ASSESSMENT OF TWO FAULT LOCATION ALGORITHMS IN A MATLAB APPROACH

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REZUMAT. In lucrare sunt prezentati doi algoritmi de localizare a defectelor (Chen si Istrate) pentru liniile de trasnport al energiei electrice. Acestia folosesc esantioane preluate din undele de tensiune si curent din regimul de defect de la ambele extremitati ale liniei monitorizate. Autorii au modelat in Matlab o retea simpla cu tensiunea nominala de 400 kV compusa din doua surse interconecate print-o linie de 210 km. De asemenea in Matlab a fost imaginat si un model de locator de defect in care au fost implementati algoritmii aminitit. Acest locator utilizeaza fazorii de frecventa fundamentala ai tensiunilor si curentilor, care sunt obtinuti cu ajutorul unui algoritm adaptiv. Blocurile de localizare a defectelor precum si cel pentru obtinerea fazorilor alcatuiesc o unealta flexibila folosita in analiza localizarii defectelor, luand ca parametru distanta pana la locul defectului.

Cuvinte cheie: localizarea defectului, estimarea fazorului, retele de transport al energiei electrice

ABSTRACT. This paper presents two fault location algorithms for calculation of fault location on high voltage transmission lines. The presented fault location algorithms are those of Chen and Istrate and they use the samples of the transient voltages and currents from both line ends. In order to obtain the voltage and current samples, the authors have modeled in Matlab a simple 400 kV power grid composed by two sources and a 210 km high voltage line. The line model contains ten blocks, each one modeling a line segment of 21 km. Also, in Matlab there was imagined a fault locator block that utilizes the presented algorithms in order to obtain the fault location along the considered line. The presented fault location algorithms use the fundamental voltage and current phasors which are obtained with the phasor estimation algorithm presented in [5]. The fault locator and the phasor estimation blocks form a flexible tool that is used to make an analysis taking as parameter the distance measured between the line's sending end and the location of the fault.

Keywords: fault location, phasor estimation, high voltage grids

1. INTRODUCTION

High voltage lines of any voltage level are subject to faults. To expedite repairs and restoration of power it is important to know where the fault is located. Several fault location techniques for high voltage grids that utilize digital techniques and microprocessor-based systems have been developed during the last few decades [1], [2].

Taking into account the components from the fault signal that are processed to estimate the fault location, the actual fault location algorithms can be divided in two main categories namely: those who process the power frequency components and those who process the high frequency components [1]. Furthermore, the power frequency-based algorithms can be subdivided in to algorithms that use the data available at both ends of the line to obtain the fault location and algorithms that use data only from one end of the line. The two-end data fault location algorithms present higher interest in high voltage grids due to the growing demand in system's stability, protection and control [2].

The two-end data fault location algorithms employed in this study are those of Chen [3] and of Istrate [4]. The first one processes the synchronized voltage and current phasors from both ends of the line, while the second one processes only the unsynchronized voltages from both ends of the line. For estimation of the fault location, the power frequency phasors of the voltage and current are estimated with an adaptive algorithm indicated by Rosolowsky *et al*. [5].

2. FAULT LOCATION

Phasor estimation algorithm:

From the literature [2], is well known that the classic full-period Fourier algorithm provide good results in phasor estimation when the fault signal contains no exponentially decaying dc component. The presence of such dc components in the fault signal may raise stability issues in the outputs of the classic full-period Fourier algorithm, which are more obvious for the fault current. Taking in account this remark, in [3] is presented a phasor estimation algorithm which starts from the classic full-period Fourier algorithm and adaptively suppresses an exponentially decaying dc component.

The orthogonal components of the power frequency phasor computed with the phasor estimation algorithm are as:

$$X_R[n] = X_C[n] - \delta_c[n] \tag{1}$$

$$X_I[n] = X_S[n] - \delta_s[n] \tag{2}$$

where $X_C[n]$ and $X_S[n]$ are the orthogonal components computed with the classic full-period Fourier algorithm.

$$X_C[n] = \frac{2}{N}\sum_{i=1}^{N} x[n-i]\cos(\frac{i2\pi}{N}) \tag{3}$$

$$X_S[n] = -\frac{2}{N}\sum_{i=1}^{N} x[n-i]\sin(\frac{i2\pi}{N}) \tag{4}$$

and $\delta_c[n]$, $\delta_s[n]$ are the corrections functions:

$$\delta_c[n] = d_c[n]X_0[n], \delta_s[n] = d_s[n]X_0[n] \tag{5}$$

where $x[n]$ is a generic sample from the measured fault signal with n = 1, 2,…, M (M is the number of samples considered), N is the number of samples in a fundamental period, equal in this case with the number of samples in the data window of the full-period Fourier algorithm, and i is the i^{th} sample in the data window.

Regarding (5), $d_c[n]$ and $d_s[n]$ are obtained using the formulas:

$$d_c[n] = D\cos(\frac{2\pi}{N}n + \delta) \tag{6}$$

$$d_s[n] = D\sin(\frac{2\pi}{N}n + \delta) \tag{7}$$

Also from the measured fault signal $x[n]$ there is computed an exponentially decaying dc component as follow:

$$X_0[n] = \frac{2}{N}\sum_{i=1}^{N} x[n-i] \tag{8}$$

where D and δ are computed as:

$$D = \frac{1-\exp\frac{-T_1}{N\tau}}{\sqrt{\left(\cos\frac{2\pi}{N} - \exp\frac{-T_1}{N\tau}\right)^2 - \sin^2\frac{2\pi}{N}}} \tag{9}$$

$$\delta = \tan^{-1}\left(\frac{\sin\frac{2\pi}{N}}{\cos\frac{2\pi}{N} - \exp\frac{-T_1}{N\tau}}\right) \tag{10}$$

with T_1 being the fundamental period of the power frequency. The term $r = \exp(-T_1/N\tau)$ depends on the unknown value of the time constant τ of the exponentially decaying dc component and can be estimated from the measurements at each sample:

$$r = r[n] = \frac{X_0[n]}{X_0[n-1]} \tag{11}$$

Equation (11) was obtained taking into account (8) where $X_0[n]$ stands for a sum of N elements of geometric progression with multiplier r. For stabilizing the estimator (11) there may be defined apriori values for r as:

$$r_{\min} \le r \le r_{\min} \tag{12}$$

where r_{min} and r_{max} are fixed values in accordance with the minimum and maximum assumed values of the time constant τ of the exponentially dc component.

Fault location algorithms:

First it is considered a simple two-machine grid which has the equivalent model as in figure 1.

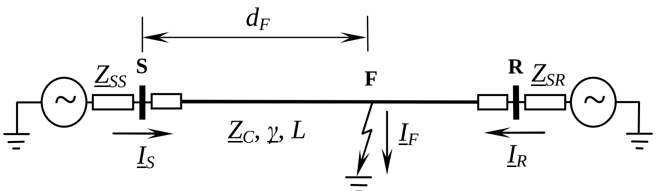

Fig. 1. One-line diagram of a faulty two-machine grid.

In figure 1, with **S** and **R** were denoted the sending and the receiving ends of the line, $\underline{Z}_{SS}$, $\underline{Z}_{SR}$ are the equivalent sending end and receiving end sources impedances considered as lumped parameters, $\underline{Z}_C$ and $\underline{\gamma}$ are the characteristic impedance and the propagation constant of the line which has the total length L and the line is assumed to be with distributed parameters; $\underline{\gamma} = \alpha + j\beta$, where α and β are the attenuation and phase constants; $\underline{I}_S$, $\underline{I}_R$ represent the sending end and the receiving end currents phasors, $\underline{I}_F$ is the current at fault point **F** and d_F represent the distance to the fault measured from the sending end **S.**

For a single phase to ground fault, the algorithm presented in [4] calculate the distance to the fault using the equation:

$$\tanh(\underline{\gamma}_1 d_F) = \underline{G} \quad (13)$$

where $\underline{G}$ is obtained from measurements as:

$$\underline{G} = \frac{1 - \dfrac{(\underline{U}_R - \underline{U}_{R1})(\cosh\underline{\gamma}_1 L + \dfrac{\underline{Z}_{C1}}{\underline{Z}_{SR1}}\sinh\underline{\gamma}_1 L)}{\underline{U}_S - \underline{U}_{S1}}}{\dfrac{(\underline{U}_R - \underline{U}_{R1})(\sinh\underline{\gamma}_1 L + \dfrac{\underline{Z}_{C1}}{\underline{Z}_{SR1}}\cosh\underline{\gamma}_1 L)}{\underline{U}_S - \underline{U}_{S1}} - \dfrac{\underline{Z}_{C1}}{\underline{Z}_{SS1}}} \quad (14)$$

Regarding (13), after the calculations are made there is obtained a system of two equations as:

$$\begin{cases} \dfrac{1-\tan^2\beta_1 d_F}{1+(\tanh\alpha_1 d_F \tan\beta_1 d_F)^2}\tanh\alpha_1 d_F = W \\ \dfrac{1-\tanh^2\alpha_1 d_F}{1+(\tanh\alpha_1 d_F \tan\beta_1 d_F)^2}\tan\beta_1 d_F = Y \end{cases} \quad (15)$$

where d_F is calculated using a numerical solution and W, Y are the real and respectively the imaginary parts of $\underline{G}$. Regarding equations (13)÷(15), the subscript ”1” denote the positive sequence, while in (14) $\underline{U}_S$, $\underline{U}_R$ represent the voltage phasors on the faulted phase and $\underline{U}_{S1}$, $\underline{U}_{R1}$ represent the posivite sequence voltage phasors at end **S** and end **R** of the considered line.

The second fault location algorithm is presented in [3], where the distance to the fault is calculated as:

$$d_F = L - \frac{\ln\dfrac{\underline{A}-\underline{C}}{\underline{E}-\underline{B}}}{2\underline{\gamma}_1} \quad (16)$$

where $\underline{A}$, $\underline{B}$, $\underline{C}$ and $\underline{E}$ are computed as:

$$\underline{A} = \frac{1}{2}(\underline{U}_{R1} + \underline{Z}_{C1}\underline{I}_{R1}) \quad (17)$$

$$\underline{B} = \frac{1}{2}(\underline{U}_{R1} - \underline{Z}_{C1}\underline{I}_{R1}) \quad (18)$$

$$\underline{C} = \frac{1}{2}(\underline{U}_{S1} + \underline{Z}_{C1}\underline{I}_{S1})\exp(\underline{\gamma}_1 L) \quad (19)$$

$$\underline{E} = \frac{1}{2}(\underline{U}_{S1} - \underline{Z}_{C1}\underline{I}_{S1})\exp(-\underline{\gamma}_1 L) \quad (20)$$

As it can be seen from the above equations, to compute the fault location the presented algorithms use only the positive sequence quantities in the fault regime. Since the positive quantities appear in all fault types, results that the presented algorithms can be used to compute the fault location for single-phased faults as well as for the poly-phased ones.

Some differences between the presented algorithms are the following: Chen’s algorithm [3] uses both the voltage and current phasors from the line ends; Istrate’s algorithm uses only the voltage phasors from the line ends; Chen’s algorithms requires synchronized data while Istrate’s algorithm can use unsynchronized data. Taking into account the differences presented, it can clearly be seen that Chen’s algorithm requires sophisticated equipment to obtain the synchronized phasors.

3. SIMULATION RESULTS

In order to obtain the simulated faulty voltages and currents, the authors have modeled in Matlab a 400 kV transmission grid which has the nominal frequency fixed at 50 Hz. Also in Matlab there were imagined phasor estimation and fault location blocks that take into account the equations used by each presented algorithm, as in figure 2.

Regarding figure 2, the following notations were made: $\underline{Z}_{eq.S}$, $\underline{Z}_{eq.R}$ represent the equivalent sources impedances; the shortcircuit power of the source connected at end **S** is 4650 MVA and of the source connected at end **R** is 3050 MVA; u_{Si}, i_{Si}, u_{Ri}, i_{Ri} are the sampled voltages and currents obtained at end **S** and respectively **R** and $\underline{U}_{Si}$, $\underline{I}_{Si}$, $\underline{U}_{Ri}$, $\underline{I}_{Ri}$ are the associated phasors obtained with the phasor estimation block; in the fault location block are implemented the presented fault location algorithms and to compute the distance to the fault there are used, in addition, the line parameters; the high voltage line is modeled with 10 blocks, each one corresponding to a 21 km line segment. The sequence parameters of the modeled high voltage line are shown in table I, where R is the resistance of the line, X is the reactance of the line, bothl in Ω/km and B is the susceptance of the line in S/km.

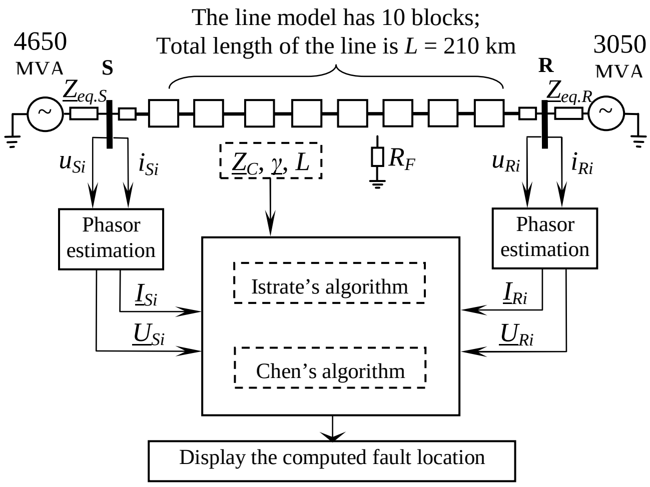

Fig. 2. The block-diagram of the fault locator

The simulation results presented in table II were obtained considering many single-phased faults along the modeled transmission line. In all cases, the fault's resistance R_F is considered 5 Ω, while the fault inception angle is considered π/2 rad

Table I – The sequence parameters of the line

Seq. param.	*R* [Ω/km]	*X* [Ω/km]	*B* [S/km]
Pos. / Neg.	0,038	0,331	$3{,}4\cdot10^{-6}$
Zero	0,180	1,131	$2{,}3\cdot10^{-6}$

The faults were simulated from ten to ten percent from total line's length, measured from end **S**. The computed fault locations are presented in two forms: in [km] and [%] from total length of the line measured from end **S** of the line.

Table II – The sequence parameters of the line

Real fault location		Chen		Istrate	
[km]	[%]	[km]	[%]	[km]	[%]
21	10	27,88	13,28	27,78	13,23
42	20	46,242	22,02	48,11	22,91
63	30	65,751	31,31	65,79	31,33
84	40	86,163	41,03	86,66	41,27
105	50	106,722	50,82	107,60	51,24
126	60	127,785	60,85	128,35	61,12
147	70	148,911	70,91	149,24	71,07
168	80	170,268	81,08	170,12	81,01
189	90	191,604	91,24	190,97	90,94
210	100	212,94	101,4	211,91	100,91

From table 2 it can be observed that for Istrate's algorithm the estimations are continuously improved with the increase of the distance between the end of the line and the location of the fault. In the other hand, for Chen's algorithm the estimations of the fault location are precise for distances between 30% ÷ 80% from total length of the line measured from end **S**. For all of the presented fault location algorithms it can be observed that the estimations are unprecise for short distances between the location of the fault and the end of the line.

4. CONCLUSIONS

In this paper there were presented some simulation results regarding the estimation accuracy of two double-end data fault location algorithms. In order to obtain the simulated faulty voltages and currents the authors modeled and then transposed into Matlab a simple high voltage grid as well as the fault location block. The fault location algorithms have in common the phasor estimation module presented in [5]. To compute the fault location, the algorithms of Istrate and Chen use the positive sequence quantities of the faulted grid.

The results were obtained taking as parameter the location of the fault along the line when single phased faults were simulated.

The estimations provided by the above mentioned algorithms are unprecise when the fault takes place near the line's end, but they are highly impoved with the increase of the distance between the line's end and the location of the fault. In the case of Istrate's algorithm it is observed a continuous decrease of the fault location error with the increase of the distance measured between the location of fault and the line's end. In the case of the algorithms of Chen, the fault location errors are minimal when the fault takes place in the middle area of the faulted line

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