A power system modeling and a forward sweep-based proposal for fault location in power distribution systems

A. Panesso-Hernández, J. Mora-Flórez, S. Pérez-Londoño

***Abstract*— All of the recently proposed fault location approaches for power distribution systems require prior knowledge of system variables at the faulted section. This is a problem in power distribution systems because these usually have measurements of voltages and currents only at the main substation. As a consequence, this document proposes a power system modeling and a forward sweep-based method aimed to estimate the values of voltage and current at the faulted section, using the power system parameters, topology and the measurements at the substation.**

By applying the new approach here proposed, the distance estimation error is reduced in nearly 1% from the original value. It helps to develop more precise methods for locating faults in power distribution systems, contributing in this way to improve the supply continuity and as a consequence the power quality.

***Index Terms*— Fault location, forward sweep-based method, power distribution systems.**

I. INTRODUCTION

FAULT location in power distribution systems has acquired a remarkable importance in recent years, since the adequate power quality delivery is fundamental to the utility customers. In Colombia, the regulatory energy and gas commission (CREG) establishes the parameters to determine the electricity service continuity for power distribution systems, by considering two indexes, so-called IRAD and ITAD [1]. Therefore, by the adequate location of permanent faults at the power distribution system is possible to reduce the time of interruption and also the number of fault events, by following an adequate preventive maintenance schedule at the critical points of the electric network.

The fault location methods proposed to solve the problem in power distribution systems are normally based on the circuit model, which allow an efficient estimation of the faulted node [2-4]. The main disadvantage of these methods is the requirement of exact values of voltage and current at the beginning of faulted section.

Several authors have presented approaches which help to estimate the apparent reactance of the system using the information available at the substation [5], additionally including capacitive effects [6], proposing approaches to determine the load current downstream of the fault section [7], taking into account variations in load size [8], among others. However, all of these approaches use approximations to estimate the voltages and currents at the faulted section, which reduce the locator efficiency.

On the other hand, the power flow methods for distribution systems may be classified into two groups: 1) these which propose changes in the methods used in power systems, and 2) sweep methods, which are the most used [9]. The main problem of these methods is the requirements of a complete knowledge of parameters and topology of the analyzed power distribution system.

The proposed approach presented in this paper allows estimating the voltages and currents at the faulted sections, using the line impedance and admittance and the phase measurements at the substation of the analyzed power system. This also considers the no homogeneity along the line sections and lumped loads. The here proposed approach reduces the fault distance estimation errors.

II. THEORETICAL BASIC ASPECTS

A. Fault location principles

Power distribution systems usually have radial topology, heterogeneous section lines, tapped loads, single and three phase laterals, measurements only available at the substation and usually have high fault rates.

By considering the above mentioned, an alternative to avoid the high unavailability rates of in any power system is by using fault location methods, which are normally defined only at the faulted section to determine the fault distance, based on measurements in one or both terminals. Figures 1 and 2 shows a one-line diagram of a faulted section before and during a fault, respectively.

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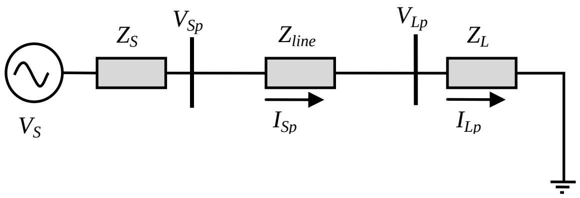

Fig. 1. Simplified power system at pre-fault condition.

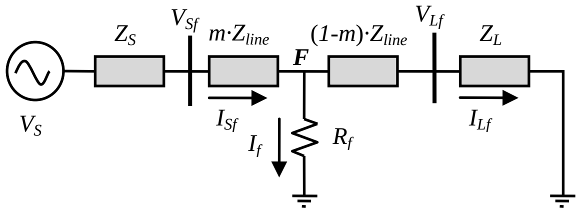

Fig. 2. Simplified power system during fault condition.

To obtain the distance to the fault, precise information about voltage and current per phase (or only at the faulted phase) at the initial node of the faulted section are required. In the case of a fault at the power distribution system, a good strategy to reduce the number of mathematical operations to find the faulted point is the use of superimposed circuits, which were proposed in [10] and used in [11]. This method is based on the substation measurements, to determine the values of superimposed components of voltage and current at any node along on the power line, and is widely used by other fault location methods of such as the one proposed by Novosel *et al.* at [11]. A superimposed component is defined as the difference between the values of voltage and current during the fault and the pre-fault steady state, as presented in Fig. 3. The superimposed components of the non-faulted phases, takes its minimum value at the faulted node **F** [2].

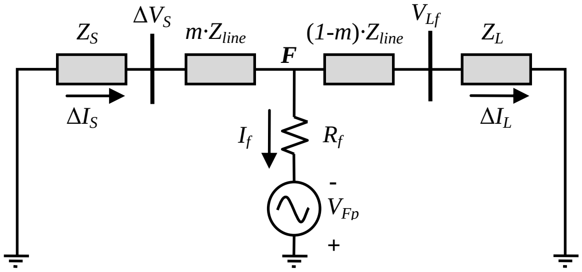

Fig. 3. Superimposed circuit obtained from Figs. 1 and 2.

The strategy proposed in [11] consider the effects of tapped loads between the initial part of the circuit and the faulted node, but its efficiency still depends of a good estimation of voltage and current at the terminals of the faulted section, during the pre-fault and fault steady states.

B. *Conventional power system modeling*

On the other hand, power distribution systems have several elements which require of appropriate models, and these must be taken into account to obtain an optimal estimation of any system variable at any node.

In [12] the authors discuss about the capability of the transmission parameters to describe the characteristic of an overhead line or a cable. Also describes the transmission parameters *A*, *B*, *C* and *D* as elements which represent respectively, the ratio of the open circuit voltage, the negative transference impedance during short circuit, the transference admittance in open circuit and the ratio of the negative current in short circuit.

Electric power lines in a distribution system also can be modeled using lumped parameters at a one-line π equivalent circuit [13]. This model is suitable for power distribution systems to increase the performance of the fault locators, only if all of the parameters are available.

Equations from (1) to (4) allow obtaining the voltages and currents in a one-line π modeled line.

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \cdot \begin{bmatrix} V_R \\ I_R \end{bmatrix} \tag{1}$$

$$V_S = V_R + Z\left(I_R + \frac{Y}{2}V_R\right) \tag{2}$$

$$I_S = I_R + \frac{Y}{2}V_R + \frac{Y}{2}V_S \tag{3}$$

where

$$A = \frac{Z \cdot Y}{2} + 1 \qquad B = Z$$
$$C = Y\left(\frac{Z \cdot Y}{4} + 1\right) \quad D = \frac{Z \cdot Y}{2} + 1 \tag{4}$$

III. PROPOSED MODELING APPROACH

At the specific case of the presented method, the matrixes of transmission parameters of all power system elements are required. This helps to guarantee the high confidence of the estimated voltages and currents at any node of the power system, using only the substation phasor measurements and the forward sweep-based method also proposed in section IV of this paper.

In this section the used power system modeling strategy is described.

A. *Lines proposed modeling*

It is possible to know the parameters of the power distribution system using information extracted from the utility databases. Power lines are usually represented by serial models that despise the shunt admittance; these give good approximations of the power distribution systems because of the low level of voltage and the short section line length.

Lately in proposals presented in [6, 7, 14, 15], the authors show how the capacitive effect has considerable influence in fault location. As a consequence, the capacitive effect has to be considered in such cases of lightly loaded systems, long and underground lines [16].

Normally, the power distribution systems are unbalanced then the one-line model is not adequate to represent distribution lines. As a consequence it is necessary to use a best model to represent the lines and a new methodology to estimate the system state from voltages and currents at the substation, as the proposed model presented in figure 4.

From figure 4, the impedance and admittance parameters of lines along the power distribution system are obtained as is given in (5).

$$[Z]=\begin{bmatrix} Z_{aa} & Z_{ab} & Z_{ac} \\ Z_{ba} & Z_{bb} & Z_{bc} \\ Z_{ca} & Z_{cb} & Z_{cc} \end{bmatrix},[Y']=\frac{1}{2}\begin{bmatrix} Y_{aa} & Y_{ab} & Y_{ac} \\ Y_{ba} & Y_{bb} & Y_{bc} \\ Y_{ca} & Y_{cb} & Y_{cc} \end{bmatrix} \qquad (5)$$

Then, the currents flowing through each phase are obtained using the lumped impedance, starting with phase a, as is presented in (6).

$$\begin{aligned} I_{La} &= I_{Ra}+\frac{Y_{aa}}{2}V_{Ra}+\frac{Y_{ab}}{2}(V_{Ra}-V_{Rb})+\frac{Y_{ac}}{2}(V_{Ra}-V_{Rc}) \\ &= I_{Ra}+\left(\frac{Y_{aa}}{2}+\frac{Y_{ab}}{2}+\frac{Y_{ac}}{2}\right)V_{Ra}-\frac{Y_{ab}}{2}V_{Rb}-\frac{Y_{ac}}{2}V_{Rc} \end{aligned} \qquad (6)$$

Equation (6) is generalized as presented in (7).

$$I_{Li}=I_{Ri}+\left(\sum_{j=1}^{n}\frac{Y_{ij}}{2}\right)V_{Ri}-\left(\sum_{j=1,j\neq i}^{n}\frac{Y_{ij}}{2}\right)V_{Rj} \qquad (7)$$

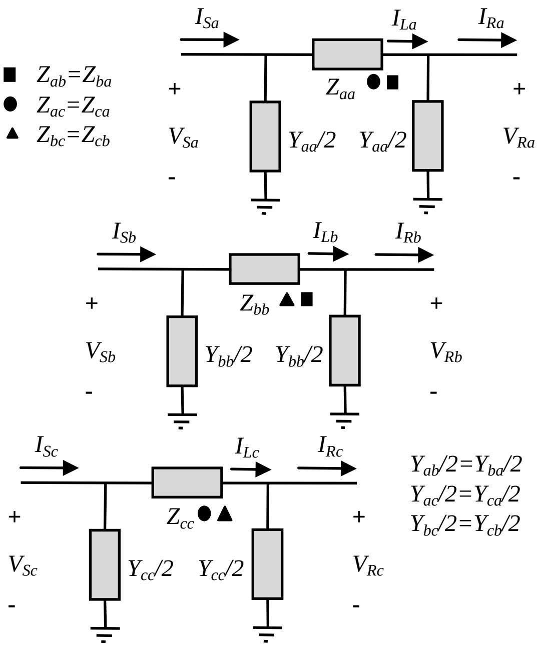

Fig. 4. Model of a three-phase line section considering mutual effect.

Using (7) is possible to obtain an expression for other phases or wires. The next step is devoted to arrange the phase currents in a matrix form, as is given at (8).

$$[I_L]=[Y][V_R]+[I_R] \qquad (8)$$

The admittance matrix is redefined as is presented in (9).

$$[Y]=\frac{1}{2}\begin{bmatrix} Y_{aa}+Y_{ab}+Y_{ac} & -Y_{ab} & -Y_{ac} \\ -Y_{ba} & Y_{ba}+Y_{bb}+Y_{bc} & -Y_{bc} \\ -Y_{ca} & -Y_{cb} & Y_{ca}+Y_{cb}+Y_{cc} \end{bmatrix} \qquad (9)$$

By knowing the line current I_L of each phase, is possible to find the voltages at the sending node, as is presented in (10) for the phase a.

$$V_{Sa}=Z_{aa}I_{La}+Z_{ab}I_{Lb}+Z_{ac}I_{Lc}+V_{Ra} \qquad (10)$$

Similarly, for other phases or wires (11) is obtained, where i represent the corresponding phase.

$$V_{Si}=\sum_{j=1}^{n}Z_{ij}\,I_{Lj}+V_{Ri} \qquad (11)$$

Equation (11) is arranged in matrix form and by considering (8), the sending voltage is a function of the variables at the receiving node, as is presented in (12).

$$\begin{aligned} [V_S] &= [Z][I_L]+[V_R] \\ &= [Z]([Y][V_R]+[I_R])+[V_R] \\ \Rightarrow [V_S] &= \begin{bmatrix}[Z][Y]+[I] & [Z]\end{bmatrix}\begin{bmatrix}[V_R] \\ [I_R]\end{bmatrix} \end{aligned} \qquad (12)$$

Where $[I]$ is identity matrix. Then, the sending currents are estimated based on the variables of receiving node as given in (13).

$$\begin{aligned} I_{Sa} &= I_{La}+\frac{Y_{aa}}{2}V_{Sa}+\frac{Y_{ab}}{2}(V_{Sa}-V_{Sb})+\frac{Y_{ac}}{2}(V_{Sa}-V_{Sc}) \\ &= I_{La}+\left(\frac{Y_{aa}}{2}+\frac{Y_{ab}}{2}+\frac{Y_{ac}}{2}\right)V_{Sa}-\frac{Y_{ab}}{2}V_{Sb}-\frac{Y_{ac}}{2}V_{Sc} \end{aligned} \qquad (13)$$

Likewise, the currents in the sending node given as a function on the phase currents and voltages at the receiving node, for other phases are presented in (14).

$$I_{Si}=I_{Li}+\left(\sum_{j=1}^{n}\frac{Y_{ij}}{2}\right)V_{Si}-\left(\sum_{j=1,j\neq i}^{n}\frac{Y_{ij}}{2}\right)V_{Sj} \qquad (14)$$

Then, sending currents are arranged in matrix form as is presented in (15).

$$\begin{aligned} [I_S] &= [Y][V_S]+[I_L] \\ &= [Y]\big(([Z][Y]+[I])[V_R]+[Z][I_R]\big)+[Y][V_R]+[I_R] \\ \Rightarrow [I_S] &= \begin{bmatrix}[Y](2[I]+[Z][Y]) & [Y][Z]+[I]\end{bmatrix}\begin{bmatrix}[V_R] \\ [I_R]\end{bmatrix} \end{aligned} \qquad (15)$$

$[V_S]$ and $[I_S]$ are integrated as shown in (16).

$$\begin{bmatrix}[V_S] \\ [I_S]\end{bmatrix}=\begin{bmatrix}[Z][Y]+[I] & [Z] \\ [Y](2[I]+[Z][Y]) & [Y][Z]+[I]\end{bmatrix}\begin{bmatrix}[V_R] \\ [I_R]\end{bmatrix} \qquad (16)$$

In summary, equation (16) presents the matrix of transmission parameters *A*, *B*, *C* and *D*, as in (17).

$$\begin{aligned} A &= [Z][Y]+[I] & B &= [Z] \\ C &= [Y](2[I]+[Z][Y]) & D &= [Y][Z]+[I] \end{aligned} \qquad (17)$$

Equation (16) is a generalized expression that involves voltages and currents at the sending and the receiving nodes, where the transmission matrix elements shown in (17) are similar to these elements presented in (4).

According to equations form (6) to (17), it is possible to develop a general procedure aimed to consider power lines with neutral wire and ground effect (Carson's correction). In this case the resulting matrices *A*, *B*, *C* and *D* in (17) have a *n*×*n* dimension and therefore it may be necessary to reduce the dimensions of this matrix as presented in [17], to obtain square matrices of 3×3 (Kron reduction technique).

B. *Series elements modeling*

One of the most important advantages by using the here proposed forward sweep method in a radial circuit, is associated to the consideration of these elements connected in series to the line. This is the case of capacitors, reactors, reclosers, active power compensators, among others, which are represented as is shown in Fig. 5.

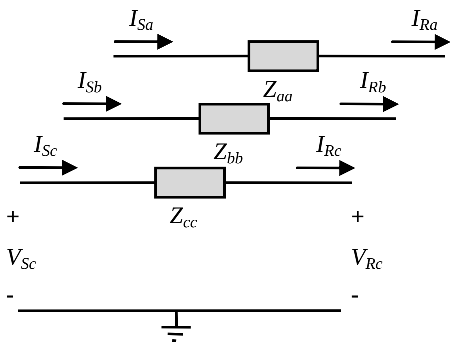

Fig. 5. Diagram of elements connected in series at the power distribution line.

Considering the mentioned above, the series elements are located along the system lines and can be formulated in a general form as given in (4), where matrix elements are presented in (18).

$$\begin{aligned} A &= [I] \quad B = [\Psi] \\ C &= [0] \quad D = [I] \end{aligned} \tag{18}$$

Matrix $[\Psi]$ contains the model that represents the impedance of each element, such as capacitors, inductors or other device connected to the network.

C. *Shunt elements modeling*

The model of shunt connected elements is similar to these presented for elements in series; the difference is that these shunt elements are exposed to the phase potential, which is supposed equal for both the sending and received nodes as is presented in Fig.6.

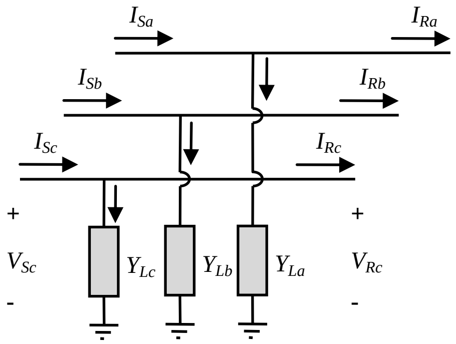

Fig. 6. Diagram of a load shunt connected to the power distribution feeder.

Equation (19) presents the variation at the system current, when shunt elements are connected to radial network.

$$\begin{aligned} A &= [I] \quad B = [0] \\ C &= [Y_L] \quad D = [I] \end{aligned} \tag{19}$$

1) *Spot loads*

Power distribution systems supply energy to a different load types as like single-, two- and three-phase connected loads. According to the connection between the lines and the reference, it changes the value of the load admittance, implying the variation of the C parameter of the transmission matrix as presented in (19).

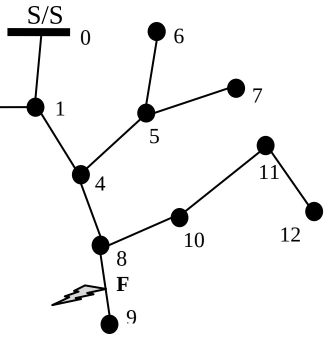

Fig. 7. Faulted power distribution system.

2) *Lumped radial loads*

To find the voltage and current at the faulted node of the power system presented in Fig.7, the value of the admittance of all equivalent laterals seen by the analyzed feeder have to be determined [18].

In case of a fault located at the line section between the nodes 8 and 9 from Fig.7, is necessary to know the equivalent admittance of the radial composed by the nodes (0-1-4-8-9), then, the admittance observed by the radial in nodes 1, 4 and 8 have to be estimated.

In [19] authors propose (20), which is used to obtain the equivalent admittance of a lateral at the node n, considering the parameters of this line.

$$C = \left[Y_n^{eq}\right] = [Y_n] + ([Z_n] + [Y_{n+1}]^{-1})^{-1} \tag{20}$$

Where Y_n^{eq} is the equivalent admittance of loads and lines sections at node n, Y_n is the admittance matrix of the other line sections located in the node n, Z_n is the impedances matrix of the line between the nodes n and $n+1$, and Y_n+1 is the equivalent admittance matrix at the node $n+1$.

For any node n in which contains equivalent laterals and tapped loads, the matrix C is given by (21).

$$C = [Y_{Ln}] + \left[Y_n^{eq}\right] \tag{21}$$

Where Y_{Ln} is the load admittance.

A similar technique is proposed in [6], to define the current that flows into the circuit downstream to the faulted node.

D. *Distribution power transformers modeling*

Transformers are elements connected in series with the lines of the distribution feeders. The inclusion of this elements cause variations in voltage and current levels. For that reason, the applied considerations are different to these presented until now to the previously considered elements. Authors in references [20, 21] introduce a generalized model in admittance matrices form, for different transformer connections which is presented in (22).

$$\begin{bmatrix} [I_{Sabc}] \\ [I_{Rabc}] \end{bmatrix} = \begin{bmatrix} Y_{pp} & Y_{ps} \\ Y_{sp} & Y_{ss} \end{bmatrix} \cdot \begin{bmatrix} [V_{Sabc}] \\ [V_{Rabc}] \end{bmatrix} \tag{22}$$

Where $[Y_{trafo}] = [Y_{pp}\ Y_{ps};\ Y_{sp}\ Y_{ss}]$ can be turned to a transmission matrix that relates the same elements, as shown in (23). The subscripts p and s indicate primary and secondary windings respectively.

$$\begin{aligned} A &= -\left[Y_{sp}\right]^{-1}[Y_{ss}] & B &= \left[Y_{sp}\right]^{-1} \\ C &= \left[Y_{ps}\right] - \left[Y_{pp}\right]\left[Y_{sp}\right]^{-1}[Y_{ss}] & D &= \left[Y_{pp}\right]\left[Y_{sp}\right]^{-1} \end{aligned} \tag{23}$$

Likewise that the models presented in earlier sections, at three-phase systems, the submatrices *A*, *B*, *C* and *D* has 3×3 dimension. Moreover, equations from (24) to(26) shows the YI, YII and YIII matrix, which generalize the most common connections for three-phase transformers as shown in Table I.

$$\mathrm{YI} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot \mathrm{y_t} \tag{24}$$

$$\mathrm{YII} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \cdot \mathrm{y_t} \tag{25}$$

$$\mathrm{YIII} = \frac{1}{\sqrt{3}}\begin{bmatrix} -1 & 1 & 0 \\ 0 & -1 & 1 \\ 1 & 0 & -1 \end{bmatrix} \cdot \mathrm{y_t} \tag{26}$$

Where $\mathrm{y_t}$ is the dispersion admittance of the power transformer in per unit.

TABLE I
CONNECTION SUBMATRICES FOR VOLTAGE REDUCER TRANSFORMERS

Connection		Self-Admittance		Mutual Admittance	
Primary	Secondary	Y_{pp}	Y_{ss}	Y_{ps}	Y_{sp}
Yg	Yg	YI	YI	-YI	-YI
Yg	Y	YII	YII	-YII	-YII
Yg	Δ	YI	YII	YIII	YIII^{T}
Y	Yg	YII	YII	-YII	-YII
Y	Y	YII	YII	-YII	-YII
Y	Δ	YII	YII	YIII	YIII^{T}
Δ	Yg	YII	YI	YIII	YIII^{T}
Δ	Y	YII	YII	YIII	YIII^{T}
Δ	Δ	YII	YII	-YII	-YII

Finally, in [20] the authors describe the admittance matrix for any connection of transformer banks, considering taps on both sides.

IV. PROPOSED FORWARD SWEEP-BASED METHOD

In most of the power distribution systems, the voltages and currents are measured at the substation, and then it is necessary to obtain an expression to determine these values at the faulted line section.

Applying the expressions (17)-(19) and (23), all power distribution system elements are modeled as a matrix to relate voltages and currents at the input and output of one power system part, as is presented in (27).

$$\begin{bmatrix} [V_{Ri}] \\ [I_{Ri}] \end{bmatrix} = \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix}^{-1} \cdot \begin{bmatrix} [V_{Si}] \\ [I_{Si}] \end{bmatrix}, \forall\, i = 1,2,\dots,n \tag{27}$$

Constants *A*, *B*, *C* and *D*, are estimated from the system parameters for each section or element *i*. Considering that is possible to know the parameters of the electric power system, such as line impedance and susceptance matrixes, it is possible to obtain the voltage and current of any line end just knowing these values on the other line end. This is useful because there is not necessary to execute a three-phase power flow when a fault happens, besides carry out a power flow without the complete knowledge of the value and location of the fault impedance in the system would be worthless.

Additionally, considering that all of the elements in distribution systems are connected in cascade, it is possible to obtain the voltage and current values for any node of the radial power system using (28).

$$\begin{bmatrix} [V_{Rn}] \\ [I_{Rn}] \end{bmatrix} = \left(\prod_{i=1}^{n} \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \right)^{-1} \cdot \begin{bmatrix} [V_{S/E}] \\ [I_{S/E}] \end{bmatrix} \tag{28}$$

V. SIMULATION RESULTS AND ANALYSIS

In this section, several tests are performed, to show the good results obtained by the application of the proposed forward sweep-based method.

A. Test system

The 24,9 kV IEEE 34-bus test feeder presented in Fig. 8 is used to analyze the proposed approach. The test system contains a three-phase main feeder, single-phase laterals, multiple conductor gauges, single and three-phase tapped loads [22].

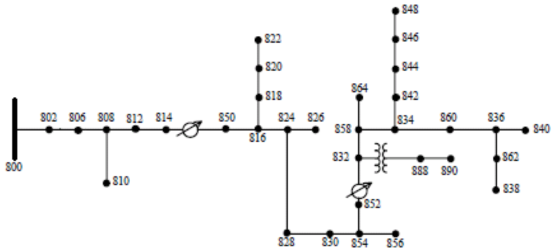

Fig. 8. IEEE 34-bus test feeder.

Fault distance estimation error is determined by using (29).

$$\%Error = \frac{actual\ location - estimated\ location}{length\ of\ distribution\ feeder} * 100\% \tag{29}$$

The test system in [22] presents different load models such as constant impedance, current and power. For testing purposes, the proposed forward sweep-based method, considers the load modeling as constant impedance, as originally modeled at the software EMTP/ATP, which is selected as the simulation software in this paper.

B. Comparison of magnitudes and phase angles

To validate the proposed forward sweep-based method, which helps to obtain the voltage and current per phase at any node of the power system when a fault occurs, a single phase to ground fault (*a-g*) is simulated in several nodes along the main radial of the test system. Tables II and III present a comparison between simulated and calculated values of voltage and current, respectively, for faulted nodes 802, 850, 828 and 858, considering a fault resistance of 10 Ω.

TABLE II
COMPARISON OF PERFORMANCE RESULTS FOR NODAL VOLTAGE BETWEEN SIMULATED AND CALCULATED VALUES

Node		Phase a		Phase b		Phase c	
		|V| [kV]	θV [º]	|V| [kV]	θV [º]	|V| [kV]	θV [º]
802	Sim.	5.7619	-88.183	14.1715	-153.294	14.0518	88.167
	Calc.	5.7619	-88.170	14.1711	-153.294	14.0518	88.166
850	Sim.	2.3282	-79.535	15.3566	-159.769	14.1103	96.209
	Calc.	2.3256	-78.482	15.2604	-159.853	14.0619	96.096
828	Sim.	2.1429	-78.386	15.3195	-159.809	14.0011	96.574
	Calc.	2.3648	-71.520	15.2262	-159.579	13.9178	96.139
858	Sim.	1.4842	-74.152	14.9793	-159.710	13.4044	97.799
	Calc.	1.4740	-69.905	14.7723	-159.801	13.2845	97.543

TABLE III
COMPARISON OF PERFORMANCE RESULTS FOR SENDING CURRENT BETWEEN SIMULATED AND CALCULATED VALUES

Node		Phase a		Phase b		Phase c	
		|I| [A]	θI [º]	|I| [A]	θI [º]	|I| [A]	θI [º]
802	Sim.	591.170	-88.666	28.8831	-177.300	26.4028	56.562
	Calc.	591.170	-88.666	28.8833	-177.300	26.4025	56.563
850	Sim.	242.886	-80.033	29.4816	175.978	24.7570	59.883
	Calc.	242.889	-80.032	31.6663	176.414	26.6733	59.831
828	Sim.	222.345	-78.728	26.2921	175.458	24.3448	59.970
	Calc.	216.493	-79.270	28.7681	175.410	26.3138	60.024
858	Sim.	155.106	-74.692	26.0445	172.788	22.8112	59.008
	Calc.	155.938	-74.917	29.4898	174.134	26.4353	59.609

As noticed from tables, the differences between the measured values and those calculated by the proposed methodology are very small. This shows that just knowing all of parameters of the power system, and having the measurements at the substation, it is possible to have a good estimation of the state in any node of the power system.

C. Fault performance test

Additionally, several tests of the fault locator were performed using the method proposed in [11] for single phase, phase to phase and three phase faults. The tests are performed first considering the original method, and then considering a modified version which includes the proposed methodology used to update voltages and currents at each line section.

Figs. 9-11 show the behavior of the fault location technique for single-phase, phase to phase and three phase faults, respectively. The pairs of figures consider the option with and without applying the proposed approach to obtain the voltages and currents at the beginning of the faulted section line.

For the three types of faults, the behavior of the fault location technique is improved due the application of the proposed approach used to estimate the currents and voltages at the faulted section.

VI. CONCLUSIONS

This paper presents a new forward sweep method to adequately estimate the voltages and currents at the faulted section, using values of series impedance and shunt admittance of the power distribution system and the substation phase measurements, also in the case of unbalanced feeders.

This method is useful for improving the performance of fault locators, because does not require information of what is connected downstream of the faulted section to perform and adequate right localization.

Finally, an appropriate location of the faulted node helps to improve the continuity indexes in power distribution systems, maintaining the electric power quality.

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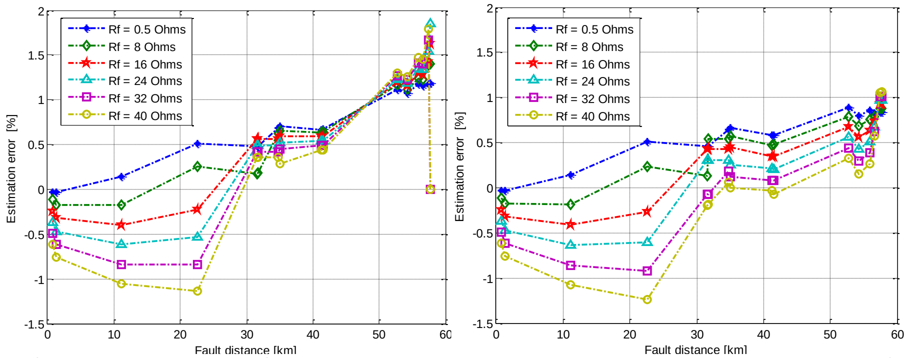

Fig. 9. Errors in fault-location for single-phase to ground faults considering the proposed approach (right) and avoiding this use (left).

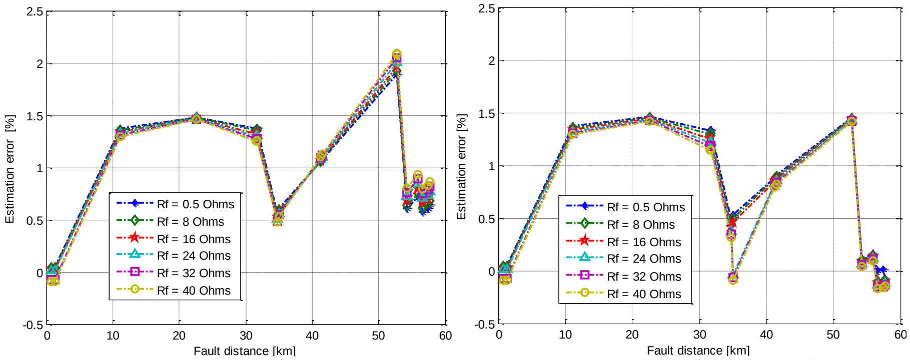

Fig. 10. Errors in fault-location for phase-phase faults considering the proposed approach (right) and avoiding this use (left).

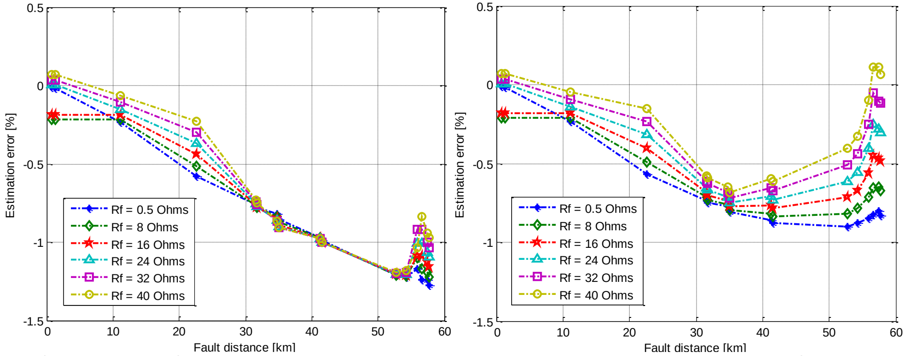

Fig. 11. Errors in fault-location for three-phase faults considering the proposed approach (right) and avoiding this use (left).

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