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UNBALANCE FAULT LOCATION IN ELECTRICAL DISTRIBUTION SYSTEM

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Abstract: Fast fault location in distribution system is very important to improve the reliability of power supply. Once a fault has been cleared, fault need to be located before restoration can be conducted. By having a fast fault location method, outage time can be reduced. This research outlines some existing methods and its application in determining the location of a fault on ac distribution lines. The studies methods are Reactive component method, Takagi method, Richards and Tan method, Srinivasan and St-Jacques method, Girgis method and Das method. However, in this research part of Das method is applied to locate a faulted section due to its simplicity and economical in distribution system. The proposed method is tested using Saskpower distribution system of Sask State from Canada. The system is modeled using power system PSCAD/EMTDC power system simulator. Fault is simulated at various locations and the voltage and current measurements at the primary substation is used to calculate apparent reactance. Then, the apparent reactance is compared with line reactance to find the faulted section. The tests have been conducted at few locations to study the effectiveness of the proposed method. Besides, different fault types were also been tested. Overall, the test shows promising results.

I. Introduction

The deregulation of power industry has resulted in a greater emphasis on the reliability of power supply. One of the factors that affect the reliability index is Customer Average Interruption Duration Index (CAIDI) due to weather condition, human error or equipment aging in the system. Although faults are unavoidable, it is effect can be minimized by fast location. A fast fault location will reduce the outage time and therefore minimize losses both to the customer and electrical power utilities.

In some rural distribution system, fault location is uses basic approaches to locate a fault such as visual inspection, switching procedure or using fault indicators. Although these approaches are time consuming, it is still in practice due to most of rural distribution systems do not supported by advance monitoring equipments such as SCADA system to assist in locating a fault. The only available monitoring equipment is available located at the primary substation. Thus, a fault location method that based on limited measurement is crucially needed for such distribution system. In literature, most of fault location methods are based on travelling-wave methods, artificial-intelligence methods and impedance methods [1]-[7].

By having a fast fault location, the following benefits can be obtained [3]-[5]:

- Fault location helps to speed up the restoration process
- by locating the faulted node it is possible to perform sectionalize switching operations to reduce the affected area
- by locating permanent faults it is possible to perform scheduled preventive maintenance tasks to avoid future faults

Once a fault has been located in the system, a maintenance engineer can check the location of fault to identify the causes. A prevention plan to avoid the same fault problem in the future can be proposed. Thus, the reliability of the system can be improved.

II. Statement of the problem

The electrical power system contents of two parts: transmission line and distribution lines.

Transmission is the main system to transfer electrical energy to customer from the main the power stations such as hybrid electrical station or nuclear power station. Distribution system is the Electrical network that is connected is to transmission lines. The main purpose of Distribution lines is transfer electrical energy to the different customers with different amount of loads. Although, the numbers of the lines in the distribution system is more than transmission system as shown in Figure 1.1, measure and control devises are limited. Thus, fault location in distribution system is challenging since there are very limited data that can be used to locate a fault. Often monitoring equipment is installed at the primary section [2], for example in Figure 1; the monitoring equipment is at node N.

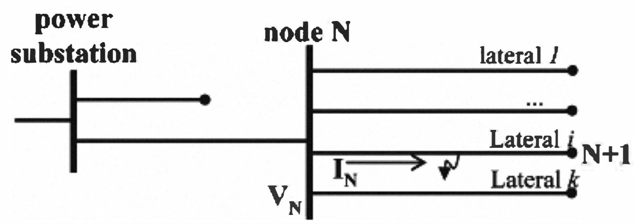


Figure 1 Three shaped power distribution system.

III. Fault location methods

In general, fault location methods can be classified into two categories; two measurement and single measurement. In the following, some well-known methods for finding fault location on AC distribution systems are described. The studied methods are as follows:

- Takagi algorithm [11].
- Reactive component method [9], [10].
- Richards and Tan algorithm [12].
- Srinivasan and St-Jacques algorithm [13].
- Girgis algorithm [14].
- Impedance based method part of Das method [15], [6].

The impedance based method just takes voltage and current by using measurement and finds the apparent reactance from the terminal measurement to the place of fault. It is possible to calculate the reactance as distance kilometers or miles [15]. On the other hand, Stan and Paithankar [9], [8] create the same method for estimating fault by measuring the steady state fundamental frequency voltage and current at one terminal of lines. Then it is possible to calculating the apparent impedance from this data. Finally, one figure and formula will be described the based knowledge for distance method for finding the location of fault [1].Issue in estimate of fault location for single line diagram for three phase fault on power system network by using local data is described in Figure 2.

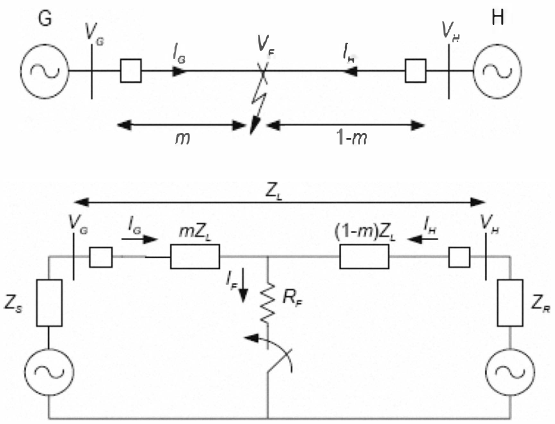


Figure 2 Analysis three phase faults.

In this part some parameters will be defined and trying to find apparent impedance when the fault is appeared [1].

V_G is the voltage at terminal G.

M is the distance to the fault in per unit.

Z_L is the line impedance between terminals G and H.

I_G is the line current from terminal G.

R_F is the fault resistance.

I_F is the total fault current.

Using of KVL method for the circuit during the fault and the equation is:

$$V_G = mZ_LI_G + R_FI_F \tag{2.1}$$

So, in this part for finding equal Impedance Just necessary to dividing voltage to the current and the equation is:

$$Z_{FG} = \frac{V_G}{I_G} = mZ_L + R_F\,\frac{I_F}{I_G} \tag{2.2}$$

Z_{FG} is the apparent impedance to the fault measured at terminal G

The Takagi method just can estimate the single phase to ground fault in Electrical power system models. If other kinds of faults appear the result of fault location has large error. Srinivasan and St-Jacques method use the simple Model of network for real network and all kind of fault. This method can estimate the place of fault but it is so expensive and it is not economical because the instruments of collecting data are expensive. The Girgis method has some limitations for finding the location of fault as following. The network for analyzing this method is a simple network. An electrical power distribution system has parallel and lateral loads. Testing system just includes single phase fault, not all kind of the fault.

The impedance based method is the best practical and economical method.

IV. Test network

Sask power 25 KV network of Sask State in Canada is designed in PSCAD/EMTDC.

Single phase diagram is shown in Figure 3 as follows.

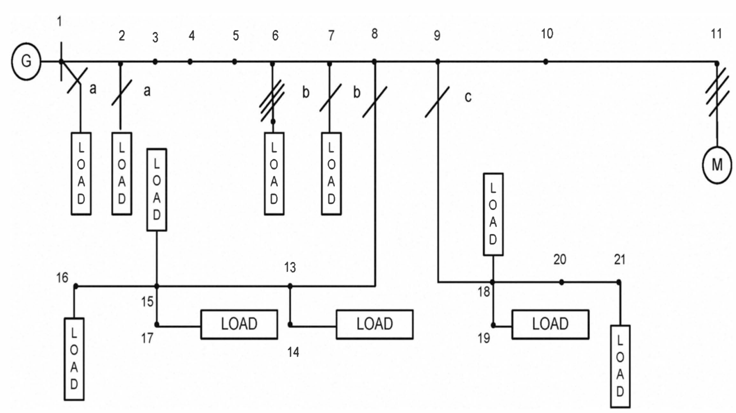


Figure 3 The Sask power 25 KV circuit. [15].

This network is the real distribution Sask network that is designed in the PSCAD/EMTDC for analyzing impedance based method. [15].

Impedance based method just needs one measurement for finding the location of fault. This measurement is installed at first feeder of distribution system or after generator for distribution system to measure the value of current, voltage, active and reactive power.

The network has 21 sections; these lines are different in impedance value that is shown in Table 1.

Table 1 Value of different lines for new components (series impedance).

Section Between Nodes	Length Of Section (Km)	Series Impedance (Ohms/Km)
		Zero Sequence
1&2	2.414	0.5254+j1.704
2&6	16.092	0.5254+j1.704
6&7	4.023	0.5254+j1.704
7&8	5.150	0.7290+j1.727
8&9	2.414	0.7290+j1.727
9&10	4.506	0.7290+j1.727
10&11	2.414	0.5254+j1.704
6&12	2.414	0.5254+j1.704
8&13	2.414	7.3977+j0.8998
13&14	2.414	7.3977+j0.8998
13&15	2.414	7.3977+j0.8998
15&16	2.414	7.3977+j0.8998
15&17	2.414	7.3977+j0.8998
9&18	2.414	7.3977+j0.8998
18&19	2.414	7.3977+j0.8998
18&20	3.219	7.3977+j0.8998
20&21	3.219	7.3977+j0.8998

V. Sequence impedance calculation

The zero sequence can be calculated using measured data. The calculation is described as follows.

For calculation of phase angle (angle between current and voltage).

$$\tan^{-1}\frac{Q_{(a,b,c)}}{P_{(a,b,c)}} = \theta_{(a,b,c)}$$

Where:

P_a , P_b and P_c is active power of phase A, phase B and Phase C respectively. Q_a , Q_b and Q_c is reactive power of phase A, phase B and Phase C respectively.

To calculate the value of sequence voltage of current and voltage, the following equations are used:

$$\begin{bmatrix} V_a^{(0)} \\ V_a^{(1)} \\ V_a^{(2)} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V_a < 0^o \\ V_b < 0^0 \\ V_c < 0^0 \end{bmatrix}$$

$$\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a < \theta_a^0 \\ I_b < \theta_b^0 \\ I_c < \theta_c^0 \end{bmatrix}$$

Where:

V_a is voltage of phase A during the fault.
V_b is voltage of phase B during the fault.
V_c is voltage of phase C during the fault.
I_a is current of phase A during the fault.
I_b is current of phase B during the fault.
I_c is current of phase C during the fault.

$a=1<120^0$ $,a^2 = 1 < 240^0$ $,a^3 = 1 < 360^0$

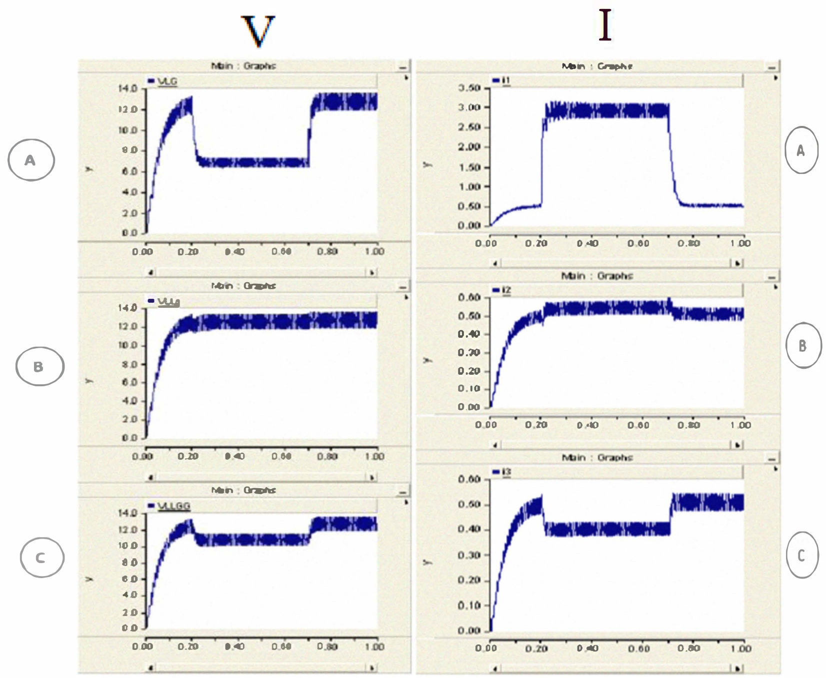
Table 2 Value of different data of measurement in Sask Power distribution system.

Data	Section	Single Line to ground fault				Line to line to ground fault				Line to line fault			
		Node 2	Node 6	Node 8	Node 11	Node 2	Node 6	Node 8	Node 11	Node2	Node 6	Node 8	Node 11
Phase A	V(KV)	6.40	11.00	11.55	11.85	5.15	10.30	11.29	11.48	5.36	10.30	11.30	11.83
	I(KA)	2.73	0.77	0.55	0.47	2.08	0.83	0.60	0.48	2.08	0.81	0.59	0.48
	P(KW)	7.60	5.00	4.26	3.60	9.35	6.00	4.70	3.63	11.13	6.90	4.90	4.79
	Q(KVAR)	17.00	7.66	5.25	4.75	6.25	6.71	5.56	4.48	-5.05	5.42	5.05	3.63
	θ(Degree)	65.91	56.86	50.94	52.48	33.76	47.91	49.79	52.78	-24.40	38.15	45.86	52.84
Phase B	V(KV)	11.60	11.80	11.75	11.85	6.02	11.08	11.62	11.48	7.94	11.30	11.60	11.83
	I(KA)	0.52	0.55	0.53	0.47	3.01	0.88	0.61	0.48	2.27	0.82	0.59	0.47
	P(KW)	3.76	7.66	4.40	3.64	3.66	4.28	3.84	3.63	-2.00	2.86	3.38	4.82
	Q(KVAR)	5.00	5.60	4.84	4.72	19.65	9.74	6.59	4.79	20.23	9.81	6.62	3.61
	θ(Degree)	53.05	54.46	47.72	52.36	79.45	66.27	59.77	52.48	-5.64	73.74	62.95	53.16
Phase C	V(KV)	10.00	11.50	11.80	11.85	9.64	11.75	11.77	11.84	11.89	11.80	11.90	11.86
	I(KA)	0.73	0.44	0.41	0.47	0.41	0.50	0.45	0.48	0.47	0.47	0.47	0.47
	P(KW)	3.76	3.90	3.44	3.59	2.48	4.25	3.89	3.63	3.6	3.62	3.60	4.81
	Q(KVAR)	2.92	3.50	3.77	4.66	3.13	4.38	4.18	4.78	4.70	4.73	4.69	3.61
	θ(Degree)	47.99	41.90	47.62	53.39	47.78	45.86	47.05	52.78	52.55	52.57	54.02	53.11

Sequence of apparent impedance;

$$\begin{bmatrix} Z_a^{(0)} \\ Z_a^{(1)} \\ Z_a^{(2)} \end{bmatrix} = \frac{\begin{bmatrix} V_a^{(0)} \\ V_a^{(1)} \\ V_a^{(2)} \end{bmatrix}}{\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix}}$$

In this simulation, fault is simulated When the value of impedance sequence is calculated, value of apparent impedance sequence should be analyzed with different faulted section on ac distribution system. A general equation to calculate the sequence impedance can be program using Matlab program.

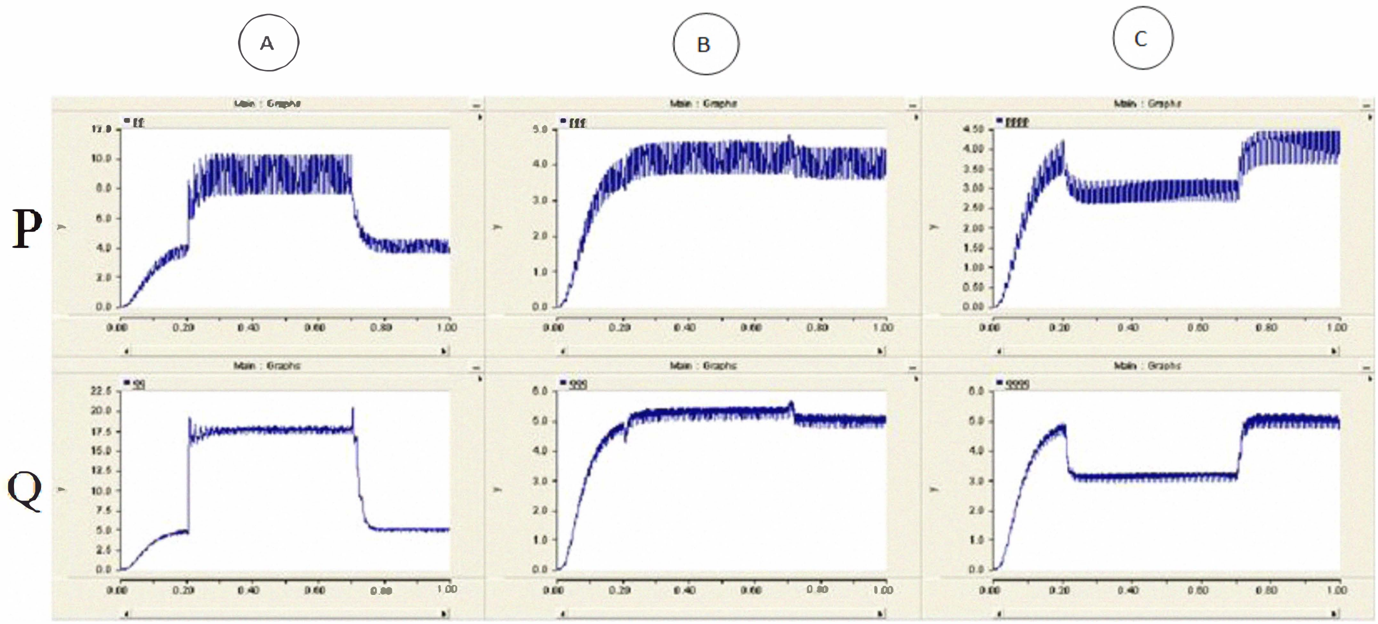


(a) (b)

Figure 4 (a) Voltage wave form of voltage in each phase during the single line to ground fault. (b) Current wave form of voltage in phase during the single phase to ground fault.

VI. Output data of measurement (During fault)

Single line to ground fault is simulated at different nodes on Saskpower distribution system in the PSCAD\EMTDC software. The purpose of this part is to analyze the value of apparent sequence impedance for each kind of fault for different sections. In this simulation,



Figurer 5 above figure is shown Active power and next figure is shown reactive power for each phase.

Fault is simulated at 0.2 second until 0.7 second. The measurement data which are voltage, current, active and reactive power are taken at 0.45 second and the taken data are shown in Table 2. For example: The output wave form of the network that is simulated in PSCAD/EMTDC software such as; current and voltage and active and reactive power are shown in Figures 4 & 5 for single line to ground fault.

VII. Analysis of apparent impedance value

Apparent impedance for different kind of unblance faults and different sections on Saskpower distribution system During fault was calculated as follows.

A) Single phase to ground at nodes 2, 6, 8 and 11. When fault appears at node 2:

$$\begin{bmatrix} Z_a^{(0)} \\ Z_a^{(1)} \\ Z_a^{(2)} \end{bmatrix} = \frac{\begin{bmatrix} V_a^{(0)} \\ V_a^{(1)} \\ V_a^{(2)} \end{bmatrix}}{\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix}} = \begin{bmatrix} 3.6300 - 6.9319i \\ -0.0144 + 1.9858i \\ -1.3452 + 1.4902i \end{bmatrix}$$

When fault appears at node 6:

$$\begin{bmatrix} 12.1173 - 15.6611\mathrm{i} \\ 1.1877 + 2.2345\mathrm{i} \\ -1.7192 + 0.9264\mathrm{i} \end{bmatrix}$$

When fault appears at node 8:

$$\begin{bmatrix} 15.5110 - 17.7790i \\ 0.1758 + 1.4508i \\ -2.0247 + 0.6022i \end{bmatrix}$$

When fault appears at node 11:

$$\begin{bmatrix} 15.2638 - 19.94941 \\ 0 \\ 0 \end{bmatrix}$$

It can be seen that when single phase to ground fault occurred at different sections to approach the absolute value of zero impedance sequence's reactance part at (node2 = 6.9319 , node 6 = 15.6611 , node 8 = 17.7790 and node 11 = 19.94941) are increased as distance o f fault increasing.

B) Line to line to ground Fault at nodes 2, 6, 8 and 11.

When fault appears at node 2:

$$\begin{bmatrix} Z_a^{(0)} \\ Z_a^{(1)} \\ Z_a^{(2)} \end{bmatrix} = \frac{\begin{bmatrix} V_a^{(0)} \\ V_a^{(1)} \\ V_a^{(2)} \end{bmatrix}}{\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix}} = \begin{bmatrix} 1.73 + 1.15i \\ 0.55 + 2.96i \\ 0.27 + 0.30i \end{bmatrix}$$

When fault appears at node 6:

$$\begin{bmatrix} 8.8147 - 12.5112i \\ 4.7415 + 3.4183i \\ -1.6886 + 0.7883i \end{bmatrix}$$

When fault appears at node 8:

$$\begin{bmatrix} 12.7146 - 16.6722i \\ 3.6739 + 2.7806i \\ -1.5163 + 0.6833i \end{bmatrix}$$

When fault appears at node 11:

$$\begin{bmatrix} 15.0225 - 19.6846i \\ 0 \\ 0 \end{bmatrix}$$

Thus, when line to line to ground fault is simulated at different sections to approach the absolute value of zero impedance sequence's reactance part at (node2 = 1.1500 , node6= 12.5112 , node8 = 16.6722 and node11= 19.6846) are increased as distance of fault.

C) Line to line Fault appears in node 2, 6, 8 and 11.

When fault appears at node 2:

$$\begin{bmatrix} Z_a^{(0)} \\ Z_a^{(1)} \\ Z_a^{(2)} \end{bmatrix} = \frac{\begin{bmatrix} V_a^{(0)} \\ V_a^{(1)} \\ V_a^{(2)} \end{bmatrix}}{\begin{bmatrix} I_a^{(0)} \\ I_a^{(1)} \\ I_a^{(2)} \end{bmatrix}} = \begin{bmatrix} 1.1712 + 2.3080i \\ 0.3747 - 0.6952i \\ -0.3334 - 0.4287i \end{bmatrix}$$

When fault appears at node 6:

$$\begin{bmatrix} 9.4667 - 13.7018i \\ 1.8273 - 10.8744i \\ -1.7347 + 0.5178i \end{bmatrix}$$

When fault appears at node 8:

$$\begin{bmatrix} 12.4570 - 17.4928i \\ -0.3148 - 11.4465i \\ -1.7571 + 0.8350i \end{bmatrix}$$

When fault appears at node 11:

$$\begin{bmatrix} 15.22229 - 20.2971i \\ -2.5980 + 1.5000i \\ 2.5980 + 1.5000i \end{bmatrix}$$

Thus, when Line to line fault is simulated at different sections to approach the absolute value of zero impedance sequence's reactance part at (node2 = 2.3080 , node6 = 13.7018, node8 = 17.4928 and node11 = 20.2971) are increased as distance of fault.

Comparing between zero sequence's reactance part of line impedance and zero sequence's reactance part of apparent impedance during fault is shown in Figures 6, 7&8.

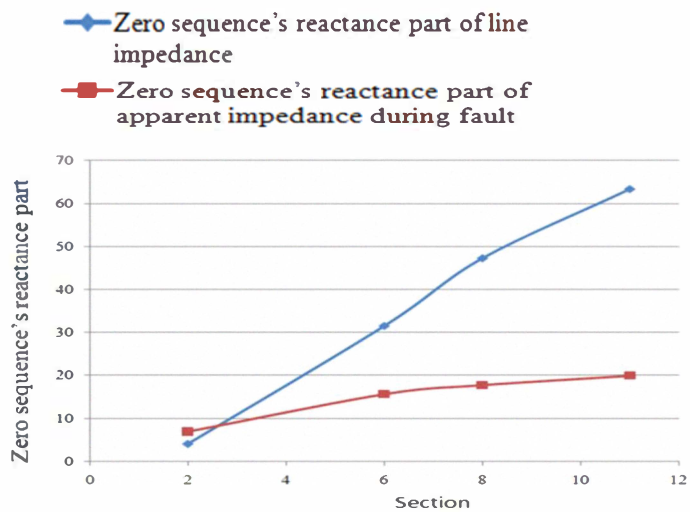


Figure 6 Comparation of line impedance and apparent impedance during fault Single phase to ground.

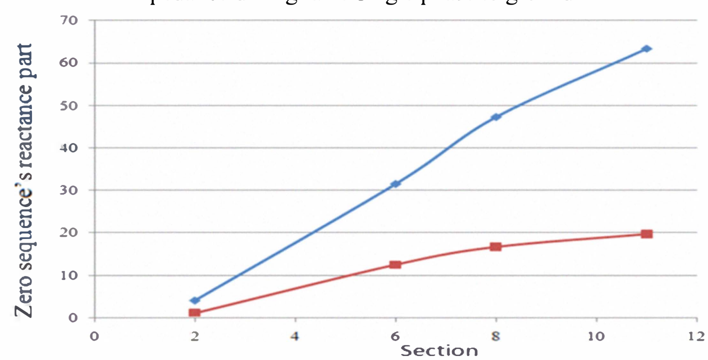


Figure 7 Comparation of line impedance and apparent impedance during fault Line to line to ground.

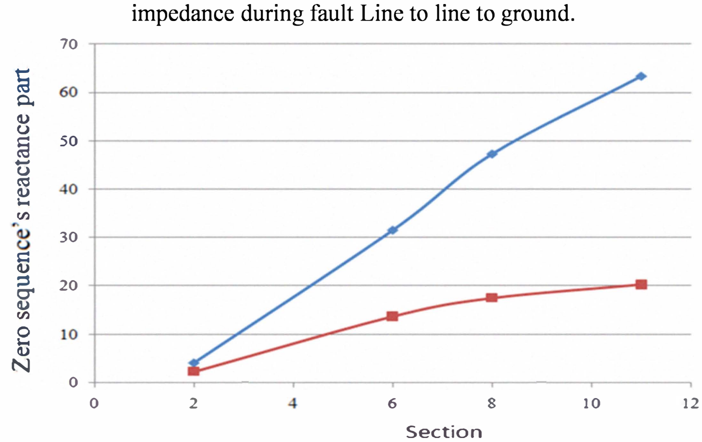


Figure 8 Comparation of line impedance and apparent impedance during fault Line to line Fault.

VIII. CONCLUSION

From the comparison of these methods, it was found that the impedance based method in the most practical and economical implication. The correlation between fault distances and apparent impedance are studied. This is presented in last chapter, whereby the graphs show that as the fault distance increases the sequence apparent reactance is also increasing. The method has been tested using unbalance fault, this method finds the location of fault by analyzing the Zero sequence's reactance part value. From the test result, it was found that the method able to identify the section where the unbalanced fault occurs.

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