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PARAMETERS' SELECTION FOR METAL OXIDE SURGE ARRESTERS MODELS USING GENETIC ALGORITHM

P.F. Evangelides, C.A. Christodoulou, I.F. Gonos, I.A. Stathopulos

High Voltage Laboratory, School of Electrical and Computer Engineering, National Technical University of Athens,
9 Iroon Politechniou Street, Zografou Campus, Athens 15780, Greece
panayiotisevangelides@hotmail.com, christod@mail.ntua.gr, igonos@ieee.org, sthathop@power.ece.ntua.gr

ABSTRACT

The efficient representation of surge arrester's dynamic behavior by the appropriate equivalent circuit models improves the quality and reliability of the lightning performance studies; hence, the appropriate modeling of metal-oxide surge arresters and the determination of their parameters are significant issues. In the present work a genetic algorithm is developed, for the evaluation of the parameters of surge arrester's models. The developed genetic algorithm computes the optimum circuit model parameters, in order to minimize the error between the simulated peak residual voltage value and the one given by the manufacturer.

1 INTRODUCTION

Lightning and switching overvoltages are common reasons of faults and interruptions in power systems. In order to improve the lightning performance of the high voltage transmission networks and reduce the annual failure rate, overhead ground wires are installed intercepting the lightning strikes and protecting the phase conductors. Several power corporations install additionally surge arresters between phase conductors and ground, providing a low-impedance path to ground for the overvoltage current. The selection of the arresters electrical and housing characteristics, their energy absorption capability and the installation interval (which are depended on the keraunic level, the tower geometry, the basic insulation level and the tower footing resistance) is a complex technoeconomical problem, since the minimization of the lighting failure and the cost are, simultaneously, demanded.

The appropriate modeling of metal-oxide surge arresters and the determination of the equivalent circuit parameters are significant issues, since the efficient representation of the arresters improves the quality and reliability of the lightning performance studies. Measurements of the residual voltage of metal oxide surge arresters indicate dynamic characteristics, and specifically, the residual voltage increases as the current front time descends and the residual voltage reaches its maximum before the arrester current reaches its peak. For these reasons, the metal oxide surge arresters cannot be modeled only by a non-linear resistance, since their response depends on the magnitude and the rate of rise of the surge pulse.

Several frequency dependent models have been proposed, in a way that the model simulation results correspond to the actual behavior of the arrester [1-4]. The parameters' determination for each model, in a way that the simulated curve fits to the real recorded waveform is the main and critical issue, in order to extract reliable estimations for insulation coordination studies. To this direction, the current work suggests an appropriate genetic algorithm for the circuit parameter values evaluation, which uses the initial values obtained by adjustment methods defined for each model, in order to minimize the error between the computed and the manufacturer's residual voltage curves.

2 SURGE ARRESTERS MODELS

The most used frequency-depended arrester models, that represent efficiently the arresters performance are: the IEEE model [2], the Pincetti-Gianettoni [3] and the Fernandez-Diaz model [4]; the last two models are based on the IEEE model, but they differ in the parameters computation.

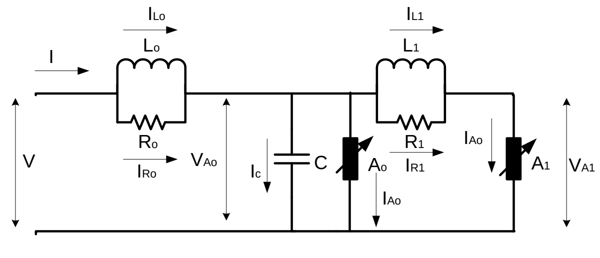

Fig. 1 The IEEE model [2].

The IEEE Working Group 3.4.11 [2] proposes the model of Fig. 1, including the non-linear resistances A_0 and A_1, separated by a R-L filter. For slow front surges the filter impedance is low and the non-linear resistances are in parallel. For fast front surges filter impedance becomes high, and the current flows through the non-linear resistance A_o.

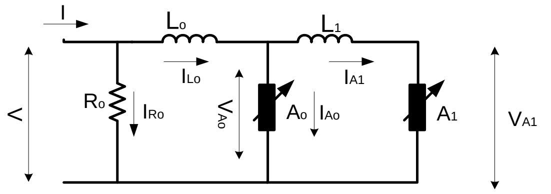

Fig. 2 The Pinceti-Gianettoni Model [3].

The Pinceti-Gianettoni model has no capacitance and the resistances R_o and R_1 are replaced by one resistance (approximately 1 MΩ) at the input terminals, as shown in Fig.2. The non-linear resistors are based on the curves of [2]. The advantage of this model in comparison to the IEEE model is that there is no need for arresters' physical characteristics, but there is only need for electrical data, given by the manufacturer.

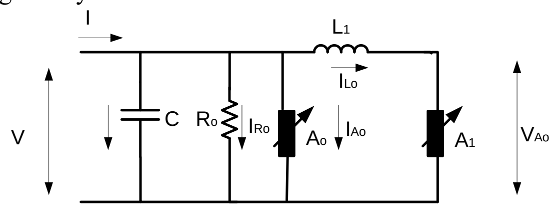

Fig. 3 The Fernandez-Diaz Model [4].

The Fernandez–Diaz Model is also based on IEEE model, A_0 and A_1 are separated by L_1, while L_0 is neglected (Fig 3). C is added in arrester terminals and represents terminal-to-terminal capacitance of the arrester. The procedure for the computation of the parameters is given in [4].

Table 1 Models' parameters computation.

	IEEE	**Pianceti-Gianettoni**	**Fernandez-Diaz**
R_o	*(100 d)/n* $_1$Ω	1 MΩ	1 MΩ
R_1	*(65 d)/n$_1$* Ω	-	-
L_o	*(0.2 d)/n$_1$* μH	$\frac{1}{4}\cdot\frac{V_{r(1/T_2)}-V_{r(8/20)}}{V_{r(8/20)}}\cdot V_n$ *	-
L_1	*(15 d)/n$_1$* μH	$\frac{1}{12}\cdot\frac{V_{r(1/T_2)}-V_{r(8/20)}}{V_{r(8/20)}}\cdot V_n$ *	$n_2\ L_1'$ **
C	*(100 $_{n1}$)/d* pF	-	*100/d* pF

* n_1 is the number of parallel columns of metal oxide in the arrester, V_n is the arrester's rated voltage, $V_{r(8/20)}$ is the residual voltage for a 8/20 10 kA lightning current and $V_{r(1/T2)}$ is the residual voltage for a $1/T_2$ 10 kA lightning current

** n_2 is a scale factor and L_o' is obtained from diagrams [4]

Table 1 presents the equations for the parameters computation for each frequency depended equivalent circuit model.

3 PROBLEM ANALYSIS

The predicted residual voltage for an injected impulse current of each model must be as closer to the measured residual voltage (manufacturer's datasheet). Considering that the accuracy of the computed residual voltage depends on the model parameters, these can be determined by minimizing the function [5]:

$$e=\left|\frac{V_c-V_m}{V_m}\right| \tag{1}$$

where:
V_c is the peak value of the computed residual voltage and
V_m is the measured by the manufacturer residual voltage.
x is a column vector containing the parameters $x_1, x_2,\ldots,x_n$ of each one model:
for the IEEE model [8]

$$x=[x_1,x_2,x_3,x_4,x_5]^T=[R_0,\,R_1,\,L_0,\,L_1,\,C]^T \tag{2}$$

for the Pianceti–Gianettoni model [10]

$$x=[x_1,x_2,x_3]^T=[R_0,\,L_0,\,L_1]^T \tag{3}$$

for the Fernandes–Diaz model [11]

$$x=[x_1,x_2,x_3]^T=[R_o,\,L_1,\,C]^T \tag{4}$$

Application of an appropriate method will determine the optimum values x_i, in a way that equation (1) will be minimized. The simulation of each model is performed using Matlab, solving the state equations for each non linear equivalent circuit model. The two non linear resistors A_0 and A_1 are represented by piecewise linear functions:

$$V_{Ao}=aI_{Ao}+b \tag{5}$$

$$V_{A1}=AI_{A1}+B \tag{6}$$

Analytically, for the IEEE model:

$$\frac{L_o}{R_o}\cdot\frac{dI_{Lo}}{dt}=I-I_{Lo} \tag{7}$$

$$\frac{L_1}{R_1}\cdot\frac{dI_{L1}}{dt}=I_{A1}-I_{L1} \tag{8}$$

$$C\frac{dV_{Ao}}{dt}=I-I_{Ao}-I_{A1} \tag{9}$$

$$V=V_{Ao}+L_o\frac{I_{Lo}}{dt} \tag{10}$$

For the Pinceti-Gianettoni model:

$$I=I_{Ro}+I_{Lo} \tag{11}$$

$$L_o\frac{dI_{Lo}}{dt}+V_{Ao}=V \tag{12}$$

$$I_{Lo}=I_{Ao}+I_{A1} \tag{13}$$

$$V_{Ao} = L_1 \frac{dI_{A1}}{dt} + V_{A1} \quad (14)$$

$$V = (I - I_{Lo}) \cdot R \quad (15)$$

For the Fernadez-Diaz model:

$$I = I_C + I_R + I_{Ao} + I_{A1} \quad (16)$$

$$C\frac{dV}{dt} + \frac{V}{R_o} = I - I_{Ao} - I_{A1} \quad (17)$$

$$L_1 \frac{dI_{A1}}{dt} = V_{A1} - V_{Ao} \quad (18)$$

$$I_{Ao} = \frac{V-b}{a} \quad (19)$$

$$V = I \cdot R_o \quad (20)$$

4 GENETIC ALGORITHMS

Genetic algorithms (GA) are adaptive algorithms widely applied in science and engineering for solving practical search and optimization problems. This paper proposes a methodology, which uses the developed GA for the optimization of the parameters of the metal oxide surge arresters equivalent circuit models. This GA has been developed using Matlab. The same GA produces excellent results in several other optimization problems [6-11]. It has been applied for the computation of earth structure parameters [6, 7], factorization of multidimensional polynomials [8], filter design [9], calculation of arc parameters at polluted insulators [10] and estimation of electrostatic discharge current parameters [11].

A simple GA relies on the processes of reproduction, crossover and mutation to reach the global or “near-global” optimum. To start the search, GAs require the initial set of the points P_s, which called population, analogous to the biological system. A random number generator creates the initial population. This initial set is converted to a binary system and is considered as chromosomes, actually sequences of “0” and “1”. The next step is to form pairs of these points that will be considered as parents for a reproduction. Parents come to reproduction and interchange N_p parts of their genetic material. This is achieved by crossover. After the crossover there is a very small probability P_m for mutation. Mutation is the phenomenon where a random “0” becomes “1” or a “1” becomes “0”. Assume that each pair of "parents" gives rise to N_c children. Thus the GA generates the initial layouts and obtains the objective function values. The above operations are carried out and the next generation with a new population of strings is formed. By the reproduction, the population of the "parents" is enhanced with the "children", increasing the original population since new members are added. The parents always belong to the considered population. The new population has now $P_s+N_c \cdot P_s/2$ members. Then the process of natural selection is applied. According to this process only P_s members survive out of the $P_s+ N_c \cdot P_s/2$ members. These P_s members are selected as the members with the lower values of *e*, since a minimization problem is solved. Repeating the iterations of reproduction under crossover and mutation and natural selection GAs can find the minimum of *e*. The best values of the population converge at this point. The termination criterion is fulfilled if either the mean value of *e* in the P_s-members population is no longer improved or the number of iterations is greater than the maximum number of iterations N_{max}. Briefly, in Fig. 4, the basic function of the algorithm is shown. The goal of the GA is to reduce their amplitude through successive repeats. The optimization error function that was used by the developed GA in order to receive best values for the related parameters of the arrester is eq. (1).

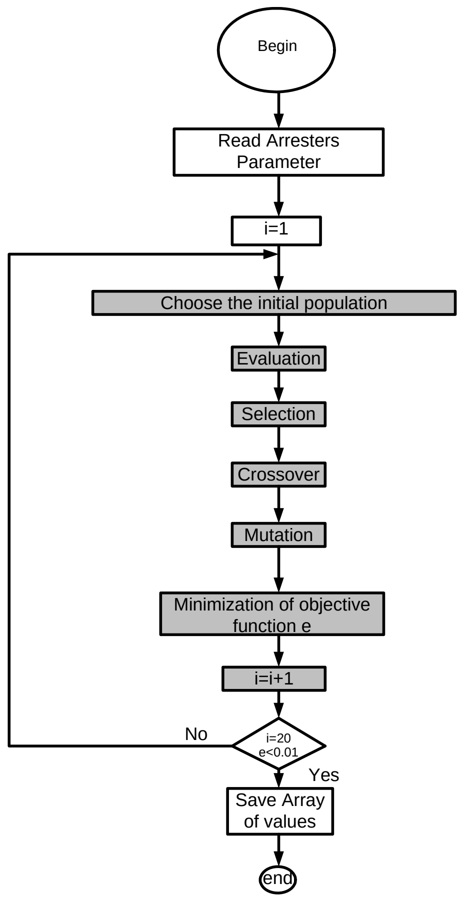

Fig. 4 Flow chart of the Genetic Algorithm.

5 RESULTS

The developed genetic algorithm is applied to each model for a high voltage metal oxide surge arrester, in order to compute the models parameters that minimize the function *e* (eq. 1). The electrical and insulation characteristic data of the examined surge arrester are presented in Table 2.

Table 2 Electrical and insulation data of arrester.

Maximum continuous operating voltage		12 kV
Rated voltage		15 kV
Nominal discharge current		10 kA
Maximum residual voltage with lightning current 8/20μs	**5 kA**	36.72 kV
	10 kA	38.88 kV
	20 kA	43.37 kV
Height		183 mm
Insulation material		silicon rubber

In tables 3-5 the initial computed parameters for each one model are shown, according to the computations described in section 2, as well as the optimum parameter values obtained using the genetic algorithm described in section 4.

Table 3 Parameters for the IEEE model.

Parameters	Initial values	Optimized values
L_1	2.745 uH	1.017 uH
R_1	11.895 Ohm	17.85 Ohm
L_o	0.0366 uH	0.278 uH
R_o	18.3 Ohm	25.43 Ohm
C	546.45 pF	967.21 pF

Table 4 Parameters for the Pinceti-Gianettoni model.

Parameters	Initial values	Optimized values
L_1	0.148 uH	0.0435 uH
L_o	0.049 uH	0.376 uH
R_o	1 MOhm	0.895 MOhm

Table 5 Parameters for the Fernandez-Diaz model.

Parameters	Initial values	Optimized values
L_1	0.349 uH	1.371 uH
C	546.45 pF	675.5 pF
R_o	1 MOhm	1.465 MOhm

In Table 6 are given the computed peak value of the residual voltage for each model (for initial and optimized parameters) and the relative errors (for initial and optimized parameters) comparing these values to the manufacturer's measurements, for the nominal discharge current of the arrester.

Table 6 Residual voltages and relative errors for each model for the nominal discharge current 10kA (manufacturer's peak residual voltage: 38.88kV)

	Residual Voltage (kV)		Relative Error (%)	
Model	**Initial parameters**	**Optimized parameters**	**Initial parameters**	**Optimized parameters**
IEEE	39.34 kV	38.88 kV	1.1%	≈0%
Pinceti-Gianettoni	38.06 kV	38.87 kV	2.1%	0.0067%
Fernandez-Diaz	39.50 kV	38.88 kV	1.6%	≈0%

The application of the optimum parameter values in the equivalent circuit models almost eliminates the error between the manufacturer's and the simulated residual voltage peak, something very important, sine the arresters models can be more reliable for insulation coordination studies, representing more efficiently the metal oxide arresters behavior and resulting in more precise analysis. The three examined models reproduce adequately the frequency dependent behavior of the arresters, giving a negligible error for the residual voltage peak value, after the genetic algorithm application. The decision about which model will be used is based on the available data, the complexity of the system and the crisis of each user.

6 CONCLUSIONS

In this work a genetic algorithm was developed in order optimum surge arrester equivalent circuit model parameters to be determined. The minimization of the error between the computed and the manufacturer's residual voltage for a given injected impulse current was the criterion of the optimization. The obtained results prove the efficiency of the method and the optimum obtained parameters improve the behavior of the models, since the error between theoretical and measured residual voltage peak value is eliminated. The proposed methodology can be proved useful in the achievement of more accurate and reliable results in transient analysis and lighting performance studies.

The main advantage of the method is that gives accurate results, taking into account a wide range of the parameters values, in comparison with other compatible optimization methods (simplex, Powell, downhill, etc), where the optimum solution is strongly depended on the initial values. The developed genetic algorithm analyzes the possible combinations of the parameters values for each model, resulting in the best solution that reduces the objective function. Additionally, the user can choose the speed of the simulation and the desired accuracy, selecting the range of the values parameters, the number of parents and the iteration number.

In future work the algorithm should be improved, in order to compare not only the peak value of the residual voltage, but also the slope and the injected energy, simultaneously for the three impulse current levels (5 kA, 10kA, 20kA) obtaining more accurate evaluation about the curve fitting of the measured and computed waveforms.

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