

# A NEW ACCURATE FAULT LOCATION METHOD USING $\alpha\beta$ SPACE VECTOR ALGORITHM

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**Abstract** – In this paper, a new Fault Location methodology for electrical power system networks is proposed. This methodology uses the  $\alpha\beta$  space vector to identify and locate all different types of Faults (Phase-to-earth, Two-phase-to-earth, Phase-to-phase and Three-phase short-circuit). It is based on the modified version of Clarke's Transform, which is more suitable for real time implementations with invariant power, which is known by Clarke-Concordia transformation. For data signals interpretation it is used the eigenvalue approach.

The applied methodology is subdivided into several main steps: - Data acquisition, corresponding on three-phase current signals; - Mathematical treatment by the Clarke-Concordia Transformation; - Fault Identification, obtained by comparison of fault and pre-fault characteristic curves (on  $\alpha$ - $\beta$  plan); - Fault location. The fault location is obtained from the relationship between distance and the eigenvalue of line currents matrix.

Simulation results are presented showing the effectiveness of the proposed Algorithm for a correct Fault Location on distribution power system networks.

**Keywords:** Fault Location,  $\alpha\beta$  Space Vector Technique, Distribution Power System

## 1 INTRODUCTION

One of the most important issues on power system network at the present is the service quality. The major aspect to consider is perhaps to guarantee the continuity of service on transmission power lines. For this purpose Fault Classification and Fault Location have significant importance even in a medium voltage network.

Basically, most of the existing algorithms, which the objective is to find the unknown distance to the fault, belong to the following groups:

- Phasor-based algorithms;
- Partial differential equation-based algorithm.

The phase-based algorithms use only the fundamental components of the signals. The line model is usually the lumped-parameter model, applying symmetrical components [1] - [3].

The partial differential equation-based algorithms use the transient components of the signals. The line model is usually the distributed-parameter model. Besides the resolution of partial differential equations, an advanced

approach is also applied, the travelling-wave-based method [4].

Artificial intelligence methods (AI) are frequently used as an improvement for two main tasks: - a) recognition of the fault; - b) location of the fault. In particular the artificial neural networks (ANN) can be applied in association to single-ended fault location of transmission lines using voltage and current data [5] - [7].

Numerical algorithms are predominantly developed in the complex/spectral domain for fault detection and distance protection [8]. Once more, the method is based on voltage and current phasors.

To incorporate the uncertainties associated to system modelling and phasor estimation, fuzzy-logic based software is often used [9] - [12].

In this paper a new approach is presented for single-end fault location on electrical power distribution system networks, based on the application of  $\alpha\beta$  Space Vector Technique and Eigenvalue Approach.

The proposed methodology is able to locate where a specific type of fault occurs (Phase-to-earth fault, two-phase-to-earth fault, phase-to-phase fault, three-phase fault).

This methodology has been applied to an electric power distribution network (particularly an urban underground cable network), with fault conditions simulations on "Matlab/Simulink" software.

The first step of the methodology consists in the transformation of the line currents on  $\alpha\beta$  components (Single-end line data measurements are taken). Thus, applying eigenvalue approach it is possible to obtain a specific eigenvalue that is related with the fault distance.

To make it simpler, previous conditions are considered as follows: - underground medium voltage radial distribution network; - symmetrical load located on the remote end line.

It remains as one of the main characteristics of this method, that it is enough to consider only three current signals, for each feeder of the network. This is not an important feature for fault detection. However, for fault location it is an important characteristic since the normal procedures are based on voltage and current phasors analysis.

Another characteristic, of significant importance, it is the immunity to different perturbations such as harmonics and noise, since the method uses the eigenvalue approach for data analysis and is based on comparing patterns.

Other characteristic is the possibility to detect and locate earth faults even for weak fault currents.

## 2 PROPOSED METHODOLOGY

The proposed methodology is basically subdivided in three main stages:

- The first stage corresponds to the conversion of line currents into  $\alpha\beta$  components applying the Clarke-Concordia transformation (1);
- The second stage corresponds to the application of the eigenvector operator. This approach is used to obtain a specific eigenvalue that enables the definition of fault location expression;
- The third stage corresponds to the application of fault location expression, which gives us the distance where the fault has occurred.

### 2.1 First Stage

Clarke Transform is a well-known de-coupling method for three phase line parameters. The stationary two-phase variables of the Clarke Transform are denoted as “alpha” and “beta”. A third one it is known by zero-sequence component.

For this work we have considered a modified version, more suitable for real time implementations, known by Clarke-Concordia transformation [13].

In this approach it is assumed that “alpha” axis coincides with phase-1 and the “beta” axis lags the “alpha” axis by  $\pi/2$ .

$$[T_c] = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (1)$$

To characterise the different fault states, it is not necessary to include the zero-sequence component, i. e.  $i_0 = 0$ . Therefore, a new simplification can be obtained considering only the following currents:

$$\begin{bmatrix} i_{\dot{a}} \\ i_{\dot{b}} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} \quad (2)$$

### 2.2 Second Stage

To interpret the entire set of data signals (after Clarke-Concordia transformation) eigenvalue approach

was used. This technique is able to represent the line currents, using eigenvalues of data sample correlation matrix.

The first step is to obtain a data sample of the transformed line currents in matrix form (3). The number of significant samples  $n$  will correspond to the number of rows of matrix  $A$ . The currents  $i_\alpha$  and  $i_\beta$  form the columns of matrix  $A$ .

In (3)  $t_0$  is the initial time of data sample and  $\Delta t$  is the sample interval (period of time between samples).

$$A = \begin{bmatrix} i_\alpha(t_0) & i_\beta(t_0) \\ i_\alpha(t_0 + \Delta t) & i_\beta(t_0 + \Delta t) \\ \vdots & \vdots \\ i_\alpha(t_0 + (n-1)\Delta t) & i_\beta(t_0 + (n-1)\Delta t) \end{bmatrix} \quad (3)$$

As a method to obtain the eigenvalue, correlation matrix of  $A$  will be obtained applying:

$$B = A^T \cdot A \quad (4)$$

To obtain eigenvalues of matrix  $B$  we have used the operator “eig” that is included on Matlab/Simulink software. The results are given by matrix  $V$  and matrix  $D$ , as presented in (5) to (7).

$$[V, D] = \text{eig}(B) \quad (5)$$

Matrix  $D$  (6) row vector elements corresponds to eigenvalues  $\lambda_\alpha$  and  $\lambda_\beta$ .

$$D = \begin{bmatrix} \lambda_\alpha & 0 \\ 0 & \lambda_\beta \end{bmatrix} \quad (6)$$

Thus, for each case two different eigenvalues are obtained which are related with eigenvectors directions.

Only the major eigenvalue is used to allow the definition of the fault distance.

Matrix  $V$  (7) columns corresponds to eigenvectors  $e_1$  and  $e_2$ , related to vectors  $e_\alpha$  and  $e_\beta$  (8).

$$V = \begin{bmatrix} e_{11} & e_{12} \\ e_{21} & e_{22} \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} e_1 & e_2 \end{bmatrix} = \begin{bmatrix} \bar{e}_\alpha & \bar{e}_\beta \end{bmatrix} \begin{bmatrix} e_{11} & e_{12} \\ e_{21} & e_{22} \end{bmatrix} \quad (8)$$

### 2.3 Third Stage

For each type of fault, it is possible to establish a relationship between the distance and the eigenvalue, obtained as indicated in section 2.2.

This relationship can be obtained using polynomial regression, among other possible methods.

In those circumstances, the main expression for fault location can be defined as follows:

$$m = a(\lambda)^k + b \quad (9)$$

Where:

- $m$ : Distance to the fault point (in percentage of total length line);
- $a, b$ : Fault location coefficients (depending on fault type  $k_F$  and system pre-fault load  $k_C$  coefficients);
- $k$ : Fault type parameter. It is equal to 1 for phase-to-earth, -0.555 for phase-to-phase-to-earth, -0.552 for phase-to-phase and -0.551 for three-phase;
- $\lambda$ : Characteristic eigenvalue (of greatest value);

The appointed coefficients  $a, b$  will be defined by line conditions assuming rated values, i.e. presumed fault conditions at the sending end ( $m = 0$  and  $\lambda = \lambda_0$ ) and at the receiving end ( $m = 1$  and  $\lambda = \lambda_1$ ), with maximum capacity load.

Therefore, assuming

$$\zeta = \frac{\lambda_0}{\lambda_1} \quad (10)$$

The main expressions for  $a$  and  $b$  can be the following:

$$a = \frac{k_F k_C}{\zeta} \quad (11)$$

$$b = \frac{k_F k_C \lambda_1}{\zeta} \quad (12)$$

## 3 ALGORITHM STRUCTURE

The main steps of the proposed algorithm, which generic structure is represented in figure 1, are the following:

- Step 1) Single-end line data acquisition, from power system currents. Sample and hold and digital conversion.
- Step 2) Mathematical treatment of the obtained data acquisition applying Clarke-Concordia transformation. Storage of a complete treated sample.
- Step 3) Eigenvalue approach obtaining eigenvectors and eigenvalues of correlation matrix.
- Step 4) Fault Identification - Compare fault and pre-fault characteristic eigenvalues. After a new incoming treated sample, this one is compared to the one previously memorised, having as an objective

the identification of possible existing fault. If there is a significant difference of pre-set value it is assumed that a fault occurred and the location algorithm is activated. Otherwise the storage sample is erased.

- Step 5) Pre-evaluation of parameters " $k_F$ " and " $k_C$ ". Definition of coefficients " $a$ " and " $b$ " associated with fault type " $k_F$ ", and pre-fault load characteristic " $k_C$ ". Assumed as pre-setting the fault resistance ( $R_d$ ).
- Step 6) Fault Location – Definition of the adequate type fault location expression, as described in section 2. Computing for distance calculation (Obtained fault distance as a percentage of total length distribution line).

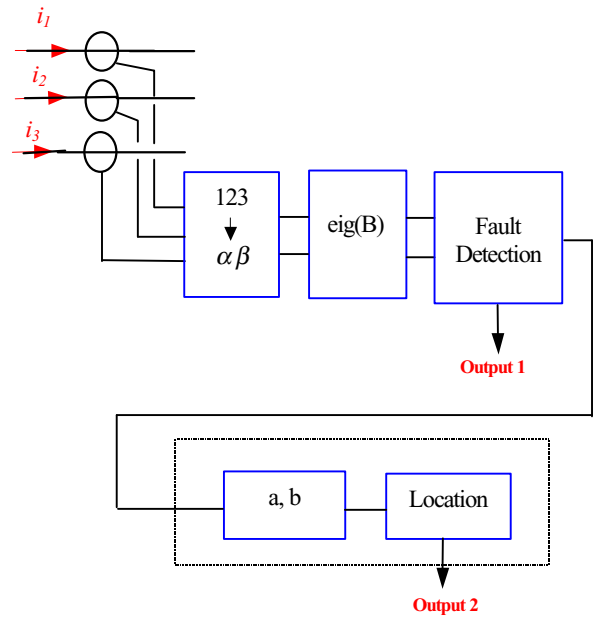


Figure 1: Algorithm structure.

## 4 CASE STUDY

### 4.1 Power Distribution Network Data

The case study corresponds to a typical Portuguese electric power distribution network for 10 kV, formed by:

- Distribution line - underground three aluminium conductors cable, with
  - $S = 95 \text{ mm}^2$ ;
  - $R = 0.382 \text{ Ohm/km}$ ;
  - $L = 0.33 \text{ mH/km}$ .
- Source - Substation power transformer of 20 MVA, 60/10 kV, Y/d, artificial neutral formed by short-circuit current limiting impedance for 1 kA;
- Load - Substation power transformers of 10/0,4 kV – Dyn, with total power of 3.6 MVA, which corresponds to maximum presumed capacity line.

#### 4.2 Simulated Results

In order to confirm the effective performance of the new method a high number of computer simulations were performed (considering different kinds of conditions).

With the obtained results, the following fault types were identified:

- Phase-to-earth fault;
- Two-phase-to-earth fault;
- Phase-to-phase fault;
- Three-phase fault.

The following basic conditions were considered for fault location simulations:

- Admissible distance fault variation of 0 to 100%, total line length;
- Resistance fault pre-definition of 1 Ohm. For three-phase fault it is assumed 0 Ohm for resistance fault;
- Load value variation for steps 10%, 30%, 67% and 100% of total load.

Table 1 to 4 illustrates some typical results obtained for different fault situations. On those, pre-fault situation considers 100% total load. The results are presented for five different points: on the sending-end (0 %), at 25 %, 50 % and 75 % of the line length, on the receiving-end (100 %).

From the analysis of the eigenvectors ( $e_1, e_2$ ) position in  $\alpha, \beta$  space vector plan it is possible to identify any fault type. This is the starting condition for the definition of fault location algorithm, as related previously.

The obtained results for steady state shows equal eigenvalues  $\lambda_\alpha, \lambda_\beta$  are of the same value. Obviously, they are dependent of load. For example:

- Considering 30 % of total admissible load we have calculated  $\lambda_\alpha = \lambda_\beta = 13.33$  (p.u.);
- Considering 100 % of total admissible load we have calculated  $\lambda_\alpha = \lambda_\beta = 161.78$  (p.u.).

Eigenvectors  $e_1$  and  $e_2$  have no special significance in those cases.

Distance (m)	Eigenvectors		Eigenvalues	
	$e_1$	$e_2$	$\lambda_\alpha$	$\lambda_\beta$
0.00	-0.99e $\alpha$ +0.13e $\beta$	-0.13e $\alpha$ - 0.99e $\beta$	2590.3	114.1
0.25	-0.99e $\alpha$ +0.13e $\beta$	-0.13e $\alpha$ - 0.99e $\beta$	2574,3	115.8
0.50	-0.99e $\alpha$ +0.13e $\beta$	-0.13e $\alpha$ - 0.99e $\beta$	2553.3	117.5
0.75	-0.99e $\alpha$ +0.13e $\beta$	-0.13e $\alpha$ - 0.99e $\beta$	2531,3	119.2
1.00	-0.99e $\alpha$ +0.13e $\beta$	-0.13e $\alpha$ - 0.99e $\beta$	2508.5	121.0

**Table 1:** Phase 1 to Earth Fault.

Distance (m)	Eigenvectors		Eigenvalues	
	$e_1$	$e_2$	$\lambda_\alpha$	$\lambda_\beta$
0.00	- 0.88e $\alpha$ +0.47e $\beta$	+0.47e $\alpha$ - 0.88e $\beta$	191 270 1E+03	20
0.25	- 0.88e $\alpha$ +0.47e $\beta$	+0.47e $\alpha$ - 0.88e $\beta$	10 467 1E+03	50
0.50	- 0.88e $\alpha$ +0.47e $\beta$	+0.47e $\alpha$ - 0.88e $\beta$	2 859.1 1E+03	100
0.75	- 0.88e $\alpha$ +0.47e $\beta$	+0.47e $\alpha$ - 0.88e $\beta$	1 309 1E+03	110
1.00	- 0.88e $\alpha$ +0.47e $\beta$	+0.47e $\alpha$ - 0.88e $\beta$	749.33 1E+03	120

**Table 2:** Phase 3 to Phase 1 to Earth Fault.

Distance (m)	Eigenvectors		Eigenvalues	
	$e_1$	$e_2$	$\lambda_\alpha$	$\lambda_\beta$
0.00	- 0.87e $\alpha$ +0.49e $\beta$	+0.49e $\alpha$ - 0.87e $\beta$	190 110 1E+03	200
0.25	- 0.87e $\alpha$ +0.49e $\beta$	+0.49e $\alpha$ - 0.87e $\beta$	10 420 1E+03	100
0.50	- 0.87e $\alpha$ +0.49e $\beta$	+0.49e $\alpha$ - 0.87e $\beta$	2 846.3 1E+03	100
0.75	- 0.87e $\alpha$ +0.49e $\beta$	+0.49e $\alpha$ - 0.87e $\beta$	1 300.9 1E+03	100
1.00	- 0.87e $\alpha$ +0.49e $\beta$	+0.49e $\alpha$ - 0.87e $\beta$	742.25 1E+03	70

**Table 3:** Phase 3 to Phase 1 Fault.

Distance (m)	Eigenvectors		Eigenvalues	
	$e_1$	$e_2$	$\lambda_\alpha$	$\lambda_\beta$
0.00	- 0.86e $\alpha$ - 0.51e $\beta$	- 0.86e $\alpha$ - 0.51e $\beta$	255 000 1E+03	255 000 1E+03
0.25	- 0.86e $\alpha$ - 0.51e $\beta$	- 0.86e $\alpha$ - 0.51e $\beta$	23 399 1E+03	23 399 1E+03
0.50	- 0.86e $\alpha$ - 0.51e $\beta$	- 0.86e $\alpha$ - 0.51e $\beta$	6 382 1E+03	6 382 1E+03
0.75	- 0.86e $\alpha$ - 0.51e $\beta$	- 0.86e $\alpha$ - 0.51e $\beta$	2 912.7 1E+03	2 912.7 1E+03
1.00	- 0.86e $\alpha$ - 0.51e $\beta$	- 0.86e $\alpha$ - 0.51e $\beta$	1 659 1E+03	1 659 1E+03

**Table 4:** Three-Phase Fault.

For three-phase fault it is possible to conclude almost the same: eigenvectors  $e_1$  and  $e_2$  have no special significance and eigenvalues  $\lambda_\alpha$ ,  $\lambda_\beta$  are of the same value. Nevertheless, eigenvalues in three-phase faults are much higher than in healthy situations.

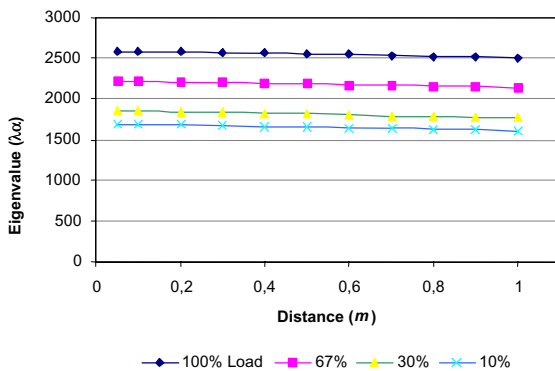
In most circumstances, earth fault currents are not enough to operate the line protection. Nevertheless, eigenvalues  $\lambda_\alpha$  and  $\lambda_\beta$  are different and, probably, they are greater than the correspondent  $\lambda_\alpha$  or  $\lambda_\beta$  for steady state. Thus, it is possible to detect the existence of such a fault even for weak resistance fault value.

Checking the relationship between eigenvalue  $\lambda_\alpha$  or  $\lambda_\beta$  and the correspondent fault distance it is possible to confirm expression (9).

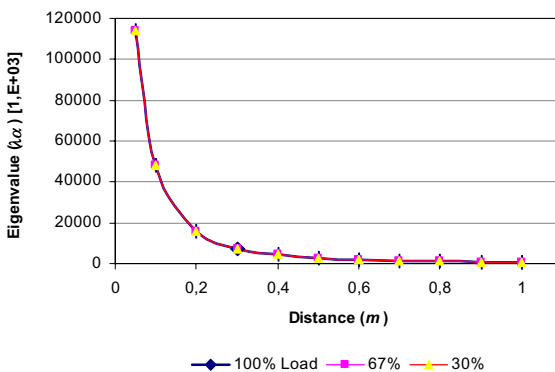
Figures 2 to 5 represents fault location functions for different types of fault.

The analysis of those figures show that location functions are:

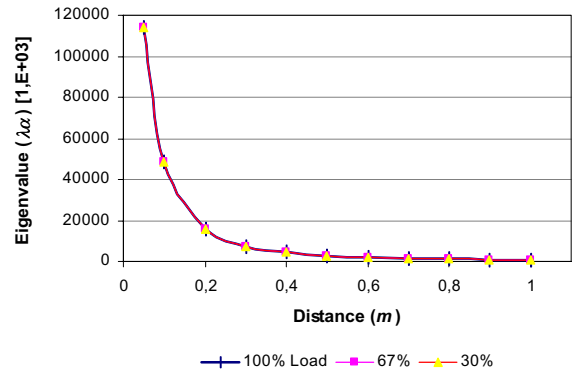
- Dependent of load for phase-to-earth faults;
- Practically identical and independent of load for two-phase-to-earth and phase-to-phase faults;
- Independent of load for three-phase faults.



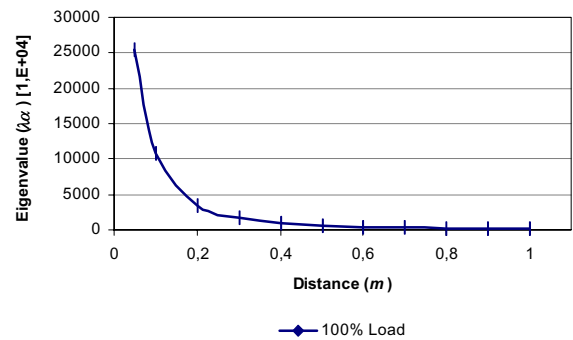
**Figure 2:** Distance versus “eigenvalue” for phase-to-earth fault.



**Figure 3:** Distance versus “eigenvalue” for two-phase-to-earth fault



**Figure 4:** Distance versus “eigenvalue” for phase-to-phase fault



**Figure 5:** Distance versus “eigenvalue” for three-phase fault

## 5 CONCLUSIONS

This paper presents a new method for fault location on radial distribution power networks. The proposed method uses the so-called  $\alpha\beta$  space vector algorithm that is based on the Clarke-Concordia transformation. It is also used the eigenvalue approach for transformed data interpretation.

This method is able to extract a functional relationship, which allows the definition of distance where a fault occurs.

The main characteristics of the proposed method are:

- Reduced number of input signals – only the three line currents for each feeder of the network (for fault location it is an important characteristic since the normal procedures are based on voltage and current phasors analysis);
- Off-line analyses – analyses of the anomaly even if transitory;
- Location and detection of an earth fault even for weak current fault value;
- Independence of noise or harmonics. Thus filtering can be considered unnecessary.

Simulation results for each one of the possible faults or steady-state situations have been presented, showing the effectiveness of the proposed technique for a correct Fault Location.

## REFERENCES

- [1] M. M. Saha, J. Izykowski, E. Rosolowski, R. Kasztenny; "A New Accurate Fault Locating Algorithm for Series Compensated Lines". IEEE Trans. on Power Systems. Vol. 14, N° 3, July 1999, pp. 789-797.
- [2] Tsai-Hsiang Chen, Mo-Shing Chen, Wei-Jen Lee, Paul Kotas, Peter van Olinda; "Distribution System Short Circuit Analysis". IEEE. N° , 1991, pp. 7.
- [3] A. S. Alfuhaid, M. A. El-Sayed; "A Recursive Least-Squares Digital Distance Relaying Algorithm". IEEE Trans. on Power Delivery. Vol. 14, N° 4, October 1999, pp. 1257-1262.
- [4] M. H. J. Bollen; "Travelling-Wave based Protection of Double-Circuit Lines". IEE Proc. – Generator, Transmission and Distribution. Vol. 140, N° 1, January 1993, pp. 37-47.
- [5] A. Poeltl, K. Frohlich; "Two New Methods for Very Fast Fault Type Detection by Means of Parameter Fitting and Artificial Neural Networks". IEEE Trans. on Power Delivery. Vol. 14, N° 4, October 1999, pp. 1269-1275
- [6] Z. Chen, J.C. Maun; "Artificial Neural Network Approach to Single-Ended Fault Locator for Transmission Lines". IEEE Trans. on Power Systems. Vol. 15, N° 1, February 2000, pp. 370-375
- [7] D. V. Coury, D. C. Jorge; "Artificial Neural Network Approach to Distance Protection of Transmission Line". IEEE Trans. on Power Delivery; Vol. 13, N° 1, Jan 1998, pp. 102-108
- [8] Zoran M Radojevic, Vladimir V Terzija, Milenko Djuric; "Numerical Algorithm for Overhead Lines Arcing Faults Detection and Distance and Directional Protection". IEEE Trans. on Power Delivery; Vol. 15, N° 1, January 2000, pp. 31-37
- [9] Hubert Podvin; "Fault location .on MV networks". PMAPS' 2000; September 2000, pp. 6
- [10] Huisheng Wang, W. W. L. Keerthipala; "Fuzzy-Neuro Approach to Fault Classification for Transmission Line Protection". IEEE Trans. on Power Delivery Vol. 13, N° 4, 1998, pp. 1093-1104
- [11] H Monsef, A. M. Ranjbar, S. Jadid; "Fuzzy rule-based system for power system fault diagnosis". IEE Proc. Generators Transmission, Distribution. Vol. 144, N° 2, March 1997, pp. 186-192
- [12] C. S. Chang, J. M. Chen, D. Srinivasan, F.S. Wen, A. C. Liew; "Fuzzy logic approach in power system fault section identification". IEE Proc. Generators Transmission, Distribution. Vol. 144, N° 5, September 1997, pp. 406-414
- [13] C. V. Jones; "The unified theory of electrical machines". Plenum Press, 1967.