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Full Length Research Paper

Detection of fault location in the transmission lines with voltage sampling and CT deletion by network impedance matrix method

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There are a lot of methods for fault location using synchronized phasor measurement. Most of these methods are based on using measured voltage and current in one or two ends of a transmission line. Current measurement accuracy is limited according to the used current transformer's (CT) accuracy. In this paper, besides various methods of fault distance location detection in power transmission lines, a new method based on the current Tran's removal and use of the voltage sampling by network impedance matrix method is described. This fault distance location detection method is sufficiently accurate and precise fault location is calculated with minimum error difference. At first, relations to calculate the fault location of this method are proved. Then the location of the single phase to ground and phase-phase fault of the network to ground is detected using the electromagnetic transient program (EMTP) software in two cases: First regarding the capacity of the lines' capacitors and then regardless of that. This simulation method can determine the fault location online and with the minimum time.

Key words: Fault locator, Synchronized phasor measurement, Fault analysis, impedance matrix, EMTP.

INTRODUCTION

Fault locating in a transmission line using synchronized phasor measurement had been studied in the past. Using current and phasor voltage of a terminal based on reactive power and the use of voltage and current phasor from two ends of the transmission line show the technology to remove synchronized faults (Takagi et al., 1982; Girgis et al. 1992; Abe et al. 1995; Gopalakrishnan et al. 2000). Methods in which the phasor current is used to locate the fault are as follows: Three-phasic analysis to obtain the fault point distance by solving the six equations in transmission line (Girgis et al., 1992), presenting a method based on reactive power and developing several united terminals, in the transmission line (Abe et al., 1995), using a phasor method based on transmission line equations for fault location detection (Gopalakrishnan et al., 2000), introducing a numerical algorithm by fault and current fault phases from a transmission line terminal (Djuric et al., 1998), using an auxiliary method to convert the time domain to frequency domain and use of artificial neural network for evaluating the fault location (Tawfik et al., 2001).

On most existing methods based on permanent state phasors, for modeling transmission lines for fault distance detection, the compact line model with neglecting line capacitors are used. Such model is not sufficiently accurate in long lines. In these methods, the voltage and current waves of one side or both sides of the line were used. Due to capacitive property of line, these voltages and currents have a wide range of components in addition to the main ones. To calculate the impedance, these components are removed with analog and digital filters. Using these filters will cause some voltage and

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Abbreviations: CT, Current transformer; **EMTP**, electromagnetic transient program.

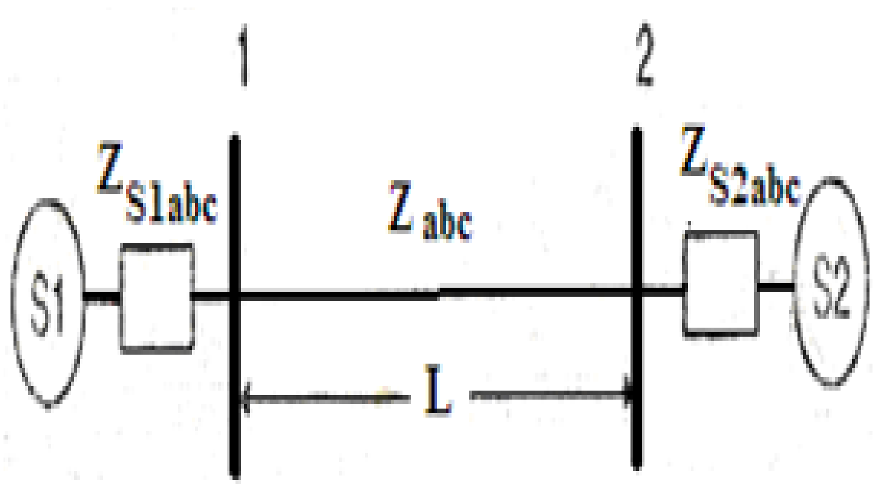

Figure 1. Single linear schema of the study network.

current data to disappear, which would cause the method for fault location detection in energy transmission lines, especially for long lines to be inaccurate. Therefore, in methods based on permanent state phasors for short lines, the compact models and for long lines, the wide transmission line model is used for distance detection. There are two methods in short lines that compact line model used:

1- Obtain information from one side of the line
2- Obtain information from both sides.

Benefits of obtaining information from both sides of the line can be a good accuracy in different operating and fault conditions, very high strength to changes in the structure of the networks connected to the two sides of the desired line, getting no influence from resistance fault and extension to systems with three-terminals. The major disadvantage of this method is need to communication lines for sending information to a place for computation and synchronization or when needed synchronizing this data. Wide transmission line models include long transmission line phasor and time domain transmission line models. In this paper, a fault locating method based on only sampling voltage is described and a model for dislocated and non-dislocated transmission lines and without fault caused by current transformer (CT), application is introduced. This model was used for the long lines and results simulated by electromagnetic transient program (EMTP) software are shown.

THE PROPOSED METHOD

Figure 1 shows a transmission line that Z_{S1abc} and Z_{S2abc} are impedance matrices of three-phase sources and L denotes the length of transmission line and Z_{abc} is three-phase impedance of transmission line which is obtained through the following parameter matrices:

$$Z_{abc}=\begin{bmatrix} z_{aa} & z_{ab} & z_{ac} \\ z_{ba} & z_{bb} & z_{bc} \\ z_{cz} & z_{cb} & z_{cc} \end{bmatrix} \tag{1}$$

Admittance matrix of the line can be obtained by impedance matrix of the line. According to the Figure 1, admittance matrix form a network is obtained from the following equations:

$$y_{abc}=\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \tag{2}$$

$$y_{11}=\frac{1}{Z_{s1abc}}+\frac{1}{Z_{abc}\times L} \tag{3}$$

$$y_{22}=\frac{1}{Z_{S2abc}}+\frac{1}{Z_{abc}\times L} \tag{4}$$

$$y_{12}=y_{21}=-\frac{1}{Z_{abc}\times L} \tag{5}$$

All matrices elements of the network are 3×3 matrices. So admittance bus is a 6×6 matrix. To study the fault along the transmission line in the study network, we consider a short circuit along the line with the L_1 distance from bus 1 and L_2 from bus 2, and thus a new bus (bus 3) or fault bus is added to the network. Network admittance matrix in this case is:

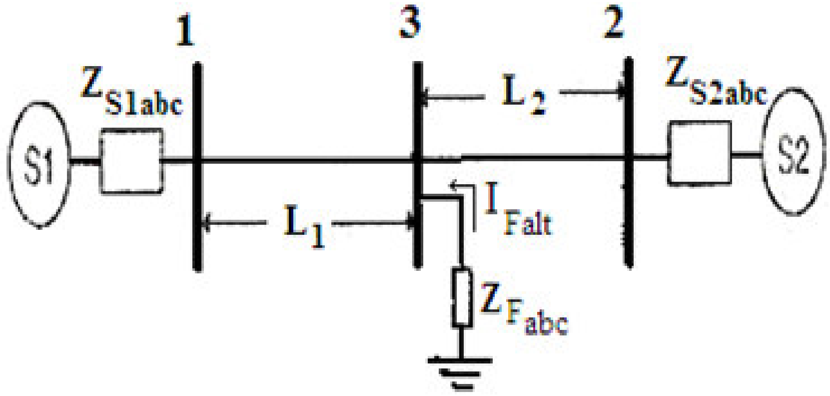

Figure 2. Equivalent network with fault created along the line.

$$y_{bus\ fault} = \begin{vmatrix} y'_{11} & y'_{12} & y'_{13} \\ y'_{21} & y'_{22} & y'_{23} \\ y'_{31} & y'_{32} & y'_{33} \end{vmatrix} \quad (6)$$

$$y_{11}' = \frac{1}{Z_{S_{1abc}}} + \frac{1}{Z_{abc} \times L} \quad (7)$$

$$y'_{12} = y'_{21} = 0 \quad (8)$$

$$y'_{13} = y'_{31} = -\frac{1}{Z_{abc} \times L_1} \quad (9)$$

$$y'_{22} = \frac{1}{Z_{S_{2abc}}} + \frac{1}{Z_{abc} \times L_2} \quad (10)$$

$$y'_{23} = y'_{32} = -\frac{1}{Z_{abc} \times L_2} \quad (11)$$

$$y'_{33} = \frac{1}{Z_{abc} \times L_1} + \frac{1}{Z_{abc} \times L_2} + \frac{1}{Z_{f\ abc}} \quad (12)$$

In this case, each element of the bus admittance matrix are a 3×3 matrix, thus admittance bus is a 9×9 matrix. With this short connection along the line and admittance and impedance matrix of the network, network equations can be expressed as follows:

$$V_{bus}^{\ 0} = \begin{bmatrix} V_1^0 \\ V_2^0 \\ V_3^0 \end{bmatrix} \quad (13)$$

Each of the V_{bus}^0 matrix elements are 3×1 matrix.Prefault voltages can be achieved from analysis and spread of the thevenin. Eliminating active sources of the network and displaying generators and lines with suitable equivalent impedances, network can be achieved. In this network, bus voltages indicate the changes from short circuit. These changes are called ΔV_1, ΔV_2 and ΔV_3 and are shown by V_T thevenin voltage matrix which elements are 3×1 matrix.

$$V_T \stackrel{\Delta}{=} \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \Delta V_3 \end{bmatrix} \quad (14)$$

According to the thevenin theory, after fault bus voltages that form the above matrix will be obtained by the following sum:

$$V^f_{\ bus} = V^0_{\ bus} + V_T \quad (15)$$

Which V^f_{bus} is the bus voltage matrix after the fault and V0bus is the bus voltage matrix before the fault.

With the obtained after fault admittance bus matrix called $y_{busfault}$ and reversing it, the network impedance matrix can also be achieved.

$$Z_{busfault} = (y_{busfault})^{-1} \quad (16)$$

In the equivalent thevenin network, the fault mode which is shown in Figure 2, I_f current is only injected to a bus (bus 3).

Therefore, the current bus matrix equals the short circuit current matrix (Novosel et al.1996).

$$I_f = \begin{bmatrix} 0 \\ 0 \\ I_{fabc} \end{bmatrix} \quad (17)$$

In general, the relationship between voltage and injected currents to the bus is obtained according to the network impedance matrix:

$$V_{bus} = Z_{bus} . I_{bus} \quad (18)$$

Therefore, in fault state, according to the current matrix this equation can be corrected as follows:

$$V_T = Z_{bus} . I_f \quad (19)$$

Finally, with placement of the V_T equivalent in the above relation we will have:

$$V^f{}_{bus} = V^0{}_{bus} + Z_{bus} . I_f \quad (20)$$

That Z_{bus} is impedance matrix of the buses in fault and short circuit modes. Therefore, it can also be called $Z_{busfault}$. The above equations will be simplified as follows:

$$V_T \overset{\Delta}{=} \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \Delta V_3 \end{bmatrix} = Z_{busfault} \begin{bmatrix} [0] \\ [0] \\ I_{fabc} \end{bmatrix} \quad (21)$$

[0] is a zero matrix with 3×1 dimensions and I_{fabc} is current fault matrix in bus 3 with three-phases which its dimensions are 3×1, ΔV_i is changes in three-phase voltage at i^{th} bus (difference of i^{th} bus voltage before and after the fault and $Z_{busfault}$ is impedance matrix for network in the fault state in the network. Also, considering the following relationship network equation can be rewritten:

$$Z_{busfault} = (y_{busfault})^{-1} \quad (22)$$

$$\begin{bmatrix} [0] \\ [0] \\ I_{fabc} \end{bmatrix} = y_{busfaul} \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \Delta V_3 \end{bmatrix} \quad (23)$$

$$\begin{bmatrix} [0] \\ [0] \\ I_{fabc} \end{bmatrix} = \begin{bmatrix} y'_{11} & y'_{12} & y'_{13} \\ y'_{21} & y'_{22} & y'_{23} \\ y'_{31} & y'_{32} & y'_{33} \end{bmatrix} \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \Delta V_3 \end{bmatrix} \quad (24)$$

$$[0] = y'_{11}\ \Delta V_1 + y'_{12}\Delta V_2 + y'_{13}\Delta V_3 \quad (25)$$

$$[0] = y'_{21}\Delta V_1 + y'_{22}\Delta V_2 + y'_{23}\Delta V_3 \quad (26)$$

$$[I_{fabc}] = y'_{31}\Delta V_1 + y'_{32}\ \Delta V_2 + y'_{33}\ \Delta V_3 \quad (27)$$

Which for network analysis to find the fault location for independency of equations to current fault and the impedance fault the first two equations can be used. Therefore we have:

$$[0] = \left(Y_{11} - \frac{y_{abc}}{L} + \frac{y_{abc}}{L_1} \right) \Delta V_1 + ([0]\Delta V_2 + (-\frac{y_{abc}}{L_1})\Delta V_3 \quad (28)$$

$$[0]_{3\times1} = ([0])\ \Delta V_1 + \left(Y_{22} - \frac{y_{abc}}{L} + \frac{y_{abc}}{L_2} \right) \Delta V_2 + (-\frac{y_{abc}}{L_2})\Delta V_3 \quad (29)$$

The above two equations can be expressed by L_1 and L_2 as follows:

$$\frac{1}{L_1}\Delta V_1 - \frac{1}{L_1}\Delta V_3 = -(y_{abc})^{-1}(Y_{11} - \frac{y_{abc}}{L})\Delta V_1 \quad (30)$$

$$\frac{1}{L_2}\Delta V_2 = \frac{1}{L_2}\Delta V_3 = -(y_{abc})^{-1}(Y_{22} - \frac{y_{abc}}{L})\Delta V_2 \quad (31)$$

Assuming

$$P = \mathrm{Z_{abc}}(\frac{y_{abc}}{\mathrm{L}} - Y_{11})\Delta V_1 \quad (32)$$

$$Q = \mathrm{Z_{abc}}(\frac{\mathrm{y_{abc}}}{\mathrm{L}} - Y_{22})\Delta V_2 \quad (33)$$

We will have:

$$\frac{1}{L_1}\Delta V_1 - \frac{1}{L_1}\Delta V_3 = P \quad (34)$$

$$\frac{1}{L_2}\Delta V_2 - \frac{1}{L_2}\Delta V_3 = Q \quad (35)$$

To reduce the complexity of equations, x and y values can replace the following values:

$x = \frac{1}{L_1}$ *and* $\mathrm{y} = \frac{1}{\mathrm{L_2}}$ or $y = \frac{x}{xL-1}$ and

$$\frac{1}{x} + \frac{1}{y} = L$$

In which case:

$$x\ \Delta V_1 - x\ \Delta V_3 = P \quad (36)$$

$$y\ \Delta V_2 - y\Delta V_3 = Q \quad (37)$$

According to the last statements, the above two equations are expressed based on 3×3 matrices:

$$x\begin{bmatrix}\Delta V_{1a}\\ \Delta V_{1b}\\ \Delta V_{1c}\end{bmatrix} - x\begin{bmatrix}\Delta V_{3a}\\ \Delta V_{3b}\\ \Delta V_{3c}\end{bmatrix} = x\begin{bmatrix}P(1)\\ P(2)\\ P(3)\end{bmatrix} \quad (38)$$

Since all lines of the above matrix expressed in the equation are true, so the first elements of each of the equation elements can be used to simplify the equations so that we will have:

$$x\Delta V_1(1) - x\,\Delta V_3\,(1) = P\,(1) \quad (39)$$

$$y\Delta V_1(1) - y\ \Delta V\,(1) = Q\,(1) \quad (40)$$

As ΔV_3 is not accessible because fault location is unspecified, therefore the equation should be rewritten independent to this element:

$$\begin{cases} \dfrac{x\Delta V_1(1)\text{ - }P(1)}{x} = \dfrac{y\Delta V_2(1) - Q(1)}{y} \\ y = \dfrac{x}{xL-1} \rightarrow \dfrac{1}{y} = \dfrac{xL-1}{x} = L - \dfrac{1}{x} \end{cases} \quad (41)$$

$$\Delta V_1(1) - \frac{P(1)}{x} = \Delta V_2(1) - \frac{Q(1)}{y} \quad (42)$$

$$\Delta V_1(1) - \Delta V_2(1) = \frac{P(1)}{x} - \frac{Q(1)}{y}$$

$$\Delta V_1(1) - \Delta V_2(1) = \frac{P(1)}{x} - (L - \frac{1}{x})Q(1)$$

$$\Delta V_1(1) - \Delta V_2(1) = \frac{P(1)}{x} - \frac{Q(1)}{x} - LQ(1)$$

$$\Delta V_1(1) - \Delta V_2(1) + LQ(1) = \frac{1}{x}(P(1) + Q(1))$$

Because $\dfrac{1}{x} = L_1$, so:

$$L_1 = \frac{(\Delta V_1(1) - \Delta V_2(1) - LQ(1)}{(P(1) + Q(1))} \quad (43)$$

Thus, the fault location distance detection according to the above equations will be obtained.

SIMULATION AND NUMERICAL STUDIES

The model used in simulation is a 200 miles length long transmission line, and 500 KV voltage (Makram and Grigis, 1988). Presented plan for the fault location with values obtained from fault analysis program was examined in the steady state (Jiang et al., 2000).

Examining the results and changes in three-phase voltages in bus 1 and 2, a fault location can be estimated in the network. This is applied by means of the above plan in equation 43.

Deviation percent in fault location estimation by the mentioned model is in the range of 0.073% to 3% in the stated condition. All of the deviances are in the resistance fault less than 1%. This method was evaluated for 10 different locations with different types of fault and L_1distances. The error of locating fault and deviation is measured as:

$$Error\ (\%) = \frac{|\text{Actual fault location} - \text{Estimated fault location}|}{\text{Length of transmission line}}$$

Cause of deviations and fault in estimation of fault location is considering and does not consider the transmission line capacity. Another factor is inaccurate transmission line model in EMTP software and is inaccuracy of voltages' phasor measurement. The considered transmission line is an unusual long transmission one. Line capacity for most lines with regular voltages is less than the amount used in this paper. Also the proposed algorithm for a long line of 100 miles has been tested too.

Simulation improved in all stages and the suggested method provided a very high improvement in earth connection faults. The above method is generally free from current transformers' mistakes and this independence to current provides high accuracy results. Phasor synchronized estimation with synchronous phasor measurement units and use of a synchronized pulse by GPS satellite systems can be very precise. Investigations show that the proposed model is very clear and obvious.

Figures 3 and 4, show the simulated transmission line to obtain the V_1 and V_2 voltages before and after the fault, by EMTP software in the two modes of single-phase connection to the earth and the phase-phase connection. In this section, for better observation of the results, we evaluate the faults in three different conditions of this method.

Single phase to ground fault

In the first case, fault location is 180 mile and impedance

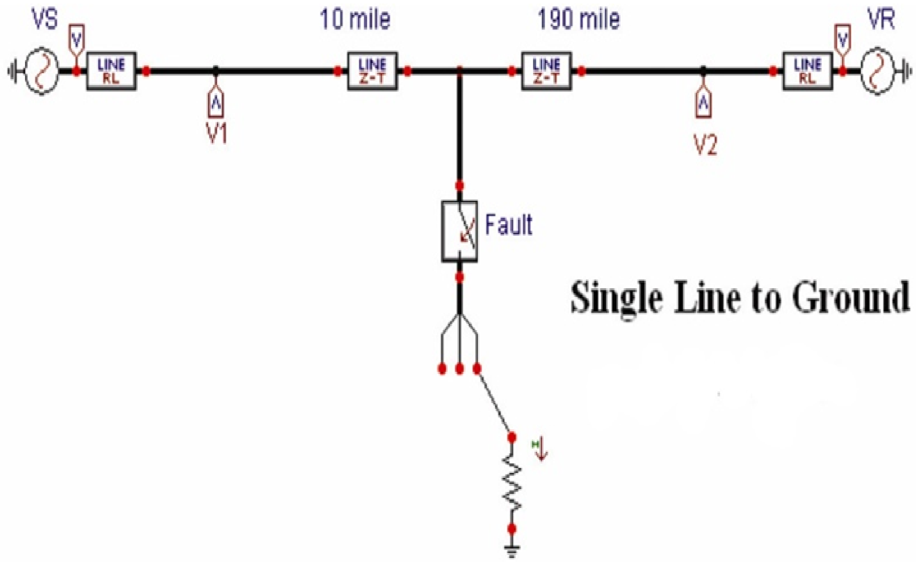

Figure 3. The simulation of transmission line and faults by EMTP.

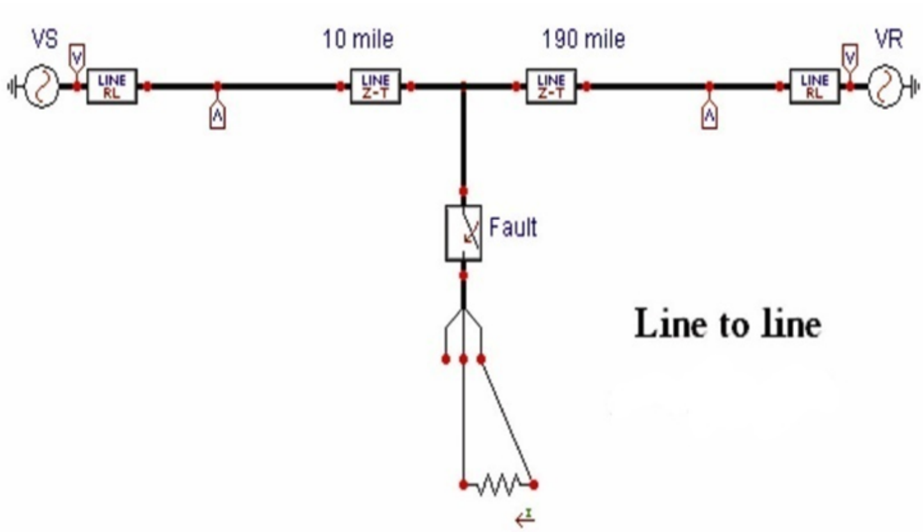

Figure 4. The simulation of transmission line and faults by EMTP.

fault is 10Ω. Figures 5 and 6 show the V_1 and V_2 voltages before and after the fault. Table 1 shows the V_1 and V_2 voltage profiles before and after the fault.

Type 1 phase-phase fault

In the second case, fault location is 100 mile with fault impedance of 50 Ω. Type of the fault is phase-phase. Figures 7 and 8, show V_1 and V_2 voltages before and after the fault. And also Table 2 shows the characteristics of V_1 and V_2 voltages before and after the fault.

The second type of phase-phase

In the third case, fault location is 180 mile and fault impedance of 10 Ω. Type of fault is phase-phase. In this case the capacitance of capacitor is not considered. Figure 9 and 10 show V_1 and V_2 voltages before and after the fault. Length of fault distance and its estimation fault according to the related relations are: Estimated L_1=180.6

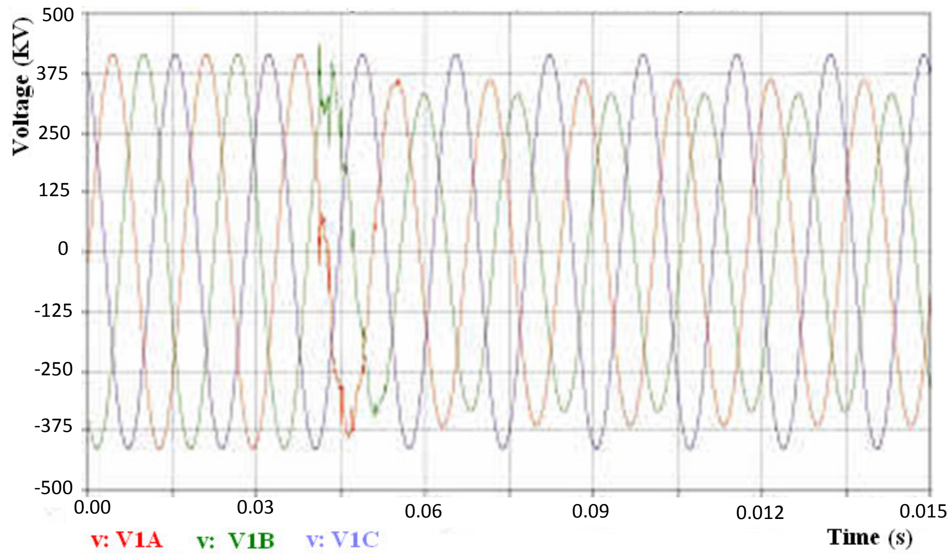

Figure 5. V_1 voltage before and after the single phase to ground fault.

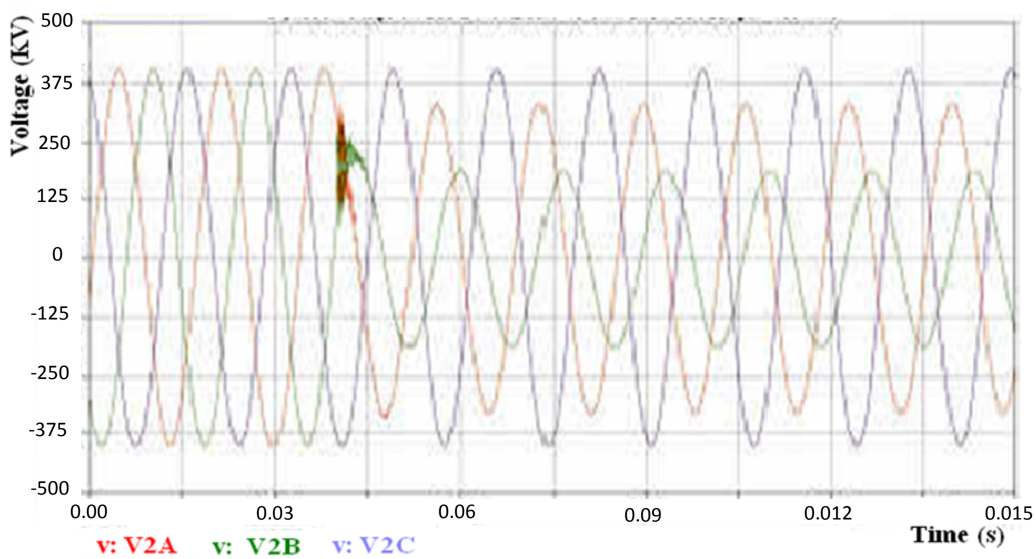

Figure 6. V_2 voltage before and after the single phase to ground fault.

Table 1. Voltage profile before and after the single phase to ground fault.

		Before fault	After fault
V_1	a	284≤3	227≤11
	b	284≤123	228≤114
	c	284≤243	284≤243
V_2	a	274≤11	171≤51
	b	274≤131	127≤99
	c	274≤251	274≤251

Length of fault distance and its estimation fault according to the related equation is: Estimated L_1, 180.87; Fault%, 0.43%.

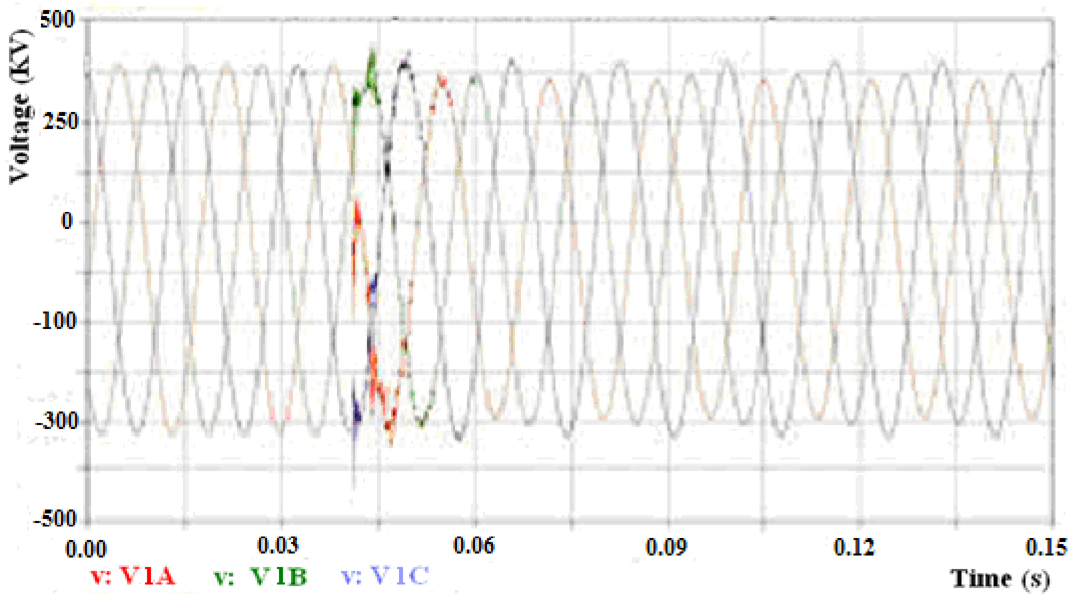

Figure 7. V_1 voltage before and after phase-phase fault, type 1.

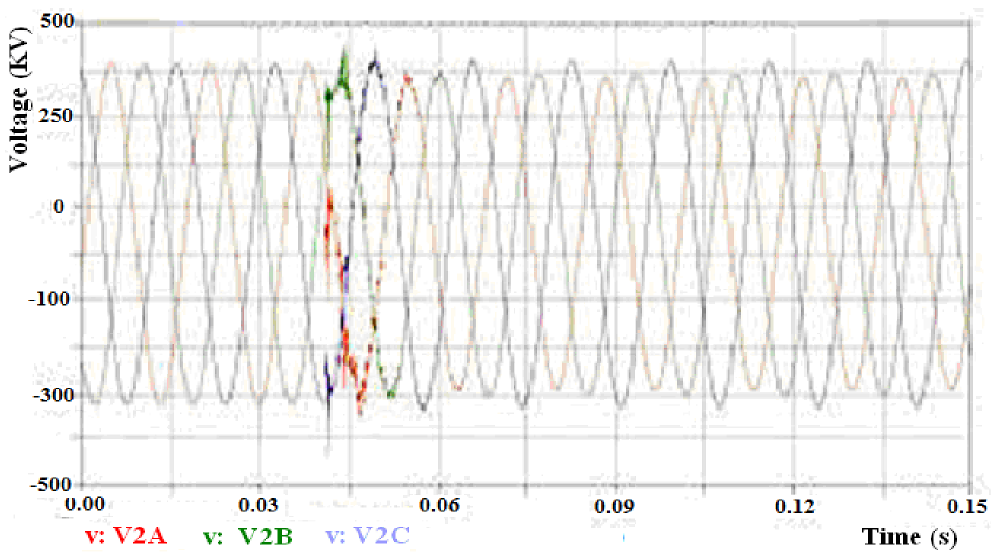

Figure 8. V_2 voltage before and after phase-phase fault, type 1.

Table 2. Voltage profile before and after phase-phase fault.

		Before fault	After fault
V_1	a	284≤3	234≤18
	b	284≤123	202≤117
	c	284≤243	284≤243
V_2	a	274≤11	238≤28
	b	274≤131	190≤130
	c	274≤251	274≤251

Fault distance length and estimated fault according to the related relations are: Estimated L_1, 100.17; Fault %, 0.089%.

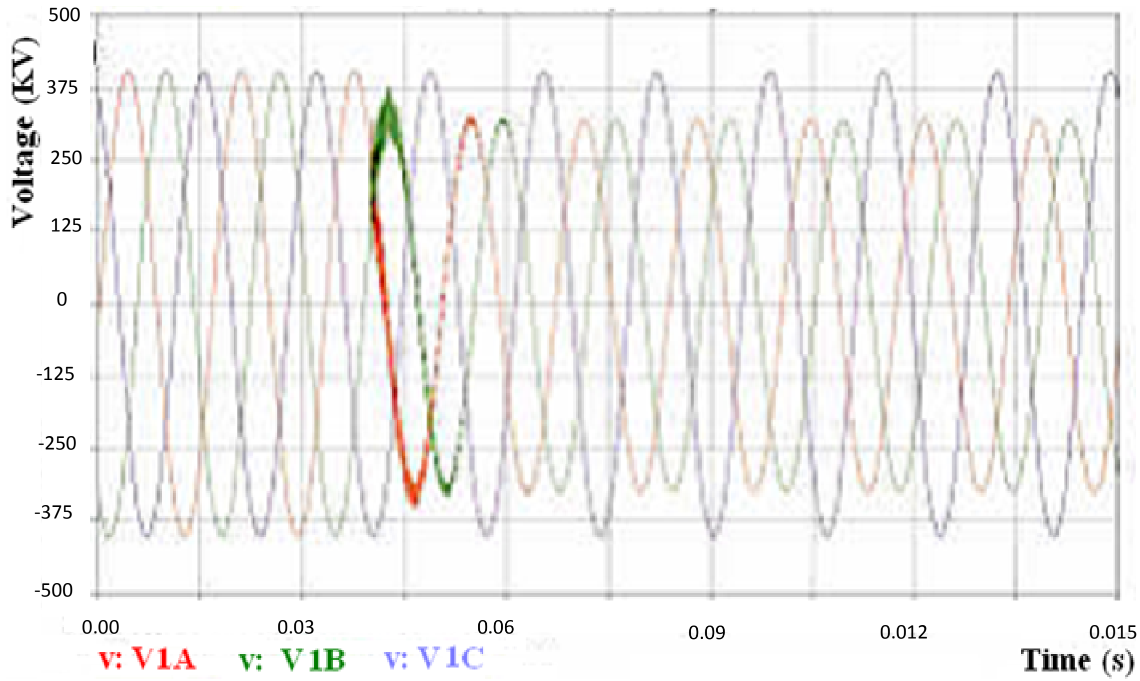

Figure 9. V1 voltage before and after phase-phase fault, type 2.

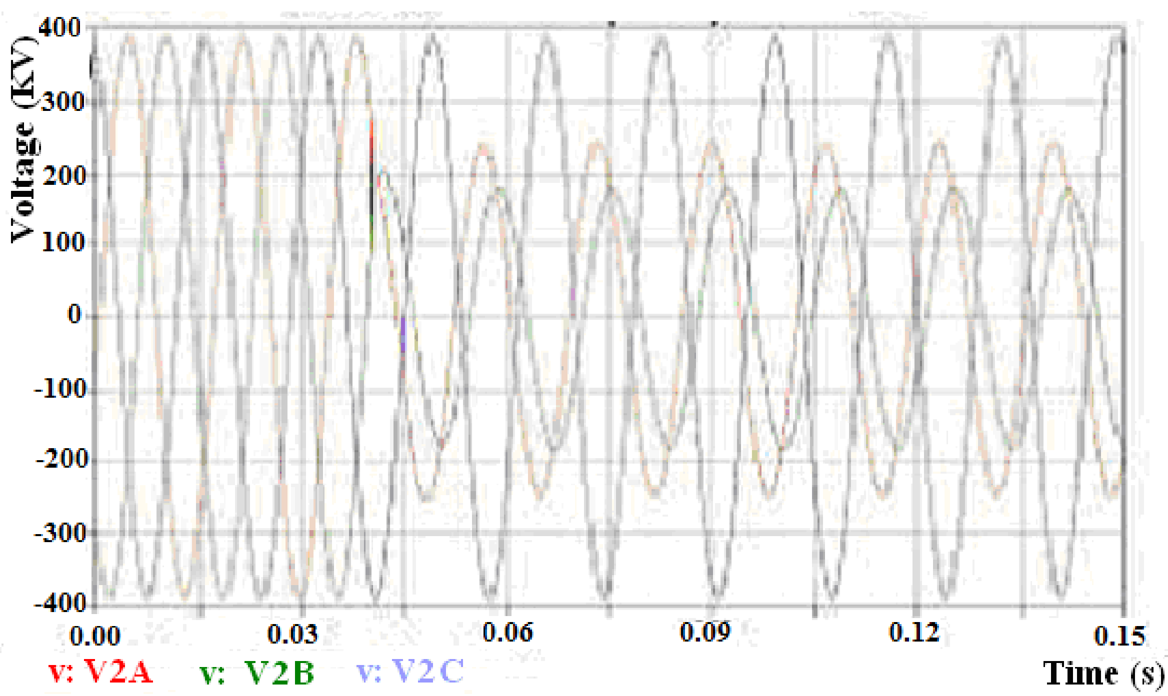

Figure 10. V2 voltage before and after phase-phase fault, type 2.

Fault% = 0.3% It is observed that simulation results are better without considering the capacity of capacitors, in comparison to considering their capacitance.

CONCLUSION

A method of fault locating was presented in which CT is deleted. In other words, sampling is not from the current and the voltage is only sampled. In this method, mistake and deviation in estimation of fault location in shorter lines and common voltages are decreased. Moreover, this method can adjust itself in displaced lines and other conditions and also the calculation time in this method is very low.

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