Indonesian Journal of Electrical Engineering and Computer Science
Vol. 8, No. 3, December 2017, pp. 770 ~ 778
DOI: 10.11591/ijeecs.v8.i3.pp770-778

Fault Distance Identification Using Impedance and Matching Approaches on Distribution Network

Lilik Jamilatul Awalin*[1], H. Mokhlis[2], M. K. Rahmat[3], Sophi Shilpa[4], Fadi Albatsh[5], Bazilah Ismail[6]
[1,3,5,6] Universiti Kuala Lumpur, British Malaysian Institute
Jalan Sungai Batu 8 Gombak, Selangor Malaysia, telp/fax of institution/affiliation
[2] Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia
[4] Department of Electrical and Electronics Engineering, Amrita University, Bengaluru India
*Corresponding author, e-mail: lilik@unikl.edu.my

Abstract

In this paper, impedance based method and matching approaches were used separately to detect three phase to ground fault (LLLGF). In order to observe the accuracy of each method, Non-homogeneous distribution network was used as a tested network. Actual data from TNB (Tenaga National Berhad) Malaysia was adopted to model the network by using PSCAD/EMTDC simulation program. Both methods were tested to observe the accuracy of fault distance estimation. The comparison result shows different accuracy for each section which simulated in the middle of section. Based on the complexity of the distribution network, it possible to contribute difficulty to obtain the maximum accuracy. The result was obtained through the complete process which involves the database formation acquired through the PSCAD/EMTDC software simulator and the fault location distance calculation carried out by the MATLAB software.

***Keywords**: fault distance, three phase to ground fault, impedance based method, matching approaches, Non homogeneous distribution network*

1. Introduction

Fault in a distribution network is a phenomenon that cannot be avoided. Generally, faults could be caused by storms, lightning strike, snow, freezing rain, insulation breakdown and short circuits caused by external objects. If a fault occurs in any location in the network, it has the potential to cause temporary interruption such as voltage drop, temporary losses of supply, or even a blackout in the whole network. Consequently, it can harm or even damage power utility and customer equipment. From survey in [1], it was found that more than 80% the interruption is caused by fault. For example in the industry sector, for a short period of power interruption can cause sensitive equipment like power electronic components and control devices to be shutdown. Hence, it is very important for the utility to identify the fault as quickly as possible to minimize the impact of fault and time interruption.

A fast fault location will also improve reliability indexes such as System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), System Average Interruption Frequency Index (SAIFI), Momentary Average Interruption Frequency Index (MAIFI), Customer Average Interruption Frequency Index (CAIFI), Customers Interrupted per Interruption Index (CIII), and the Average Service Availability Index (ASAI). These indices are very important for utility to gain trust from the customers mainly in deregulated business environment.

Nowadays, there are many activities in using fault location method, namely impedance based method, travelling wave, knowledge based, etc. Impedance based was determined fault distance based on values of impedance line and load impedance which mentions in paper [2-11]. Impedance based have ability to determine fault distance with the various fault resistance. Only depending on the one measurement of voltage sag and current swell, this method was able to detect fault distance. Another fault location method is travelling wave. This method is one of fault location method that the transmission time of current signal. The reflection of current

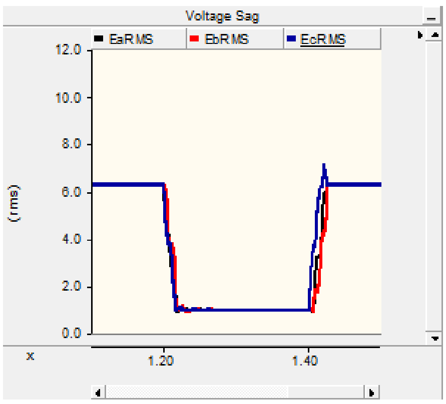
Received August 2, 2017; Revised October 27, 2017; Accepted November 12, 2017

which injected in the distribution network was utilized to determine fault distance. However, this method not applicable in the network with many branches. Travelling wave method was introduce in paper [12].

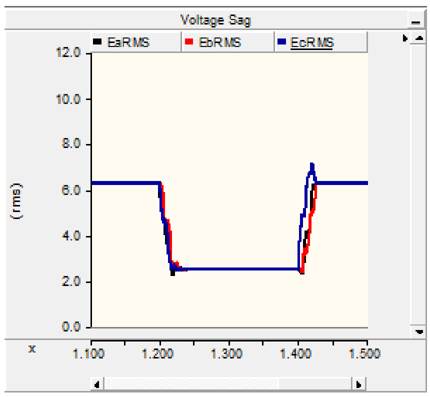
On the other hand, another research in fault location method was used knowledge based method. Knowledge Based is a method based on knowledge, such as genetic algorithm, artificial neural network, matching approach, linier model [13-14], etc. Many discussion of knowledge based method which mention about the accurate result obtained. Based the advantage of upon discussion of the types of fault location methods, this paper will discuss about fault location method based on impedance and matching approaches. Adopted from impedance based in paper [2] and matching approaches [13-14], the accuracy of both fault location method will tested by using non homogeneous distribution network. Comparison result from both method will observe to shows the advantage and disadvanatage of each method. Voltage sag and current swell also discussed in this paper due to impedance based method and matching approaches was utilizing voltage sag and current swell pattern.

2. Voltage Sag and Current Magnitude Pattern

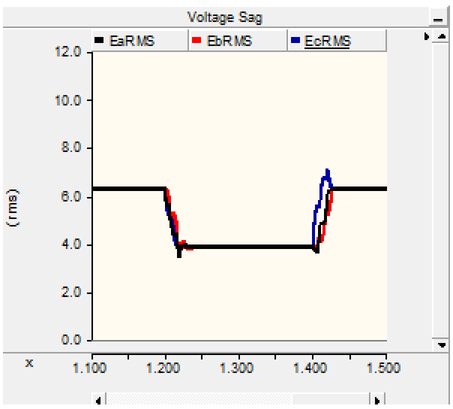
In order to justify the use of voltage and current magnitude in locating faults, studies on the voltage sag magnitude and current variation for different locations was conducted. For this purpose, faults are created at different nodes. The pattern of voltage sag and current swell magnitude due to Three Phase to Ground fault at node 3 are shown in Figure 1 and Figure 2.



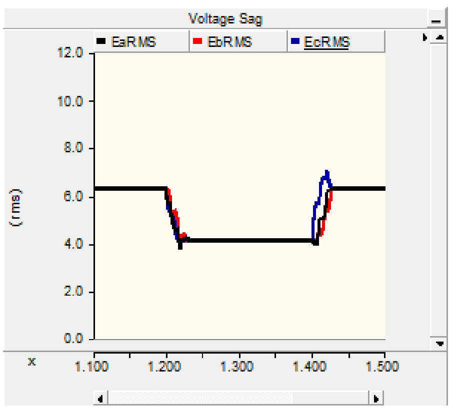
(a) Voltage Sag Magnitude at Node 3



(b)Voltage Sag Magnitude at Node 4

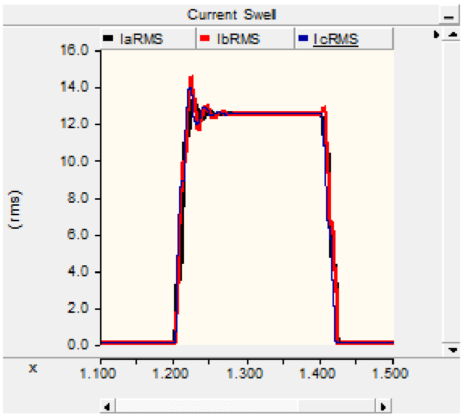


(c)Voltage Sag Magnitude at Node 9

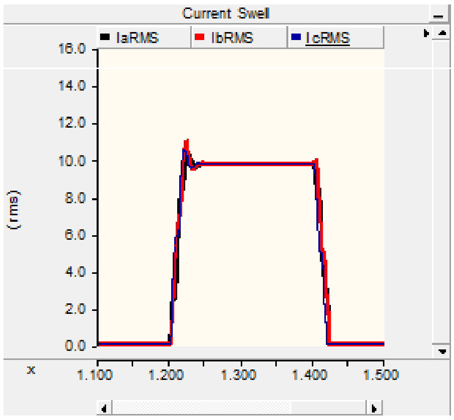


(d)Voltage Sag Magnitude at Node 11

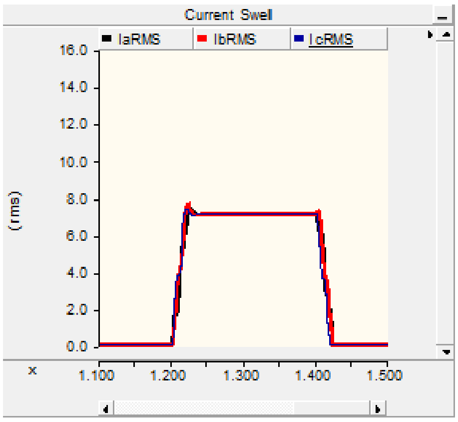
Figure 1. Voltage Sag Magnitude Pattern at Different Node



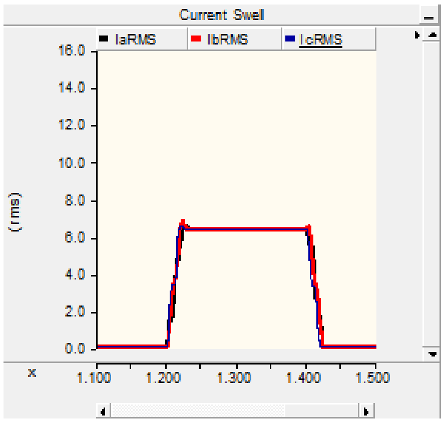
(a)Current Swell Magnitude at Node 3



(b) Current Swell Magnitude at Node 4



(c) Current Swell Magnitude at Node 9



(d) Current Swell Magnitude at Node 11

Figure 2. Current Swell Magnitude Pattern at Different Node

From Figure 1(a-d), it can be seen that the voltage sag magnitude decreases as the fault distance is closer to the monitoring node. Voltage at node 3 is deepest sag followed by voltage sag at node 4, node 9 and node 11. For the current swell is presented in Figure 2. The magnitude increases, as the fault distance is closer to the monitoring node. When the fault occur in node 3, the current swell magnitude have the highest value due to node 3 is the closest node. More distance from the measurement node will reduce current swell magnitude. In general, the LLLGF has the similar value of voltage sag and current swell for all phases.

3. Matching Approaches Technique

In order to analyse the fault distance by using matching approaches, this paper was adopted paper [13-14]. To explain the basic concept of matching approaches, figure 3 is represent the method. The fault distance is determined by assuming that the length of a faulty section *p*-*q* (any two adjacent nodes of a section) corresponds to the distance between point *p* and *q* of the voltage sags data, as shown in Figure 3.

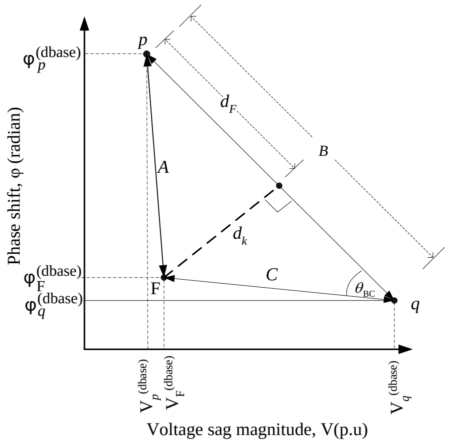


Figure. 3. Basic concept of the fault distance calculation

From Figure 3, the distance between 2 nodes is assumed as linier model of the straight line. The fault distance is estimated by the fault distance d_F from node p. The distance (d_F) can be calculated based on the cosine rule as follows.

$$d_F = \left[l_{pq} \times \sqrt{A^2 - d_k^2} \right] / B \quad (1)$$

$$F_d = d_F \times Real \quad length \quad (2)$$

where:

$$\theta_{BC} = cos^{-1} \left[\left(B^2 + C^2 - A^2 \right) / \left(2 \times B \times C \right) \right] \quad (3)$$

$$A = \sqrt{\left(\varphi_p^{(dbase)} - \varphi_F^{(meas)} \right)^2 + \left(V_F^{(meas)} - V_p^{(dbase)} \right)^2} \quad (4)$$

$$B = \sqrt{\left(\varphi_p^{(dbase)} - \varphi_q^{(dbase)} \right)^2 + \left(V_q^{(dbase)} - V_p^{(dbase)} \right)^2} \quad (5)$$

$$C = \sqrt{\left(\varphi_F^{(meas)} - \varphi_q^{(dbase)} \right)^2 + \left(V_q^{(dbase)} - V_F^{(meas)} \right)^2} \quad (6)$$

l_{pq} is the length of cable/line for section *p-q* in km

4. Impedance Based Method

Paper [2] was chosen to represent one of impedance fault location method due to most early impedance fault location method was proposed in this paper.

$$Z_{app} = \frac{V_{select}}{I_{select}} = R_{app} + X_{app} \quad (7)$$

$$I_{select} = I_a + k\, I_0 = I_{s1} + j\, I_{s2} \quad (8)$$

$$I_{sm}^2 = I_{s1}^2 + I_{s2}^2 \quad (9)$$

where:

$$k = \frac{Z_0 - Z_1}{Z_1} \quad (10)$$

By separating it into real and imaginary parts of Equation 7 and 9, each component in that equation can be submitted in the equation 11. The fault distance is expressed as:

$$D = \frac{\left(R_{app}\, M - X_{app}\, L \right)}{(R_1 M - X_1 L)} \quad (11)$$

where:

$$L = \frac{\left(I_d\, I_{s1} - I_q\, I_{s2}\right)}{(I_{sm}^2)} \quad (12)$$

$$M = \frac{\left(-I_d\, I_{s2} - I_q\, I_{s1}\right)}{(I_{sm}^2)} \quad (13)$$

$$V_{select} = Vc - Va \quad (14)$$

$$I_{select} = Ic - Ia \quad (15)$$

$$I_{comp} = \Delta Ic - \Delta Ia \quad (16)$$

The fault distance in each bus was determined based on the calculation of the voltage and current using the updated voltage and current by using static impedance load model, as adopted from paper [2].

5. Tested Network

In order to analyze the impedance based and knowledge based method performances, a real distribution network, as shown in Figure 4, which belongs to a Malaysian power utility company TNB, is used. This network is connected to the grid via a step down 132/11 kV transformer (Y-Δ), and it consists of 6 branches, with a total of 34 line sections and 38 buses. The network is made up of cables that are fully underground.

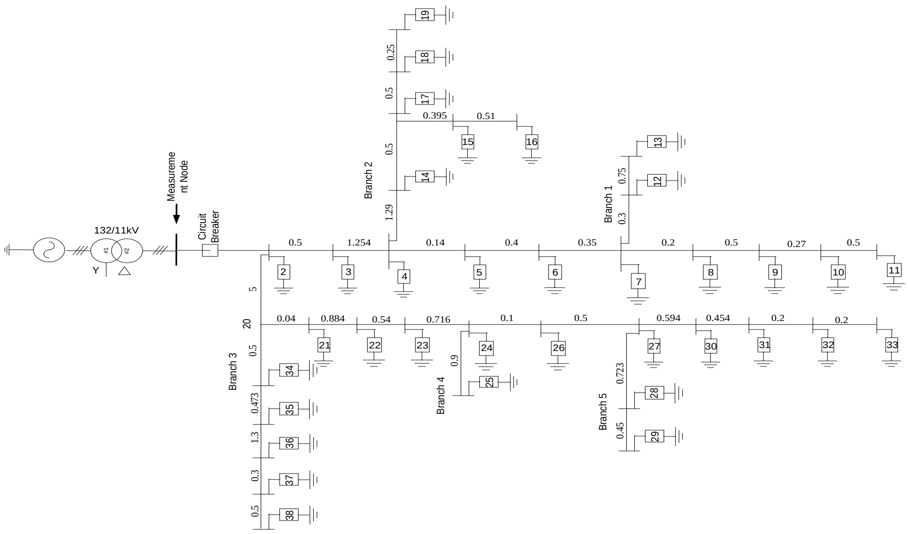


Figure. 4. Test of the distribution network

5. Result and Analysis

To observe the accuracy of fault distance, equation 17 is used to calculate the percentage error of fault distance. The differences between real fault distance and estimation of fault distance was utilized to observe the accuracy of fault distance.

$$Error\ Fd = \left|\frac{F_d^{Est} - F_d^{real}}{F_{total}}\right| \quad (17)$$

Where:

F_d^{Est} = Fault distance estimation

F_d^{real} = Real fault distance

F_{total} = Total fault distance

Table 1 was shows 3 column which presented real distance, fault distance estimation by considering impedance based method and matching approach for Three Phase to Ground Fault (LLLGF) test case. The fault distance is calculated based on the mid-point of each section in Km. Start point was decided from the sending node until receiving node. For Example section 3-4, it is means that node 3 as the sending node and node 4 as the receiving node.

Table 1. Test Result of LLLGF at Mid Point of LineSection

Real Distance / EachSection (Km)	Fault Distance Estimation Using Impedance (Km)	Fault Distance Estimation Using Matching Approach (Km)
0.25 / 2-3	0.2502	0.2512
0.625 / 3-4	0.6260	0.3147
0.07 / 4-5	0.0712	0.0840
0.135 / 9-10	0.1456	0.0401
0.25 / 10-11	0.2633	0.0814
0.25 / 20-34	0.2728	0.0778
0.25 / 37-38	0.3027	0.0733

From Table 1, it can be seen that most of fault distance estimation by considering impedance based are closer with the real distance. It is mean that impedance based have smaller error compare with matching approach consideration. As an example, when fault simulated in the mid-point of section 2-3 with the real fault distance is 0.25, the value of impedance based method (0.2502 Km) was show more closer with the real fault distance (0.25 Km) compare with matching approach (0.2512 Km). Even in the long fault distance in section 37-38, it can be seen that impedance based (0.3027 Km) is closer with real fault distance (0.25 Km) than matching approach (0.0733 Km). For the full fault distance estimation error is presented as illustrated in Figure 5 – 8 as follows.

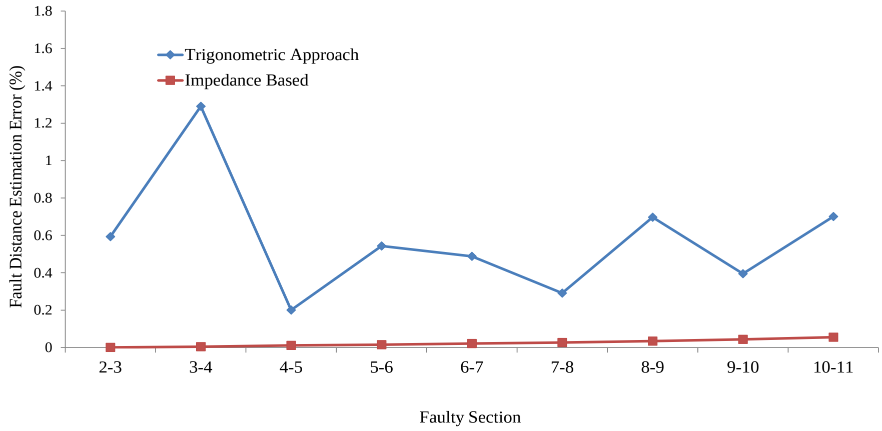


Figure 5. Fault Distance Estimation Error on Main Line 1

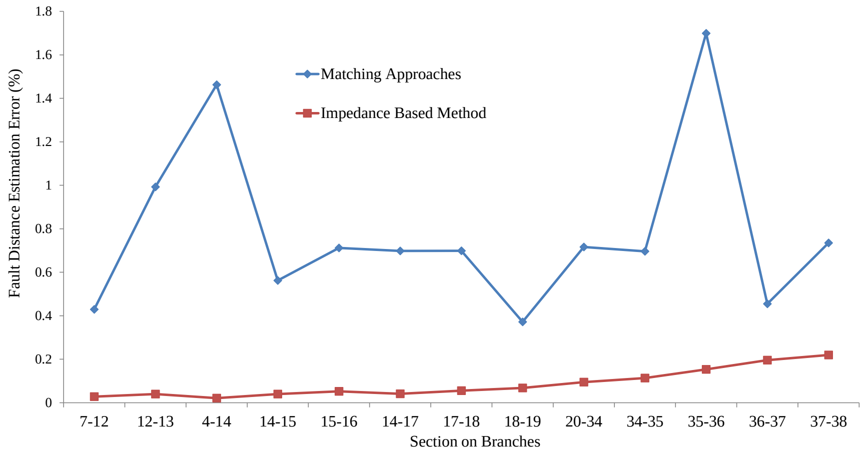


Figure 6. Fault Distance Estimation Error on Branches 1,2

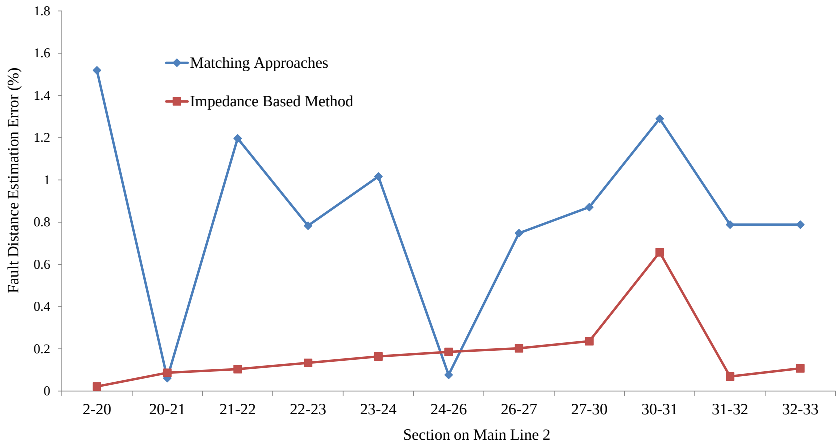


Figure 7. Fault Distance Estimation Error on Main Line 2

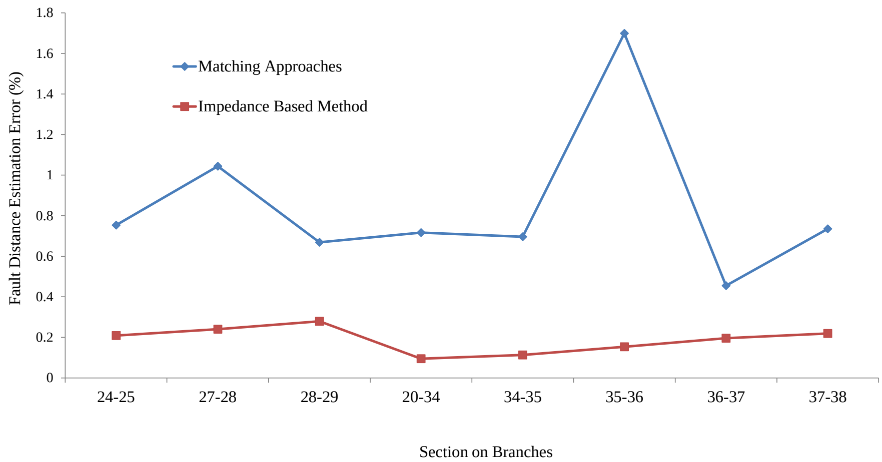


Figure 8. Fault Distance Estimation Error on branches 3,4,5

The results indicate that the fault distance error by using matching approach for LLLGF test cases is higher than impedance method. The maximum error by using matching approach occurred on test section 35-36, is around 1.6988% or equivalent to 0.4083 km from the actual fault location. This is due to assumption in the matching approach which assume that the fault point have the linear correlation with the database.

On the other hand, most of the fault distance errors using impedance based method are very low. The maximum error by using impedance based method is obtained at test section 30-31, which is around 0.6577% or equivalent to 0.1581 km in the actual length. This is possible due to section 30-31 which lies in a long distance line with complex network and branches. By comparing both methods, it can be noted that impedance based method produces more significant accuracy than matching approach. However, the matching approach still shows the reasonable accuracy.

6. Conclusion

This paper has discussed a comparison study of impedance based method and matching approach. Non homogeneous distribution network was adopted as a test network. Voltage sag and current swell pattern was used to analyze the fault distance. Based on the obtained result, it can be concluded that most of the impedance based method shows more accurate result compare with matching approach. However, the accuracy on section 24-26 shows that matching approach technique obtain the better result compare with impedance based method. It is possible due to section 24-26 is the shortest section in the long distance from the measurement node. So, it will contribute the unique pattern of voltage sag and current swell which impact to the better accuracy for matching approaches. However, for impedance based method will contribute to the impedance line values which effect to the accuracy of fault distance calculation. In general, the better accuracy fault distance was generated by impedance based method compare with matching approaches. However, matching approaches still shows the reasonable accuracy.

References

[1] Force, U.-C. P. S. O. T., Abraham, S., et al. *Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations*: US-Canada Power System Outage Task Force. 2004.

[2] A. A. Girgis, C. M. Fallon, and D. L. Lubkeman. A fault location technique for rural distribution feeders. *IEEE Trans. Ind. Appl*. 1993; 29(6) Nov. /Dec: 1170–1175.

[3] Jun Zhu, D.L. Lubkeman, A.A Girgis. Automated fault location and diagnosis on electric power distribution feeders. *Power Delivery, IEEE Transactions on*. 1997; 12(2) Apr; 801-809.

[4] M.M. Saha, J. Izykowski, E. Rosolowski, B. Kasztenny. A new accurate fault locating algorithm for series compensated lines. *Power Delivery, IEEE Transactions on*. 1999; 14(3) Jul; 789-797.

[5] Seung-Jae Lee, Myeon-Song Choi, Sang-Hee Kang, Bo-Gun Jin, Duck-Su Lee, Bok-Shin Ahn, Nam-Seon Yoon, Ho-Yong Kim, Sang-Bong Wee, "*An intelligent and efficient fault location and diagnosis scheme for radial distribution systems*," Power Delivery, IEEE Transactions on. 2004, 19(2) April: 524- 532.

[6] R.H.Salim, M. Resener, A.D. Filomena, K RezendeCaino de Oliveira, A.S. Bretas. Extended Fault-Location Formulation for Power Distribution Systems. *Power Delivery, IEEE Transactions on*. 2009; 24(2) April: 508-516.

[7] André D. Filomena, Mariana Resener, Rodrigo H. Salim, Arturo S. Bretas, Fault location for underground distribution feeders: An extended impedance-based formulation with capacitive current compensation, *International Journal of Electrical Power & Energy Systems*. 2009; 31(9) October: 489-496. ISSN 0142-0615, 10.1016/j.ijepes.2009.03.026

[8] R.A.F. Pereira, L.G.W. da Silva, M. Kezunovic, J.R.S. Mantovani. Improved Fault Location on Distribution Feeders Based on Matching During-Fault Voltage Sags. *Power Delivery, IEEE Transactions on*. 2009; 24(2) April: 852-862.

[9] Myeon-Song Choi, Seung-Jae Lee, Duck-Su Lee, Bo-Gun Jin. A new fault location algorithm using direct circuit analysis for distribution systems. *Power Delivery, IEEE Transactions on*. 2004; 1(1) Jan:, 35- 41.

[10] J. Horak. *Zero sequence impedance of overhead transmission lines," Protective Relay Engineers*, 2006. 59th Annual Conference for. 4-6 April 2006.

[11] E.B. Davison, A. Wright. Some factors affecting the accuracy of distance-type protective equipment under earth-fault conditions. *Electrical Engineers, Proceedings of the Institution of*. 1963; 110(9) September: 1678-1688.

[12] H. K. K. Abolfazl Jalilvand, Hadi Fotoohabadi, High Impedance Fault Detection Using Duffing Oscillator and FIR Filter. *International Review of Electrical Engineering.* 2010*:* 5: 10.
[13] Awalin, Lilik Jamilatul, Hazlie Mokhlis, and A. H. A. Halim. Improved fault location on distribution network based on multiple measurements of voltage sags pattern. *Power and Energy (PECon), 2012 IEEE International Conference on*. IEEE, 2012.
[14] Awalin, Lilik Jamilatul, et al. A generalized fault location method based on voltage sags for distribution network. *IEEJ Transactions on Electrical and Electronic Engineering.* 2013; 8(1).