IMPROVING THE PERFORMANCE OF DISTANCE RELAYS IN THE PROTECTION OF SHORT TRANSMISSION LINES BASED ON THE CURRENT ESTIMATION OF THE LINE END

Seyed Mohammad Sadegh HOSSEINIMOGHADAM[1], Masoud DASHTDAR[2], Majid DASHTDAR[3]

This paper proposes a method to improve the performance of distance relays in short transmission lines. The most important problems of distance relays in short lines protection are the effect of fault resistance and the problem of small voltage at the relay location and as a result, increase the error of voltage transformers (CVT). Eliminates the mentioned drawbacks by using the current magnitude at the end of the line which improves the performance of the distance relay. The performance of the proposed method has been evaluated and analyzed using simulation in ATP-EMTP software and has been compared with the existing methods.

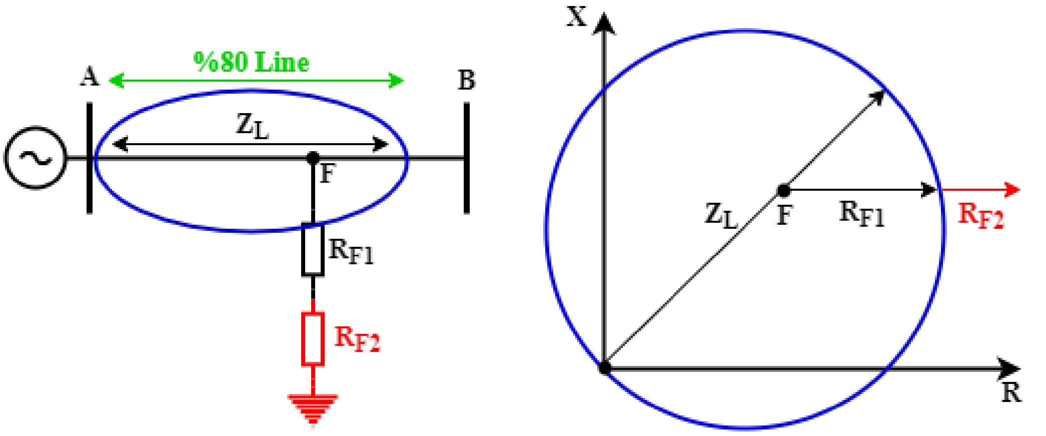
Keywords: Distance Protection, Short Transmission Line, Digital Relays, Fault Resistance

1. Introduction

The transmission line is one of the most important equipment of the power system, the protections which is very important from maintaining the stability of the system aspects and preventing the damage of the equipment due to the short circuit current. Moreover, the large distance between the terminals at the beginning and end of the line, transmission line protection is one of the most complex types of protection in the power system. Transmission line protection has applied in different ways. The most common line protection method is for medium and long lines is distance protection [1]. This protection method performs the protection operation by calculating the impedance seen from the relay location to the fault location and comparing it with the pre-defined protection areas. In addition to the distance method, several other methods have been proposed in different references. Even though the introduction of alternative methods for

[1] Electrical Engineering Department, Bushehr branch, Islamic Azad University, Bushehr, Iran, e-mail: ms_hosseinimoghadam@yahoo.com
[2] Electrical Engineering Department, Bushehr branch, Islamic Azad University, Bushehr, Iran, e-mail: dashtdar.masoud@gmail.com
[3] Electrical Engineering Department, Bushehr branch, Islamic Azad University, Bushehr, Iran, e-mail: dashtdar.m@gmail.com

distance protection, and this protection method is still the most common method of line protection. One of the main problems of the distance relay is the effect of fault resistance. Typically, the effect of resistance on phase-to-phase faults is less because the only spark resistance is between the two-phases. But when short-circuit occurs with ground resistance at the ends of the protection zone, the impedance measured by the relay will be overreached from its protection zone and the relay will not operate (According to Fig. 1). The effect of fault feeding from different sources will also exacerbate the adverse effect of fault resistance [2-4].



a) Transmission line protection **b) Functional characteristic of distance relay**

Fig. 1. The effect of fault resistance on the performance of the distance relay

In the case of short lines, the use of distance protection, in addition to the above-mentioned problems, also faces other problems. Due to the small impedance of short lines, Source to Line Impedance Ratio (SIR) is a large number. In general, in protection, a short zone refers to a line whose SIR is large. So a 30 km line with a low SIR will look like a long line. But a 100 km line with a high SIR behaves like a short zone. Lines with a SIR larger than 4 km are usually considered short zones of protection [2]. According to the definition provided for the short zone, if an internal short-circuit occurs, the voltage seen at the relay location will be much smaller than the nominal voltage of the system. Because this voltage is obtained by dividing the voltage between the line and the equivalent source of the network. This causes the smallest voltage measurement error to interfere with relay performance. Because the voltage of transformers has high performance around the nominal values, if the voltage at the relay location is much lower than the nominal voltage of the system, the error of the voltage transformers will be significant. When the SIR ratio increases according to

Equation (1), the voltage at the relay location (V_R in Fig. 2) drops intensity. This high voltage drop causes the capacitor transformers to malfunction.

$$V_R = \frac{Z_L}{Z_S+Z_L} V_S = \frac{1}{1+\frac{Z_S}{Z_L}} V_S = \frac{1}{1+SIR} V_S \quad (1)$$

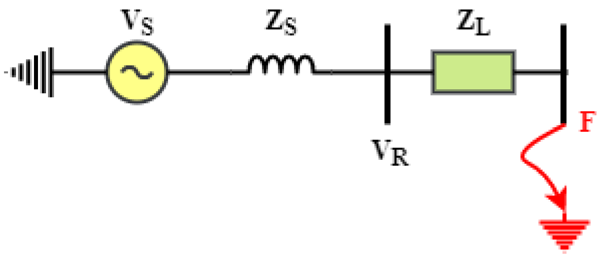


Fig. 2. Fault at point F inside the short transmission line

Even if voltage transformers are ignored, the distance relays will not perform reliably for small voltages. Also, the short lines distance relays are exposed to transient vision increase due to the transient states of capacitive voltage transformers [2]. Due to the above problems, the use of current methods in the protection of short zones has become common. Current methods have been implemented in a variety of ways, including comparing the current phase and using the current difference [4-8]. These methods generally require a complex and fast communication channel to exchange information between two posts. Therefore, the use of these methods, in addition to the high cost of implementation, has the problem that any error in the communication channel will cause improper or incorrect operation of the relay. However, one of the advantages of current methods is that there is no need for voltage information. Therefore, the relay which uses the mentioned method is simpler and at the same time, the need for voltage transformer is eliminated. However, voltage transformers are still needed for purposes such as measuring and synchronizing. In contrast, this method is highly dependent on the communication channel, and any error in the channel will cause the relay to malfunction. Therefore, the telecommunication equipment used needs support equipment, and as a result, the cost of the project increases. Reference [9] presents a different method for short transmission line protection. This method uses a high-frequency signal sent from the relay to the line and uses a phase comparator to differentiate between lagging and leading currents when a ground fault occurs. The advantage of this method is its high-performance speed. The use of high-frequency signals, if there is a noise, effects of this method performance. Another method that can be used to line protection is neural networks. These networks have been studied in several papers to implement the transmission line protection [11-18]. In some of these methods, the neural network determines the fault location based on the voltage and current information on both sides of the line. Naturally, this method requires a fast and secure telecommunication channel to transmit three-phase voltage and current information to the opposite post. In reference [13] only the fault direct is sent through the channel and the relay uses it and local information about the fault is decided. In reference [21], considering that the voltage and current of the fault location are the same phase and using the voltage and current information, the fault location is determined.

In this paper, in the second part, a method for calculating the voltage at the relay location of the short transmission line is proposed. Then, considering that the voltage drop on the short transmission line is negligible, the fault current at the end of the transmission line is estimated. Finally, the fault location is determined using the current values as well as the estimated voltage. In the third part, the simulation has done, and the analysis of its results has presented. Finally, in the fourth section, the conclusion has presented.

2. The proposed method for protection of short transmission lines

According to Fig. 3, when a fault occurs in a short transmission line, fault currents are generated from both ends of the transmission line to the fault location. In Fig. 3, Z_L is the impedance of the entire transmission line and x percent of the line length at which the fault occurred. In this section, the proposed method for short transmission lines protection against various faults has presented. The purpose of this method is to overcome the problems caused by the low voltage of the relay location and the effect of fault resistance.

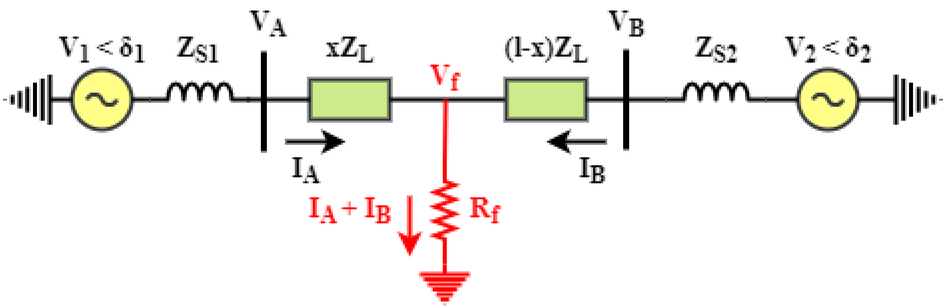


Fig. 3. The fault with R_f resistance inside the short transmission line

2.1. Single-phase fault to ground

If the single-phase fault to ground a-g occurs according to Fig. 4 at distance x from terminal A, Equation (2) can be used to estimate the fault location and the fault resistance value [21].

$$\begin{bmatrix} x \\ R_f \end{bmatrix} = \begin{bmatrix} M_{1m} & I_{Fm_r} \\ M_{2m} & I_{Fm_i} \end{bmatrix}^{-1} \begin{bmatrix} V_{Am_r} \\ V_{Am_i} \end{bmatrix} \tag{2}$$

In Equation (2), indices i and r represent the imaginary part and the real part of the corresponding parameter, respectively. V_{Am} represents the phase m voltage at the beginning of the transmission line in volts and x indicates the distance of the fault location from the beginning of the transmission line in meters and I_{Fm} represents the fault current, which is the sum of the fault current at the beginning of the transmission line (I_{Am}) and the end of the transmission line (I_{Bm}) in amperes. Also:

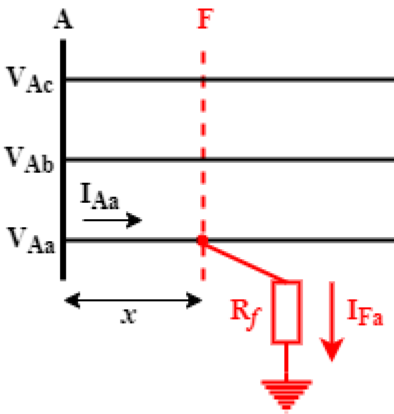


Fig. 4. Single-phase-ground fault at distance x from terminal A

$$M_{1m} = \sum_k \left(Z_{mk_r} I_{Ak_r} - Z_{mk_i} I_{Ak_i}\right) \quad (3)$$

$$M_{2m} = \sum_k \left(Z_{mk_r} I_{Ak_i} + Z_{mk_i} I_{Ak_r}\right) \quad (4)$$

Wherein:

k: a, b, c phases

Z_{mk}: Mutual impedance between phase m and phase k in ohm per meter.

I_{Ak}: Phase k current at the beginning of the transmission line in amperes.

I_{Bk}: Phase k current at the end of the transmission line in amperes.

In Equation (2), the only parameter that is not directly available to the relay at the beginning of the transmission line is the end current of the transmission line that is being passed to the fault point (I_{Ba} current in Fig. 4). In the following, a method for estimating the current at the end of the transmission line is proposed and then the fault location and fault resistance are calculated using Equation (2).

The steps for performing the proposed method for single-phase-ground fault are as follows:

1) It is assumed that the Thevenin equivalent impedance of the sources on both sides of the short transmission line, ie Z_{S1} and Z_{S2} in Fig. 3, is provided in the relay. Thevenin impedance refers to the impedance of network equivalent symmetric components.

2) Under normal conditions, the Thevenin source voltage (positive component source voltage) is calculated from the beginning of the transmission line, ie $V_1 < \delta_1$ in Fig. 3, using V_A voltage values and I_A current, as well as the source impedance Z_{S1}.
3) Given the current and voltage in normal conditions, the V_B voltage and I_B current at the end of the transmission line are calculated by the line transfer matrix, according to Equation (5).

$$\begin{bmatrix} V_A \\ I_A \end{bmatrix} = \begin{bmatrix} 1 & Z_L \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_B \\ I_B \end{bmatrix} \tag{5}$$

4) The Thevenin equivalent source voltage (positive component source voltage) at the end of the transmission line, ie $V_2 < \delta_2$ in Fig. 3, is calculated similarly to step 2.
5) It is assumed that when a single-phase-ground fault occurs (a-g), the voltage at the fault location is equal to the voltage at the beginning of the transmission line and that is equal to the voltage at the end of the transmission line. That is, the voltages V_{Aa}, V_{Ba}, and V_{fa} in Fig. 4 are equal.

$$V_{Aa} = V_{Ba} = V_{fa} \tag{6}$$

This assumption is made by considering that the impedance of the transmission line is small and the voltage drop across is negligible. As a result, the symmetrical components of the voltage are equal.

$$V_{A+} = V_{B+} = V_{f+} \tag{7}$$

6) The equivalent circuit of the symmetrical components of the network when a single-phase (a-g) fault occurs, in the form of Fig. 5.
Considering the Equation (7) and that the voltage drop across the transmission line is negligible, the symmetric components of the voltage are calculated as Equations (8) to (11).

$$V_{f+} = V_1 < \delta_1 - Z_{S1+} I_{A+} \tag{8}$$

$$V_{f-} = -Z_{S1+} I_{A-} \tag{9}$$

$$V_{f0} = -Z_{S10} I_{A0} \tag{10}$$

Phase-a voltage is calculated using Equation (6) to (11).
7) According to Fig. 4, to calculate the current I_{B+}, the voltage drop across the transmission line is eliminated. Therefore, the positive component of the end current of the transmission line is calculated using Equation (11).

$$I_{B+} = \frac{V_2 < \delta_2 - V_{f+}}{Z_{S2+}} \tag{11}$$

8) As shown in Fig. 5, the components of the fault current are equal to each other. The fault current is in the form of an Equation (12).

$$I_f = I_{A+} + I_{B+} = I_{A-} + I_{B-} = I_{A0} + I_{B0} \tag{12}$$

Therefore, the negative and zero components of the end current of the line are calculated using Equations (11) and (12).

$$I_{B-} = I_{A+} + I_{B+} - I_{A-} \tag{13}$$

$$I_{B0} = I_{A+} + I_{B+} - I_{A0} \tag{14}$$

As a result, the end current of the transmission line is calculated using Equation (11) to (14).

9) Finally, all the necessary parameters for estimating the fault location by Equation (2) are available to the relay. Therefore, the relay will calculate the fault location and the value of fault resistance.

10)

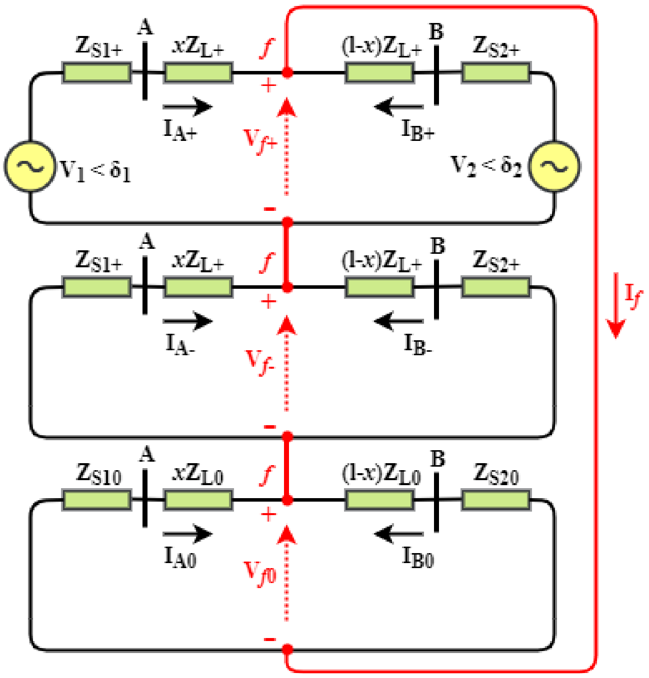


Fig. 5. The equivalent circuit of the symmetrical components of the network in single-phase-ground fault mode

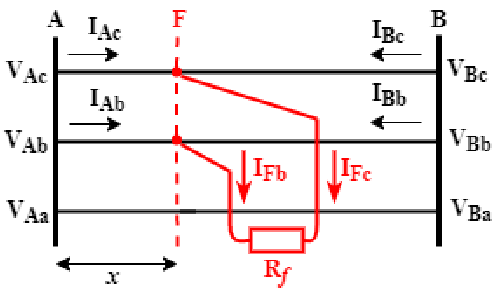


Fig. 6. Two-phase fault at a distance x from terminal A

2.2. Two-phase fault

If the two-phase fault b-c occurs according to Fig. 6 at distance x from terminal A, Equation (15) could be used to estimate the fault location and the fault resistance value [21].

$$\begin{bmatrix} x \\ R_f \end{bmatrix} = \begin{bmatrix} M_3 & I_{Fm_r} \\ M_4 & I_{Fm_i} \end{bmatrix}^{-1} \begin{bmatrix} V_{Am_r} - V_{An_r} \\ V_{Am_i} - V_{An_i} \end{bmatrix} \tag{15}$$

In Equations (15), M_3 and M_4 are defined as Equations (16) and (17). In Equations (15) to (17), m and n are the phases involved in the fault.

$$M_3 = \sum_k \left[(Z_{mk_r} - Z_{nk_r}) I_{Ak_r} - (Z_{mk_i} - Z_{nk_i}) I_{Ak_i} \right] \tag{16}$$

$$M_4 = \sum_k \left[(Z_{mk_r} - Z_{nk_r}) I_{Ak_i} + (Z_{mk_i} - Z_{nk_i}) I_{Ak_r} \right] \tag{17}$$

Wherein:

k: a, b, c phases

Z_{mk}: Mutual impedance between phase m and phase k in ohm per meter.

Z_{nk}: Mutual impedance between phase n and phase k in ohm per meter.

I_{Ak}: Phase k current at the beginning of the transmission line in amperes.

I_{Bk}: Phase k current at the end of the transmission line in amperes.

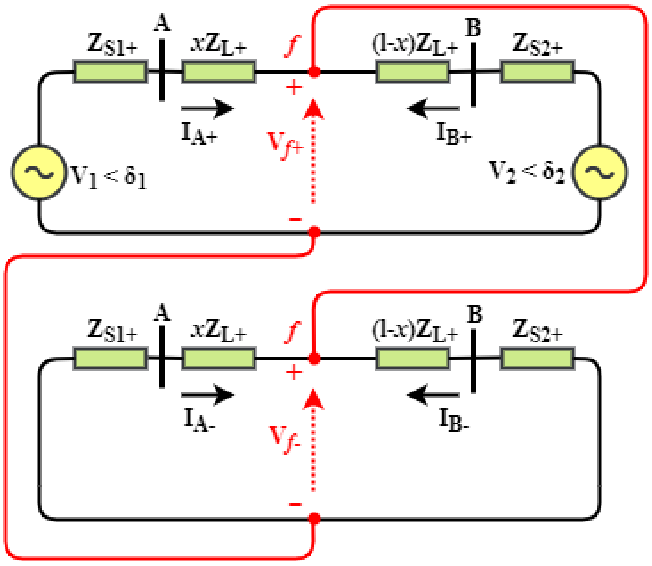


Fig. 7. The equivalent circuit of the symmetrical components of the network in two-phase fault mode

The steps for performing the proposed method for the fault of two-phase together are as follows:

Stages 1 to 6 for this type of fault are similar to steps 1 to 6 in Sections 2-1, except that in this section the fault is b-c and therefore instead of Equation (10) from Equation (18) should be used.

$$V_{f0} = 0 \quad (18)$$

Similar to single-phase-ground faults, phase b and c voltages are calculated using Equations (8), (9), and (18). The equivalent circuit of the symmetrical components of the network when a two-phase (b-c) fault occurs in the form of Fig. 7.

The continuation of the algorithm from step 7 is as follows:

7) According to Fig. 7, to calculate the components of the current at the end of the line, the voltage drop across the transmission line is eliminated. Therefore, the symmetrical components of the current of the transmission line end are calculated using Equation (19) to (21).

$$I_{B+} = \frac{V_2 < \delta_2 - V_{f+}}{Z_{S2+}} \quad (19)$$

$$I_{B-} = \frac{-V_{f-}}{Z_{S2+}} \quad (20)$$

$$I_{B0} = 0 \quad (21)$$

Therefore, the current at the end of the transmission line is calculated using the Equation (19) to (21).

8) Finally, all the necessary parameters for estimating the fault location by Equation (15) are available to the relay. Therefore, the relay could calculate the fault location.

9)

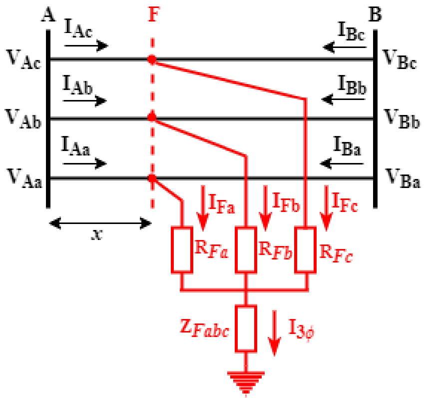


Fig. 8. Three-phase-ground fault at distance x from terminal A

2.3. Three-phase fault

If the three-phase fault a-b-c occurs according to Fig. 8 at distance x from terminal A, Equation (22) could be used to estimate the fault location and the fault resistance value [21].

$$\begin{bmatrix} x \\ R_{Fa} \\ R_{Fb} \\ R_{Fc} \\ R_{Fabc} \\ X_{Fabc} \end{bmatrix} = \begin{bmatrix} M_{1a} & I_{Fa_r} & 0 & 0 & I_{3\emptyset_r} & -I_{3\emptyset_i} \\ M_{2a} & I_{Fa_i} & 0 & 0 & I_{3\emptyset_i} & I_{3\emptyset_r} \\ M_{1b} & 0 & I_{Fb_r} & 0 & I_{3\emptyset_r} & -I_{3\emptyset_i} \\ M_{2b} & 0 & I_{Fb_i} & 0 & I_{3\emptyset_i} & I_{3\emptyset_r} \\ M_{1c} & 0 & 0 & I_{Fc_r} & I_{3\emptyset_r} & -I_{3\emptyset_i} \\ M_{2c} & 0 & 0 & I_{Fc_i} & I_{3\emptyset_i} & I_{3\emptyset_r} \end{bmatrix}^{-1} \begin{bmatrix} V_{Aa_r} \\ V_{Aa_i} \\ V_{Ab_r} \\ V_{Ab_i} \\ V_{Ac_r} \\ V_{Ac_i} \end{bmatrix} \tag{22}$$

In Equation (22), the parameters M_1 and M_2 of each phase are calculated using Equations (3) and (4). Also:

$$I_{3\emptyset} = I_{Fa} + I_{Fb} + I_{Fc} \tag{23}$$

$$Z_{Fabc} = R_{Fabc} + jX_{Fabc} \tag{24}$$

The proposed method steps for a three-phase fault to the ground are as follows:

Stages 1 to 6 for this type of fault are similar to steps 1 to 6 in Sections 2-1, except that in this section the fault is a-b-c-g and therefore instead of Equation (9) and (10) from Equation (25) and (26) should be used.

$$V_{f-} = 0 \tag{25}$$

$$V_{f0} = 0 \tag{26}$$

The symmetrical components of the voltage and therefore the voltage of phases a, b and c are calculated using Equations (8), (25), and (26). The equivalent circuit of the symmetrical components of the network when a three-phase fault (a-b-c-g) occurs in the form of Fig. 9.

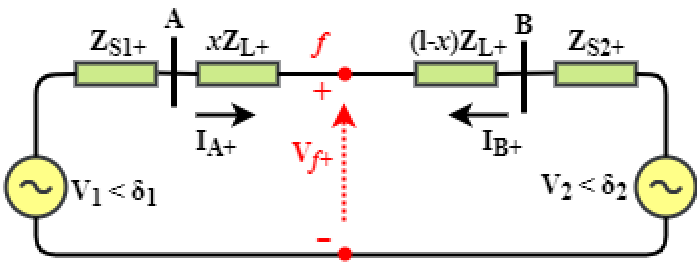


Fig. 9. The equivalent circuit of the symmetrical components of the network in three-phase-ground fault mode

The continuation of the algorithm from step 7 is as follows:

7) According to Fig. 9, to calculate the current I_{B+}, the voltage drop across the transmission line is eliminated. Therefore, the positive component of the current of the transmission line end is calculated using Equation (27).

$$I_{B+} = \frac{V_2 < \delta_2 - V_{f+}}{Z_{S2+}} \tag{27}$$

8) Due to the symmetry, the negative and zero components of the current will not exist and are considered equal to zero. Therefore, the phase currents at the end of the transmission line are calculated and the fault location is calculated through Equation (22).

As explained in the proposed method, first the type of short-circuit must be known, then the protection algorithm will perform the appropriate performance based on the type of short-circuiting. It is important to note that the short-circuit type detection in relays, especially new relays, could be easily detected by fault detector units. These units usually easily identify the type of short-circuit by comparing the present current sample with the previous cycle current sample [22].

3. System modeling and simulation results

Fig. 10 shows the network used to simulate the proposed protection methods. The simulation has done in ATP-EMTP software and the network equivalent sources specifications are as follows.

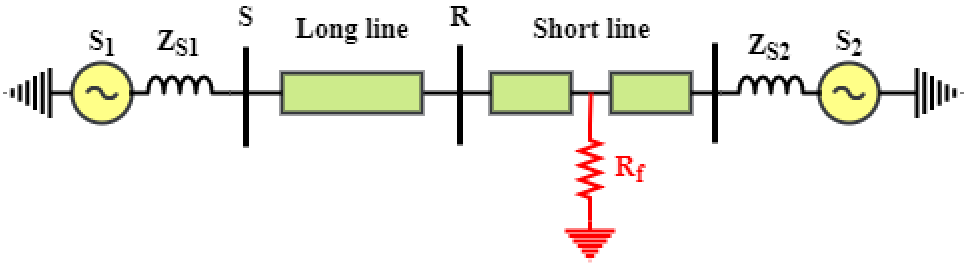


Fig. 10. The equivalent circuit of the symmetrical components of the network in three-phase-ground fault mode

S_1: 230 kV, 50Hz, $Z_{S1+} = 0.64+ j8.32\Omega$, $Z_{S10} = 3.2+ j13.44\Omega$, $\delta_1= 10^\circ$

S_2: 230 kV, 50Hz, $Z_{S2+} = 1.28+ j33.12\Omega$, $Z_{S20} = 0.96+ j27.84\Omega$, $\delta_1= 20^\circ$

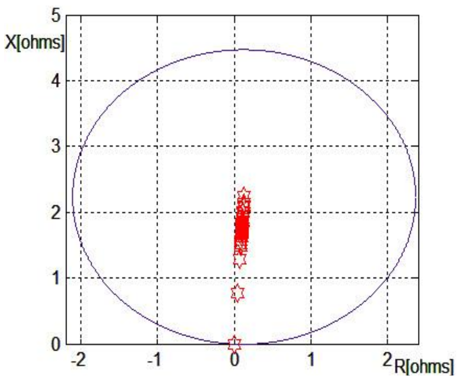


Fig. 11. Impedance observed single-phase fault to the ground at a distance of 5 km from the beginning of the transmission line and with a resistance of 20 ohm

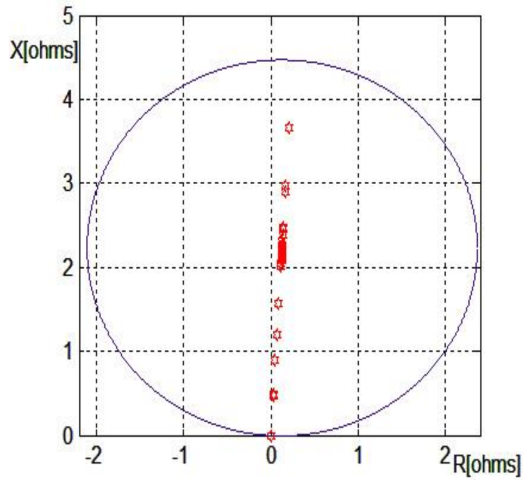


Fig. 12. Impedance observed single-phase fault to the ground at a distance of 5 km from the beginning of the transmission line and with a resistance of 5 ohm

The long transmission line is 200 km, and the short transmission line is 20 km, and the impedance of the positive component is 0.0162+ j0.2793 Ω/km and the impedance of the zero component is 0.1588+ j0.6458 Ω/km. The self-impedances are 0.063686+ j0.401414 Ω/km and the mutual impedance between phases is 0.047526+ j0.122181 Ω/km. Also, the rapid protection zone of the distance relay is set to 80% of the transmission line.

All voltage and current signals are saved as a matrix via ATP-EMTP software. These matrices are then called in the MATLAB software and the necessary calculations are performed on these signals. The method used to estimate the phasor is the return Fourier algorithm method [23-24]. If a single-phase-ground fault occurs 5 km from the beginning of the short transmission line with a resistance of 20 ohms, the relay performance is shown in Fig. 11. If a single-phase-ground fault occurs 5 km from the beginning of the short transmission line with a resistance of 5 ohms, the relay performance is shown in Fig. 12.

Fig. 13 shows the value of relay impedance when two-phase faults occur at a distance of 15 km from the beginning of the transmission line. The fault resistance, in this case, is considered to be 10 ohms. Fig. 14 shows the value of relay impedance when two-phase faults occur at a distance of 10 km from the beginning of the transmission line. The fault resistance, in this case, is considered to be 5 ohms.

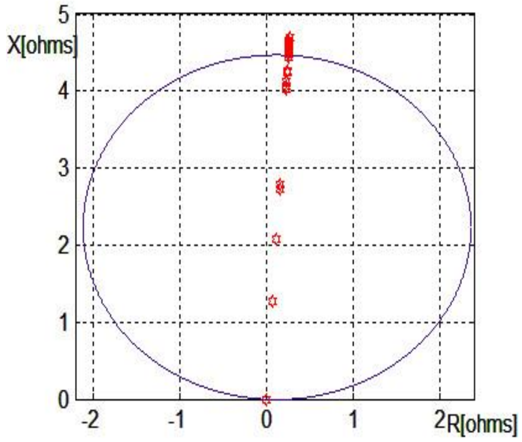


Fig. 13. Impedance observed two-phase fault at a distance of 15 km from the beginning of the transmission line and with a resistance of 10 ohm

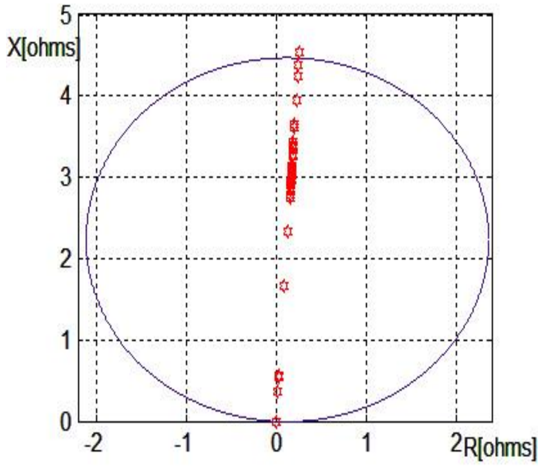


Fig. 14. Impedance observed two-phase fault at a distance of 10 km from the beginning of the transmission line and with a resistance of 5 ohm

Fig. 15 shows the value of relay impedance when three-phase faults occur at a distance of 2 km from the beginning of the transmission line. The fault resistance, in this case, is considered to be 1 ohm. Fig. 16 shows the value of relay impedance when three-phase faults occur at a distance of 10 km from the beginning of the transmission line. The fault resistance, in this case, is considered to be 10 ohms.

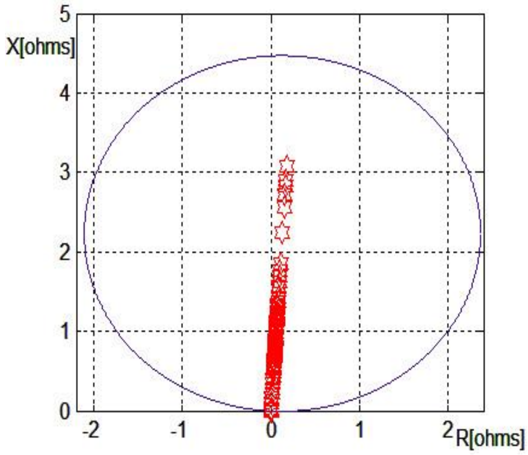


Fig. 15. Impedance observed three-phase fault to the ground at a distance of 2 km from the beginning of the transmission line and with a resistance of 1 ohm

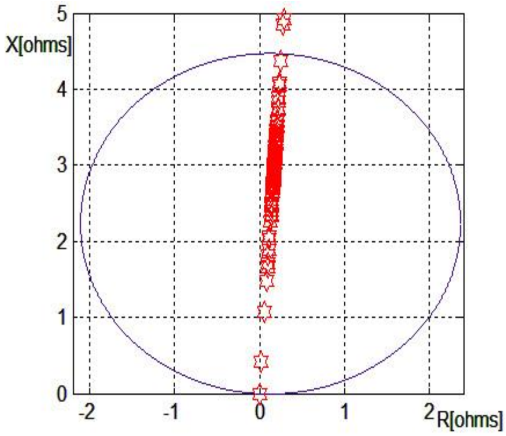


Fig. 16. Impedance observed three-phase fault to the ground at a distance of 10 km from the beginning of the transmission line and with a resistance of 20 ohm

Table 1

Percentage of impedance measurement error in the case of a fault a-g

Fault location (km)	Fault resistance (ohm)	Common distance	Method [20]	The proposed method
5	1	98	22	54
	5	865	80	53
	10	1742	154	50
	20	3613	150	42
10	1	36	30	27
	5	473	46	23
	15	1425	128	20
	20	1936	178	18
15	1	20	13	16

	5	300	34	15
	10	674	60	14
	20	1300	120	9

The following is a comparison between the proposed method with the common distance method and also the method presented in reference [20] in Tables 1 to 3. In the method presented in reference [20,] considering that the impedance of the fault path is often ohmic property when the fault occurs, and as a result the voltage angle and current of the fault location are equal, the fault location is estimated. Tables 1 to 3 compare single-phase to ground faults, two-phase and three-phase faults, respectively. Also, as shown in Fig. 2, the voltage at the relay location in short transmission lines drops sharply when a fault occurs. Therefore, voltage measuring transformers under these conditions will face error measures. In comparison, the voltage measurement transformer error is considered to be 6% in amplitude and 4-degree phase difference. The magnitude of this error is based on the reference [25] for voltage transformers.

Table 2

Percentage of impedance measurement error in the case of a fault b-c

Fault location (km)	Fault resistance (ohm)	Common distance	Method [20]	The proposed method
5	1	114	32	6
	5	900	166	24
	10	1900	260	34
10	1	41	20	7
	5	500	80	11
	15	1020	130	16
15	1	20	11	7
	5	366	53	7
	10	717	86	10

Table 3

Percentage of impedance measurement error in the case of a fault a-b-c-g

Fault location (km)	Fault resistance (ohm)	Common distance	Method [20]	The proposed method
5	1	7	6	6
	5	7	6	6
	10	7	6	5
10	1	7	5	5
	5	10	5	4
	15	10	7	3
15	1	8	6	5
	5	10	6	4
	10	10	6	4

4. Analysis of simulation results

Based on the simulations presented in Section 3, the following results are obtained:

- The proposed method does not require a voltage signal during the short-circuit. Because one of the main problems with short transmission lines protection is the error of voltage measuring transformers at low voltages, the lack of need for voltage signal during the fault significantly improves the performance of the proposed method compared to previous methods.
- As could be seen from the results obtained in Tables 1 to 3, except in cases where the fault resistance is considered to be very low, in other cases the proposed method has less error than other methods. However, it should be noted that usually, the minimum fault resistance is due to the presence of a spark, the value which is about 5 ohms. Therefore, the proposed method is more practical in comparison with the previous two methods.
- The proposed method does not require a communication channel to communicate between the stations at the beginning and end of the transmission line. The voltage and current at the end of the transmission line are estimated using the values of voltage and current at the beginning of the transmission line. As a result, error problems due to errors in sending information or errors in the telecommunication channel that exist in the common methods will not be present in the proposed method.

As the fault resistance increases, the accuracy of the proposed method increases compared to other methods. Because in this case, the voltage drop across the short transmission line impedance is less. As a result, the voltage at the beginning of the transmission line, which is assumed to be equal to the voltage at the end, has a lower error. Therefore, increasing fault resistance improves the performance of the proposed method.

5. Conclusion

In this paper, a method for improving the performance of the distance relay in the protection of short transmission lines was proposed. This method uses voltage data before the fault occurs as well as the current during short-circuit, estimates the voltage and current at the end of the transmission line, and then use this information to estimate the fault location. The approximations used in this method and the lack of need for voltage during short-circuit increase the efficiency of the proposed method compared to similar methods. The proposed method for fault resistance of up to 20 ohms has had a more appropriate response than other similar methods in improving the performance of short transmission lines distance relays.

R E F E R E N C E S

[1]. Eissa, M. M., and M. Masoud. "A novel digital distance relaying technique for transmission line protection." IEEE Transactions on Power Delivery 16, no. 3 (2001): 380-384.

[2]. Elmore, Walter A. Protective relaying: theory and applications. Vol. 1. CRC Press, 2003.

[3]. Horowitz, Stanley H., and Arun G. Phadke. Power system relaying. Vol. 22. John Wiley & Sons, 2008.

[4]. Sun, Shan C. "Phase comparison relaying system with the single-channel communications link." U.S. Patent 4,935,837, issued June 19, 1990.

[5]. Warrington, AR van C. "Protective relaying (or long transmission lines." Electrical Engineering 62, no. 6 (1943): 261-268.

[6]. Dambhare, Sanjay, S. A. Soman, and M. C. Chandorkar. "Adaptive current differential protection schemes for transmission-line protection." IEEE Transactions on Power Delivery 24, no. 4 (2009): 1832-1841.

[7]. Rosolowski, Eugeniusz, Jan Izykowski, and Murari M. Saha. "Fault location algorithm for use with current differential protective relays of double-circuit line." In 2009 IEEE Bucharest PowerTech, pp. 1-6. IEEE, 2009.

[8]. Dashtdar, Masoud, and Majid Dashtdar. "Fault Location in Distribution Network Based on Fault Current Profile and The Artificial Neural Network." Mapta Journal of Electrical and Computer Engineering (MJECE) 2, no. 1 (2020): 30-41.

[9]. El-Alaily, A. A., and M. M. Mandour. "A comprehensive form for the protection of very short transmission lines." Electric power systems research 14, no. 3 (1988): 227-232.

[10]. Sadinezhad, I., and M. Joorabian. "A new adaptive hybrid neural network and fuzzy logic-based fault classification approach for transmission lines protection." In 2008 IEEE 2nd International Power and Energy Conference, pp. 895-900. IEEE, 2008.

[11]. Aggarwal, R. K., J. Iglesias Lorenzo, and A. L. Orille. "Implementation and laboratory test of a fully integrated neural network-based protection relay for high voltage transmission lines." (2004): 72-75.

[12]. Dashtdar, M., M. Esmaeilbeig, M. Najafi, and M. Esa Nezhad Bushehri. "Fault Location in the Transmission Network Using Artificial Neural Network." Automatic Control and Computer Sciences 54, no. 1 (2020): 39-51.

[13]. Dashtdar, Masoud, Mostafa Esmailbeag, and Mojtaba Najafi. "Fault Location in the Transmission Network based on Zero-sequence Current Analysis using Discrete Wavelet Transform and Artificial Neural Network." Computational intelligence in electrical engineering 10, no. 4 (2019): 87-102.

[14]. Dashtdar, Majid, and Masoud Dashtdar. "Fault Location in the Transmission Network Using a Discrete Wavelet Transform." American Journal of Electrical and Computer Engineering 3, no. 1 (2019): 30-37.

[15]. Dashtdar, Majid, and Masoud Dashtdar. "Fault location in the transmission network based on extraction of fault components using wavelet transform." The Scientific Bulletin of Electrical Engineering Faculty 19, no. 2 (2019): 1-9.

[16]. Oonsivilai, Anant, and Sanom Saichoomdee. "Appliance of the recurrent neural network toward distance transmission lines protection." In TENCON 2009-2009 IEEE Region 10 Conference, pp. 1-4. IEEE, 2009.

[17]. Lahiri, Uttama, A. K. Pradhan, and S. Mukhopadhyaya. "Modular neural network-based directional relay for transmission line protection." IEEE Transactions on Power Systems 20, no. 4 (2005): 2154-2155.
[18]. Wu, Q. H., J. F. Zhang, and D. J. Zhang. "Ultra-high-speed directional protection of transmission lines using mathematical morphology." IEEE transactions on power delivery 18, no. 4 (2003): 1127-1133.
[19]. Dashtdar, Masoud, Rahman Dashti, and Hamid Reza Shaker. "Distribution network fault section identification and fault location using artificial neural network." In 2018 5th International Conference on Electrical and Electronic Engineering (ICEEE), pp. 273-278. IEEE, 2018.
[20]. Xu, Zhen Yu, G. Xu, Li Ran, S. Yu, and Q. X. Yang. "A new fault-impedance algorithm for distance relaying on a transmission line." IEEE transactions on power delivery 25, no. 3 (2010): 1384-1392.
[21]. Salim, Rodrigo Hartstein, Mariana Resener, André Darós Filomena, Karen Rezende Caino De Oliveira, and Arturo Suman Bretas. "Extended fault-location formulation for power distribution systems." IEEE transactions on power delivery 24, no. 2 (2009): 508-516.
[22]. Ziegler, Gerhard. Numerical distance protection: principles and applications. John Wiley & Sons, 2011.
[23]. Darwish, Hatem A., and Magdy Fikri. "Practical considerations for recursive DFT implementation in numerical relays." IEEE Transactions on Power Delivery 22, no. 1 (2006): 42-49.
[24]. Phadke, Arun G., and James S. Thorp. Computer relaying for power systems. John Wiley & Sons, 2009.
[25]. ALSTOM (Firm). Network protection & automation guide. Alstom, 2002.