Fault Location in Distribution Systems

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Abstract: ***Distribution system is a main link between the power supply and the consumers and when a fault occurs in the distribution system it can affect the system continuity so it is essential to restore the system as quickly as possible .For the quick restoration fault location is essential. In this work the problem of fault location in distribution system for the IEEE 13 node test feeder is studied using the two techniques. The two techniques are Impedance based method and the Reactance based method. The main disadvantages of the impedance based method are the multiple estimation of faults due to the presence of different possible faulty points at the same distance. This drawback is overcome using the reactance based method so the results of these two techniques are compared for the different types of faults for different fault locations. There are different simulation tools available for the analysis of distribution systems such as Grid LAB-D, open DSS etc and in this work MATLAB simulation is used. The IEEE 13 node test feeder is simulated for verifying the existing fault location methods.***

Keywords: Distribution system, Service restoration, Fault location, Multiple estimation**.**

1. Introduction

Distribution system plays a very important role in the electrical power system. In generally the distribution systems supply power to the consumers using the distribution substation [1]. Distribution substation is heart of the distribution system and the function of distribution substation is to decrease the high voltages to the distribution voltage levels and also it regulates the system voltage that means in order to maintain the consumer's voltage as within the range the voltage at the distribution substation is changes when the load changes [2]. In practical radial configuration is used for operating the distribution system and the cost of this radial network is very low and radial network having only one path for the power transfer from the distribution substation to the consumers so the design of the radial network is simple. When a fault occurs in the distribution system it effect the service continuity so the consumers face the power cut problems so it is necessary to restore the fault in the minimum time [3]-[6]. The service continuity is measured using the two terms they are system average interruption frequency index(SAIFI) and system average interruption duration index(SAIDI) For the restoration of the system locating the faults is important and the fault location speed up the restoration process. The faults are detected by using the alarms and when a fault occurs in the system feeder circuit breakers and fault indicators are present along the path and these indicators gives the information of the fault immediately [7]. In recently smart distribution systems are developed in US and smart distribution systems are have the remote control switches and the smart meters. smart meters is having two way communications and smart meters transfers the data of the energy consumption and the information of the system operation [8]. The applications of the smart meters are automatic customer billing and the data from the smart meters are used in the state estimation of the distribution system [9]. Fault location is crucial for restore the system in minimum time there are different methods for fault location in the distribution systems. They are impedance based Method, sparse measurement method, travelling wave based method, and learning based method and integrated method [10]. Most commonly used method for fault location is impedance based method because this method is very simple compared with the other methods and this algorithm uses the fundamental values of current and voltages at the distribution substation [11]. But the main drawback of the impedance based method is the problem of multiple estimates due to the existence of similar fault points. The problem of multiple estimates is overcome by using the travelling wave based methods [12]. In this method uses the voltage recorders and fault indicators and PQ monitoring devices at the substation. But the cost of these equipments is high and this improves the accuracy of the system. Due to the cost base this method is not applied .In this paper reactance based method is used to eliminate the multiple estimation problems [13]. The IEEE 13 node feeder is simulated and verified in this paper and the data for the IEEE 13 node feeder is given from the IEEE distribution system subcommittee.

2. Methodology

Multiple Estimation Problem: In the impedance based method calculate the impedance from the main feeder it finds there is any same impedances for the fault locations that means it draws a circle centered from main feeder with the measurement of the radius of the seen impedance. It finds there are any intersections with the network for the possible fault locations. Another method for reducing the multiple estimation problems locating the fault indicators at the substation. If any fault occurs the fault indicators gives the information about the fault but the implementation cost of these fault indicators is high compared with the impedance based algorithm. But the in the network already fault indicators are installed then it is a good approach for eliminating the multiple estimation problem. Reactance based method is eliminate the multiple estimation problem and also the cost is minimum.

3. IEEE 13 node test feeder

The IEEE 13 node test feeder is used here to test the fault location algorithms. The one line diagram of an IEEE 13 node test feeder is present in figure.1 and the data for this system is collected from the IEEE distribution system subcommittee [4]. IEEE 13 node configuration data's are specified in Table 1 to Table 8.

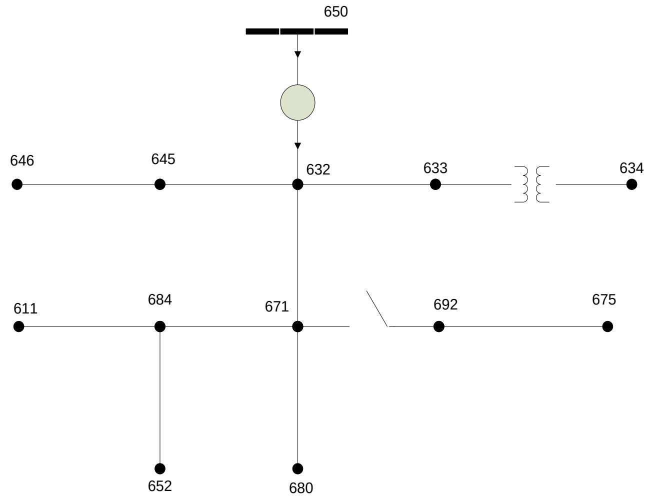

Figure 1: IEEE 13 node test feeder

Table 1: Underground line configuration data

Configuration	Phasing	Cable	Neutral	Space
606	ABCN	250,000AA,CN	None	515
607	A N	1/0AA,TS	1/0Cu	520

Table 2: Overhead line configuration data

Configuration	Phasing	Phase ACSR	Neutral ACSR	Spacing ID
601	BACN	556,500,26/7	4/0 6/1	500
602	CABN	4/0 6/1	4/0 6/1	500
603	C B N	1/0	1/0	505
604	A C N	1/0	1/0	505
605	C N	1/0	1/0	510

Table 3: Line Segment Data

Node A	Node B	Lenght(ft)	Configuration
632	645	500	603
632	633	500	602
633	634	0	XFM-1
645	646	300	603
650	632	2000	601
684	652	800	607
632	671	2000	601
671	684	300	604
671	680	1000	601
671	692	0	Switch
684	611	300	605
692	675	500	606

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Table 4: Capacitor Data

Node	Ph-A	Ph-B	Ph-C
	KVAR	KVAR	KVAR
675	200	200	200
611			100
Total	200	200	300

Table 5: Regulator Data

Regulator ID	1		
Line Segment	650-632		
Location	650		
Phases	A-B-C		
Connection	3-Ph,LG		
Monitoring Phase	A-B-C		
Bandwidth	2.0 volts		
PT Ratio	20		
Primary CT Rating	700		
Compensator Settings	Ph-A	Ph-B	Ph-C
R-Setting	3	3	3
X-Setting	9	9	9
Voltage Level	122	122	12

Table 6: Transformer Data

	KVA	KV high	KV-low	R-%	X-%
Substation	5000	115-D	4.16Gr.Y	1	8
XFM-1	500	4.16Gr.W	0.48Gr.W	1.1	2

Table 7: Spot Load Data

Node	Load	Ph-1	Ph-1	Ph2	Ph-2	Ph-3	Ph-3
	Model	KW	KVAR	KW	KVAR	KW	KVAR
634	Y-PQ	160	110	120	90	120	90
645	Y-PQ	0	0	170	125	0	0
646	D-Z	0	0	230	132	0	0
652	Y-Z	128	86	0	0	0	0
671	D-PQ	385	220	385	220	385	220
675	Y-PQ	485	190	68	60	290	212
692	D-I	0	0	0	0	170	151
611	Y-I	0	0	0	0	170	80
	TOTAL	1158	606	973	627	1135	753

Table 8: Distributed Load Data

Node A	Node B	Load	Ph-1	Ph-1	Ph-2	Ph-2	Ph-3	Ph-3
		Model	KW	KVAR	KW	KVAR	KW	KVAR
632	671	Y-PQ	17	10	66	38	117	68

4. Proposed fault location method

4.1 Impedance based method

The impedance based fault location algorithm uses the fundamental values of voltage and current and frequency measurements at the substation and this method is very easy for locating the faults and calculation process is also simple compared with the other fault location methods [1]. But problem with the impedance based method is only the multiple estimation of the faults. For reducing this problem reactance based method is used [9].

Impedance based method calculations are specified in equations (1) to (2)

$$Z_{ag} = \frac{V_a}{I_a + KI_0}$$

$$Z_{bg} = \frac{V_b}{I_b + KI_0} \qquad (1)$$

$$Z_{cg} = \frac{V_c}{I_c + KI_0}$$

$$Z_{ab}(or)Z_{abg} = \frac{V_a - V_b}{I_a - I_b}$$

$$Z_{bc}(or)Z_{bcg} = \frac{V_b - V_c}{I_b - I_c} \qquad (2)$$

$$Z_{ca}(or)Z_{cag} = \frac{V_c - V_a}{I_c - I_a}$$

4.2 Reactance based method

Reactance based fault location method is used in this paper for eliminating the multiple estimation of the fault .In this paper both impedance based method and reactance based fault location method results are compared for different fault locations. The IEEE 13 node test feeder is used for verifying these two methods and actually a fault is created at the 632 node of the IEEE 13 node test feeder (632 represents the node identification in 13 nodes in IEEE 13 node test feeder). At 632 node different faults are created and for different fault locations results are obtained and these results are compared with each other and by observing these results we conclude that the reactance based method have the better results compared with the impedance based method and the error is reduced in the reactance based method for different fault locations.

4.2.1 Reactance based method calculations for different types of faults

Taking the unbalanced nature of the power distribution systems, the proposal here presented considers phase analysis instead of symmetrical components. The line impedance and load impedances equations (3) and (4) are

$$Z_{line} = \begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix} \qquad (3)$$

$$Z_{load} = \begin{bmatrix} Z_{La} & Z_{Lab} & Z_{Lac} \\ Z_{Lba} & Z_{Lb} & Z_{Lbc} \\ Z_{Lca} & Z_{Lcb} & Z_{Lc} \end{bmatrix} \qquad (4)$$

The reactance based fault location method only takes account the faulted phases and neglects the load effect. In this proposed method all three phases and loads at the non faulted phases are considered and this method is also considers the fault types presents below.

4.2.1.1 Single Phase Faults:

$$fault\ distance\ m = \frac{imag\left(\left(\frac{V_a}{I_a}\right)\right)}{imag\left(Z_{aa} + Z_{ab}\left(\frac{I_b}{I_a}\right) + Z_{ac}\left(\frac{I_c}{I_a}\right)\right)} \qquad (5)$$

In addition, another two independent equations are obtained from the complex equation set. The additional possible solutions of m in equation (5), only take into account the imaginary components because this part remains relatively constant the equations are below

$$m_1 = \frac{imag\left((V_a - V_b + V_c)/I_a + B.\left(\frac{I_b}{I_a}\right) + C.\left(\frac{I_c}{I_a}\right)\right)}{imag(Z_{aa} - Z_{ab} + Z_{ca} + A)} \qquad (6)$$

$$m_2 = \frac{imag\left((V_a + V_b - V_c)/I_a - B.\left(\frac{I_b}{I_a}\right) - C.\left(\frac{I_c}{I_a}\right)\right)}{imag(Z_{aa} + Z_{ba} - Z_{ca} + A)} \qquad (7)$$

Here m1 and m2 in the equations (6) and (7) are the non faulted phases distance
Where constants A, B, C are given in equation (8) as

$$A = Z_{ab}\left(\frac{I_b}{I_a}\right) + Z_{ac}\left(\frac{I_c}{I_c}\right)$$
$$B = Z_{bb} + Z_{Lb} - Z_{cb} - Z_{Lcb} \qquad (8)$$
$$C = Z_{bc} + Z_{Lbc} - Z_{cc} - Z_{Lc}$$

According to the previously presented information, the most suitable equation to estimate the fault distance is the presented in the above equation where the load current is neglected at the faulted phase due to its low effect in the total fault current measured at the distribution system.

4.2.1.2 Double phase to ground faults:

Double phase to ground fault calculation equations (9), (10) and (11) are

$$fault\ distance\ m = \frac{imag\left(\frac{V_a - V_b}{I_a - I_b}\right)}{imag\left(\frac{D.I_a + E.I_b + F.I_c}{I_c - I_b}\right)} \qquad (9)$$

$$D = Z_{aa} - Z_{ba}$$
$$E = Z_{ab} - Z_{bb} \qquad (10)$$
$$F = Z_{ac} - Z_{bc}$$

$$m_1 = \frac{imag\left(\frac{V_a - V_b - V_c}{I_a - I_b} + (Z_{cc} + Z_{lc})\left(\frac{I_c}{I_a - I_b}\right)\right)}{imag\left((D - Z_{ca}).I_a + (E - Z_{cb}).I_b + F.\frac{I_c}{I_a - I_b}\right)} \quad (11)$$

4.2.1.3 Phase to phase faults:

The calculation process of the phase to phase faults and the double phase to ground faults are similar and the formulas are same.

5. Tests and results

The two techniques for fault location they are impedance based method (I.B.M) and reactance based method (R.B.M) and the results of these two methods are compared. Comparison of fault location results in the IEEE 13 node feeder at 632 node is illustrated in table.9

5.1 For L-L faults

The table.9 gives the results of the IEEE 13 node test feeder and these results are for the LL fault and LL fault is created at the 632 node of the IEEE 13 node test feeder. By observing the table the fault is located at the different locations such as for 100ft, 200ft, 250ft,300ft,350ft,400ft. Actually in the system the 632 node is having a length of 500ft only so from that we take fault location distances up to the 450ft. In the impedance based method (I.B.M) the fault distance is not an exact value it is an error up to 50% that means the actual distance is 100ft and the I.B.M method gives the fault distance at the 150ft. But in the reactance based method (R.B.M) the error is reduced compared with the I.B.M method. For the same distance of 100ft it gives the fault distance at the 134 ft.

Table 9: For L-L fault

Fault Type	Actual Distance	Fault Distance in I.B.M	Fault Distance in R.B.M
LL	0.0305km(100ft)	0.0460km(150ft)	0.0409km(134ft)
	0.0610km(200ft)	0.0764km(250ft)	0.0637km(208ft)
	0.0762km(250ft)	0.0917km(300ft)	0.0755km(247ft)
	0.0914km(300ft)	0.1069km(350ft)	0.0874km(286ft)
	0.1067km(350ft)	0.1221km(400ft)	0.0993km(325ft)
	0.1219km(400ft)	0.1373km(450ft)	0.1112km(364ft)

5.2 For L-L-G faults

The Table.10 gives the results of the IEEE 13 node test feeder for the LLG fault. The two faults (LL, LLG) are having same formulas as discussed earlier. From the results the impedance based method is simple but having the problem of multiple estimation of the fault this problem overcome in the reactance based method and the reactance based method gives better results with less error. That means for the same actual distance of the 100ft the I.B.M gives the fault distance at the 152ft and the R.B.M method gives the 134 ft fault distance.

Table 10: For L-L-G fault

Fault Type	Actual Distance	Fault Distance in I.B.M	Fault Distance in R.B.M
LLG	0.0305km(100ft)	0.3124km(152ft)	0.0414km(134ft)
	0.0610km(200ft)	0.0763km(250ft)	0.0643km(210ft)
	0.0762km(250ft)	0.0915km(300ft)	0.0762km(250ft)
	0.0914km(300ft)	0.1067km(350ft)	0.0881km(289ft)
	0.1067km(350ft)	0.1520km(398ft)	0.0316km(340ft)
	0.1219km(400ft)	0.1369km(449ft)	0.119km(367ft)

5.3 For L-G faults

The Table.11 gives the results of the IEEE 13 node test feeder for the LG fault. For the LG fault different formulas are used compared with the LL fault and LLG fault. These are also discussed in this paper earlier. From table we observe that the reactance based method have the better results compared with the impedance based method and also reactance based method eliminates the multiple estimation of the fault also. The quick location fault can improve the service continuity.

Table 10: For L-G fault

Fault Type	Actual Distance	Fault Distance in I.B.M	Fault Distance in R.B.M
LLG	0.0305km(100ft)	0.0214km(70ft)	0.0312km(102ft)
	0.0610km(200ft)	0.0712km(233ft)	0.0625km(205ft)
	0.0762km(250ft)	0.0845km(277ft)	0.0789km(258ft)
	0.0914km(300ft)	0.0986km(323ft)	0.0932km(305ft)
	0.1067km(350ft)	0.1176km(385ft)	0.1070km(351ft)
	0.1219km(400ft)	0.1318km(432ft)	0.1231km(403ft)

6. Conclusion

In this paper fault locations results for IEEE 13 node test feeder is obtained and it gives an approach for eliminating the multiple estimation problem of the impedance based fault location method using the reactance based method and the two methods results are compared. These two methods use the measurements of fundamental values of voltage, current and frequencies.

Tests are performed for the IEEE 13 node test feeder for different faults such as line to ground faults, line to line faults and double line to ground faults. According to the results the reactance based fault location methods have better results compared with the impedance based fault location method. Finally this method contributes to improve the power continuity in the distribution systems by quick fault location

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