ATP-EMTP Investigation for Fault Location in Medium Voltage Networks

M. M. Saha, *Senior member, IEEE*, E. Rosolowski *Senior member, IEEE*, J. Izykowski *Senior member, IEEE*

Abstract-- This paper presents a new fault location (FL) method for medium voltage (MV) networks operating with the neutral solidly grounded or grounded across a small resistance. The FL algorithm is based on the impedance measurement principle and uses the recorded three-phase voltage and current signals as well as the network impedance for the particular symmetrical components – pre-calculated after each change in the network configuration and stored in the database. The phase voltages are measured at the supplying bus-bar, while the three-phase currents are considered as delivered from the faulted feeder. The currents can also be taken from the supplying transformer, if only one centralized-type digital fault recorder is installed at the substation.

Keywords: medium voltage network, steady-state and fault analysis, fault location, ATP-EMTP, simulation.

I. Introduction

FAULT location in distribution medium voltage (MV) networks has been a subject of interest to utility engineers and researchers [1-3]. Information on accurate fault location available just after the fault helps utility personnel to expedite service restoration and to make adequate reconfiguration of the network for reducing outage time and operating costs. Therefore, more efficient methods for fault location, supply restoration and high quality customer service, which reduce the overall costs, are highly required [4-5].

Fault location in distribution networks (DN) creates new problems comparing with the same task in HV and EHV transmission lines. In HV and EHV networks each transmission line may be equipped with the dedicated Fault Locator (FL). In such a case, the FL algorithm is a numerical procedure that converts voltage and current, given in a digital form, into a single number being a distance to fault. In contrary to the transmission lines, the distribution networks are usually non-homogeneous, with branches and loads along the line which make the fault location difficult [1, 3].

In DN networks, FLs are usually assumed to be of a centralized type, i.e., they measure the quantities common for the whole substation (busbar voltages and transformer currents) what makes the accurate fault location more difficult. Three fundamental factors contribute to this:

- if a current of a faulty line is not directly available to the FL, certain error is introduced when assuming the transformer current during a fault to be a current of the faulty line; moreover, it is not possible to compensate accurately for the pre-fault load current of the faulty line;
- MV lines may be multi-terminal and/or contain loops what creates well known problems for one–end fault location as, in general, there is no indication on a single fault position (few alternatives appear as possible);
- in the case of a MV line, there are often loads located between the fault point and the busbar; since the loads change and are unknown to the FL it is difficult to compensate for them;
- MV lines are mainly cable feeders what creates additional problems with adequate representation of the equivalent scheme, when comparing with overhead lines.

The paper describes the algorithm for calculation of the distance to fault (Sections II, III) as well as the EMTP simulations and analysis of the algorithm - Section IV.

II. The Proposed Algorithm

The presented method overcomes the above mentioned difficulties by utilizing the following two-step procedure for fault location in distribution networks (Fig.1).

- First, the equivalent positive- ($\underline{Z}^f_{1k}$) and zero-sequence ($\underline{Z}^f_{0k}$) impedance of the network is computed in pre-fault steady-state for all $k = 1,..,M$ nodes of the network based on existing topology, loads and feeder parameters. These values represent positive- and zero-sequence impedance as seen from the substation up to a given k node of the

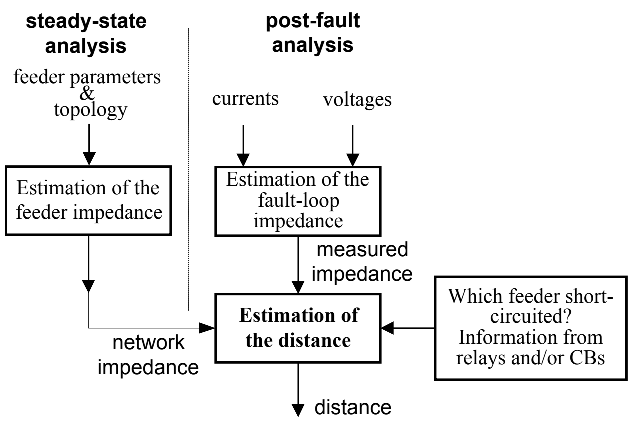

Fig. 1. Basic block diagram of the proposed fault location algorithm.

M. M. Saha is with ABB Automation Technologies Västerås, Sweden, (e-mail: murari.saha@se.abb.com).
E. Rosolowski is with Wroclaw University of Technology Wroclaw, Poland, (e-mail: rose@pwr.wroc.pl).
J. Izykowski is with Wroclaw University of Technology Wroclaw, Poland, (e-mail: jan.izykowski@pwr.wroc.pl).

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network.

- Then after the fault the specific fault-loop parameters are calculated depending on the fault type (phase-to-phase or phase-to-ground) and the place of measurements (at the supplying transformer or at the faulty feeder).

The fault place is determined as a result of checking the following set of conditions for consecutive nodes of the network:

$$\mathrm{Im}(\underline{Z}_{ek}) \geq 0\,,\ k = 1,2,..M \tag{1}$$

where:

$$\underline{Z}_{ek} = \begin{cases} \underline{Z}^{f}_{1k} - \underline{Z}_{1f} & -\text{for ph - to - ph fault} \\ \underline{Z}^{f}_{1k} + \underline{k}_{I}\,\underline{Z}^{f}_{0k} - \underline{Z}_{1N} & -\text{for ph - to - grnd fault} \end{cases} \tag{2}$$

$$\underline{k}_{I} = \frac{\underline{I}_{pN}}{3\underline{I}_{p} - \underline{I}_{pN}}\,, \qquad \underline{Z}_{1N} = \frac{3\underline{V}_{ph}}{3\underline{I}_{p} - \underline{I}_{pN}} \tag{3}$$

and: $\underline{V}_{ph}$ - voltage at the faulty phase, $\underline{Z}_{1f}$ - positive-sequence fault-loop impedance obtained from measurements, $\underline{I}_{p}$, $\underline{I}_{pN}$ - adequately: fault-loop and residual currents obtained from measurements.

The final distance to fault will be chosen when the condition as in (1) is fulfilled. The method of calculation of the parameters ($\underline{Z}_{1f}, \underline{I}_{p}, \underline{I}_{pN}$) depends on the place of measurement (at the substation or at the feeder).

A. Measurements at the faulty feeder

As far as only one-end supplied radial networks are considered, the positive sequence fault-loop impedance is calculated according to well known equations depending on the type of fault (Fig.2).

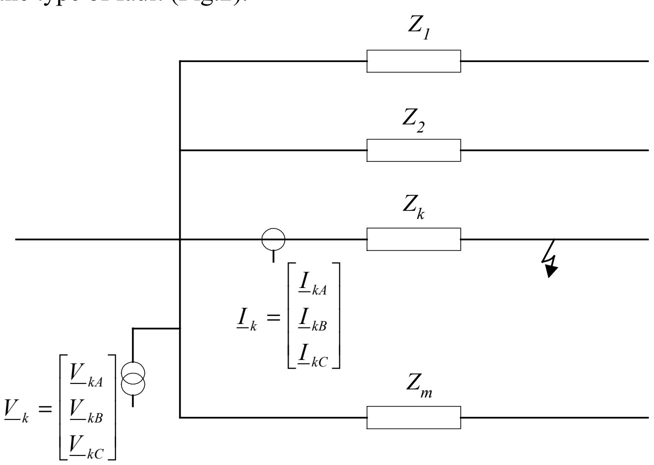

Fig. 2. Diagram of the network: measurements are taken in the faulty feeder.

- Phase-to-phase fault loop (phase-to-phase, phase-to-phase-to-ground or three phase fault):

$$\underline{Z}_{k} = \frac{\underline{V}_{pp}}{\underline{I}_{kpp}} \tag{4}$$

where:

$\underline{V}_{pp}$ - phase-to-phase fault loop voltage, for example: $\underline{V}_{pp} = \underline{V}_{A} - \underline{V}_{B}$,

$\underline{I}_{kpp}$ - phase-to-phase fault loop current, for example: $\underline{I}_{kpp} = \underline{I}_{kA} - \underline{I}_{kB}$.

- Phase-to-ground fault loop (a phase-to-ground fault):

$$\underline{Z}_{k} = \frac{\underline{V}_{ph}}{\underline{I}_{kph} + \underline{k}_{kN}\,\underline{I}_{kN}} \tag{5}$$

where:

$\underline{V}_{ph}$, $\underline{I}_{kph}$ - voltage and current from a faulty phase,

$$\underline{k}_{kN} = \frac{\underline{Z}'_{0} - \underline{Z}'_{1}}{3\underline{Z}'_{1}} \tag{6}$$

$\underline{Z}'_{0}, \underline{Z}'_{1}$ - zero and positive sequence impedance per length of the faulted feeder,

$$\underline{I}_{kN} = \underline{I}_{kA} + \underline{I}_{kB} + \underline{I}_{kC} \tag{7}$$

B. Measurements at the substation level

In this case we assume that the faulty line is identified. Moreover, some of the described below pre-fault parameters of the network are also known or can be estimated from the SCADA information.

Let a faulty feeder (say feeder *k*) from the considered radial network has the pre-fault equivalent impedance $\underline{Z}_{Lk}$ (Fig. 3). The remaining parallel-connected feeders are represented with the equivalent branch of the impedance $\underline{Z}_{L}$ (i.e. $1/\underline{Z}_{L} = 1/\underline{Z}_{1} + 1/\underline{Z}_{2} + ... + 1/\underline{Z}_{m}$). Both $\underline{Z}_{Lk}$ and $\underline{Z}_{L}$ are assumed to be the positive sequence impedance.

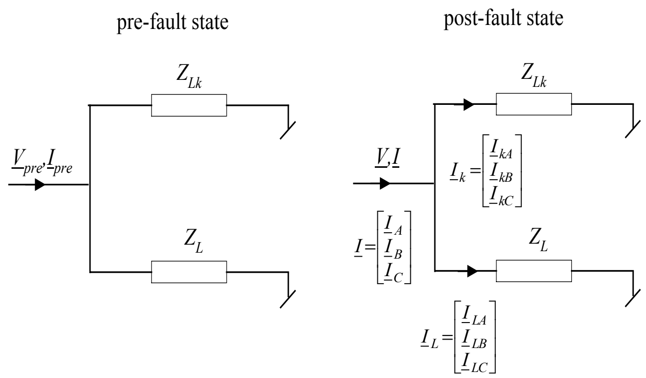

Fig. 3. Equivalent circuits of the distribution network.

The aim of the analysis is to determine the post-fault positive sequence impedance $\underline{Z}_{k}$ under assumption that the equivalent impedance $\underline{Z}_{L}$ remains unchanged during a fault. The following equation is valid for the pre-fault state (Fig. 3):

$$\underline{Z}_{pre} = \frac{\underline{V}_{pre}}{\underline{I}_{pre}} = \frac{\underline{Z}_{L}\,\underline{Z}_{Lk}}{\underline{Z}_{L} + \underline{Z}_{Lk}} \tag{8}$$

where: $\underline{V}_{pre}, \underline{I}_{pre}$ - are phase-to-phase or phase-to-ground (for symmetrical condition) variables.

Two post-fault cases should be considered:

- Phase-to-phase fault loop (phase-to-phase, phase-to-phase-to-ground or three phase fault).

The positive sequence impedance seen from the substation is obtained from the equation:

$$\underline{Z} = \frac{\underline{V}_{pp}}{\underline{I}_{pp}} = \frac{\underline{Z}_L \underline{Z}_k}{\underline{Z}_L + \underline{Z}_k} \tag{9}$$

where:

$\underline{V}_{pp}$ - phase-to-phase fault loop voltage, for example: $\underline{V}_{pp} = \underline{V}_A - \underline{V}_B$,

$\underline{I}_{pp}$ - phase-to-phase fault loop current taken at the substation, for example: $\underline{I}_{pp} = \underline{I}_A - \underline{I}_B$,

Combining (8) and (9) yields:

$$\underline{Z}_k = \frac{\underline{Z}\,\underline{Z}_{pre}}{\underline{Z}_{pre} - \underline{Z}(1-\underline{k}_{zk})} \tag{10}$$

where:

$$\underline{k}_{zk} = \frac{\underline{Z}_{pre}}{\underline{Z}_{Lk}} = \frac{\underline{S}_{Lk}}{\underline{S}_{\Sigma}} \tag{11}$$

$\underline{S}_{Lk}$ - power in the faulty line in the pre-fault conditions,

$\underline{S}_{\Sigma}$ - power in all the lines in the pre-fault conditions.

Combining (8) and (11) one also obtains

$$\underline{k}_{zk} = \frac{\underline{Z}_L}{\underline{Z}_L + \underline{Z}_{Lk}} \tag{12}$$

The coefficient $\underline{k}_{zk}$ for each line is estimated on the basis of the pre-fault steady-state conditions. In a substation with a large number of feeders these coefficients are close to zero and change only a little, e.g. for two identical lines: $\underline{k}_{zk} = 0.5$ (if only line reactance is taking into account) while for twenty lines: $\underline{k}_{zk} = 0.05$. One should observe that, in general, $\underline{k}_{zk}$ is a complex number.

From equation (10) one can calculate the fault loop impedance using the measurements from the substation. Dividing numerator and denominator of (10) by $\underline{Z}_{pre}$ and substituting (9) for $\underline{Z}$, equation (10) can be rewritten in a more convenient form:

$$\underline{Z}_k = \frac{\underline{V}_{pp}}{\underline{I}_{pp} - (1-\underline{k}_{zk})\dfrac{\underline{V}_{pp}}{\underline{Z}_{pre}}} \tag{13}$$

- Phase-to-ground fault loop (phase-to-ground fault).

In the case of a phase-to-ground fault, the positive sequence fault loop impedance is calculated according to the second equation in (2). One can observe that as only a single phase-to-ground fault is considered (say, in feeder k) the zero sequence current measured in the substation contains the faulty feeder current $\underline{I}_{kN}$ and the zero-sequence current flows through capacitances of the healthy feeders $\underline{I}_{CL}$. Knowing voltage and current measurements at the substation and network parameters the fault loop impedance can be established in the similar way as for measurements from the feeder [6, 7].

Summarizing the above derivations we can represent currents I_p, I_{pN} in (3) as follows:

for measurements in the feeder:

$$\underline{I}_p = \underline{I}_{ph}, \tag{14a}$$

$$\underline{I}_{pN} = \underline{I}_N = \underline{I}_A + \underline{I}_B + \underline{I}_C \tag{14b}$$

for measurements at the substation:

$$\underline{I}_p = \underline{I}_{ph} - (1-\underline{k}_z)\frac{\underline{V}_{ph} - \underline{V}_0}{\underline{Z}_{pre}} \tag{15a}$$

$$\underline{I}_{pN} = \underline{I}_N - \frac{(1-k_{zk0})\underline{V}_0}{-jX_{C0}} \tag{15b}$$

where:

$k_{zk0} = \dfrac{X_{C0}}{X_{C0k}} = \dfrac{C_{0k}}{C_{C0}}$

C_{0k} - zero-sequence capacitance of the faulty feeder,

C_{C0} - zero-sequence capacitance of all MV network,

$\underline{k}_{zk}$ as in (11),

$\underline{Z}_{pre} = \dfrac{\underline{V}_{pre}}{\underline{I}_{pre}}$ - pre-fault positive-sequence impedance at the supplying transformer,

index *ph* stands for the faulty phase.

Moreover, the positive sequence fault loop impedance $\underline{Z}_{1f}$ seen from the substation can be obtained from division of adequate voltage drop by difference of currents:

$$\underline{Z}_{1f} = \frac{\underline{V}_{pp}}{\underline{I}_{pp}} \tag{16}$$

where: $\underline{V}_{pp}$ - phase-phase voltage, $\underline{I}_{pp}$ - phase-phase current, e.g. for *A-B* fault: $\underline{V}_{pp} = \underline{V}_A - \underline{V}_B$, $\underline{I}_{pp} = \underline{I}_A - \underline{I}_B$.

Having the network impedance $\underline{Z}_{1k}^f$ and $\underline{Z}_{0k}^f$ for steady-state condition, and fault loop parameters: $\underline{Z}_{1f}$, $\underline{k}_I$, $\underline{Z}_{1N}$ given from measurements according to (2, 3) with respect to (4-6) it is possible o utilize the criterion (1) for distance to fault calculation.

III. Distance to Fault Estimation

Distance to fault can be determined on the basis of criterion (1). In the searching algorithm two impedances: first one calculated for steady state while the second - obtained from measurements should be compared against matching the criterion. Two different algorithms are used depending of the fault loop type: phase-to-phase or phase-to-ground fault loops.

A. Phase-to-phase fault

In this case the measured impedance in (2) is represented by the positive-sequence impedance $\underline{Z}_{1f}$ which is compared with the impedance $\underline{Z}_{1k}^{f}$ for successive $k = 1,..,M$ network nodes. Let us consider the phase-to-phase fault at node *k* of the network as in Fig. 4. It is assumed that the impedance $\underline{Z}_{1k}^{f}$ (positive-sequence network impedance as seen from the substation under assumption that the fault with no resistance occurs at the node *k*) is known from steady-state calculations and $\underline{Z}_{1f}$ is obtained from measurements according to (6).

For further analysis the fault loop seen from the substation is represented with the equivalent scheme as in Fig. 6. The following condition is fulfilled for this scheme:

$$\underline{Z}_{1k}^{f} = (1-m)\underline{Z}_{1k}^{f1} + \frac{m\underline{Z}_{1k}^{f1}\underline{Z}_{1k}^{f2}}{m\underline{Z}_{1k}^{f1} + \underline{Z}_{1k}^{f2}} \tag{17}$$

The separate impedance in (7) can be easily determined from the known impedance $\underline{Z}_{1k}^{f}$ by choosing the parameter *m* ($0 < m \le 1$).

Representation of the impedance $\underline{Z}_{1k}^{f}$ in a form as in Fig. 5 gives possibility to include the fault resistance into considered fault loop what is depicted in Fig. 5a. The residual impedance $\Delta\underline{Z}_{f}$ represents the equivalent impedance involved in the fault loop due to the fault resistance R_f, if the fault occurs at node *k* or behind them. The equivalent scheme for representing the impedance $\Delta\underline{Z}_{f}$ is shown in Fig. 5b. Here:

$\underline{Z}_{1k}$ - equivalent shunt impedance at node *k*,

$\underline{Z}_{L}$ - impedance of the cable section between nodes *k*, *k*+1,

$\underline{Z}_{1(k+1)}^{u}$ - equivalent impedance of the network seen from the node *k*+1 up to the end of the feeder.

The impedance $\underline{Z}_{1(k+1)}^{u}$ should be also calculated for steady-state conditions for all network nodes and stored in the database.

The distance to fault d_f, m is determined as a sum of a distance d [m] from substation up to node *k* (Fig. 5b) and a distance xl_k, m inside a given section:

$$d_f = d + xl_k \tag{18}$$

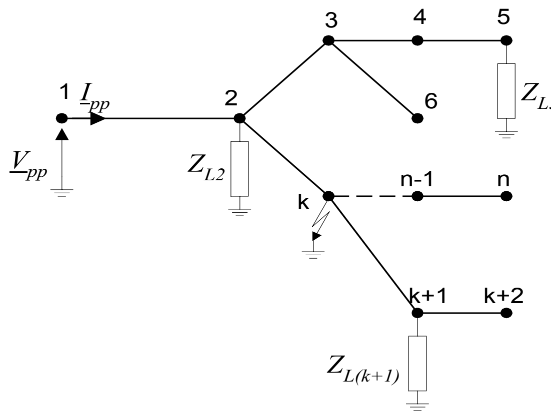

Fig.4. Scheme of the network for phase-to-phase fault at node *k*.

where l_k is a length of the section.

The algorithm for the distance x calculation is derived as follows:

1. The fault-loop impedance $\underline{Z}_{1f}$ measured at the substation meets the following relation (Fig. 5a):

$$\underline{Z}_{1f} = (1-m)\underline{Z}_{1k}^{f1} + \frac{\left(m\underline{Z}_{1k}^{f1} + \Delta\underline{Z}_{f}\right)\underline{Z}_{1k}^{f2}}{m\underline{Z}_{1k}^{f1} + \Delta\underline{Z}_{f} + \underline{Z}_{1k}^{f2}} \tag{19}$$

2. After rearranging (19) the value for residuum impedance can be obtained as:

$$\Delta\underline{Z}_{f} = \frac{\left(\underline{Z}_{1k}^{f1} - \underline{Z}_{1f}\right)\left(m\underline{Z}_{1k}^{f1} + \underline{Z}_{1k}^{f2}\right) - \left(m\underline{Z}_{1k}^{f1}\right)^2}{m\underline{Z}_{1k}^{f1} - \underline{Z}_{1k}^{f2} - \left(\underline{Z}_{1k}^{f1} - \underline{Z}_{1f}\right)} \tag{20}$$

3. The impedance $\Delta\underline{Z}_{f}$ represents the scheme seen from the node *k* up to the fault place (Fig. 5b) what can be determined as:

$$\Delta\underline{Z}_{f} = \frac{\underline{Z}_{1k}\left(x\underline{Z}_{L} + \dfrac{R_f\left((1-x)\underline{Z}_{L} + \underline{Z}_{1(k+1)}^{u}\right)}{R_f + (1-x)\underline{Z}_{L} + \underline{Z}_{1(k+1)}^{u}}\right)}{\underline{Z}_{1k} + x\underline{Z}_{L} + \dfrac{R_f\left((1-x)\underline{Z}_{L} + \underline{Z}_{1(k+1)}^{u}\right)}{R_f + (1-x)\underline{Z}_{L} + \underline{Z}_{1(k+1)}^{u}}} \tag{21}$$

4. Right-hand sides of (20) and (21) should be equal what leads to determination of the unknown fault resistance:

$$R_f = x^2 A - xB + C \tag{22}$$

where: $A = \dfrac{Z_L^2\left(Z_{1k} - \Delta Z_f\right)}{M}$, $B = \dfrac{Z_L\left(M + 2\Delta Z_f Z_{1k}\right)}{M}$,

$C = \dfrac{\Delta Z_f Z_{1k}\left(Z_L + Z_{1(k+1)}^{u}\right)}{M}$,

$M = \left(Z_{1k} - \Delta Z_f\right)\left(Z_L + Z_{1(k+1)}^{u}\right) - \Delta Z_f Z_{1k}$.

5. Distance to fault *x* can be obtained from (22) under condition that the fault resistance takes real value:

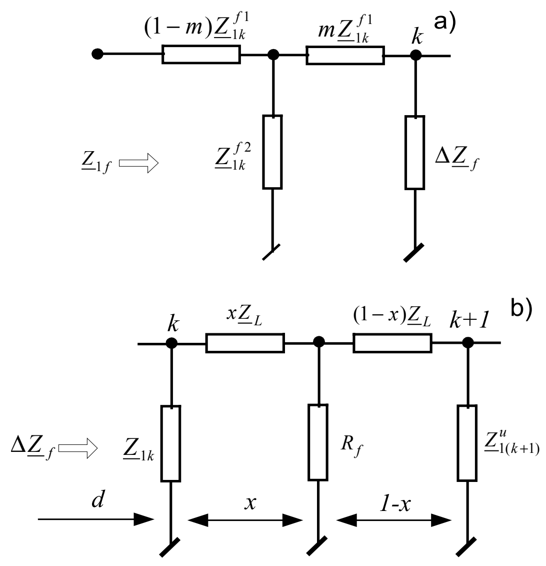

Fig. 5. Equivalent scheme of the fault loop: a - from the substation up to the fault point, b - beyond the fault point.

$$\mathrm{Im}(R_f) = x^2 A_i - x B_i + C_i = 0 \tag{23}$$

where: $A_i = \mathrm{Im}(A)$, $B_i = \mathrm{Im}(B)$, $C_i = \mathrm{Im}(C)$

After rearranging one obtains:

$$x_1 = \frac{B_i + \sqrt{p}}{2A_i}, \quad x_2 = \frac{B_i - \sqrt{p}}{2A_i} \tag{24}$$

where: $p = B_i^2 - 4A_iC_i$.

First root of (24) takes unrealistic value so, finally, a distance to fault is determined as $x = x_2$.

B. Phase-to-ground fault

For phase-to-ground faults the criterion for distance to fault estimation, defined by (1) with respect to the second equation in (2) is equivalent to the following condition (for simplicity the equality is considered):

$$\underline{Z}_{1k}^f = \underline{Z}_{1N} - \underline{k}_I \underline{Z}_{0k}^f \tag{25}$$

where: $\underline{k}_I$ and $\underline{Z}_{1N}$ are defined by (3).

The parameters $\underline{k}_I$ and $\underline{Z}_{1N}$ in (25) can be calculated from measurements whereas $\underline{Z}_{lk}^f$ and $\underline{Z}_{0k}^f$ are actual positive- and zero-sequence impedance of the assumed fault loop and are available from steady-state conditions.

Equivalent scheme of the fault loop circuit, which satisfies the condition (25) is similar to the phase-to-phase one (Fig. 6). Instead of $\underline{Z}_{1f}$ now the impedance combination $\underline{Z}_{1N} - \underline{k}_I \underline{Z}_{0k}^f$ is used. Bearing this in mind, the algorithm for a distance *x* [p.u.] to the fault at section *k*, *k*+1 can be derived by repeating points 1-5 from the previous section. Final relation is represented by (22), where:

$$A = \frac{Z_{eL}^2 \left(Z_{ek} - \Delta Z_f\right)}{M}, \quad B = \frac{Z_{eL}\left(M + 2\Delta Z_f Z_{ek}\right)}{M},$$

$$C = \frac{\Delta Z_f Z_{ek}\left(Z_L + Z^u_{\mathrm{e(k+1)}}\right)}{M},$$

$$M = \left(Z_{ek} - \Delta Z_f\right)\left(Z_{eL} + Z^u_{\mathrm{e(k+1)}}\right) - \Delta Z_f Z_{ek},$$

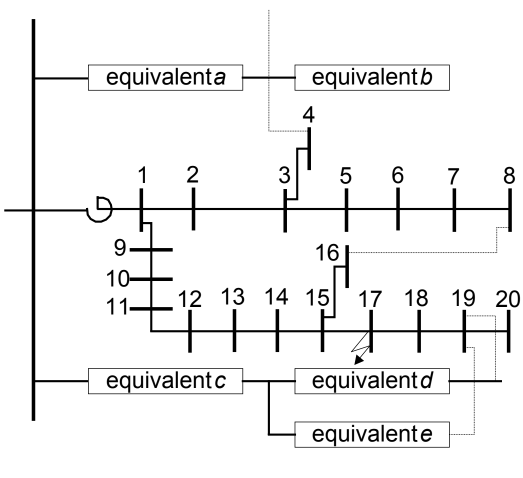

Fig. 7. Equivalent scheme of the analyzed network; dotted lines are for grounding system connection.

$$\underline{Z}_{eL} = \frac{2\underline{Z}_{1L} + \underline{Z}_{0L}}{3}, \quad \underline{Z}_{ek} = \frac{2\underline{Z}_{1k} + \underline{Z}_{0k}}{3}, \quad \underline{Z}_e^u = \frac{2\underline{Z}_{e1}^u + \underline{Z}_{e0}^u}{3}$$

Index e relates to the equivalent impedance of the scheme in Fig. 6b.

The distance to fault is also calculated according to (18).

IV. Simulation Results

The considered 10 kV substation is supplied from 150 kV system. The cable network is operated in a radial way. Measurements of current are available at the supplying transformer or at the feeders. Cable shield is considered as grounded only at the load points.

For a distance to fault calculation the each feeder should be represented by the detail scheme with adequate line and load models. In the cable networks grounding system has different structure than feeders have (open cables may have connected grounding circuits), what should be also represented in the model. This requires representing all feeders connected in a given substation in the general simulation model. However, for proper post-fault transient analysis some simplifications can be introduced: - supplying system is described by steady-state parameters; - analyzed feeder is represented in detail; - all other feeders are represented by equivalent schemes with reproducing only the grounding system connections.

Example of the analyzed network is presented in Fig. 7. Cable sections are represented by appropriate π-schemes, while loads and equivalent circuits are reflected by $R-L$ or $R-L-C$ scheme. EMTP/ATP model [8] of the analyzed network has been extensively used for investigation of the proposed fault location algorithm. The MV network consists of 16 feeders which, except of the particular analyzed feeder, are represented by their equivalent schemes. Let us consider

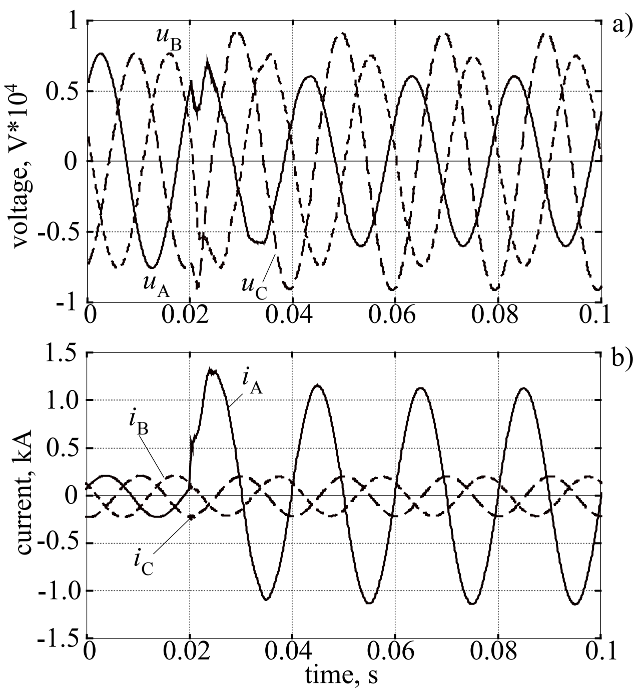

Fig. 8. Phase voltages (a) and currents (b) during A-G fault at node 17

an example of A-G (phase A to ground) fault at node 17 in the analyzed feeder (actual distance to fault - 8138 m., Fig. 7) with assuming the fault resistance $R_f = 0.1\,\Omega$. Phase voltages and currents observed at the substation during A-G and 3-phase faults are presented in Figs. 8 and 9, respectively.

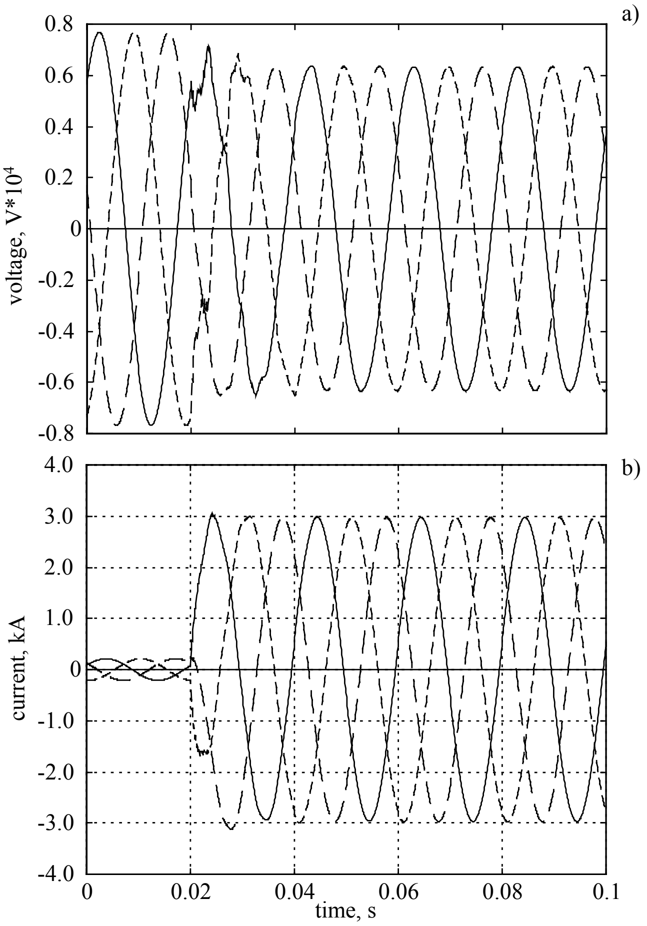

Fig. 9. Phase voltages (a) and currents (b) during 3-phase fault at node 17

Results of distance to fault estimation for 3-phase and phase-to-ground fault are gathered in Table 1. It can be seen that the algorithm gives quite good results.

TABLE I
RESULTS OF DISTANCE TO FAULT ESTIMATION

Type of fault	Fault resistance, Ω	Obtained result, m	Error, m
3-phase	0.1	8145	+7
	2.0	8135	-3
A-G	0.1	8131	-7
	2.0	8081	-57

V. CONCLUSIONS

The presented fault location algorithm for distribution networks is based on voltage and current phasor estimation. The algorithm was investigated and proved on the basis of voltage and current data obtained from versatile EMTP/ATP simulations.

The developed algorithm utilizes the current measurements delivered from the faulty feeder or from the substation. In the latter case the estimation error depends on accuracy of pre-fault condition determination in the MV substation. The distance to fault estimation error depends on the accuracy of measurements as well as cable parameters. Successful tests on fault data from EMTP/ATP detailed model suggest that the method can be viable.

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VII. BIOGRAPHIES

Murari Mohan Saha (M´76, SM´87) was born in 1947 in Bangladesh. He received B.Sc.E.E. from Bangladesh University of Engineering and Technology, Dhaka in 1968 and completed M.Sc.E.E. in 1970. In 1972 he completed M.S.E.E. and in 1975 he was awarded with Ph.D. from the Technical University of Warsaw, Poland. Currently he is a Senior Research and Development Engineer at ABB Automation Technologies, Västerås, Sweden. His areas of interest are power system simulation, and digital protective relays

Eugeniusz Rosolowski (M'97, SM'00) was born in Poland in 1947. He received M.Sc. degree in Electrical Eng. from the Wroclaw University of Technology (WUT) in 1972 and Ph.D. from Kiev Politechnical Institute in 1978. In 1993 he received D.Sc. from the WUT. Presently he is a Professor in the Institute of Electrical Engineering and Director of this Institute. His research interests are in power system analysis and microprocessor applications in power systems.

Jan Izykowski (M'1997, SM'04) was born in Poland in 1949. He received his M.Sc., Ph.D. and D.Sc. degrees from the Faculty of Electrical Engineering of Wroclaw University of Technology (WUT) in 1973, 1976 and in 2001, respectively. Presently he is an Associate Professor in Institute of Electrical Engineering of the WUT. His research interests are in power system simulation, protection and control, and fault location.