ANNALS OF FACULTY ENGINEERING HUNEDOARA
– International Journal of Engineering
Tome XI (Year 2013) – FASCICULE 4 (ISSN 1584 – 2673)

1. Dine MOHAMED, 2. Sayah RAFIK, 3 Sayah HOUARI

ACCURATE FAULT LOCATION ALGORITHM FOR SERIES COMPENSATED TRANSMISSION LINES WITH USE OF LIMITED MEASUREMENTS

1-3. DEPARTMENT OF ELECTRICAL ENGINEERING, UNIVERSITY OF DJILLALI LIABES 220 00, SIDI BEL ABBES, ALGERIA

ABSTRACT: This paper presents accurate fault location method for series-compensated transmission lines. The algorithm utilizes limited measurements at one-end from the bus, where the fault locator (FL) is installed with additional information on amplitude of load current from the remote section. Two subroutines designated for locating fault distance—one for fault behind the series capacitors and another one for fault in front of the series capacitors. Then a special procedure to select the correct solution is utilized. This algorithm requires estimation of three-phase voltage drops across capacitors bank. For this purpose a nonlinear differential equation is solved on-line using a novel, numerically efficient algorithm. The other interest of this algorithm is independent of fault resistance and does not require any knowledge of source impedance. The proposed approach was tested via digital simulation using MATLAB. Applied test results corroborate the superior performance of the proposed approach.
KEYWORDS: transmission line, series-compensation, MOV, fault location algorithm, MATLAB

INTRODUCTION

Rapid grow of power system grids during last years caused an increase in both the number of lines and their total length. Along with power energy consumption rise, a continuous and reliable energy supply is demanded. Transmission lines are essential parts of a power system for power energy delivery from generating plants to end customers. They are a part of the system where faults occur most likely. These faults result mostly from mechanical failures and have to be removed before re-energization of the line. Accurate fault location is highly required by operators and utility staffs to expedite service restoration, reduce outage time, operating costs and customer complains. Fault location is still the subject of rapid further developments. Research efforts are focused on developing efficient fault location algorithms intended for application to more and more complex networks [1]-[2]. Varieties of fault location algorithms have been developed so far. The majority of them are based on an impedance principle, making use of the fundamental frequency voltages and currents. Depending on the availability of the fault locator input signals, they can be categorized as the following:

- one-end algorithms [1-7];
- two-end algorithms [7–12].

One-end impedance-based fault location algorithms estimate a distance to fault with the use of voltages and currents acquired at a particular end of the line. Such a technique [8] is simple and does not require communication means with the remote end. Therefore, it is attractive and is commonly incorporated into the microprocessor-based protective relays. However, it is subject to several sources of error, such as the reactance effect, the line shunt capacitance, and the fault resistance value [1-7].

Two-end algorithms [8]–[12] process signals from both terminals of the line and thus larger amount of information [8]–[12] is utilized. Performance of the two-end algorithms is generally superior in comparison to the one-end approaches. Digital measurements at different line terminals can be performed synchronously if the global positioning system (GPS) [10] is available. Otherwise, or in case of loss of the signal from the GPS, the digital measurements from the line terminals are acquired asynchronously and, thus, do not have a common time reference. Two-end measurements allow simple and accurate fault location [9], [11-12].

The series capacitor (SC) is widely used in long transmission systems to improve power transfer capability. It also increases transient stability margins, optimizes load sharing between parallel transmission lines and reduces system losses. One of the main considerations in the design and application of series capacitors is their protection against overvoltage. In modern installations, the traditional gap type scheme, which bypasses the series capacitor to avoid overvoltage, is replaced by

© copyright FACULTY of ENGINEERING - HUNEDOARA, ROMANIA

Metal Oxide Varistor (MOV) protection. However, location of fault point and protection of systems with series compensated lines is considered as one of the most difficult tasks for relay manufacturers and utility engineers. The problem is not in the inclusion of capacitance in the series path but in the operation of the MOV in parallel with the capacitor. Series capacitors together with their MOVcreate a nonlinear and current dependent circuit. This nonlinear circuit must be taken into consideration in accurate fault location algorithm [9].

Recently some research efforts have been focused on fault location in series compensated lines. In particular, the impedance-based approach [1-3]-[11-12] is the mostly utilized one. In [2], the application of artificial neural networks (ANNs), combined with the impedance-based approach to fault location, has been presented. Use of artificial neural networks, combined with the discrete wavelet transform for fault location on thyristor-controlled series-compensated lines has been considered in [1]. In turn, in [7], different options for traveling-wave methods have been considered for locating faults on teed circuits with mutually coupled lines and series capacitors. The reference [9-10] deals with application of two-end synchronized measurements for fault location, which appears attractive, however requires the communication means and the GPS.

In this paper, we introduce a new and accurate fault location algorithm for series compensated transmission lines. The distance to fault is determined using two-end currents, while voltage from only one-end of the line. The over-voltage protection of the series capacitor (MOV) is taken into consideration and for algorithm development. The proposed fault location algorithm is composed from two subroutines. One of them is for faults behind the series capacitors and another one for faults in front of the series capacitors. When the fault is beyond the series compensation unit (SCU), voltage drop across the capacitor need to be calculated and deducted from the fault equation before estimating the fault location. With applying these subroutines, we will obtain two solutions for point of fault. Then a special procedure to select the correct solution is utilized.

FAULT LOCATION APPROACH - PRINCIPE

Fig. 1 presents schematically the considered two-end fault location on series compensated transmission line AB. It is considered that the fault locator (FL) is installed at the terminal A, and is supplied with three-phase currents and voltage available at the FL installation point (bus A). Additionally, the three-phase phasors of currents (I_B) measured at the remote bus B is provided via the communication channel.

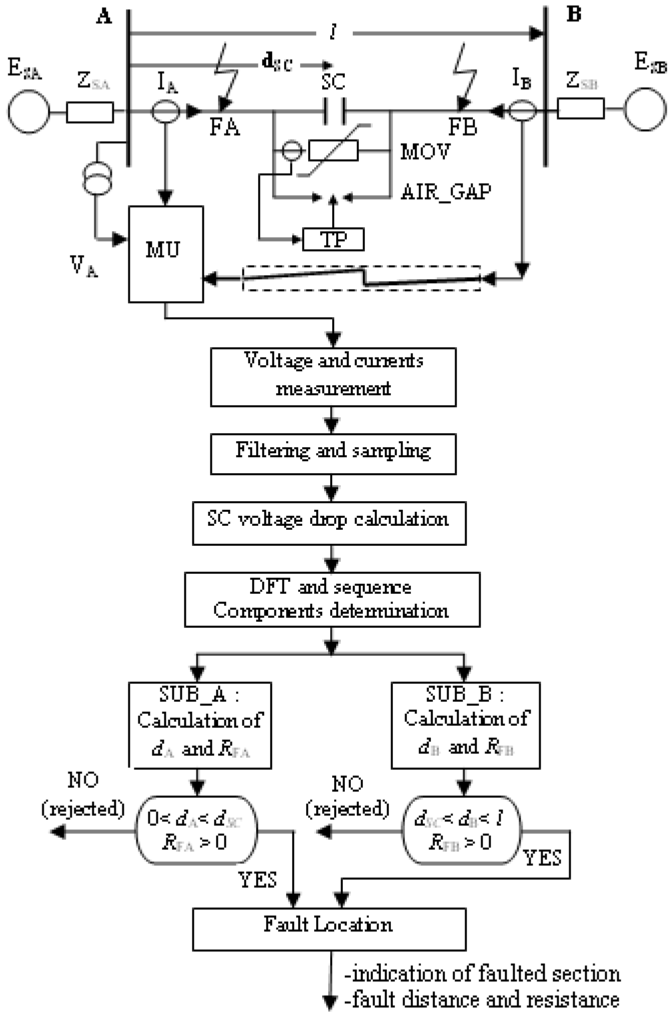

Figure 1. Schematic diagram for fault location in series-compensated line

The measured voltage and currents are extracted, filtred with analogue filters using the second order Butterworth model with cut-off frequency equal to 300Hz and sampled. Fault location was performed by estimating the phasors with the use of the DFT algorithm working with 20 samples per cycle. The fault location algorithm (Fig.1) makes use of the division of the transmission line into two sections: A- from terminal A to the SCU, B- from the SCU to terminal B, and for them the two subroutines: SUB_A, SUB_B, are applied. Each subroutine determines the distance to fault: dA, dB, and fault resistance: R_{FA}, R_{FB}, assuming that the fault has occurred within its line section. Then, the valid subroutine, which corresponds to the real fault case, is chosen with using the fault distance and fault resistance calculations.

ESTIMATION OF VOLTAGE DROP ACROSS SC AND MOV

Consider a parallel connection of the series capacitor, and the MOV shown in Fig. 2(a). The v-i characteristic of the MOV [Fig. 2(b)] is commonly approximated by the following exponential equation [1-2], [4]:

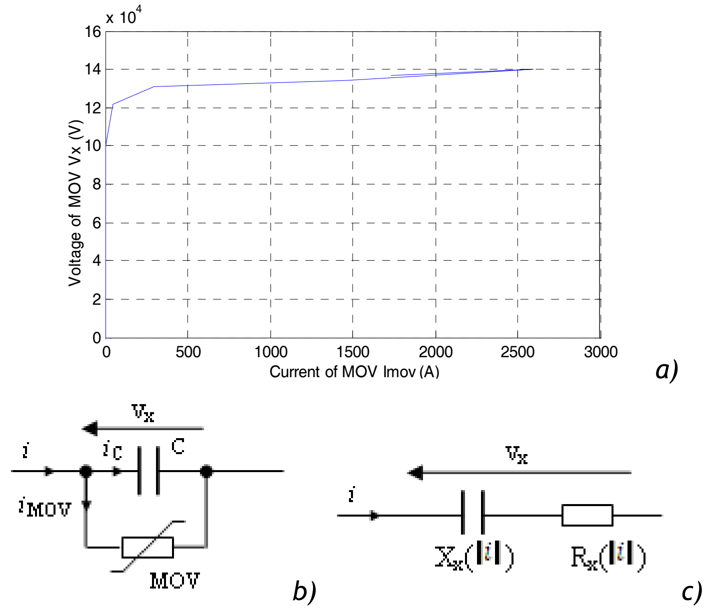

Figure 2.equivalent model of the compensating bank: a) voltage-current characteristic of MOV, b) original circuit, c) scheme of the fundamental frequency equivalent.

$$i_{MOV} = P\left(\frac{v_x}{V_{REF}}\right)^q \quad (1)$$

In the above relationship: i_{MOV} and v_x are MOV current and voltage, respectively;
P and V_{REF} are the reference quantities;
q is an exponent of the characteristic.

Assuming the analytical approximation of the MOV (1), the nonlinear circuit of Fig. 2(b) can be described by the following nonlinear differential equation:

$$C\frac{dv_x}{dt} + P\left(\frac{v_x}{V_{REF}}\right)^q - i = 0 \quad (2)$$

In this equation, all the parameters are known and constant; the current i entering the bank is measured (neglecting the shunt parameters of the line this is the current in the substation); while the voltage drop v_x is to be calculated.

To solve for v_x one needs to transform the continuous-time differential equation (2) into its algebraic discrete-time form. The 2nd order Gear differentiation rule is recommended for this purpose, i.e., the following substitutions apply:

$$i(t) \to i_{(n)},\ v_x(t) \to v_{x(n)} \quad (3a)$$

$$\frac{dv_x}{dt}(t) \to D\left(3v_{x(n)} - 4v_{x(n-1)} + 4v_{x(n-2)}\right) \quad (3b)$$

$$D = \frac{2\pi f}{2\sqrt{\left(1-\cos(a)\right)^4 + \left(2\sin(a) - \frac{1}{2}\sin(2a)\right)^2}} \quad (3c)$$

where: f is the system rated frequency,

$a = 2\pi f\ T_S$,

T_S is a sampling period, and n is a discrete time index.

Inserting (3) into (2) yields:

$$F(x) = A_q x^q + A_1 x - A_0 = 0 \quad (4)$$

In this algebraic equation:

$$x = \frac{v_{x(n)}}{V_{REF}} \quad (5a)$$

$$A_q = P,\ A_1 = 3DCV_{REF} \quad (5b)$$

$$A_0 = i_{(n)} + \frac{A_1}{3V_{REF}}\left(4v_{x(n-1)} - v_{x(n-2)}\right) \quad (5c)$$

Thus, x is a pu value of the sought voltage drop v_x at the present sampling instant n and equation (4) is to be solved for x .The two parameters of this equation, A_q and A_1 , are constants controlled by the parameters of the MOV and the capacitance of the capacitor. The third parameter, A_0, varies depending on the present sample of the current entering the bank and the two historical samples of the voltage drop.

In order to ensure good convergence of the algorithm, appropriately modified Newton method is used for solving (4).

The form (4) of the equation is numerically efficient for “small” values of A_0 while for “large” values of A_0, equation (4) should be re-written to:

$$F(y) = A_q y + A_1 y^{1/q} - A_0 = 0 \quad (6)$$

(where: $y = x^q$) and solved for y .

The border value of A_0 alternating the optimal forms (4) and (6) is:

$$A_0^* = A_q\left(\left(\frac{A_1}{qA_q}\right)^{1/(q-1)}\right)^q + A_1\left(\left(\frac{A_1}{qA_q}\right)^{1/(q-1)}\right) \quad (7)$$

The form (4) is solved iteratively using the Newton method by applying the following algorithm:

$$x_{new} = x_{old} - \frac{A_q x_{old}^q + A_1 x_{old} - A_0}{qA_q x_{old}^{q-1} + A_1} \quad (8)$$

The form (6) is solved iteratively using the Newton method by applying the following algorithm:

$$y_{new} = y_{old} - \frac{A_q y_{old} + A_1 y_{old}^{1/q} - A_0}{A_q + \dfrac{A_1}{q} y_{old}^{(1-q)/q}} \quad (9)$$

Certainly, if (8) is applied, the sought voltage drop is eventually computed from:

$$v_{x(n)} = V_{REF}\,x \quad (10a)$$

while if (9) is applied, the voltage drop is obtained from:

$$v_{x(n)} = V_{REF}\,y^{1/q} \quad (10b)$$

The algorithm is accurate and numerically efficient owing to the following factors:

- *The difference in the signal levels (voltage in thousands while current in tens or hundreds) is removed by solving for the pu value of the voltage drop.*
- *The strong nonlinearity of the equation is moderated by alternating between two optimal forms of (4) depending on the operating point of the MOV.*

The algorithm ensures satisfactory accuracy for time steps as large as 1/20th of a cycle (it needs 2-3 iterations to find a solution). For shorter time steps (higher sampling frequencies) the algorithm performs even better.

Subroutine SUB_A

The subroutine SUB_A is designed for locating faults within the line section A (faults in front of the serie compensating bank Fig.3). The following generalized fault loop model [5] is utilized:

$$V_{Ap} - d_A Z_1 I_{Ap} - R_{FA} I_{FA} = 0 \quad (11)$$

where: V_{Ap}, I_{Ap}*: fault loop voltage and current,* d_A*: unknown distance to fault,* R_F*: unknown fault resistance,* Z_1*: positive-sequence impedance of the line,* I_F*: total fault current.*

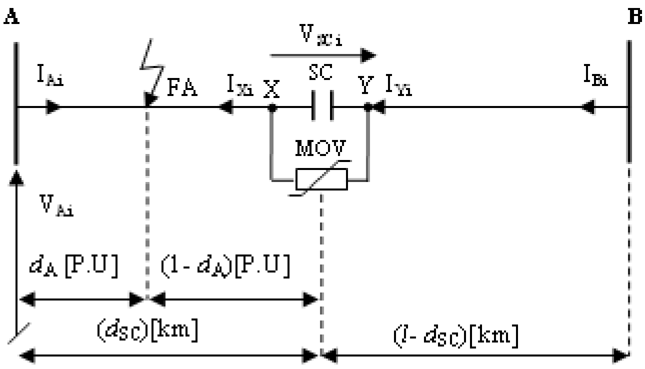

Figure 3. Subroutine SUB_A - scheme of series-compensated line for ith symmetrical component under fault F_A.

The total fault current I_{FA} *is determined as a sum of currents from both ends of the faulted section A-X, and may be expressed as:*

$$I_{FA} = I_A + I_X \quad (12)$$

where: I_A*: is the fault current contribution from terminal A,* I_X*: is the fault current contribution from the point X, when neglecting the line shunt capacitances it is equal to the current I_B, and thus one obtains:*

$$I_{FA} = I_A + I_B \quad (13)$$

Resolving (11) into real and imaginary parts yields:

$$\mathrm{real}(V_{Ap}) - d_A \mathrm{real}(Z_1 I_{Ap}) - R_{FA}\mathrm{real}(I_{FA}) = 0 \quad (14a)$$

$$\mathrm{imag}(V_{Ap}) - d_A \mathrm{imag}(Z_1 I_{Ap}) - R_{FA}\mathrm{imag}(I_{FA}) = 0 \quad (14b)$$

The sought fault distance is obtained after eliminating R_{FA} from the set (14a)-(14b):

$$d_A = \frac{\mathrm{real}(V_{Ap})\mathrm{imag}(I_{FA}) - \mathrm{imag}(V_{Ap})\mathrm{real}(I_{FA})}{\mathrm{real}(V_{LA})\mathrm{imag}(I_{FA}) - \mathrm{imag}(V_{LA})\mathrm{real}(I_{FA})} \quad (15)$$

where : $V_{LA} = Z_1 I_{Ap}$

For fault loop voltage, current (V_{Ap}*,* I_{Ap}*) and fault current (*I_{FA}*) in equation (15) can be determined by considering the boundary conditions for a particular fault type (various types of faults are summarized in Table 1).*

Table I. Composition of fault loop signals

	V_{Ap}	I_{Ap}	I_{FA}
a-g	V_{A_a}	$I_{A\_a}+k_0 I_{A\_0}$	$I_{A\_a}+I_{B\_a}$
b-g	V_{A_b}	$I_{A\_b}+k_0 I_{A\_0}$	$I_{A\_b}+I_{B\_b}$
c-g	V_{A_c}	$I_{A\_c}+k_0 I_{A\_0}$	$I_{A\_c}+I_{B\_c}$
a-b, a-b-g *a-b-c, a-b-c-g*	$V_{A\_a}-V_{A\_b}$	$I_{A\_a}-I_{A\_b}$	$(I_{A\_a}+I_{B\_a})-(I_{A\_b}+I_{B\_b})$
b-c, b-c-g	$V_{A\_b}-V_{A\_c}$	$I_{A\_b}-I_{A\_c}$	$(I_{A\_b}+I_{B\_b})-(I_{A\_c}+I_{B\_c})$
c-a, c-a-g	$V_{A\_c}-V_{A\_a}$	$I_{A\_c}-I_{A\_a}$	$(I_{A\_c}+I_{B\_c})-(I_{A\_a}+I_{B\_a})$
Where: $k_0=(Z_{0LA}-Z_{1LA})/Z_{0LA}$			

Having the fault distance calculated (17), the fault resistance can be determined as an average from (16a) and (16b):

$$R_{FA}=0.5[\mathrm{real}(V_{Ap})-d_A\mathrm{real}(V_{LA})]/\mathrm{real}(I_{FA})+0.5[\mathrm{imag}(V_{Ap})-d_A\mathrm{imag}(V_{LA})]/\mathrm{imag}(I_{FA}) \qquad (16)$$

Subroutine SUB_B

The subroutine SUB_B is designed for locating faults within the line section B (faults in behind of the serie compensating bank Fig.4).

An analytic transfer of three-phase measurements: V_A, I_A from the bus A towards the compensating bank, up to the point X, with strict taking into account the distributed parameter line model, is performed. Such transfer has to be performed separately for each of the i-th type of symmetrical component of three-phase voltages and currents (Fig.4).

Transferring of voltage from the bus A to the point X results in:

$$V_{Xi}=\cosh(\gamma_i d_{sc})V_{Ai}-Z_{ci}\sinh(\gamma_i d_{sc})I_{Ai} \qquad (17)$$

where: $Z_{ci}=\sqrt{Z_i^{'}/Y_i^{'}}$: surge impedance of the line for the i-th sequence,

$\gamma_i=\sqrt{Z_i^{'}Y_i^{'}}$: propagation constant of the line for the i-th sequence,

$Z_i^{'}$: impedance of the line for the i-th sequence,

$Y_i^{'}$: admittance of the line for the i-th sequence,

d_{SC} - total length (km) from terminal A to the SCU .

Transferring the ith symmetrical sequence current from the beginning of the line section (bus A) to the end point (X) of the un-faulted section A-X gives:

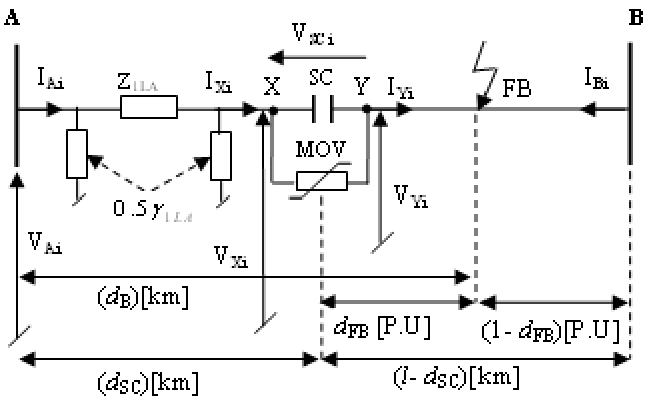

Figure 4. Subroutine SUB_B - scheme of series-compensated line for ith symmetrical component under fault F_B.

$$I_{Xi}=[-\sinh(\gamma_i d_{SC})V_{Ai}]/Z_{ci}+\cos(\gamma_i d_{SC})I_{Ai} \qquad (18)$$

If there is no internal fault in the compensating bank, then at both sides of the bank we have identical currents (Fig 4):

$$I_{Yi}=I_{Xi} \qquad (19)$$

In contrast, at both sides of the compensating bank there is a different voltage due to presence of voltage drops across the SC&MOV in particular phases. These voltage drops V_{SCi} can be calculated with use of equation (10) (section II.B).

The i-th sequence of voltage at the point Y is determined as:

$$V_{Yi}=V_{Xi}-V_{SCi} \qquad (20)$$

Then, using these transferred signals (19), (20), the fault loop voltage V_{Yp}, current I_{Yp} and fault current I_{FB} are composed, analogously as in (Table 1). In order to determinate the distance to fault occurring in the section B, the following fault loop model is used:

$$V_{Yp} - d_{FB} Z_1 I_{Yp} - R_{FB} I_{FB} = 0 \qquad (21)$$

After splitting (21) into the real and imaginary parts one obtains the formula for the distance to fault:

$$d_{FB} = \frac{\mathrm{real}(V_{Yp})\mathrm{imag}(I_{FB}) - \mathrm{imag}(V_{Yp})\mathrm{real}(I_{FB})}{\mathrm{real}(V_{LB})\mathrm{imag}(I_{FB}) - \mathrm{imag}(V_{LB})\mathrm{real}(I_{FB})} \qquad (22)$$

where: $V_{LB} = Z_1 I_{Yp}$

The fault resistance is estimated analogously as in case of the subroutine SUB_A:

$$R_{FB} = 0.5[\mathrm{real}(V_{Yp}) - d_{FB}\mathrm{real}(V_{LB})] / \mathrm{real}(I_{FB}) + 0.5[\mathrm{imag}(V_{Yp}) - d_{FB}\mathrm{imag}(V_{LB})] / \mathrm{imag}(I_{FB}) \qquad (23)$$

Having the fault distance d_{FB} calculated (24), the fault distance d_B (d_{sc}<d_B< l) can be determined as:

$$d_B = d_{SC} + d_{FB} \qquad (24)$$

d_B *: fault distance from terminal A to the fault point FB.*

SELECTION OF VALID RESULT

Locating a fault with respect to the series capacitors in the system of Fig. 1 is a separate issue [3]. However, the problem narrows to the selection of the correct pair (d, R_F) from two solutions (d_A, R_{FA}) and (d_B, R_{FB}). The simple and straightforward algorithm that works in the most cases is as follow: if d_A is in [0, d_{SC}] and d_B is out of [d_{SC} , l] then accept (d_A , R_{FA}) as a solution, otherwise if d_A is out of [0, d_{SC}] and d_B is in [d_{SC} , l] then accept (d_B , R_{FB}) as a solution, otherwise the subroutine, for witch the calculated fault resistance is negative, is rejected.

Table II. Parameters of the transmission line

Component:	Parameter:	
Line AB	l	200 km
	Z'_{1L}	(0.0276+j0.3151) Ω/km
	Z'_{0L}	(0.275+j1.0265) Ω/km
	C'_{1L}	13 nF/km
	C'_{0L}	8.5 nF/km
Series compensation	X_C	0.70 X_{1L}
	d_{SC}	100 km
characteristic of MOV: $i_{MOV} = P\left(\frac{v_x}{V_{REF}}\right)^q$	P	1 kA
	V_{REF}	150 kV
	q	23
Equivalent system at terminal A and B	Z_{1SB}	(1.312+j15) Ω
	Z_{0SB}	(2.334+j26.6) Ω

EVALUATION

MATLAB simulation program was applied to evaluate performance of the developed fault location algorithm. Different two-terminal networks were modeled for generation of fault data used in evaluation of the presented fault location algorithm. In particular, 400 kV, 200 km transmission line, compensated with a three-phase bank of series capacitors installed at mid-line.

The compensation rate of 70% was assumed. MOVs installed in parallel to series capacitors were modeled as nonlinear resistors defined with the analytical characteristic and its parameters as given in Table II.

The results for the cases of single phase-to-ground fault on the section A (the example 1 - Fig. 5) and on the section B (the example 2 - Fig. 6) illustrate performance of the delivered fault location algorithm.

In the example 1 (Figure 5) the following case has been considered: a-g fault in section A (fault infront of the SC) - distance to fault from terminal A: dFA= 50 km, fault resistance: RFA= 5 Ω. The continuous results were averaged within the fault period (50:70) ms. Both subroutines indicate the fault as occurring within their line sections:

The subroutine SUB_A estimates:

Distance 50.31 (km), fault resistance 4.93(Ω)

The subroutine SUB_B estimates:

Distance 88.58 (km), fault resistance -9.29 (Ω)

Applying the simple selecting algorithm (section II.E), the subroutine SUB_A gives the final estimate of the distance as 50.31 (km) with the 4.93 (Ω) fault resistance. It is worth to notice that only the subroutine SUB_A yields the result within its section with positive fault resistance whiles the remaining subroutine (SUB_B) outside their section with negative fault resistance and thus are rejected.

In the example 2 (Figure 6) the following case has been considered: a-g fault in section B(fault in behind of the SC) - distance to fault from terminal A: dFB = 180 km, fault resistance: RFB =5 Ω.

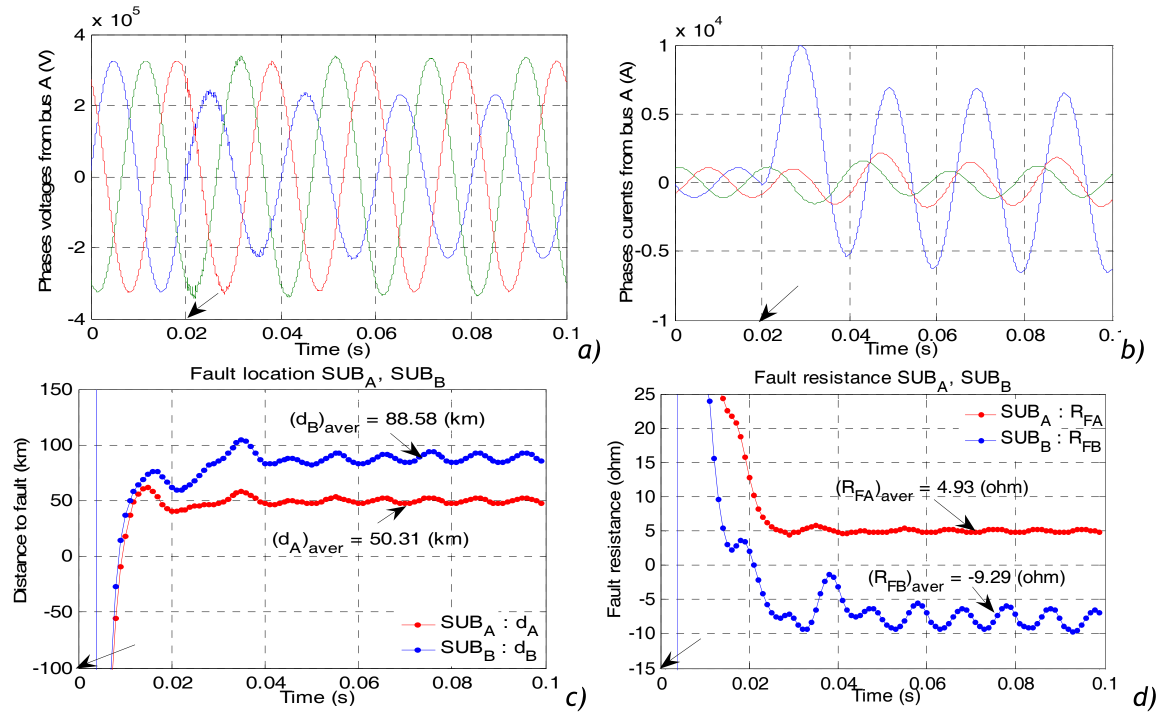

Figure 5. The example 1 - a-g fault in section A (fault in front of the SC, dFA= 50 km, RFA= 5 Ω): a) phase voltages from bus A, b) phase currents from bus A, c) estimated distance to fault, d) estimated fault resistance.

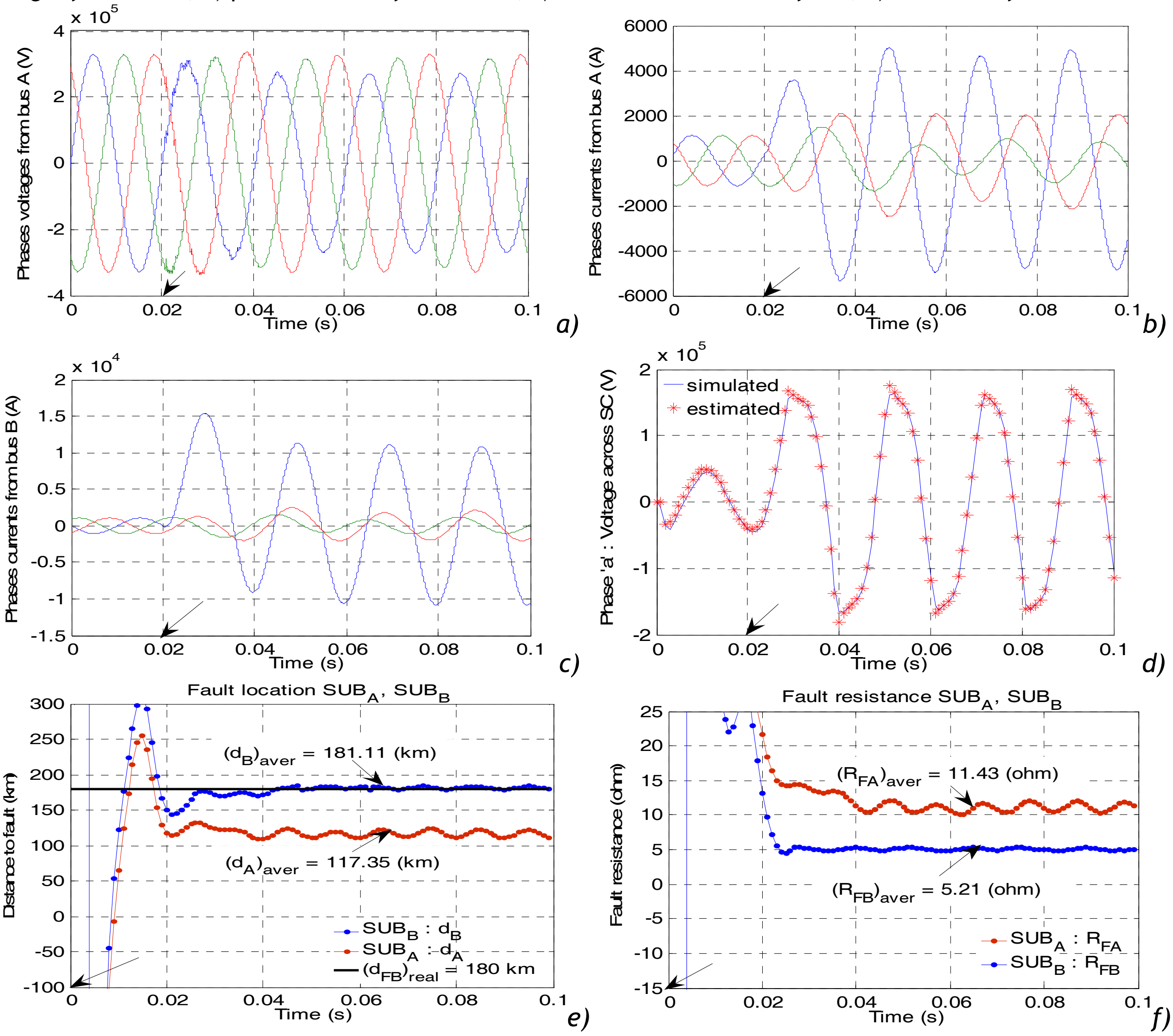

Figure 6. The example 1 - a-g fault in section B (fault in behind of the SC, dFB= 180 km, RFA= 5 Ω): a) phase Voltages from bus A, b) phase currents from bus A, c) phase currents from bus B, d) voltage drop across SCs in the faulted phase - from simulation, and estimated e) estimated distance to fault, f) estimated fault resistance.

Figure 6 displays the voltages and currents in the substation A, phase currents from bus B, the comparison of estimated and simulated voltages across SC in the faulted phase, the dynamic estimation of the distance and the fault resistance.

The subroutine SUB_A estimates:

Distance 117.35 (km), fault resistance 11.43(Ω)

The subroutine SUB_B estimates:

Distance 181.11 (km), fault resistance 5.21 (Ω)

CONCLUSIONS

This paper presents two-end accurate fault location algorithm for series compensated lines. The algorithm consists of two subroutines, designated for locating faults distance - one for faults behind the SCs, and another one for faults in front of the SCs. A special selecting procedure is proposed to pick-up the correct alternative.

The subroutines of the algorithm have been formulated with use of the generalized fault loop model, leading to the compact formulae. Taking into account the distributed parameter line model assures high accuracy of fault location. The other important advantage of the developed algorithm relies on limiting the need of calculation voltage drop serie capacitor bank for only one subroutine (SUB_B) using a novel, numerically efficient algorithm.

The developed fault location algorithm has been thoroughly tested using signals taken from MATLAB versatile simulations of faults on a series compensated transmission line. The presented fault location example shows the validity and high accuracy of the fault location algorithm and reliable selection of the valid subroutine. Maximal error in distance to fault estimation for all subroutines does not exceed 2%.

REFERENCES

[1] B. Bachmann, D. Novosel, D. Hart, Y. Hu and M. M. Saha, "Application of artificial neural networks for series compensated line protection," International Conference on Intelligent Systems Applications to Power Systems, Orlando, FL, pp. 68-73, Jan. 28-Feb. 02, 1996.

[2] Damir Novosel, Bernhard Bachmann, David Hart Yi Hu, Murari Mohan Saha, "Algorithms for locating faults on series compensated lines using neural network and deterministic methods," IEEE Transactions on Power Delivery, vol. 11, no. 4, pp. 1728-1736, Nov. 1996.

[3] M.M. Saha, J. Izykowski, E. Rosolowski, B. Kasztenny, "A new accurate fault locating algorithm for series compensated lines", IEEE Trans. on Power Delivery, vol. 14, No. 3, pp. 789-797, (1999).

[4] M.M. Saha, B. Kasztenny, E. Rosolowski, J. Izykowski, „First zone algorithm for protection of series compensated lines", IEEE Trans. on Power Delivery, Vol.16, NO.2, pp. 200-207, 2001.

[5] Jan Jzykowski, Eugenniusz Rosolowski, Murari Saha "Adaptive Digital Distance Algorithm for Parallel Transmission Lines", Power Tech. Engineers Proceedings, 2003 IEEE, Bologra, Vol 2, 23-26 June 2003, PP 6

[6] R. Dutra, L. Fabiano, M. M. Saha, and S. Lidstrom, "Fault location on parallel transmission lines with series compensation", IEEE/PES,2004, Transmission and Distribution Conference and Exposition, IEEE/PES, pp. 591-597, 2004.

[7] E. Rosolowski, J. Izykowski, and M. M. Saha, "Differential equation based fault location algorithm for series-compensated transmission line," presented at the Power Syst. Comput. Conf., Liege, Belgium, 2005, CD ROM.

[8] IEEE Std C37.114: "IEEE guide for determining fault location on AC transmission and distribution lines", IEEE PES Publ., pp. 1-42, (2005).

[9] J. Sadeh, N. Hadjsaid, A.M. Ranjbar, R. Feuillet, "Accurate fault location algorithm for series compensated transmission lines", IEEE Trans. on Power Delivery, vol. 15, No. 3, pp.1027-1033, (2000).

[10] C.-S. Yu, C.-W. Liu, S.-L. Yu, J.-A. Jiang, "A new PMU-based fault location algorithm for series compensated lines", IEEE Trans. on Power Delivery, vol. 17, No. 1, pp. 33-46, (2002).

[11] C. Fecteau, "Accurate fault location algorithm for series compensated lines using two-terminal unsynchronised measurements and Hydro Quebec's field experience", Proceedings of 33rd Annual Western Protective Relay Conference, Spokane, Washington, pp. 1-16, 2006.

[12] M.M. Saha, J. Izykowski, E. Rosolowski, P. Balcerek and M. Fulczyk, "Accurate location of faults on series-compensated lines with use of two-end unsynchronised measurements," 9th IET International Conference on Developments in Power System Protection, Glasgow, 2008, pp. 338-343.

copyright © UNIVERSITY POLITEHNICA TIMISOARA,
FACULTY OF ENGINEERING HUNEDOARA,
5, REVOLUTIEI, 331128, HUNEDOARA, ROMANIA
http://annals.fih.upt.ro