A Digital Ground Distance Relaying Algorithm to Reduce the Effect of Fault Resistance during Single Phase to Ground and Simultaneous Faults

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Received: September 2014 Revised: November 2014 Accepted: January 2015

ABSTRACT
This paper provides an algorithm of fault resistance compensation for digital ground distance relay considering the voltage and current transformer effects. Performance of the conventional ground distance relaying manner is adversely affected by different ground faults and also typical type, called a simultaneous open conductor and ground fault. The proposed scheme by using local-end data only, has shown satisfactory performances under wide variations in fault location, with different values of fault resistance and having positive and negative of power transfer angle. The presented method which has been carried out on the IEEE 14 bus benchmark is executed in PSCAD/EMTDC and MATLAB software, and the results show the accurate performance of mentioned configuration.

KEYWORDS: Digital Ground Distance Relaying; Fault Resistance Compensation; Voltage and Current Transformer; Single Phase to Ground Fault; Simultaneous Open Conductor and Ground Fault.

1. INTRODUCTION

Power system security and stability are becoming even more challenging and important characteristics due to the increasing complexity of power system operations. Since transmission lines are the vital links that enable delivering electrical power to the end users, improving reliability and security of transmission line relays is required [1].

The distance relays, both phase or ground type, give more dependable and fast decision making capability to detect fault in the zone of protection and provide the information about trip or no trip [2]. According to the literature [3], relay mal-operation contributes to 70% of the major disturbances. Finding effective means to monitor and improve distance relay operations is so important for mitigating relay mal-operations on high voltage transmission lines.

Distance relays perform a comparison between the positive sequence apparent impedance measured from one terminal of the line and the relay operation characteristic to decide between line tripping or not. This process is carried out after the fault detection, and is based on the line impedance for the trip decision [4]. Nevertheless, conventional relays do not have successful solutions to the inconvenient problems, such as the presence of high fault path resistance during different types of ground faults and remote in-feed [5]. The performance of the digital ground distance relay is also affected by a typical type of ground fault called a simultaneous open conductor and ground fault. Severe power system disturbances are often occurred during simultaneous fault circumstances, which are the reasons of incorrect operation of the conventional digital distance relays [6-8].

Eissa [9] suggested compensating the fault path resistance in a ground distance relay at the sending end of a transmission line. Although it has largely avoided under-reach, the method may increase the risk of over-reach because the fault path resistance is estimated according to the real power measured at the sending end, which affected by load. Liu *et al.* [10] developed an adaptive impedance relay with a composite polarizing voltage which comprises memorized pre-fault compensated voltage and the voltage during fault. However, the accuracy of the estimation of the compensated voltage need not be guaranteed at the time of fault. Daros *et al.* [11] presented a technique of fault resistance compensation in the phase coordinate. The fault impedance was obtained in an iterative manner with improved accuracy. This technique is only suitable for single sourced transmission lines, which may be rare for transmission lines. Subsequently, Xu *et al.* [12] proposed a fault impedance estimation algorithm for ground distance relaying. This scheme is based on the selection of three different combinations of sequence current components, namely, negative, zero, and comprehensive negative-zero sequence current components.

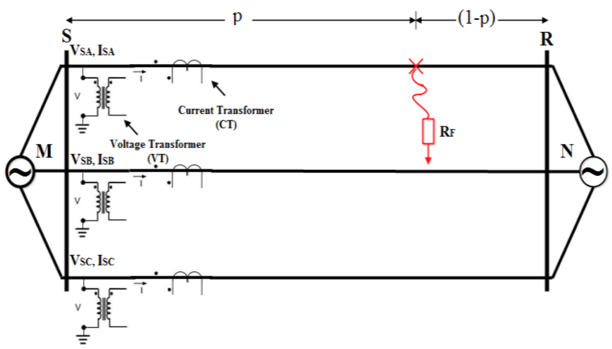


Fig. 1. Single line to ground fault in doubly on the doubly fed transmission line

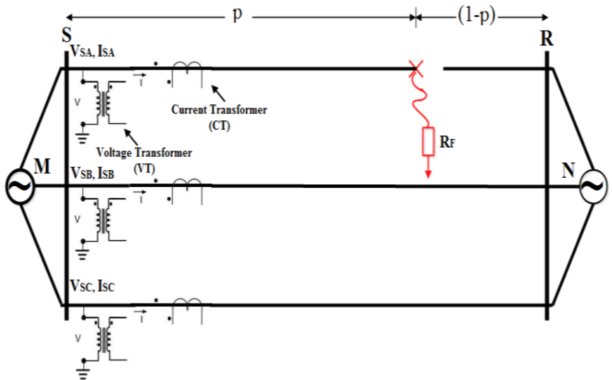


Fig. 2. Simultaneous open conductor and ground fault in doubly on the doubly fed transmission line

However, in this manner, the procedure has not been clearly mentioned for the selection of a particular sequence current component, which is required for the impedance estimation algorithm.

Therefore, none of aforesaid papers have investigated the impact of simultaneous open conductor and ground faults on transmission lines and also considering current and voltage transformers effects.

In this Paper in order to solve the problem of mal-operation of the conventional digital distance relaying scheme during a single phase to ground and simultaneous faults, the authors have presented a digital ground distance relay algorithm. The discussions have been supported with MATLAB and PSCAD/EMTDC software validation.

2. CONVENTIONAL GROUND DISTANCE RELAYING METHOD

Figure 1 indicates a single-line diagram of a portion of power system which includes a transmission line between two buses, M and N, and voltage and current transformers, during single phase to ground fault in phase A. A single-line-to-ground fault, having fault resistance, R_F, occurs at fault location, F, which is at '*p*' percentage of the transmission line from bus S.

Further, Figure 2 shows a simultaneous open conductor and ground fault condition on the doubly fed transmission line at fault location F, During a simultaneous open conductor and ground fault, the bus S side phase A of the transmission line has been broken and fallen to ground.

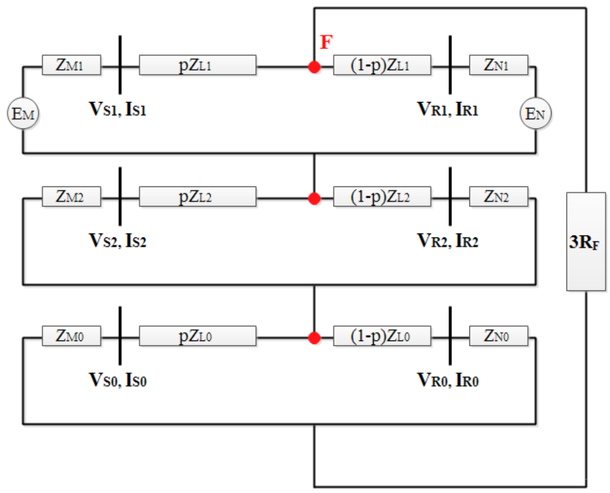


Fig. 3. Equivalent circuit for the single-line-to-ground fault in phase A on the doubly fed transmission line

Whereas, bus R side phase A of the transmission line has broken, but is held by the suspension insulators. In this situation, the conventional ground distance relay at bus S measures an incorrect value of fault impedance and it may over-reach or under-reach. Furthermore, the conventional phase and ground distance relays at bus R completely fail to detect an open conductor fault on the transmission line [6]. According to Figures 1 and 2, positive and negative sequence impedances (Z_{L1} and Z_{L2}) of the transmission line are assumed to be equal, the fault impedance (Z_{SA}) seen by the conventional ground distance relaying method located at relaying point S is given by [13];

$$Z_{SA} = \frac{V_{SA}}{I_{SA} + (k_0 \times I_{S0})} = \left(p \times Z_{L1}\right) + Z_F = Z_P + Z_F \qquad (1a)$$

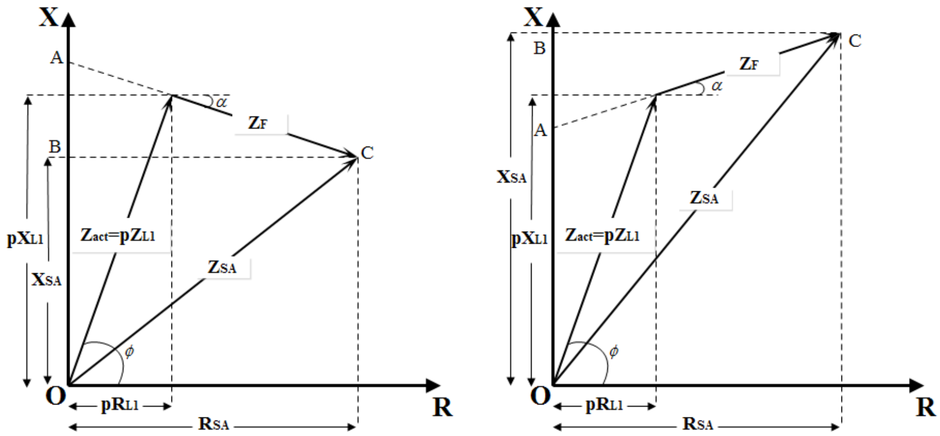
Where:

$$k_0 = \left(\frac{Z_{L0} - Z_{L1}}{Z_{L1}}\right) \qquad (1b)$$

$$Z_F = \frac{I_F \times R_F}{I_{SA} + (k_0 \times I_{S0})} \qquad (1c)$$

Where V_{SA}, I_{SA} and I_{S0}, are respectively voltage, current and zero-sequence component of current that have been seen by the conventional ground distance relaying

method. In the equations throughout the entire discussion, the positive, negative and zero-sequence components are specified by subscripts 1, 2, and 0, respectively.
It is clearly indicated by (1) that for a single phase to ground and simultaneous faults, the conventional ground distance relay measures the impedance of the faulted portion of the transmission line along with some additional impedance Z_F, which lead to incorrect computation.



(a) (b)

Fig. 4. Impedance seen for a single-line-to-ground fault, having fault resistance

3. PROPOSED GROUND DISTANCE RELAYING SCHEME

In accordance with Figure 3, which shows equivalent circuit for the single-line-to-ground fault in phase A on the doubly fed transmission line at fault location F, can be written:

$$I_{S0} = \frac{Z_{N0} + (1-p)Z_{L0}}{Z_{M0} + Z_{N0} + Z_{L0}} I_{F0} \tag{2}$$

Where Z_{M0}, Z_{N0} and Z_{L0} are respectively, the zero sequence components of impedance of the M and N sources and transmission line. Since the magnitudes of Z_{M0} and Z_{N0} are negligible with respect to Z_{L0}, generally [13], (2) can be presented as below:

$$I_{S0} = (1-p)I_{F0} \tag{3}$$

Owing to sequence current components that are equal during a single line to ground fault at point F, the total fault current can be obtained as follows:

$$I_F = I_{F1} + I_{F2} + I_{F0} = 3I_{F0} = \frac{3}{(1-p)} I_{S0} \tag{4}$$

With substituting (4) into (1), (1) can be rewritten as:

$$Z_{SA} = \frac{V_{SA}}{I_{SA} + (k_0 \times I_{S0})} = \left(p \times Z_{L1}\right) + \left(\frac{3}{(1-p)} \times \frac{I_{S0} \times R_F}{I_{SA} + (k_0 \times I_{S0})}\right) \tag{5}$$

During a single-line-to-ground fault, if the voltage at the relaying point leads with respect to the voltage at the remote end, then the impedance Z_{SA} provided by (5) is as shown in Figure 4(a). Conversely, when the voltage at the relaying point lags with respect to the voltage at the remote end, impedance Z_{SA} provided by (5) is as shown in Figure 4(b).
With using impedance value Z_{SA}, and the angle α, which can be obtained refer to Equ. 5, according to Figure 4, OA can be calculated as bellow:

$$OA = X_{SA} + (R_{SA} \times (\tan(-\alpha)) \tag{6}$$

Consequently the impedance of the faulted portion of the transmission line seen by the proposed ground distance relaying algorithm can be obtained as follows:

$$pR_{L1} = \frac{OA}{\left(\frac{X}{R}\right) - \left(\frac{OB-OA}{BC}\right)} \tag{7}$$

$$pX_{L1} = \left(\frac{X}{R}\right) \times \frac{OA}{\left(\frac{X}{R}\right) - \left(\frac{OB-OA}{BC}\right)} \tag{8}$$

Where R and X are assumed to be resistance and reactance of transmission line per unit length.
The flowchart shown in Figure 5 sets to programming in order to calculate the impedance of the faulted portion of the transmission line seen by proposed digital distance relay.

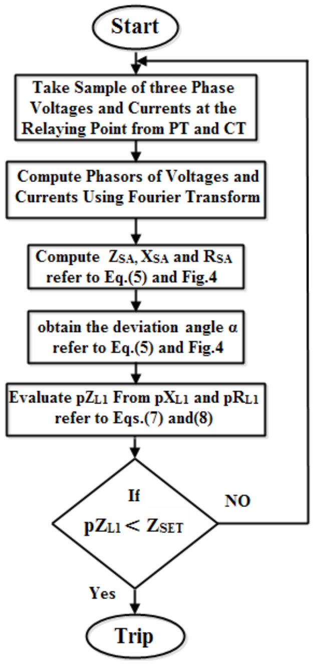


Fig. 5. Flowchart of the proposed algorithm

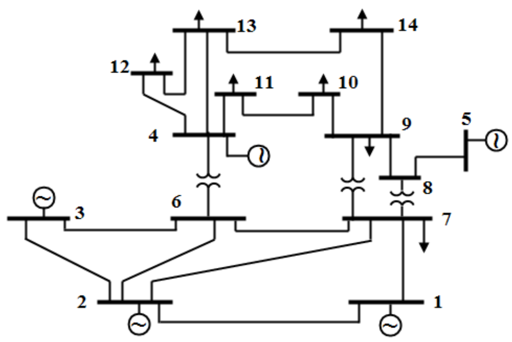


Fig. 6. IEEE 14 bus test system

In accordance with the flowchart and aforesaid manuscripts, at first samples are taken three-phase voltages and currents at the relay point by the voltage and current transformers in PSCAD/EMTDC software. Sampling rate per cycle depends on the accuracy, time and available hardware facilities. Then, Fourier transform algorithm was used to determine the voltage and current Phasor computation.

Further by using MATLAB/m_file, according to (5) and Figure 4, Z_{SA}, R_{SA} and X_{SA} are calculated. After that, the deviation angle α is computed and at the end step, it calculates pZ_{L1}, pR_{L1} and pX_{L1} by using (7) and (8). Then if it is in the scope of relay protection zone, it sends trip command to the installed breaker in line and otherwise, the algorithm is repeated again for other samples from the first step.

4. SIMULATION VERIFICATION AND DISCUSSIONS

This section presents the performance of the proposed algorithm and conventional method during a single phase to ground fault and also simultaneous fault on transmission line. The test system for simulating is IEEE 14 bus standard system shown in Figure 6, which is simulated on its transmission line between 1 and 2 buses. As actual circumstances, samples of current and voltage has been taken by CT and PT outputs. Table 1 shows specifications of these transformers which are used in Lucas type.

Table 1. Specifications of Current and Voltage Transformers Applied to Simulated System

Parameters of Current transformer		Parameters of Voltage transformer	
Parameter	Value	Parameter	Value
CT Ratio	400	PT Ratio	2000
Flux density at knee point	1 Tesla	Burden resistance_series	301 Ohm
Burden resistance	0.5078 Ohm	Burden inductance_series	2.4 Henry
Burden inductance	0.0008 Henry	Burden resistance_parallel	785 Ohm

To determine the accuracy of the proposed algorithm performance, the impact of power transfer angle (δ) considered in lag and lead states and wide variations in the magnitude of fault resistance is investigated in various locations from installed relay (0% to 80% in steps of 20%).

The presented method which has been carried out on the IEEE 14 bus benchmark is executed in PSCAD/EMTDC and MATLAB software.

4.1. Single-Line-to-Ground Fault

According to Table 2, first column of this table refers to the fault locations based on the percentages of the total length of simulated system transmission line. The second and third columns, respectively, are positive sequence components of actual resistance and reactance of the faulted portion of the transmission line. Positive sequence components of resistance and reactance for conventional method are devoted to the fourth and fifth columns. For proposed one, they are given in penultimate and last of columns of Table 2. The parameters of others tables in this section are categorized similarly.

Tables 2, 3 and 4 represent the performance of the conventional ground distance relaying method and the proposed algorithm, in terms of error in the measurement of resistance and reactance of the transmission line faulted portion for a single-line-to-ground fault, at different fault locations (0% to 80% in steps of 20%), with R_F=10 Ω, R_F=50 Ω and R_F=100 Ω respectively and having value of δ=10˚.

Table 2. Performance of the conventional ground distance relaying method and the proposed algorithm for single line to ground fault with R_F=10Ω, and having value of power angle10˚

p (%)	R_{act} (Ω)	X_{act} (Ω)	R_c (Ω)	X_c (Ω)	R_p (Ω)	X_p (Ω)
0	0	0	6.6064	1.2404	0.0873	1.2399
20	1.4298	20.3105	11.6340	20.1734	1.3977	19.8542
40	2.8596	40.6210	17.7447	42.9628	2.8068	39.8505
60	4.2894	60.9315	28.8444	61.6980	4.1863	59.4674
80	5.7191	81.2420	49.5563	86.3113	5.6555	80.3369

Table 3. Performance of the conventional ground distance relaying method and the proposed algorithm for single line to ground fault with R_F=50Ω and having value of power angle10˚

p (%)	R_{act} (Ω)	X_{act} (Ω)	R_c (Ω)	X_c (Ω)	R_p (Ω)	X_p (Ω)
0	0	0	34.1903	1.1972	0.0862	1.2247
20	1.4298	20.3105	46.6949	21.3336	1.4041	19.9453
40	2.8596	40.6210	66.7735	44.1036	2.8173	40.0204
60	4.2894	60.9315	106.2499	70.3518	4.2507	60.3826
80	5.7191	81.2420	244.8794	114.3679	5.7694	81.9550

Table 4. Performance of conventional ground distance relaying method and the proposed algorithm for single line to ground fault with R_F=100Ω and having value of power angle10˚

p (%)	R_{act} (Ω)	X_{act} (Ω)	R_c (Ω)	X_c (Ω)	R_p (Ω)	X_p (Ω)
0	0	0	72.4036	1.0567	0.0848	1.2046
20	1.4298	20.3105	96.3735	22.7714	1.4049	19.9571
40	2.8596	40.6210	139.1265	48.6621	2.8258	40.1407
60	4.2894	60.9315	236.7278	83.0792	4.2808	60.8095
80	5.7191	81.2420	754.1522	185.283	6.0052	85.3055

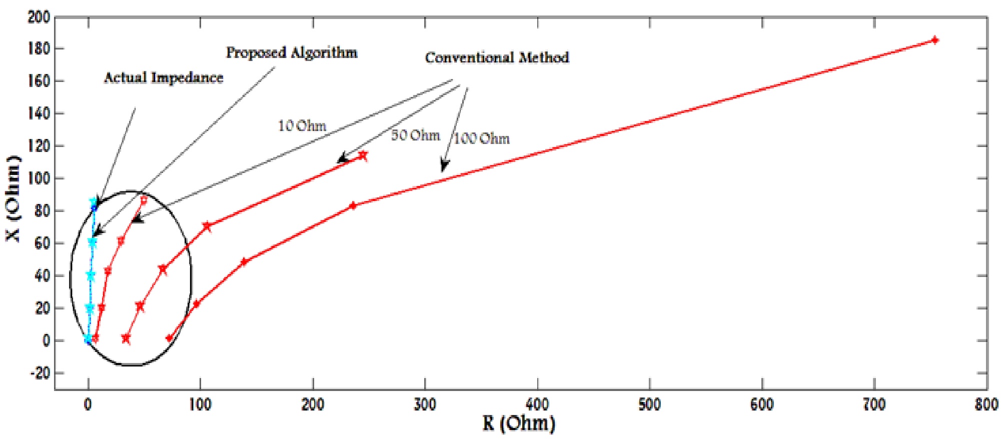


Fig. 7. The locus of fault impedance provided by the conventional ground distance relaying scheme and the proposed scheme for a single-line-to-ground fault at deferent fault locations with having value of power transfer angle 10˚

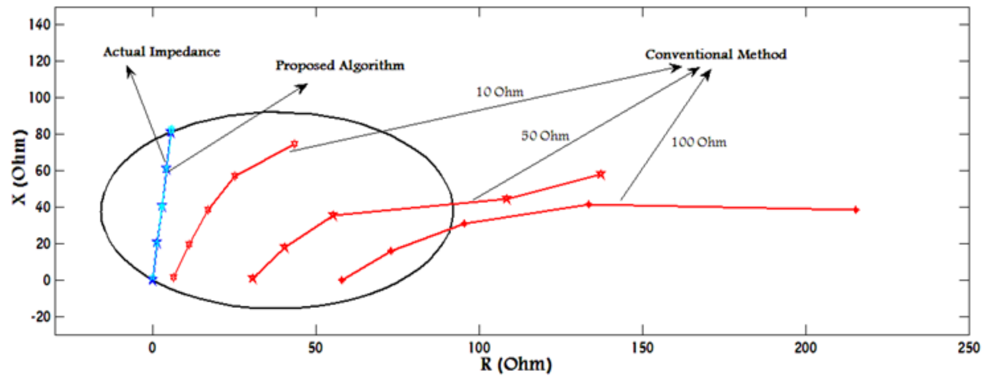


Fig. 8. The locus of fault impedance provided by the conventional ground distance relaying scheme and the proposed scheme for a single-line-to-ground fault at deferent fault locations having value of power transfer angle -10˚

It is notable from aforesaid tables that the percentage error in the measurement of resistance and reactance given by the proposed scheme is negligible.

To better clarify this issue Figure 7 dedicates the locus of fault impedance provided by the conventional ground distance relaying method and the proposed algorithm at different fault locations (0% to 80% in steps of 20%), with different values of R_F (10, 50 and 100) and having power transfer angle δ (10 and -10).

Table 5, which shows performance of the conventional ground distance relaying method and the proposed algorithm, at different fault locations (0% to 80% in steps of 20%), with R_F=100Ω, having value of δ=10˚, and Figure 8 shows the locus of fault Impedance seen by the conventional and the proposed scheme with varying fault location and negative power transfer angle δ (-10˚). Table 5 and Figure 8 indicate that the locus of impedance of the conventional relay moves very far away from the first zone boundary, since the location of fault moves away from the relaying point during the reversal of power (power flowing from bus1 to bus2).

Table 5. Performance of the conventional ground distance relaying method and the proposed algorithm for single line to ground fault with R_F=100Ω, and having power angle (-10˚)

p (%)	R_{act} (Ω)	X_{act} (Ω)	R_c (Ω)	X_c (Ω)	R_p (Ω)	X_p (Ω)
0	0	0	58.1020	-0.0713	0.0885	1.2575
20	1.4298	20.3105	72.9894	15.7341	1.4111	20.0450
40	2.8596	40.6210	95.6774	30.8179	2.8393	40.3334
60	4.2894	60.9315	133.6159	41.6914	4.2992	61.0706
80	5.7191	81.2420	215.5504	38.5590	5.8571	83.2007

4.2. Simultaneous Open Conductor and Ground Fault

This type of fault may occur on an overhead transmission line because of the breaking of a phase conductor at a point that is close to the transmission tower. The breaking conductor on the tower side is being held by the suspension insulators and that on the other side falling to ground.

Tables 6, 7 and 8 show the performance of the conventional ground distance relaying method and the proposed algorithm, in terms of error in the measurement of resistance and reactance of the transmission line faulted portion for simultaneous open conductor and ground fault at different fault locations (0% to 80% in steps of 20%), with R_F=10 Ω, R_F=50 Ω and R_F=100 Ω respectively.

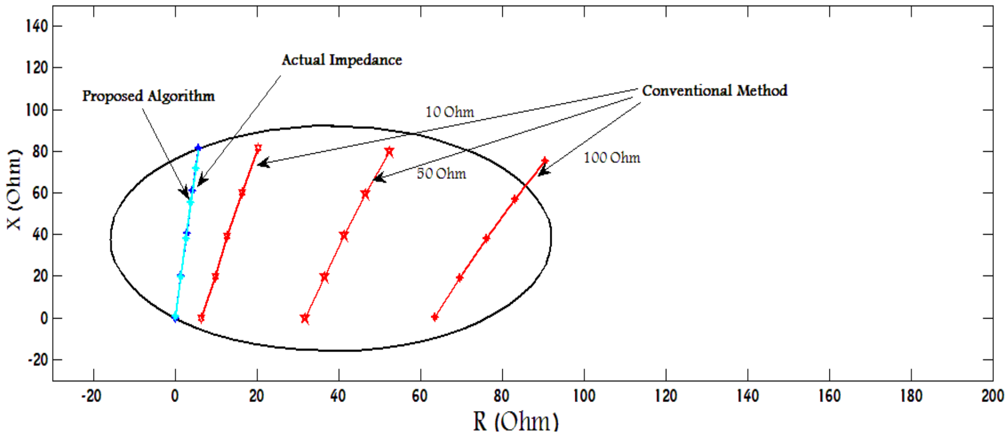


Fig. 9. The locus of fault impedance provided by the conventional ground distance relaying scheme and the proposed scheme for a simultaneous open conductor and ground fault at deferent fault locations having diferent values of fault resistance

Table 6. Performance of the conventional ground distance relaying method and the proposed algorithm for a simultaneous open conductor and ground fault with R_F=10 Ω

p (%)	R_{act} (Ω)	X_{act} (Ω)	R_c (Ω)	X_c (Ω)	R_p (Ω)	X_p (Ω)
0	0	0	6.3720	0.0024	0.0006	0.0086
20	1.4298	20.3105	9.9030	19.7968	1.3890	19.7314
40	2.8596	40.6210	12.6566	39.1201	2.7398	38.9195
60	4.2894	60.9315	16.3054	59.7554	4.1734	59.2839
80	5.7191	81.2420	20.3134	81.5733	5.6739	80.5986

Table 7. Performance of the conventional ground distance relaying method and the proposed algorithm for a simultaneous open conductor and ground gault with R_F=50 Ω

p (%)	R_{act} (Ω)	X_{act} (Ω)	R_c (Ω)	X_c (Ω)	R_p (Ω)	X_p (Ω)
0	0	0	31.8487	0.0799	0.0162	0.2301
20	1.4298	20.3105	36.6650	19.6976	1.3828	19.6430
40	2.8596	40.6210	41.4795	39.3627	2.7394	39.9137
60	4.2894	60.9315	46.7053	59.3085	4.0910	58.1131
80	5.7191	81.2420	52.4041	79.8274	5.4389	77.2614

Table 8. Performance of the conventional ground distance relaying method and the proposed algorithm for a simultaneous open conductor and ground fault with R_F=100 Ω

p (%)	R_{act} (Ω)	X_{act} (Ω)	R_c (Ω)	X_c (Ω)	R_p (Ω)	X_p (Ω)
0	0	0	63.6680	0.3291	0.0652	0.9252
20	1.4298	20.3105	69.7804	19.2339	1.3829	19.6439
40	2.8596	40.6210	76.2201	38.0145	2.6688	37.9111
60	4.2894	60.9315	83.0945	56.7338	3.9052	55.4740
80	5.7191	81.2420	90.4770	75.4898	5.0634	71.9264

Figure 9 shows the performance of the conventional ground distance relaying scheme and the proposed scheme in terms of error in the measurement of impedance of the faulted portion of the transmission line simultaneous open conductor and ground fault at different fault locations (0% to 80% in steps of 20%), with different values of R_F (10, 50 and 100). This clearly indicates that the conventional ground distance relaying scheme is unable to provide adequate protection to the transmission line against high resistance single line to ground faults. On the contrary, the locus of the proposed scheme always lies within the first zone boundary even with wide variations in the values of fault resistance and fault locations.

5. CONCLUSION

This paper introduces a method of fault resistance compensation for digital ground distance relay using local-end data only with considering current and voltage transformer effects. By implementing the proposed algorithm on the IEEE 14 bus benchmark, under different situations, it represents desirable performance. The proper results clearly indicates that the conventional ground distance relaying scheme measures the fault impedance with high percentage of error whereas the compensated fault impedance measures accurately the positive sequence component of impedance of the faulted portion of the transmission line. The proposed scheme does the same task with appropriate degree of accuracy even with wide variations in fault locations and having positive and negative of power transfer angles.

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