This article has been accepted for publication in a future issue of this conference proceedings, but has not been fully edited. Content may change prior to final publication. Citation information: DOI10.1109/SEGE.2013.6707931, 2013 IEEE International Conference on Smart Energy Grid Engineering (SEGE)

Impedance-Based Fault Location Technique for Distribution Systems in Presence of Distributed Generation

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***Abstract*— This paper presents an analytical technique for fault location in distribution systems in presence of distributed generation (DG). The presence of DG changes the nature of power flow from unidirectional to multidirectional. Therefore, the accuracy of impedance-based fault location methods will be affected by the presence of DG. The proposed technique is a modification of impedance-based methods to be suitable for systems containing DG based on voltage and current measurements at the power substation. To evaluate this technique, it is implemented on an 11 kV feeder using ATP/EMTP package. The results achieved ensure the validity and accuracy of the technique**

***Index Terms*— Distributed generation, Fault location, Impedance-based technique**

I. Introduction

Electric power distribution system faces various problems caused by lightning, storms, insulation breakdown, and others [1]. This will lead to power interruption and hence unacceptable power continuity indices [2]. Fault Location is used to reduce the outage time and hence, several fault location methods have been proposed for distribution system [3]-[5].

Fault location suffers from many sources of error (i.e. fault type, fault point, fault resistance, loads, distributed generation presence 'DG'… etc). Recently, some techniques have been developed to take into account the effect of DG presence. The impedance-based technique is one of these techniques, which may be divided into two categories. The first category depends upon measuring voltages and currents at the main substation only [6]-[8]. The second category depends upon measurements at both main substation and DG [9]-[11]. Solidly three-phase faults were treated in [6] and [7] using the first and second categories. However, fault resistance was not considered in these papers. In addition, the analysis in [6] was performed only for low DG penetration level. Ten ohm fault resistance and different levels of DG capacity were presented in [8]. Techniques described in [9]-[11] depend upon measurement at the main substation and DG, which require a suitable method for communication to transfer the signals captured at DG position to the main substation position.

Signals captured from the main substation will be used for the proposed technique presented in this paper based on the well known sequence components. The proposed technique will present a compensation method to overcome the error due to load distribution along the feeder, non homogenous feeder sections, high DG penetration level and different fault resistance values. Eleven kV feeder simulated by ATP/EMTP package [12] is used to evaluate the proposed technique. The results obtained ensure the validity of this technique to be applied on distribution systems containing DG.

II. Proposed Methodology

The single-line diagram for a typical radial feeder in a distribution network containing DG is illustrated in Fig. 1. This system is used to present the proposed technique. To generalize the investigation, the feeder is assumed to consist of sections with different cross section areas. Also, the loads may be connected to the feeder directly or through lateral. Sequence component circuits, shown in Fig. 2, are used to estimate the distance to the fault location.

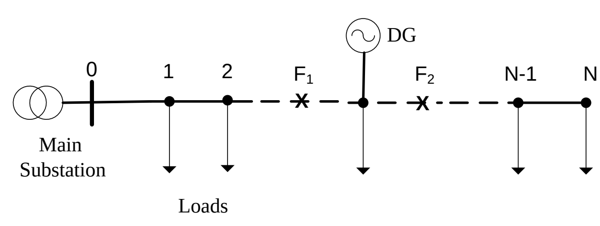

Figure 1. Single-line-diagram for distribution network with DG.

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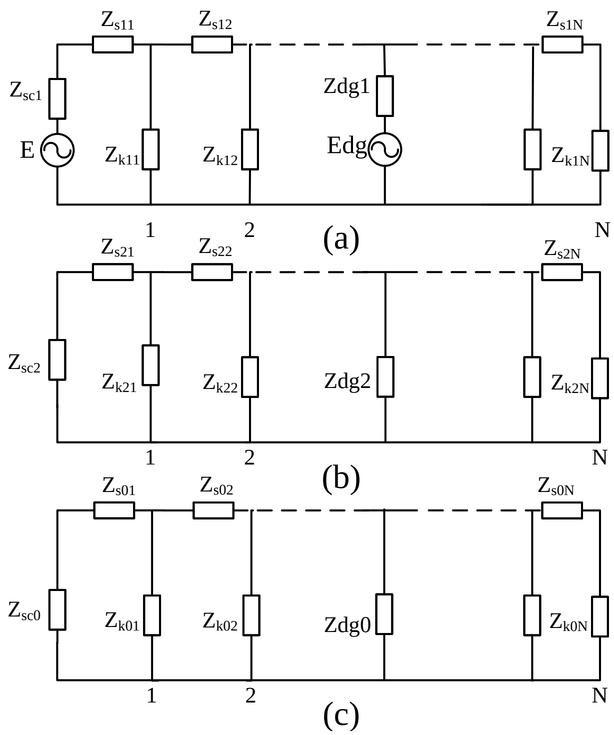

Figure 2. Sequence component circuits for typical distribution system with distributed generation.

where

Z_{sc1} ,Z_{sc2} and Z_{sc0}	Source positive, negative and zero sequence impedances.
Z_{s1i} , Z_{s2i} and Z_{s0i}	Positive, negative and zero sequence impedances of the i^{th} section.
Z_{k1i} ,Z_{k2i} and Z_{k0i}	Positive, negative and zero sequence impedances of loads at node (i).
Z_{dg1} ,Z_{dg2} and Z_{dg0}	Positive, negative and zero sequence impedances of the DG source.
E	Equivalent Thevenin voltage.
N	Number of main feeder nodes.
E_{dg}	DG source internal voltage.

The analysis according to the proposed technique can be classified according to fault location into:

- Upstream case for faults occurred between main source and DG connection point.
- Downstream case for faults occurred beyond DG connection point.

The two cases are analyzed for both single-line-to-ground and three-phase faults.

A. Upstream Single-Line-to-Ground Fault

For a single–line-to-ground fault with fault resistance of R_f occurred at point F_1, all positive, negative and zero sequence circuits are included. The system beyond the fault section in the positive sequence circuit is represented by Thevenin equivalent circuit (E_{th} and Z_{th}). Also, negative and zero sequence circuits are reduced to the equivalent impedances Z_{M1} and Z_{M0} respectively as illustrated in Fig. 3.

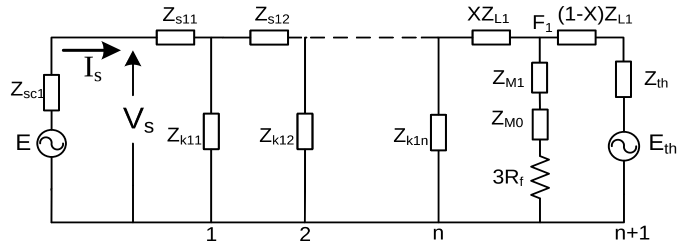

Figure 3. Equivalent circuit for upstream single-line-to-ground fault.

where

$$Z_{M1} = \frac{-Z_{L1}^2 X^2 + L_1 X + M_1}{Z_{n1}}$$
$$L_1 = Z_{L1}^2 - Z_{L1} Z_{P1} + Z_{L1} Z_{u1}$$
$$M_1 = Z_{L1} Z_{P1} + Z_{P1} Z_{u1} \qquad (1)$$
$$Z_{n1} = Z_{L1} + Z_{P1} + Z_{u1}$$

Z_{u1}	Equivalent impedance as seen from node (n+1) up to feeder end
Z_{P1}	Equivalent impedance as seen from node (n) up to substation
Z_{L1}	Positive sequence impedance of the faulted feeder section
X	Per unit faulted part of the fault section

Similarly, Z_{M0} is calculated using Eqn. (1) after replacing all positive sequence values with the corresponding zero sequence values.

Voltages and currents measured at substation are used to calculate the voltage at node (n) and current from node (n) to the fault using Eqns. (2)-(4):

$$V_{k+1} = V_k - Z_{s1(k+1)} I_k \qquad (2)$$
$$I_{L(k+1)} = Y_{L(k+1)} V_{k+1} \qquad (3)$$
$$I_{k+1} = I_k - I_{L(k+1)} \qquad (4)$$

where

V_k	Positive sequence voltage at node (k)
I_k	Positive sequence current from node (k) to node (k+1)
$I_{L(k+1)}$	Load current at node (k+1)
$Z_{s1(k+1)}$	Positive sequence impedance of feeder section between (k) and (k+1)
$Y_{L(k+1)}$	Load admittance connected to node (k+1)

At k=0, $V_0=V_s$ and $I_0=I_s$

Therefore the equivalent circuit is reduced to the circuit illustrated in Fig. 4. By analyzing this circuit, the following equations are obtained.

$$V_n - XZ_{L1} I_n = E_{th} - ((1-X)Z_{L1} + Z_{th}) I_y \qquad (5)$$
$$V_n - XZ_{L1} I_n = (3R_f + Z_{M1} + Z_{M0})(I_n + I_y) \qquad (6)$$

Rearranging Eqns. (5) and (6), Eqn. (7) can be obtained:

$$AX^2 - BX + C = 3R_f \qquad (7)$$

where

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$$A=\frac{Z_{L1}^2}{H}+\frac{Z_{L1}^2}{Z_{n1}}+\frac{Z_{L0}^2}{Z_{n0}}$$
$$B=\frac{Z_{L1}(Z_t+Z_{L1}+Z_{th})}{H}+\frac{L_1}{Z_{n1}}+\frac{L_0}{Z_{n0}}$$
$$C=\frac{Z_t(Z_{th}+Z_{L1})}{H}-\left(\frac{M_1}{Z_{n1}}+\frac{M_0}{Z_{n0}}\right) \tag{8}$$
$$H=\frac{E_{th}}{I_n}+Z_{L1}+Z_{th}-Z_t$$
$$Z_t=\frac{V_n}{I_n}$$

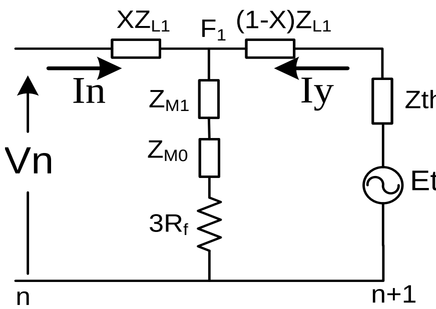

Figure 4. Equivalent circuit for upstream single-line-to-ground fault.

Under the condition that the fault resistance is a real value, thus

$$\text{imag}(R_f)=0 \tag{9}$$
$$A_i X^2-B_i X+C_i=0 \tag{10}$$

where

$$A_i=\text{imag}(A)$$
$$B_i=\text{imag}(B) \tag{11}$$
$$C_i=\text{imag}(C)$$

The per unit fault distance (X) measured from node (n) is calculated by solving Eqn. (10), which is a second order equation. Two possible solutions are given in Eqn. (12). Only one solution is accepted and the other gives unrealistic value.

$$X_1=\frac{B_i+\sqrt{B_i^2-4A_iC_i}}{2A_i}$$
$$X_2=\frac{B_i-\sqrt{B_i^2-4A_iC_i}}{2A_i} \tag{12}$$

Finally, Eqn. (13) is used to calculate the total fault distance measured from the main substation.

$$\text{Fault Distance}=XD_m+\sum_{r=1}^{r=m-1} D_r \tag{13}$$

where

D_r	Length of r^{th} feeder section
m	Fault section number

B. Downstream Single-Line-to-Ground Fault

For a single-line-to-ground fault with fault resistance of R_f occurred at point F2, Fig. 5 shows the corresponding equivalent circuit.

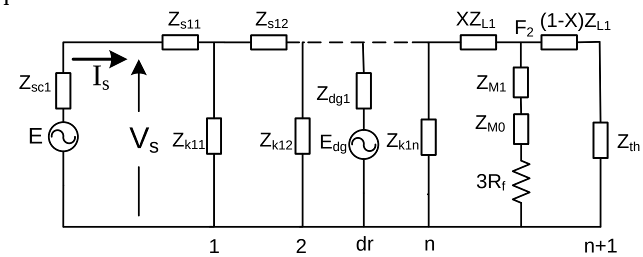

Figure 5. Equivalent circuit for downstream single-line-to-ground fault.

Eqns. (2)-(4) are used to calculate the voltage at node (n) and current from node (n) to the fault. The DG current is calculated using Eqn. (14) considering that the DG internal voltage remains constant during the fault. The current to section beyond the DG is calculated using Eqn. (15). Therefore the equivalent circuit is reduced to the circuit presented in Fig. 6.

$$I_{dg}=\frac{E_{dg}-V_{dr}}{Z_{dg1}} \tag{14}$$
$$I_{k+1}=I_k-I_{L(k+1)}+I_{dg} \tag{15}$$

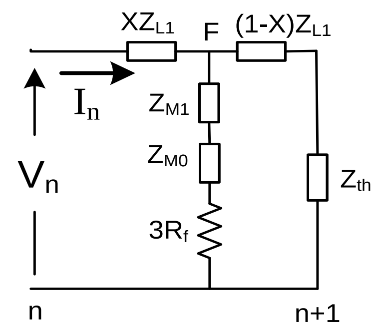

Figure 6. Equivalent circuit for downstream single-line-to-ground fault.

The circuit shown in Fig. 6 will be similar to that in Fig. 4 when Eth is set to zero. Eqns. (7)-(13) are used to calculate the distance to the fault point. The following flow chart illustrates the procedure for fault distance calculation in case of single–line-to-ground faults. In this chart, "fs" refers to the assumed fault section, "dr" is the connection node of DG and "m" is the actual fault section.

C. Three-Phase Faults

For a three-phase fault with fault resistance of R_f in either upstream or downstream, only positive sequence circuit is used. The same analysis as carried out for single-line-to-ground fault is used with three-phase fault. The resultant equations for fault location are the same as those for single-line-to-ground fault cases with setting the terms corresponding to Z_{M1} and Z_{M0} to zero.

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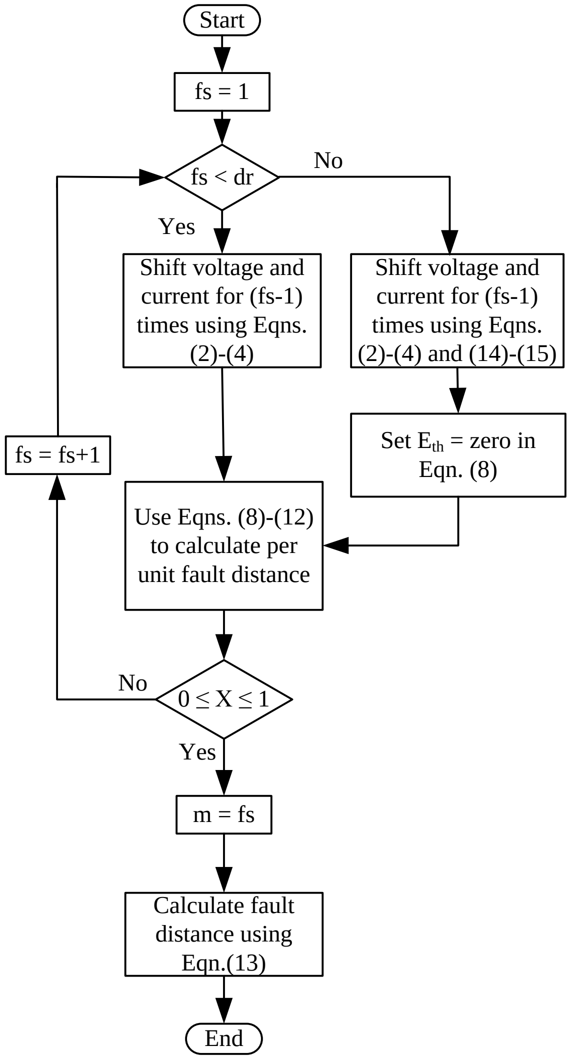

Figure 7. Flow chart for single–line-to-ground fault procedures.

III. CASE STUDY

To validate the proposed technique, a real distribution system is used. The system is a 27 node, 11 kV distribution feeder, which is an actual feeder in El-Gharbia electricity sector- Tanta city. The single line diagram of the distribution system is illustrated in Fig. 8. All main feeder sections and laterals have cross section area of 150 mm^2 and 70 mm^2 ACSR respectively. Cross section area of feeder sections and laterals that differs from these values is illustrated in Fig. 8, with lengths indicated in meters. The loading of the investigated system, which is simulated using ATP program to perform short circuit calculations of different types in different locations, is also indicated in the figure. The distribution lines parameters are estimated by Carson's equation [13]. Positive and zero sequence impedances for different cross section areas are summarized in Table I.

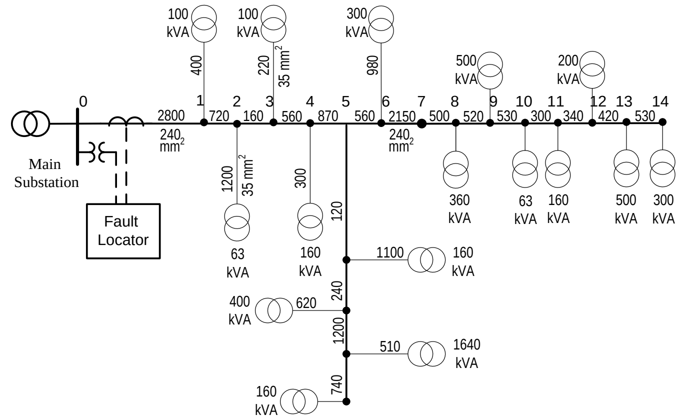

Figure 8. Distribution system used for testing the proposed technique.

TABLE I. ELECTRICAL LINES PARAMETERS OF THE TEST FEEDER

Area (mm^2)	Positive sequence (Ω/km)	Zero sequence (Ω/km)
240	0.1347 + j0.2789	0.2799 + j1.6250
150	0.2129 + j0.2935	0.3581 + j1.6396
70	0.5564 + j0.3881	0.7016 + j1.7342
35	1.0504 + j0.4006	1.1956 + j1.7467

DG is simulated by a source behind impedance connected to node 9. The technique is validated at DG level of 26% of the total system active power according to Eqn. (16). Single-line-to-ground and three-phase faults at different values for fault resistance up to 50Ω are studied. The percentage error of estimated fault distance is calculated using Eqn. (17).

$$\%\ \text{DG level} = \left(\frac{P_{dg}}{P_{dg}+P_{ss}}\right)\times 100 \tag{16}$$

$$\%\ \text{Error} = \left(\frac{D_{est}-D_{act}}{\text{Total feeder length}}\right)\times 100 \tag{17}$$

where

P_{dg}	DG active power
P_{ss}	Main substation active power
D_{est}	Estimated fault distance
D_{act}	Actual fault distance

IV. RESULTS AND DISCUSSION

This section evaluates the proposed technique under variation of fault resistance up to 50 Ω for both single-line-to-ground and three-phase faults, where 500 fault cases were simulated. Curves describing the percentage error of estimated distance for single-line-to-ground and three-phase faults are shown in Fig. 9 and Fig. 10 respectively.

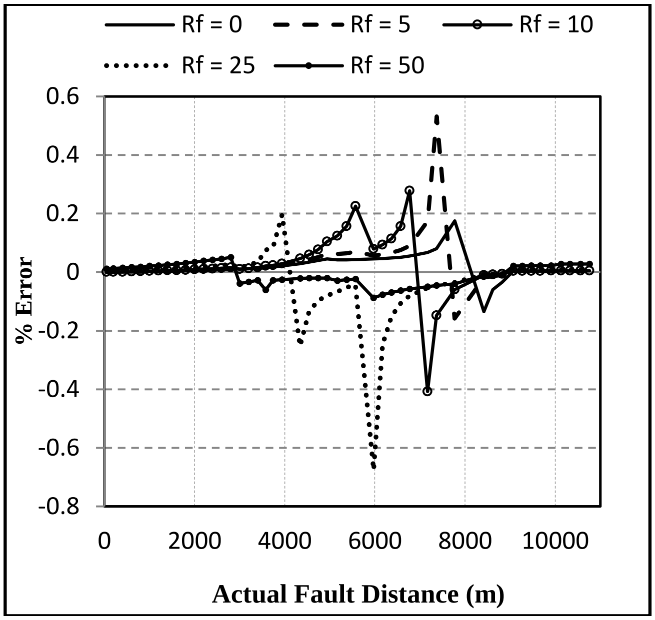

Figure 9. Percentage error of estimated distance for single-line-to-ground fault case.

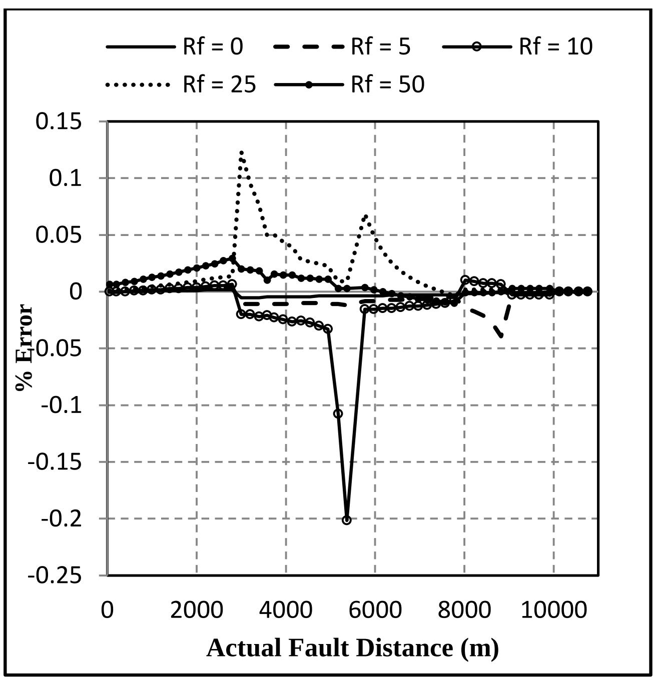

Figure 10. Percentage error of estimated distance for three-phase fault case.

It is noticed that the percentage error obtained changes in the range between – 0.67 % and 0.53 % in case of single-line-to-ground fault and between – 0.2 % and 0.12 % for three-phase fault. This demonstrates that the proposed technique is promising and helps to improve the accuracy of fault location for distribution system with DG.

V. CONCLUSION

Fault locator with improved accuracy is an effective tool to reduce the outage time and cost. This paper proposed and discussed an impedance based fault location technique in presence of DG. The technique uses only local measurements at main substation and depends on sequence components. Non homogeneous feeder sections, fault type, fault resistance, load distribution and high DG penetration level were considered. As a result of a general analysis of the method's performance, it was observed that the percentage error varies in the range of (− 0.67 to 0.53) % and (− 0.2 to 0.12) % for single-line-to-ground and three-phase faults respectively. This ensures the validity and accuracy of the proposed technique, which encourage its implementations in real systems.

REFERENCES

[1] M. M. Saha, J. Izykowski, and E. Rosolowski, "Fault Location on Power Networks". London, U.K.: Springer-Verlag London, 2009.

[2] Philipson L. Lee Willis H.(2005), "Understanding electric utilities and deregulations". CRC Press. 2 Edition. 2005.

[3] R. Das, "Determining the locations of faults in distribution system" Ph.D. University of Saskatchewan, Saskatoon, Canada, 1998

[4] R. H. Salim, K. C. O. Salim, and A. S. Bretas, "Further improvements on impedance-based fault location for power distribution systems," IET Generation Transmission & Distribution, vol. 5, pp. 467-478, Apr 2011.

[5] M. Gilany, D. K. Ibrahim and E. S. Tag Eldin, "Traveling-Wave – Based Fault-Location Scheme for Multiend-Aged Underground Cable Systems," IEEE Trans. Power Delivery, vol. 22, no. 1, pp. 82 – 88, 2007.

[6] J. U. N. Nunes and A. S. Bretas, "Impedance-based Fault Location Formulation for Unbalanced Distribution Feeders with Distributed Generation", In: International Conference on Power System Technology, October, 2010.

[7] D. Penkov, B. Raison, C. Andrieu, J.-P. Rognon and B. Enacheanu, "DG Impact on three-phase fault location. DG uses for fault location purposes?", In: International Conference on Future Power Systems, November, 2005.

[8] J. U. N. Nunes and A. S. Bretas," A Impedance-Based Fault Location Technique for Unbalanced Distributed Generation Systems." Power Tech, 2011 IEEE Trondheim.

[9] Sukumar M. Brahma, "Fault Location in Power Distribution System With Penetration of Distributed Generation", IEEE Trans. Power Delivery, vol. 26, Issue 3, pp. 1545-1553, 2011.

[10] C. Orozco-Henao, J. Mora-Florez and S. Perez-Londono, "A robust method for single phase fault location considering distributed generation and current compensation" Transmission and Distribution: Latin America Conference and Exposition (T&D-LA), 2012 Sixth IEEE/PES

[11] A. Bedoya-candena, C. Orozco-Henao and J. Mora-Florez, "Single Phase to Ground Fault Locator for Distribution Systems with Distributed Gneration" Transmission and Distribution: Latin America Conference and Exposition (T&D-LA), 2012 Sixth IEEE/PES

[12] Alternative Transient Program: ATP/EMTP, Bonneville Power Administration, 2002. [Online]. Available: http://www.emtp.org/.

[13] W. H. Kersting, "Distribution System Modeling and Analysis", Boca Ratón, 2nd ed, FL: CRC, 2007.

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