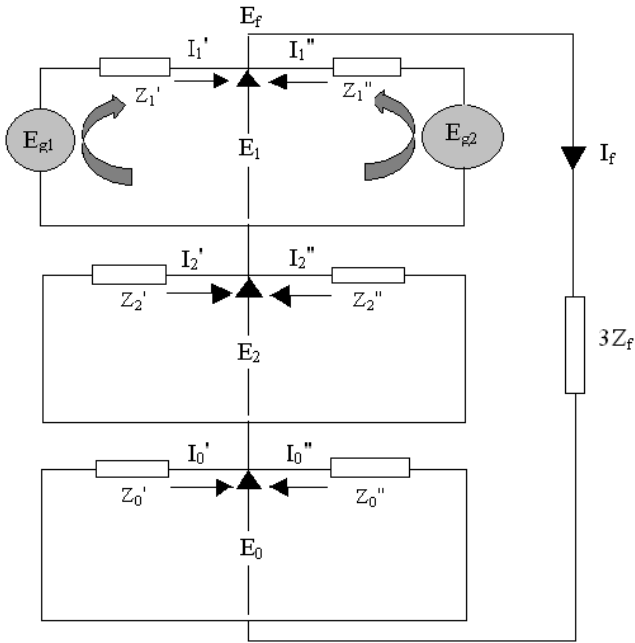


Fig. 7: Symmetrical component circuit for L-G fault (A-G fault)

$(R_f (I_{g1} + I_{g2}) / I'_{g1})$  is a source of error in distance relays, so the actual fault impedance is

$$Z'1 = E_{g1} / I'_{g1} - R_f (I_{g1} + I_{g2}) / I_{g1}. \quad (7)$$

This report aims to introduce compensated fault impedance for the above equation based on fault resistance calculation from the active power and current measurements

### C. Fault Resistance Calculation

The voltage at the fault point can be expressed by

$$E1 = (3Z_f) (I'1 + I''1) + Z'0 I'0 + Z'2 I'2 \quad (8)$$

$$E2 = -Z'2 I'2 \quad (9)$$

$$E0 = Z'0 I'0 \quad (10)$$

$$I'1 = I'2 = I'0 = E_{g1} / Z't \quad \& \quad I''1 = I''2 = I''0 = E_{g2} / Z''t \quad (11)$$

where,

$$Z't = Z'1 + Z'2 + Z'0 + 3Z_f \quad (12)$$

$$Z''t = Z''1 + Z''2 + Z''0 + 3Z_f. \quad (13)$$

The total phase quantities at the point of the fault are readily obtained from the above sequence quantities with the following results:

$$E_f = 3Z_f (E_{g1} / Z't + E_{g2} / Z''t) \quad (14)$$

$$I_f = 3 (E_{g1} / Z't + E_{g2} / Z''t). \quad (15)$$

The sequence power quantities per phase at the fault are

$$P1 + jQ1 = E1 (I'1 + I''2) \quad (16)$$

$$P2 + jQ2 = -Z'2 (I'2) (I'1 + I''2) \quad (17)$$

$$P0 + jQ0 = -Z'0 (I'0) (I'1 + I''2). \quad (18)$$

The total power quantities may be obtained by combining the sequence quantities as

$$P_t + jQ_t = 3 [(P1 + jQ1) + (P2 + jQ2) + (P0 + jQ0)] \\ = 9 Z_f (E_{g1} / Z't + E_{g2} / Z''t)^2.$$

Also, from the single phase solution, the total power quantities equal

$$P_t + jQ_t = E_a I_a + E_b I_b + E_c I_c \\ = 9 Z_f (E_{g1} / Z't + E_{g2} / Z''t)^2 \\ = Z_f (I_{g1} + I_{g2})^2. \quad (19)$$

From the above equation, it can be concluded that the total power in the fault resistance equals the power in phase "A" ( $I_b = 0$  and  $I_c = 0$ ); (Fig 3).

So,

$$P_a + jQ_a = Z_f (I_{g1} + I_{g2})^2 \quad (20)$$

Where  $P_a$  and  $Q_a$  are the power in the fault resistance from the two sources for phase A. so above equation can be expressed as

$$P_a + jQ_a = Z_f [(I_{g1})^2 + (I_{g2})^2 + 2 I_{g1} I_{g2}]. \quad (21)$$

With minimal load flow at the time of the fault [18] and the electromotive-force (emf) constant at the sending and receiving ends ( $E_{g1}$  and  $E_{g2}$ ), the current contribution  $I_{g2}$  at the receiving end is almost in phase with current  $I_{g1}$  at the sending end. Thus, the phase relationship between the fault currents ( $I_{g1}$  and  $I_{g2}$ ) and the voltages ( $E_{g1}$  and  $E_{g2}$ ) can be described by  $(\arg (I_{g1} / E_{g1}) = -90^\circ)$  and  $(\arg (I_{g1} / E_{g1}) = -90^\circ)$ .

from the above explanation, it can be concluded that the relation between the total power at the receiving end "GVA" is directly proportional with a factor  $k$  of the total power at the sending end "GVA". SO

$$GVA'' = k GVA' \quad (22)$$

Where  $k$  is defined as the distribution factor of the generated power at the receiving end with respect to the generated power at the sending end.

Consequently, the contribution power to the fault from the receiving end is also a factor of the contribution power to the fault from the sending end. So

$$P''_a + jQ''_a = k \{P'_a + jQ'_a\}. \quad (23)$$

Also, the contribution current from the receiving end to the fault is a factor from the contribution current to the fault from the sending end

$$I_{g2} = k I_{g1}. \quad (24)$$

Hence, (21) can be described as

$$P_a + jQ_a = Z_f (I_{g1})^2 [1 + k]^2. \quad (25)$$

The total power in the fault is described as

$$P_a + jQ_a = P''_a + jQ''_a + \{P'_a + jQ'_a\} \\ = k \{P'_a + jQ'_a\} + \{P'_a + jQ'_a\} \\ = \{P'_a + jQ'_a\} (1 + k). \quad (26)$$

From (25) and (26), the real part of the fault resistance is given as

$$R_f = [P'_a (1 + k)] / [I_{g1}^2 (1 + k)^2] \\ = P'_a / [I_{g1}^2 (1 + k)] \quad (27)$$

where  $P'_a$  is defined as the instantaneous power measured at the sending end and is determined as [19] and [20].

According to the above explanation, the compensated fault impedance for (5) and (7) are described, respectively, as

$$Z_{1c} = Z'1 = (E_{g1} / I'_{g1}) - (P'_a / I'_{g1} I_{g1}) \\ I'_{g1} = [I'0 (Z'0 - Z'1) / Z't] + I_{g1} \quad (28)$$

And

$$Z_{1c} = Z'1 = (E_{g1} / I'_{g1}) - (P'_a / I_{g1} I'_{g1}). \quad (29)$$

Equation (28) and (29) are the compensated fault impedance calculation for the single and three earth faults, respectively.

### III. SIMULATION AND MODELING

SIMULINK/Power System Blockset is used to create power system model for simulation. With the updated version of MATLAB/SIMULINK, the model development off power system components is onwards to perfection. Here, SIMULINK includes variant basic power components, which can be used to finish all kinds of power system network simulations.

It is very easy to create power system in SIMULINK environment, which allows building a model by simple "click and drag" procedures. Because all of the electrical

parts of the simulation interact with the SIMULINK'S extensive modeling library, it is not just possible to easily draw the power system network, but also to include its interactions with every electrical component. In addition, the simulation system of block components can set relation electrical parameters from MATLAB commands. One thing should be noted is that SIMULINK is more suitable for a small system for simulated tests. Execution speed of the simulation system will become slow when simulating system large. Luckily, the protective relays are for protection of one article of electrical equipment, so we just focus on protected equipment. Other equipment can be made in equivalent value. Therefore, by reducing the complexity of the simulation system, the simulation system result will be in high performance.

A simple 3-phase power system network as shown in Fig. was simulated to test the performance of proposed scheme. The prototype system consists of a 3-phase power supply, a transmission line represented by lumped parameters. The system parameters which have been used for simulation are given in appendix.

The main program can not only start fault simulation systems with SIMULINK but also give commands and parameters to renew simulation systems at the same time. As included in Fig. we can change parameters of simulation systems including fault location, fault resistance, fault time, and fault types etc. and then the main program will execute setting and change value. Finally the main program controls SIMULINK execution dynamic of simulation. After the simulation is finished, the simulation result data will be stored in WORKSPACE or hard disk, and its waveform can be shown directly on screen through user's command. So far we have finished fault simulation task, and then got related input data for protective program [21].

#### IV. ILLUSTRATION

The power system used for testing the proposed new method is a part of a 400 kV power system shown in fig. 8. The system include two generating station with transmission line between them and its associated components. The relay is set to protect 90% of the line. The power system is modeled and different symmetrical and unsymmetrical faults at different location with solid and fault resistance along the line will perform.

The different fault type and fault positions are as follows:

Fault type: a-g, b-g, c-g, a-b-g, b-c-g, a-c-g, a-b-c-g  
Fault Locations: 50km, 100km, 150km, 200km, 250km.

The parameters of the simulation system:

Source data at both Sending and Receiving Ends:

Positive sequence impedance =  $1.31+j15.0 \Omega$ .

Zero sequence impedance =  $2.33+26.6 \Omega$

Frequency = 50 Hz

Transmission-line Data:

Length = 300km

Voltage = 400 kV

Positive sequence impedance =  $8.25+j94.5 \Omega$

Zero sequence impedance =  $82.5+308 \Omega$

Positive-sequence capacitance = 13 nF/km

Zero-sequence capacitance = 8.5 nF/km

The obtained results will use for implementation of the proposed technique and then for testing its validity. The

voltage and current signals are measured at the relay location using a sampling frequency of 5000 Hz.

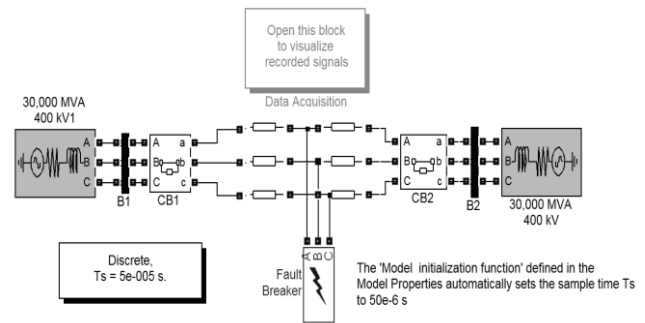


Fig. 8: Diagram of the modelled System

#### V. RESULTS AND DISCUSSION

S. r. No.	Fault type	Fault Location (km)	Actual Value		Measured Value		% error	
			$R_{act}$ ( $\Omega$ )	$X_{act}$ ( $\Omega$ )	$R_{mesu}$ ( $\Omega$ )	$X_{mesu}$ ( $\Omega$ )	R %	X %
1	a-g	50	1.375	15.75	1.369	15.2	0.44	3.49
2	a-g	100	2.75	31.5	2.67	30.75	2.91	2.38
3	a-g	150	4.125	47.25	4.113	46.25	0.229	2.12
4	a-g	200	5.5	63	5.43	62.5	1.27	0.79
5	a-g	250	6.875	78.75	6.775	77.825	1.45	1.17
6	a-b-g	50	1.375	15.75	1.3715	15.446	0.225	1.93
7	a-b-g	100	2.75	31.5	2.66	30.72	3.27	2.48
8	a-b-g	150	4.125	47.25	4.15	47.02	-0.61	0.49
9	a-b-g	200	5.5	63	5.51	63.11	-0.18	0.17
10	a-b-g	250	6.875	78.75	6.899	78.012	-0.35	0.94

Table 1: Obtained results of actual and measured impedance and error by proposed scheme

Table 1: shows simulation results obtained by the proposed scheme for different types of faults. It has been observed

that the percentage error in the measurement of resistance and reactance is within  $\pm 5\%$ .

Sr. No.	Fault type	Fault Location (km)	Actual Value		Measured Value		% error	
			$R_{act}$ ( $\Omega$ )	$X_{act}$ ( $\Omega$ )	$R_{mesu}$ ( $\Omega$ )	$X_{mesu}$ ( $\Omega$ )	$R_e$ %	$X_e$ %
1	l-g	15	0.41	5.63	0.40	5.56	2.3	1.16
2	l-g	30	0.83	11.25	0.81	10.85	1.58	3.56
3	l-g	45	1.24	16.88	1.24	15.89	0.20	5.84
2	l-g	60	1.65	22.50	1.64	21.76	0.36	3.29
4	l-g	75	2.06	28.13	2.11	28.01	2.30	0.41
5	l-g	90	2.48	33.75	2.39	33.12	3.07	1.87
3	l-g	105	2.89	39.38	2.87	38.89	0.61	1.23
6	l-g	120	3.30	45.00	3.31	44.44	0.30	1.24
7	l-g	135	3.71	50.63	3.72	50.12	0.20	1.00
4	l-g	150	4.13	56.25	4.13	57.02	0.12	1.37
8	l-g	165	4.54	61.88	4.54	61.88	0.06	0.01
9	l-g	180	4.95	67.50	4.94	67.4	0.20	0.15
5	l-g	195	5.36	73.13	5.35	73.11	0.23	0.02
10	l-g	210	5.78	78.75	5.78	78.78	0.09	0.04
11	l-g	225	6.19	84.38	6.01	84.35	2.87	0.03
12	l-g	240	6.60	90.00	6.56	89.9	0.61	0.11

Table 2: Simulation results for Single line to ground faults  
Table 2 shows simulation results obtained by the proposed scheme for single line to ground faults at different fault locations. It has been observed that for close-in faults the percentage error in the measurement of resistance and reactance is X and Y respectively whereas for remote end faults the percentage error in the measurement of resistance and reactance is X and Y respectively.

Sr. No.	Fault type	Fault Location (km)	Actual Value		Measured Value		% error	
			$R_{act}$ ( $\Omega$ )	$X_{act}$ ( $\Omega$ )	$R_{mesu}$ ( $\Omega$ )	$X_{mesu}$ ( $\Omega$ )	$R_e$ %	$X_e$ %
1	l-l-g	15	0.4125	5.625	0.405	5.61	1.82	0.27
2	l-l-g	30	0.825	11.25	0.813	11.2	1.45	0.44
3	l-l-g	45	1.2375	16.875	1.24	16.77	0.20	0.62
4	l-l-g	60	1.65	22.5	1.64	22.3	0.61	0.89
5	l-l-g	75	2.0625	28.125	2.1	28.1	1.82	0.09
6	l-l-g	90	2.475	33.75	2.48	33.33	0.20	1.33
7	l-l-g	105	2.8875	39.375	2.9	39.25	0.43	0.33
8	l-l-g	120	3.3	45	3.2	44.45	3.03	1.22
9	l-l-g	135	3.7125	50.625	3.6	50.60	3.03	0.01
10	l-l-g	150	4.125	56.25	4.01	55.17	2.79	1.92
11	l-l-g	165	4.5375	61.875	4.5	61.67	0.83	0.33
12	l-l-g	180	4.95	67.5	4.9	67.01	1.01	0.73
13	l-l-g	195	5.3625	73.125	5.25	72.72	2.10	0.55
14	l-l-g	210	5.775	78.75	5.76	77.534	0.26	1.54
15	l-l-g	225	6.1875	84.375	6.17	83.98	0.28	0.47
16	l-l-g	240	6.6	90	6.56	89.6	0.61	0.44

Table 3: Simulation results for Double line to ground faults  
Table 3 shows simulation results obtained by the proposed scheme for double line to ground faults at different fault locations. It has been observed that for close-in faults the percentage error in the measurement of resistance and reactance is X and Y respectively whereas for remote end

faults the percentage error in the measurement of resistance and reactance is X and Y respectively.

Sr. No.	Fault type	Fault Location (km)	Actual Value		Measured Value		% error	
			R <sub>act</sub> (Ω)	X <sub>act</sub> (Ω)	R <sub>mes</sub> (Ω)	X <sub>me</sub> (Ω)	R <sub>e</sub> %	X <sub>e</sub> %
1	l-l-l-g	15	0.4125	5.625	0.404	5.55	2.06	1.33
2	l-l-l-g	30	0.825	11.25	0.81	11.11	1.82	1.24
3	l-l-l-g	45	1.2375	16.875	1.21	15.89	2.22	5.84
2	l-l-l-g	60	1.65	22.5	1.64	22.01	0.61	2.18
4	l-l-l-g	75	2.0625	28.125	2.01	27.78	2.55	1.23
5	l-l-l-g	90	2.475	33.75	2.44	33.3	1.41	1.33
3	l-l-l-g	105	2.8875	39.375	2.78	38.89	3.72	1.23
6	l-l-l-g	120	3.3	45	3.21	44.44	2.73	1.24
7	l-l-l-g	135	3.7125	50.625	3.701	50.01	0.31	1.21
4	l-l-l-g	150	4.125	56.25	4.11	55.55	0.36	1.24
8	l-l-l-g	165	4.5375	61.875	4.54	60.89	-0.06	1.59
9	l-l-l-g	180	4.95	67.5	4.89	66.66	1.21	1.24
5	l-l-l-g	195	5.3625	73.125	5.31	73.01	0.98	0.16
10	l-l-l-g	210	5.775	78.75	5.67	77.77	1.82	1.24
11	l-l-l-g	225	6.1875	84.375	6.101	83.56	1.40	0.97
12	l-l-l-g	240	6.6	90	6.56	89.90	0.61	0.11

Table 4: Simulation results for Triple line to ground faults  
Table 4 shows simulation results obtained by the proposed scheme for triple line to ground faults at different fault locations. It has been observed that for close-in faults the percentage error in the measurement of resistance and reactance is X and Y respectively whereas for remote end faults the percentage error in the measurement of resistance and reactance is X and Y respectively.

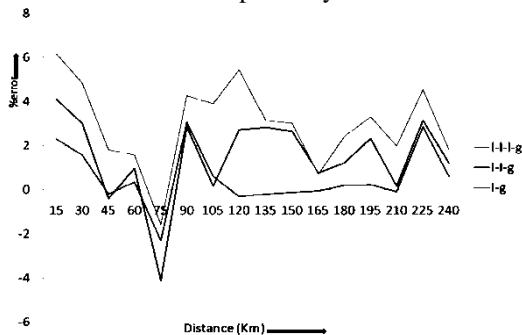


Fig. 9: Graphical representation

Graph shows simulation results obtain by the proposed scheme for single line to ground fault, double line to ground fault and triple line to ground fault at different fault location. It has been observed that the percentage error in the measurement of resistance and reactance is within  $\pm 5\%$ .

## VI. CONCLUSION

The main objective of this is to find out the limitation of the ground distance relay and the effect on the operating zone of high fault resistance. This report introduces a new method of fault impedance compensation based on fault resistance calculation. The problem of under reach in ground distance relay is solved. The suggested technique gives the solutions for the symmetrical and unsymmetrical faults. Fault impedance is accurately calculated; this will improve the relay selectivity. The techniques can be used for medium and long transmission lines.

## VII. APPENDIX A

### A. The parameters of the simulation transmission system

Source data at both Sending and Receiving Ends	
Positive sequence impedance	1.31+j15.0 Ω.
Zero sequence impedance	2.33+26.6 Ω
Frequency	50 Hz

Transmission-line Data:	
Length	300km
Voltage	400 kV
Positive sequence impedance	8.25+j94.5 Ω
Zero sequence impedance	82.5+308 Ω
Positive-sequence capacitance	13 nF/km
Zero-sequence capacitance	8.5 nF/km

## REFERENCES

- [1] M. M. Eissa, "Ground Distance Relay Compensation Based on Fault Resistance Calculation" Senior Member, IEEE, vol. 21, no. 4, pp. 1830-1835, October 2006.
- [2] T. S. Sidhu, D. S. Ghotra, and M. S. Sachdev, "An Adaptive distance relay and performance comparison with a fixed data window distance relay," IEEE Trans. Power Del., vol. 17, no. 3, pp. 691-697, Jul. 2002.
- [3] T. S. Sidhu, D. S. Ghotra, and M. S. Sachdev, "A fast distance relay using adaptive data window filters," in Proc. IEEE Power Eng. Soc. Summer Meeting, Jul. 2000, vol. 3, no. 16-20, pp. 1407-1412.
- [4] H. Kudo, H. Sasaki, K. Seo, M. Takahashi, K. Yoshida, and T. Maeda, "implementation of a digital distance relay using an interpolated integral solution of a differential equation," IEEE Trans. Power Del., vol. 3, no. 4, pp. 1475-1484, Oct. 1988.
- [5] M. S. Sachdev, T. S. Sidhu, and D. S. Ghotra, "Implementation of an adaptive data window technique in a distance relay," in Proc. 7<sup>th</sup> Int. Conf. 9-12

- Developments in Power System Protection, Apr. 2001, pp. 161-164.
- [6] H. A. J. A. Ferrer, I. D. Verduzco, and E. V. Martinez, "Fourier and Walsh digital filtering algorithms for distance protection," *IEEE Trans. Power Syst.*, vol. 11, no. 1, pp. 457-462, Feb. 1996.
- [7] D. L. WaiKAR, A. C. Liew, and S. Elangovan, "Design, implementation and performance evaluation of a new digital distance relaying algorithm," *IEEE Trans. Power Syst.*, vol. 11, no. 1, pp. 448-456, Feb. 1996.
- [8] M. M. Eissa and M. Masound, "A novel digital distance relaying technique for transmission line protection," *IEEE Trans. Power Del.*, vol. 16, no. 3, pp. 380-384, Jul. 2001.
- [9] D. L. Waikar, S. Elangovan, and A. C. Liew, "Fault impedance estimation algorithm for digital distance relaying," *IEEE Trans. Power Del.*, vol. 9, no. 3, pp. 1375-1383, Jul 1994.
- [10] M. Djuric, Z. Radojevic, and V. Terzija, "Time domain solution of fault distance estimation and arcing faults detection on overhead lines," *IEEE Trans. Power Del.*, vol. 14, no. 1, pp. 60-67, Jan. 1999.
- [11] V. Terzija and Z. Radojevic, "Numerical algorithm for adaptive autoclosure and protection of medium voltage overhead lines," *IEEE Trans. Power Del.*, vol. 19, no. 2, pp. 554-559, Apr. 2004.
- [12] Y. O. Xia, K. K. Li, and A. K. David, "adaptive relay setting for standalone digital distance protection," *IEEE Trans. Power Del.*, vol. 9, no. 1, pp. 480-491, Jan. 1994.
- [13] E. Erezzaghi and P. A. Crossley, "The effect of high resistance faults on a distance relay," in *Proc. IEEE Power Eng. Soc. General Meeting*, Jul. 2003, vol. 4, no. 13-17.
- [14] Y. Li, C. De-Shu, Y. Xiang-Gen, and Z. Zhang, "the uniform formula of single phase earth-fault distance relay with compensation," in *Proc. IEEE Power Eng. Soc. Transm. Distribution Conf. Expo.*, Sep. 2003, vol. 1, no. 7-12, pp. 245-249.
- [15] T. D. Sidhu, D. S. Baltazar, R. M. Palomino, and M. S. Sachdev, "A new approach for calculating zone-2 setting of distance relay and its use in a adaptive protection syatem," *IEEE Trans. Power Del.*, vol 19, no. 1, pp. 70-77, Jan. 2004.
- [16] "Microprocessor relays and protection system," *IEEE Tutorial Course Computer Relaying*, 1981.
- [17] T. Tanaka and H. Akagi, "A new method of harmonic power detection based on the instantaneous active power in three phase circuits," *IEEE Trans. Power Del.*, vol. 10, no. 4, pp. 1737-1742, Oct. 1999.
- [18] H. Osman, T. Abdelazim, and O. P. Malik, "Adaptive distance relaying technique using on-line trained neural network," *IEEE Trans. Power Del.*, vol. 20, no. 2, pp. 1275-1267, Apr. 1995.
- [19] V. Voloshko, O. I. Katsar, and O. P. Malik, "An approach to the design of digital algorithm for measuring power consumption characteristics," *IEEE Trans. Power Del.*, vol. 10, no. 10, pp. 607-612, Apr. 1995.
- [20] G. Ziegler, *Numerical Distance Protection Principal and Applications*. Munich, Germany; Publicist MC D, 1999.
- [21] User guide, MATLAB.