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Development of Fault Location Algorithm by using PMU for Power System Protection

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Abstract: The proposed work shows fault location estimation method in an uncompensated system and compensated system in case of single line to ground (LG) fault and double line (LL) fault. So objective of this work is to calculate distance of fault in both systems. Solution is given based on proposed fault distance estimation approach. In case of compensated system, capacitor in series reduces inductive reactance of the system for this more accurate result will occur. The method deals with only phasor measurement unit (PMU) so it is time saving and computationally efficient. Fundamental component of sequence component of current and voltage are calculated using Fast Fourier Transform. Systems modelling are done by using PSCAD/EMTDC software and results also verified.

Keywords*:* Fault location; FFT; series compensation; PMU; sequence component; PSCAD/EMTDC.

1. INTRODUCTION

Power produced by a plant is supply to load centers using transmission lines. System is in balanced condition until disturbances (i.e. fault) occur in the system. Fault occur in power system due to several reasons such as tree falling in the system, mechanical failure of transformer or other electrical equipment's failure, insulation failure, wind and an ice storm etc. System performance can be analyzed using two main quantities (i.e. voltage and current) of the line. Identify fault point distance in system is the most important part for electric utilities as exact fault location can return the system in original position as fast as possible. Fault location estimation techniques are mainly categorized as travelling wave, impedance based and knowledge based method. These all methods use data for calculating fault location from one end or both end of the system. For calculating fault location both end data use method need synchronous measurement and online communication of data where as one end data method don't requires this thing so it is easy technique to apply in more network connected systems compare to both end data method. Amir A. A. Eisa *et al.* [1] described a new one-end fault identification technique that uses transient data for calculating fault location. Simulation is done using PSCAD/EMTDC software. Y. H. Lin *et al.* [2] provided a new method for fault point detection using voltage and current phasors collecting from phasor measurement units (PMUs). System is modeled using EMTP/ATP simulator.

C. C. Shan *et al.* [3] proposed a novel fault detection as well as location method for 3-terminal systems. Data are obtained from PMUs and proposed method is verified by modeling the system using EMTP/ATP software. N. E. Eng *et al.* [4] showed a new fault exploration technique for single ended system that provides reliable and accurate location of fault. S. M. Brahma [5] proposed a new scheme to detect the fault zone first and then locate the fault point in multi-terminal transmission system. G. Manassero *et al.* [6] provided a fault point calculation technique based on two phasor (i.e. voltage and current phasor) quantities and data are obtained from electronic devices installed on transmission line terminals. T. Funabashi *et al.*

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[7] proposed fault point calculation technique in multi-terminal system for phase-phase and phase-ground fault. J. Izykowski *et al.* [8] showed fault position estimation technique considering 2-terminal impedance that uses fundamental frequency phasors of symmetrical components of the measured signals. T. Takagi *et al.* [9] showed fault location estimator based on reactance of a line. C. J. Lee *et al.* [10] proposed a numerical method for obtaining fault point that uses PMUs data placed at both terminals of the system. An innovative fault point identification technique based on distance factor in two terminal systems were given by I. Zamora *et al.* [11]. Here, fundamental component of pre-fault and fault voltage are used as input data. Mahmoud S. Awaad [12] presented a new fault estimation scheme that can use in both transmission and distribution system that uses steady state voltage and current data for fault point calculation.

From, survey of reported works it is clear that many fault location techniques have been used in case of uncompensated power system networks. For collecting data (i.e. voltage-current) PMU is used. This paper presents relatively little works which has been done using Fast Fourier Transform (FFT) for identification of fault point in case of uncompensated and compensated system. In this case we have used impedance based method for fault location. This fault location identification technique is tested for one source system using data simulated with PSCAD/EMTDC for an uncompensated system as well as compensated system

In Section 2 problems regarding fault point estimation are discussed in detail. In Section 3 results are discussed with the above issue. Section 4 concludes the paper.

2. PROBLEM STATEMENT AND SOLUTION APPROACH

Fault estimation is the most important step in both uncompensated and compensated system (i.e. power system) in implementing energy efficient and continuously power transferable power system as exact fault location can restore the system as fast as possible. In case of compensated system so many issues are there for locating the fault point. This paper shows how can exact fault location is obtained in uncompensated and compensated system. Fault location is classified as so many methods based on one or two end voltage and current information. But impedance method is used steady state value for calculation of fault location. One side information for calculating fault location in case of uncompensated and compensated system is considered in this paper.

2.1 Studied system

In short transmission and distribution lines leakage current is neglected so parallel lines with Fig. 1 [12] can be removed and system is modeled using PSCAD/EMTDC software. To induce fault in the system a point F is connected to the ground through a fault resistance.

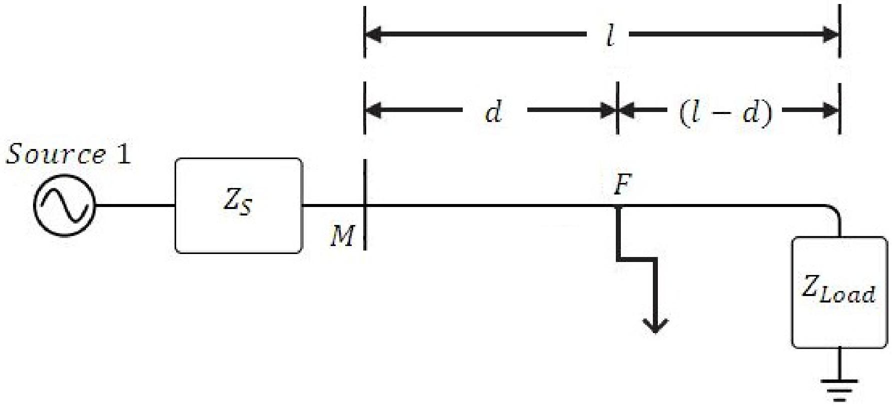

Figure 1: Single-ended power system

To simulate a fault at point F in the system, it is important to signify the system in 2-parts. If total length of the system is l then length of the first part from point M (point where fault location equipment are connected) to fault point F is d and length of second part from fault point to load point is (l-d) as shown in Fig. 2 and Fig. 3.

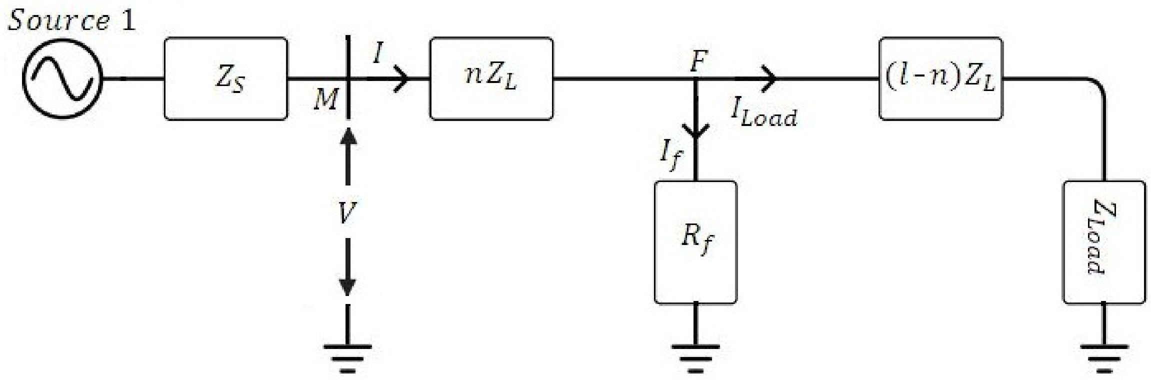

Figure 2: Single-ended uncompensated system with a fault at point F

where Z_S : impedance of source, Z_L : impedance of line, Z_C : impedance of capacitor, Z_{Load} : impedance of load, l : total line length of the system, d : length between fault location equipment and fault point, V : voltage, I : current, R_f : fault resistance, I_f : current flowing through fault, I_{Load} : current flowing through Load current, and n : The p. u length from point M (where fault location equipment is connected) to fault point F and it is given by $n = d/l$.

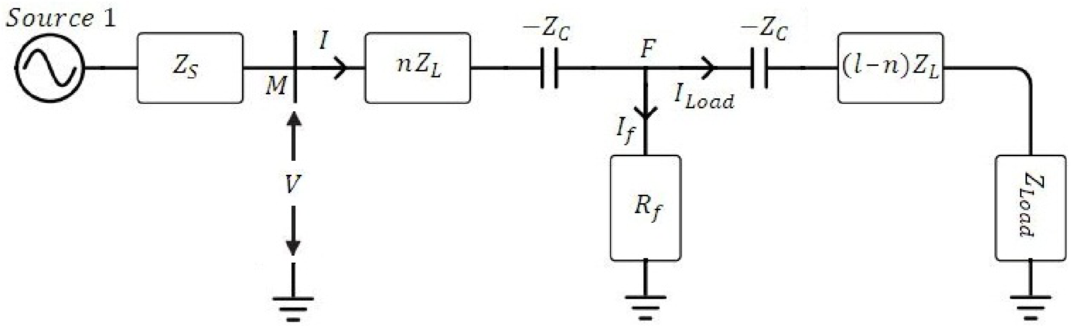

Figure 3: Single-ended compensated system with a fault at point F

where all notations carry their usual meaning which has mentioned in Fig. 2.

2.2 Power flow from bus P to R

For uncompensated system which is shown in Fig. 2.

$$V = I \cdot nZ_L + I_f R_f \tag{1}$$

Now, we can write

$$I_f = (I - I_{Load}) \tag{2}$$

Now putting the value of I_f I_f in equation (1) we obtained

$$V = I \cdot nZ_L + (I - I_{Load}) R_f \tag{3}$$

From equation (1), we can write

$$(I - I_{Load})R_f = I \cdot R_{f_1} \tag{4}$$

From equation (4) we obtained

$$R_{f_1} = ((I - I_{Load})I)/R_f \tag{5}$$

Now equation (3) becomes

$$V = I \cdot nZ_L + IR_{f_1} \tag{6}$$

Above equation is generalized complex one. So, two equations can be deduced from equation (6). These equations are

$$V_d = n(I \cdot Z_L)_d + I_d R_{f_1} \tag{7}$$

$$V_q = n(I \cdot Z_L)_q + I_q R_{f_1} \tag{8}$$

In these above two equations d represent real part and q represent imaginary part of the quantity (i.e. voltage). Now multiplying equation (7) and equation (8) by I_q I_q and I_d ,I_d we obtained

$$V_d \cdot I_q = n(I \cdot Z_L)_d \cdot I_q + I_d R_{f_1} \cdot I_q \tag{9}$$

$$V_q \cdot I_d = n(I \cdot Z_L)_q \cdot I_d + I_q R_{f_1} \cdot I_d \tag{10}$$

Now subtracting equation (10) from (9)

$$(V_d \cdot I_q - V_q \cdot I_d) = n[(I \cdot Z_L)_d \cdot I_q - (I \cdot Z_L)_q \cdot I_d]$$

$$n = (V_d \cdot I_q - V_q \cdot I_d)/[(I \cdot Z_L)_d \cdot I_q - (I \cdot Z_L)_q \cdot I_d] \tag{11}$$

For compensated system which is shown in Fig. 3.

$$V = I \cdot nZ_L - I \cdot Z_C + I_f R_f \tag{12}$$

Now, again we can write

$$I_f = (I - I_{Load}) \tag{13}$$

Putting the value of I_f I_f in equation (12), we obtained

$$V = I \cdot nZ_L - I \cdot Z_C + (I - I_{Load})R_f \tag{14}$$

From equation (12) we can write

$$(I - I_{Load})R_f = I \cdot R_{f_1} \tag{15}$$

From equation (15), we obtained

$$R_{f_1} = ((I - I_{Load})/I)R_f$$

$$R_{f_1} = (1 - \frac{I_{Load}}{I})R_f \tag{16}$$

And equation (14) becomes

$$V = I \cdot nZ_L - I \cdot Z_C + I \cdot R_{f_1} \tag{17}$$

Splitting equation (17) into two equations, we have

$$V_d = n(I \cdot Z_L)_d + I_d R_{f_1} \tag{18}$$

$$V_q = n(I \cdot Z_L)_q - I_q \cdot Z_C + I_q R_{f_1} \tag{19}$$

Now multiplying equation (18) and equation (19) by I_q I_q and I_d, we obtained.

$$V_d \cdot I_q = n(I \cdot Z_L)_d \cdot I_q + I_d R_{f_1} \cdot I_q \tag{20}$$

$$V_q \cdot I_d = n(I \cdot Z_L)_q \cdot I_d - I_q \cdot Z_C \cdot I_d + I_q R_{f_1} \cdot I_d \tag{21}$$

Now subtracting equation (21) from (20)

$$V_d \cdot I_q - V_q \cdot I_d = n[(I \cdot Z_L)_d \cdot I_q - (I \cdot Z_L)_q \cdot I_d] + I_q \cdot Z_C \cdot I_d$$

$$(V_d \cdot I_q - V_q \cdot I_d - I_q \cdot Z_C \cdot I_d) = n[(I \cdot Z_L)_d \cdot I_q - (I \cdot Z_L)_q \cdot I_d]$$

$$n = (V_d \cdot I_q - V_q \cdot I_d - I_q \cdot Z_C \cdot I_d) / [(I \cdot Z_L)_d \cdot I_q - (I \cdot Z_L)_q \cdot I_d] \tag{22}$$

Calculation of $I \cdot Z_L$ for LG fault in both compensated and uncompensated system is shown below. In case of LG fault all sequence components are present. If fault occur at phase A

$I_A = I_0 + I_1 + I_2$ and

$$V = V_A$$

So, we can write

$$IZ_L = (I_1 * Z_{L_1} * k_1) + (I_2 * Z_{L_2} * k_2) + (I_0 * Z_{L_0} * k_0)$$

$$IZ_L = Z_{L_1}[I_A - I_0] + (I_0 * Z_{L_0} * k_0) \qquad [\text{Since, } Z_{L_1} = Z_{L_2}] \tag{23}$$

Calculation of $I \cdot Z_L$ for LL fault in both compensated and uncompensated system is shown below. During LL fault positive and negative sequence components are available. If fault occur at phase A and phase B, then

$$V = V_A - V_B$$

$$I = I_1 + I_2,$$

$$I \cdot Z_L = (I_{A_1} - I_{B_1})K_1 \cdot Z_{L_1} + (I_{A_2} - I_{B_2})K_2 \cdot Z_{L_2} + 0 \text{, and}$$

$$I \cdot Z_L = (I_A - I_B)Z_{L_1}$$

3. RESULTS AND DISCUSSION

By using proposed algorithm we have obtained following result under various fault location. Formula of error calculation is shown in appendix A. Total length of the system is 80 km.

Table 1

LG fault without compensation

Fault Distance (original) (Km)	*Fault Distance (obtained) (Km)*	*% Error*
10	6.89	3.88
30	24.80	6.50
50	51.96	–2.45
70	72.16	–2.70

It is observed from the above table that if LG fault occur at distance 10 km, 30 km, 50 km and 70 km of the system then calculated distance will be 6.89 km, 24.80 km, 51.96 km and 72.16 km respectively.

Table 2

LL fault without compensation

Fault Distance (original) (Km)	*Fault Distance (obtained) (Km)*	*% Error*
10	14.87	–6.09
30	32.389	–2.98
50	47.79	2.76
70	67.35	3.31

Similarly, above table provides the result after LL fault occur in a system. Fault is created at distance 10 km, 30 km, 50 km, 70 km and calculates distance is 14.87 km, 32.389 km, 47.79 km and 67.35 km.

Table 3

LG fault with compensation

Fault Distance in Km (original)	*Fault Distance (obtained) in Km with 1 μF capacitor*	*Fault Distance (obtained) in Km with 2 μF capacitor*	*% Error with 1 μF capacitor*	*% Error with 2 μF capacitor*
10	11.90	12.24	–2.37	–2.80
30	31.655	34.24	–2.06	–5.30
50	48.29	47.56	2.13	3.05
70	71.59	67.52	–1.98	3.10

In the above table-3 result is shown if LG fault occur in a compensated system at various locations (i.e. distance from 10 km to 70 km). In this compensated system maximum calculated fault distance error in case of 1uF and 2uF capacitor is -2.37% and -5.30%.

Table 4

LL fault with compensation

Fault Distance in Km (original)	*Fault Distance (obtained) in Km with 1 μF capacitor*	*Fault Distance (obtained) in Km with 2 μF capacitor*	*% Error with 1 μF capacitor*	*% Error with 2 μF capacitor*
10	10.92	12.46	–1.15	–3.07
30	29.04	27.82	1.20	2.72
50	48.69	52.34	1.63	–2.92
70	71.63	72.31	–2.03	–2.88

This table shows that how the accuracy level improved when capacitor is connected in series with the system. From the above case it is observed that if LL fault occur in a compensated system maximum error obtained in case of 1 uF capacitor connected with system is -2.03% and in case of 2 uF capacitor connected with system is -3.07%.

5. CONCLUSION

In this paper fault estimation technique is proposed in case of uncompensated and compensated system. Steady-state data (i.e. voltage and current data) are used to estimate fault location. In uncompensated system error will occur more but when we added capacitor in series with transmission line then precise result comes. It is also observed from the table that by decreasing capacitor rating error also decreases therefore cost also minimize. So for obtaining more precise result we have to add capacitor in series with transmission line. This holds true for both the fault cases. In future optimization techniques can be used for identify fault location in the system.

APPENDIX-I

System: 400 kV, 50 Hz

Line parameters are:

Positive sequence impedance=$0.36294*10^{-4} + j0.5031*10^{-3}$ ohm/m,

Positive sequence inductive capacitance =302.151ohm/km

Zero sequence impedance=$0.37958*10^{-3} + j0.13277*10^{-2}$ ohm/m,

Positive sequence inductive capacitance =419.34ohm/km

Load:

Rated real power=100 [MW]

Rated reactive power=25 [MVAR]

Data sampling rate= 4 KHz

% Error= ((Fault distance (original)-Fault distance (obtained))/Total line length)*100 [12]

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