Parameter Identification Technique for a Dynamic Metal-oxide Surge Arrester Model

G. R. S. Lira, D. Fernandes Jr.and E. G. Costa

Abstract-- In this work is shown a parameter identification technique for a dynamic metal-oxide surge arrester model. This technique is based on the fitting of the residual voltages measured in laboratory and obtained from the surge arrester model, from the 10 kA lighting current impulse (waveshape 8/20 µs). The results obtained from the fitted surge arrester model have presented a very good accuracy. It is also evaluated, the behavior of the fitted arrester model under high current impulse (waveshape 4/10 µs), which are more severe transients than those used to estimate the arrester model parameters. The results obtained in that study have presented good agreement when compared to the measured data. At last, it is presented a comparative study of the results provided by the fitted surge arrester model with those provided by the model with the original parameter adjustment procedure. The results provided by the proposed parameter identification technique have been more accurate than the results obtained from the other procedures. Besides, the technique has the advantages of no need to know the metal-oxide surge arresters physical characteristics and no use manual procedures, based on try and error, to adjust the arrester model parameters. Therefore, the proposed technique has presented results more reliable and accurate than others procedures found in the literature.

Keywords: Parameter identification, metal-oxide surge arresters, surge arresters models, electromagnetic transients, EMTP.

I. Introduction

THE metal-oxide surge arresters (MOSAs) are equipments used in power systems protection against several kinds of surges. In this way, they effectively contribute for increase the reliability, economy and continuity of system protected by them. Due to the importance of MOSA for the electrical systems and the need of accurate representation, several models have been proposed with the aim to provide tools for studies involving: insulation coordination, energy absorption capability, diagnosis, correct selection and others [1-4].

Several MOSA models can be found in the literature. The most reported models are those proposed by [1] and [4-11]. Each one of the models proposed in the literature has a specific procedure to determine the electrical parameters. The majority of these procedures are based on tests, without any mathematical formalization. Some models use empirical equations associated to iterative process, for obtaining final values of the electrical parameters. Others procedures require physical or electrical characteristics of the surge arresters, which usually are not informed by the manufactures. Besides, the procedures to determine MOSA models parameters in the literature not always guarantee suitable parameters.

In the aim to overcome some limitations of the parameters adjust procedures normally found in the literature, in this work is presented a parameter identification technique for a dynamic MOSA model with fairly small errors. This technique is based on the fitting of the residual voltages measured and obtained from the surge arrester models, from the 10 kA lighting current impulse (waveshape 8/20 µs).

II. Laboratory Measurements

In this section is shown the laboratory measurements necessary to perform and validate the proposed technique. The tests were carried out in two samples of two types of zinc oxide varistors (type A and B) with different physical and electrical characteristics, in order to verify the generality of the proposed parameter identification technique. The data of the varistors type A and B are shown in Table I.

TABLE I
TECHNICAL DATA OF THE VARISTORS.

Data/Varistor	Type A	Type B
Height	0.0458 m	0.0230 m
Width	0.0383 m	0.0645 m
Rated voltage	7.5 kV	3.5 kV
Continuous operation voltage	6.0 kV	2.8 kV
Energy absorption capacity	3.6 kJ/kV	-
Nominal discharge current	10 kA	10 kA
Residual voltage for lighting impulse of 5 kA	19.6 kV	7.5 kV
Residual voltage for lighting impulse of 10 kA	21.0 kV	8.0 kV
Residual voltage for lighting impulse of 20 kA	23.9 kV	-

Just one standard test is necessary to apply the technique: the residual voltage test for lighting current impulse. The test was performed by the Current Impulse Generator (80 kJ/100 kV) existent in the High Voltage Laboratory of the Federal University of Campina Grande. In Fig. 1 is shown a diagram of the experimental arrangement used in the test. With this equipment/arrangement is possible to obtain some kinds of current impulse waveshapes by the appropriated adjust of *R*, *L* and *C* circuit parameters. In this work, residual voltages tests were carried out with lighting current impulses (8/20 µs waveshape) and high current impulses (4/10 µs waveshape).

The work was supported by the Brazilian National Research Council (CNPq).
G. R. S. Lira is a Ph.D. student at Federal University of Campina Grande, 58.109-970, Campina Grande, PB, Brazil (e-mail: georgelira@ee.ufcg.edu.br).
D. Fernandes Jr. and E. G. Costa are with Federal University of Campina Grande, 58.109-970, Campina Grande, PB, Brazil (e-mails: damasio@dee.ufcg.edu.br, edson@dee.ufcg.edu.br).

Paper submitted to the International Conference on Power Systems Transients (IPST2009) in Kyoto, Japan June 3-6, 2009

The current and voltage signals derived of the residual voltage tests were obtained by a shunt resistance (R_{shunt}) and a voltage divider, respectively, more a data acquisition system composed by a digital oscilloscope and a data acquisition routine developed in the Matlab [12]. The signals were stored in a PC to later treatment.

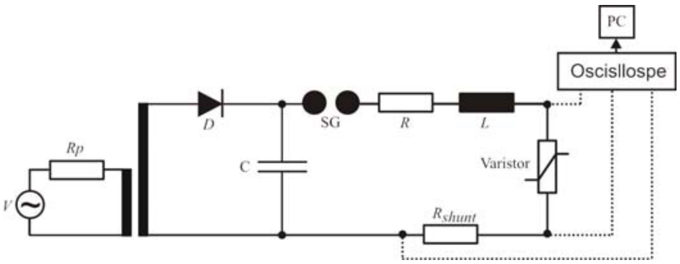

Fig. 1. Experimental arrangement used in the residual voltage tests.

III. MOSA MODELING

In this paper, the parameter identification technique was applied to the IEEE MOSA model [1], shown in Fig. 2. This choice was based on the accuracy, reliability and robustness of the IEEE model, as shown in [2-3] and [13-15]. Besides, this model is recommended by the Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems [16] in studies of fast transients.

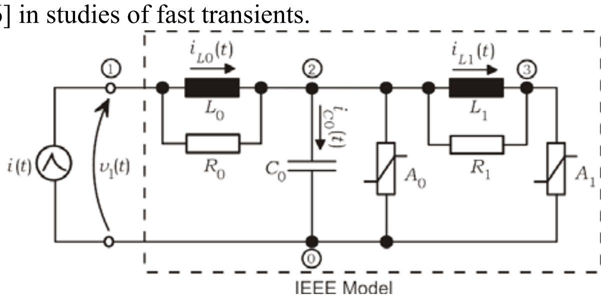

Fig. 2. Current impulse applied to the IEEE MOSA model.

The IEEE MOSA model is composed by two sections of nonlinear resistance, usually designated by A_0 and A_1, which are separated by a R-L filter, as shown in Fig. 2. For slow-front surges, the R-L filter has low impedance and the nonlinear resistances A_0 and A_1 are almost in parallel. However, for fast-front surges the impedance of the R-L filter is highest. As consequence of this, the current in nonlinear resistance A_0 increases such as the voltage. Since characteristic A_0 has a higher voltage than A_1 for a given current (as shown in Fig. 3), the result is that the arrester model generates a higher voltage for fast transients (dynamic characteristics of the MOSA).

As shown in Fig. 2, the model has also an inductance L_0, which represents the inductance associated to the magnetic field in the arrester. The resistor R_0 is used to avoid numerical troubles in the digital simulations. The capacitor C_0 represents the capacitance between the arrester terminals. The elements R_1 and L_1 compose the R-L filter that represents the dynamic behavior of the MOSA. In order to determine these parameters, the IEEE Working Group suggests a manual parameter adjust procedure based on trial and error. As initial

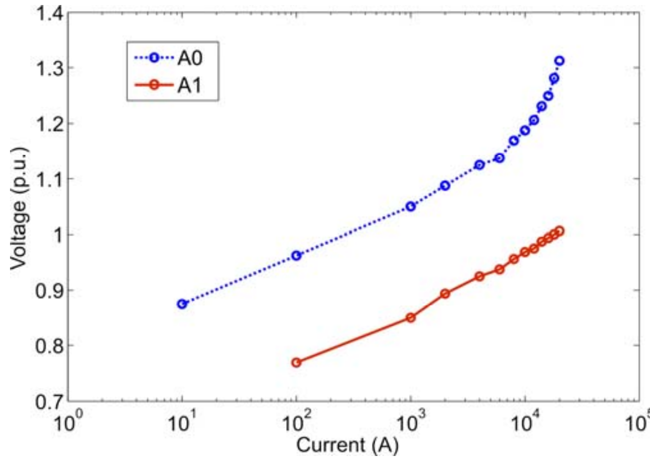

Fig. 3. Characteristic of the nonlinear elements A_0 and A_1 proposed by IEEE Working Group 3.4.11.

estimates of the parameters are suggested the following equations:

$$\begin{aligned} L_1 &= 15d/n \ (\mu\text{H}) \\ \text{R}_1 &= 65d/n \ (\Omega) \\ L_0 &= 0.2d/n \ (\mu\text{H}) \\ \text{R}_0 &= 100d/n \ (\Omega) \\ C &= 100n/d \ (\text{pF}) \end{aligned} \tag{1}$$

where:

d is the estimated height of the arrester in meters;

n is the number of parallel columns of the arrester.

A. Numerical Solution of the IEEE MOSA Model

In order to apply the proposed parameter identification technique, it is necessary to solve the circuit shown in Fig. 2 and determine $v_1(t)$ (the residual voltage), for a lighting impulse current with 10 kA ($i(t)$). This current impulse was measured in laboratory, digitalized and applied to the model.

The circuit shown in Fig. 2 was solved by the discretization of the differential equations of the elements, using the trapezoidal rule, as presented in [17]. Therefore, considering a time-step Δt, it was obtained the following equations:

$$i_{L_0}(t) = \left[v_1(t) - v_2(t)\right] / R_{L_0} + I_{L_0}(t-\Delta t), \tag{2}$$

$$i_{C_0}(t) = v_2(t) / R_{C_0} + I_{C_0}(t-\Delta t), \tag{3}$$

$$i_{L_1}(t) = \left[v_2(t) - v_3(t)\right] / R_{L_1} + I_{L_1}(t-\Delta t). \tag{4}$$

Where the equivalent resistances and the "historical" current sources calculated in previous instant of time, $t-\Delta t$, for C_0, L_0 and L_1 elements, are given by:

$$R_{L_0} = 2L_0 / \Delta t, \tag{5}$$

$$I_{L_0}(t-\Delta t) = \left[v_1(t-\Delta t) - v_2(t-\Delta t)\right] / R_{L_0} + i_{L_0}(t-\Delta t), \tag{6}$$

$$R_{C_0} = \Delta t / 2C_0, \tag{7}$$

$$I_{C_0}(t-\Delta t) = -v_2(t-\Delta t) / R_{C_0} - i_{C_0}(t-\Delta t), \tag{8}$$

$$R_{L_1} = 2L_1 / \Delta t, \tag{9}$$

$$I_{L_1}(t-\Delta t) = \left[v_2(t-\Delta t) - v_3(t-\Delta t)\right] / R_{L_1} + i_{L_1}(t-\Delta t), \tag{10}$$

The non-linear elements A_0 and A_1 presented in IEEE model were represented by the piecewise linear method, which consists in to approximate the non-linear characteristics of the resistances A_0 and A_1 by linear segments, where each segment with inclination R_{A0} or R_{A1} is modeled by a voltage source (with value equal to the linear coefficient of the segment) in series with a resistor with value equal to R_{A0} or R_{A1}. This model normally is replaced by an equivalent circuit (Norton's equivalent) composed by a current source in parallel with a resistance. In this way, the IEEE equivalent discrete circuit is shown in Fig. 4.

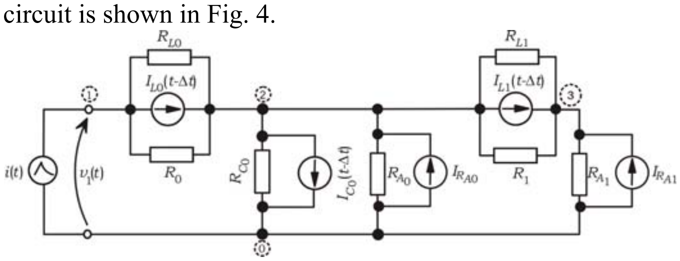

Fig. 4. IEEE equivalent discrete circuit.

In order to solve the circuit shown in Fig. 4 it was used the nodal analysis where it was obtained the following algebraic system equations, which describe the state of the system in any instant of time t:

$$\mathbf{G}\mathbf{v}(t) = \mathbf{i_c}(t) + \mathbf{I_h}(t-\Delta t)\,, \tag{11}$$

where:

$\mathbf{v}(t)$ is the vector (dimension p-1) of the unknown nodal equations, where p is the number of nodes of the circuit;

$\mathbf{G}$ is the nodal conductance matrix (p-1)×(p-1), whose elements G_{ii} are equal to the sum of the incident conductances in the node i, while the elements G_{ij} correspond to the negative of the equivalent conductance between the nodes i and j;

$\mathbf{i_c}(t)$ is the vector of p-1 dimension, whose elements correspond to algebraic sum of the known current sources connected to the evaluated node. It was adopted a positive signal to current that come in a node and negative signal in otherwise;

$\mathbf{I_h}(t-\Delta t)$ is the vector (dimension p-1) whose elements are equal to the algebraic sum of the current sources with "historical" terms. Again, it was adopted a positive signal to current that come in a node and negative signal in otherwise.

The resistances R_{A0} and R_{A1} will change the values always that the segment changes in the approximated characteristic curves of A_0 and A_1. For the analyzed circuit, $\mathbf{G}$ is given by:

$$\mathbf{G} = \begin{bmatrix} \dfrac{1}{R_0}+\dfrac{1}{R_{L_0}} & -\dfrac{1}{R_0}-\dfrac{1}{R_{L_0}} & 0 \\ -\dfrac{1}{R_0}-\dfrac{1}{R_{L_0}} & \dfrac{1}{R_0}+\dfrac{1}{R_{L_0}}+\dfrac{1}{R_{C_0}}+\dfrac{1}{R_{A_0}}+\dfrac{1}{R_1}+\dfrac{1}{R_{L_1}} & -\dfrac{1}{R_1}-\dfrac{1}{R_{L_1}} \\ 0 & -\dfrac{1}{R_1}-\dfrac{1}{R_{L_1}} & \dfrac{1}{R_1}+\dfrac{1}{R_{L_1}}+\dfrac{1}{R_{A_1}} \end{bmatrix} \tag{12}$$

The known and "historical" current sources are given by (13) and (14), respectively.

$$\mathbf{i_c}(t) = \begin{bmatrix} i(t) & I_{R_{A0}} & I_{R_{A1}} \end{bmatrix}^T. \tag{13}$$

$$\mathbf{I_h}(t-\Delta t) = \begin{bmatrix} -I_{L_0}(t-\Delta t) \\ I_{L_0}(t-\Delta t) - I_{C_0}(t-\Delta t) - I_{L_1}(t-\Delta t) \\ I_{L_1}(t-\Delta t) \end{bmatrix}. \tag{14}$$

IV. The Proposed Parameter Identification Technique

After the determination of the residual voltage $\mathbf{v}_1$ in the IEEE model using the procedure shown in the previous section, it is possible to determine the model parameters (R_0, L_0, C_0, R_1, L_1) from the values of the measured residual voltage. Usually, in these kinds of problems the goal is to minimize the errors between the measured and calculated values. In this way, the objective function is defined as following:

$$f(\mathbf{x}) = \frac{1}{2}\sum_{j=1}^{m}\left[r_j(\mathbf{x})\right]^2 = \frac{1}{2}\left\|\mathbf{r}(\mathbf{x})\right\|^2 = \frac{1}{2}\mathbf{r}(\mathbf{x})^T\mathbf{r}(\mathbf{x})\,, \tag{15}$$

where $\mathbf{r}(\mathbf{x})$ is the residual function, which is defined by:

$$\mathbf{r}(\mathbf{x}) = \mathbf{v}_m - \mathbf{v}_1\,. \tag{16}$$

In (16), $\mathbf{x}$ is the parametric vector ($\mathbf{x} = \{R_0, L_0, C_0, R_1, L_1\}$), $\mathbf{v}_m$ is the sampled residual voltage signal and $\mathbf{v}_1$ is the residual voltage signal obtained from IEEE model and calculated according to the method shown in Section III-A to a parametric vector $\mathbf{x}$.

In this way, to minimize the errors between the residual voltage measured and calculated, and therefore to minimize $f(\mathbf{x})$, it was used the Levenberg-Marquardt (LM) method. This method has global convergence characteristics [18] and it has presented reasonable results in practical situations. Therefore, the method is very used to solve nonlinear least square problems [19], as the presented here.

The LM method, initially, consists in an approximation of the objective function shown in (15) by a quadratic model, $m(\mathbf{d})$, which it is obtained by a truncated Taylor' series expansion of the $f(\mathbf{x}_0)$ around $\mathbf{x}_0$:

$$m(\mathbf{d}) \equiv f(\mathbf{x}_0) + \mathbf{d}^{\mathrm{T}}\nabla f(\mathbf{x}_0) + \tfrac{1}{2}\mathbf{d}^{\mathrm{T}}\nabla^2 f(\mathbf{x}_0)\mathbf{d}, \tag{17}$$

where $\mathbf{d} = \mathbf{x} - \mathbf{x}_0$ is the search direction of the LM method, $\mathbf{x}_0$ is initial estimate of the model parameters and $\mathbf{x}$ is new parametric vector.

The gradient ($\nabla f(\mathbf{x}_0)$) and the Hessian ($\nabla^2 f(\mathbf{x}_0)$) of $f(\mathbf{x}_0)$, normally, are expressed in terms of the Jacobian matrix of $\mathbf{r}(\mathbf{x}_0)$, which is a $m \times n$ matrix of the first order partial derivates, given by:

$$\mathbf{J}(\mathbf{x}_0) = \left[\frac{\partial r_i}{\partial x_{0_j}} \right]_{\substack{i=1,2,\ldots,m \\ j=1,2,\ldots,n}}. \tag{18}$$

In such case, the gradient and the Hessian of $f(\mathbf{x}_0)$ are given by (19) and (20), respectively.

$$\mathbf{g} \equiv \nabla f(\mathbf{x}_0) = \frac{\partial f(\mathbf{x}_0)}{\partial x_j} = \mathbf{J}(\mathbf{x}_0)^{\mathrm{T}} \mathbf{r}(\mathbf{x}_0), \tag{19}$$

$$\nabla^2 f(\mathbf{x}_0) = \frac{\partial^2 f(\mathbf{x}_0)}{\partial x_{0_j} \partial x_{0_k}} = \mathbf{J}(\mathbf{x}_0)^{\mathrm{T}} \mathbf{J}(\mathbf{x}_0) + \sum_{i=1}^{m} r_i(\mathbf{x}_0) \mathbf{r}_i''(\mathbf{x}_0). \tag{20}$$

The LM method performs two modifications in the Hessian matrix. The first one is considering that the residual $\mathbf{r}(\mathbf{x})$ is approximately linear in the vicinity of $\mathbf{x}$, so, the second term in Hessian matrix is negligible. The next modification consists in the insertion of a damping term, μ, in the Hessian approximation so that the Hessian would be positive definite and the search direction always would be a descent direction. Therefore, the Hessian matrix with the modifications above is:

$$\mathbf{H} = \mathbf{J}(\mathbf{x}_0)^{\mathrm{T}} \mathbf{J}(\mathbf{x}_0) + \mu \mathbf{I}, \tag{21}$$

where $\mathbf{I}$ is the identity matrix and μ is a constant greater than zero.

Rewriting (17) in terms of $\mathbf{g}$ and $\mathbf{H}$ it is obtained:

$$m(\mathbf{d}) = f(\mathbf{x}_0) + \mathbf{d}^{\mathrm{T}} \mathbf{g} + \tfrac{1}{2} \mathbf{d}^{\mathrm{T}} \mathbf{H} \mathbf{d}. \tag{22}$$

Performing $\nabla m(\mathbf{d}) = 0$, it is possible to find an expression to determine the new parametric vector $\mathbf{x}$ that minimize the value of $f(\mathbf{x})$:

$$\mathbf{x} = \mathbf{x}_0 - \mathbf{H}^{-1} \mathbf{g}.. \tag{23}$$

The algorithm used to determine the parametric vector $\mathbf{x}$ is based on the following steps:

1) Obtain initial estimative of the parametric vector, $\mathbf{x}_0$;

2) Supply the data of the measured residual voltage, $\mathbf{v}_m$;

3) Inform the tolerance (ε) and the maximum number of iterations ($i_{\max}$);

4) Initialize the iterations counter (i=0) and the damping term ($\mu = 10^4$, e.g.);

5) Compute $\mathbf{v}_1$ by the method shown in Section III-A;

6) Compute $\mathbf{J}$, $\mathbf{H}$, $\mathbf{r}(\mathbf{x}_0)$, $\mathbf{g}$ and $f(\mathbf{x}_0)$ by (18), (21), (16), (19) and (15), respectively;

7) While $i < i_{\max}$:
   - a) Compute the new parametric vector $\mathbf{x}$ by (23);
   - b) Compute $f(\mathbf{x})$;
   - c) If $|f(\mathbf{x}) - f(\mathbf{x}_0)| < \varepsilon$, break;
   - d) If $f(\mathbf{x}) < f(\mathbf{x}_0)$:
     - i) Divide μ by 10;
     - ii) Recalculate $\mathbf{J}$, $\mathbf{H}$, $\mathbf{r}(\mathbf{x})$, $\mathbf{g}$;
   - e) Else:
     - i) Multiply μ by 10;
     - ii) Recalculate $\mathbf{H}$;
   - f) Make $f(\mathbf{x}_0) = f(\mathbf{x})$;
   - g) Update i and return to step 7).

V. Results

The IEEE model parameters were estimated from measured data obtained in residual voltage tests for lighting current impulses performed in four metal oxide varistors (*A*1, *A*2, *B*1 and *B*2). For all cases, the proposed technique converged, i.e., it was obtained a minimizer of the problem. Due to the LM method characteristics, in some cases, it was necessary to perform a refit of the parameters to find better results. The parameters shown in Table II were used as initial guess for the IEEE model, because they yielded good results for all tests.

TABLE II
INITIAL GUESS OF PARAMETERS FOR THE IEEE MODEL.

R_0 (Ω)	L_0 (μH)	C_0 (nF)	R_1 (Ω)	L_1 (μH)
≈ 0.50	≈ 0.50	≈ 10.00	≈ 0.05	≈ 0.50

The agreement between measured and predicted residual voltage, and therefore, the quality of the fitting was verified by using R^2 statistic, which is defined as follow:

$$R^2 = 1 - \frac{SSE}{SST}, \tag{24}$$

where:

$$SSE = \sum_{j=1}^{m} \left[\mathbf{v}_m(j) - \mathbf{v}_1(j) \right]^2 \quad \text{and} \quad SST = \sum_{j=1}^{m} \left[\mathbf{v}_m(j) - \bar{\mathbf{v}}_m \right]^2,$$

in which $\mathbf{v}_m$ and $\mathbf{v}_1$ are the measured and calculated residual voltage vectors; m is the number of samples; $\bar{\mathbf{v}}_m$ is the average of the measured residual voltage; *SSE* is the sum of squares of the residuals; and *SST* is the sum of squares about the mean. When R^2 is close to 1, the quality of the fitting is the highest.

The results obtained from the parameter identification technique for each one of the evaluated varistors are shown in Table III. The varistors were submitted to lighting current impulses of 10 kA.

TABLE III
ESTIMATED PARAMETERS AND R^2 STATISTICS TO EACH VARISTOR.

Varistor	R_0 (Ω)	L_0 (μH)	C_0 (nF)	R_1 (Ω)	L_1 (μH)	R^2
*A*1	0.500	0.173	91.720	0.050	0.752	0.993
*A*2	0.724	0.263	76.740	8.675E-6	0.529	0.966
*B*1	0.500	0.366	78.410	5.586E-6	5.706	0.980
*B*2	0.500	0.474	84.360	5.198E-6	5.000	0.977

In Figs. 5 to 8 are shown the measured and fitted residual voltage waveshapes for lighting current impulses of 10 kA. The fitted waveshapes were obtained from the parameters presented in Table III.

As shown in Table III (in R^2 statistics) and in the Figs. 5 to 8 the IEEE model was fitted to the measured residual voltage with good accuracy in all the analyzed cases. It was also observed, that at least 96% of the behavior of the measured residual voltage waveshape could be explained by the IEEE model fitted with the estimated parameters shown in Table III.

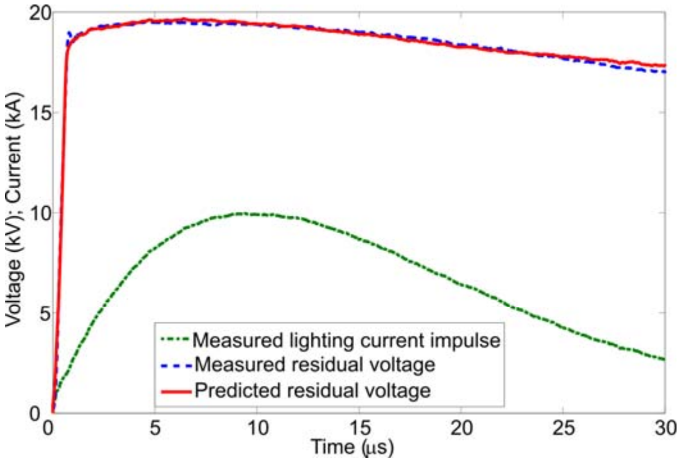

Fig. 5. Measured and fitted residual voltage waveshapes for a lighting current impulse applied to the varistor *A*1.

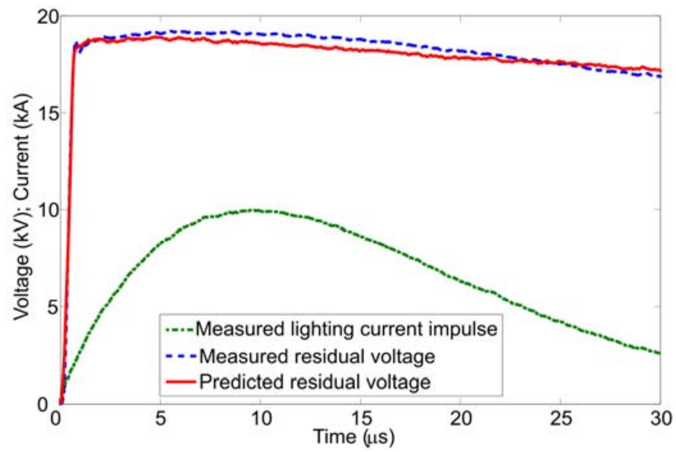

Fig. 6. Measured and fitted residual voltage waveshapes for a lighting current impulse applied to the varistor *A*2.

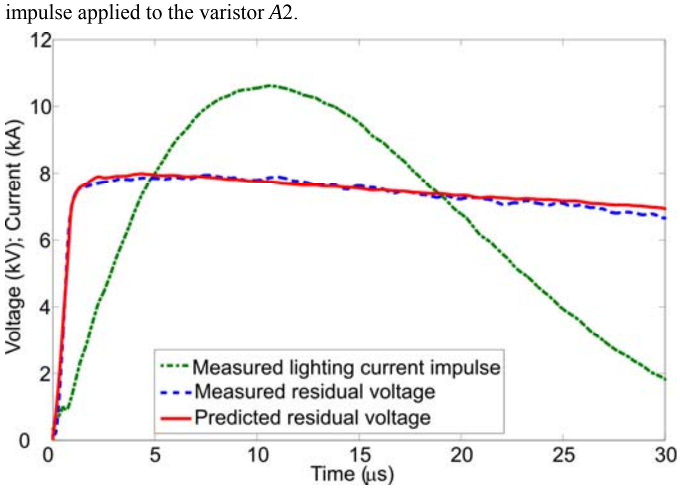

Fig. 7. Measured and fitted residual voltage waveshapes for a lighting current impulse applied to the varistor *B*1.

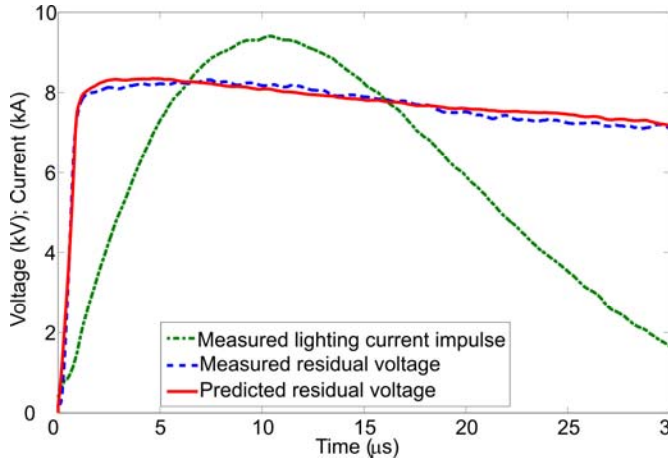

Fig. 8. Measured and fitted residual voltage waveshapes for a lighting current impulse applied to the varistor *B*2.

Now, high current impulses (4/10 μs waveshape) were applied to the IEEE model with the estimated parameters shown in Table III. Again, good results were obtained as shown in Table IV (R^2 statistics) and in Figs. 9 to 12. The R^2 statistics was greater than 90% in all the analyzed cases. Therefore, it is possible to say that, in spite of the IEEE model has been fitted to lighting current impulses, it could to represent the behavior of the surge arrester for other kind of fast transients.

TABLE IV
RESULTS FOR FITTED IEEE MODEL WHEN SUBMITTED TO HIGH CURRENT IMPULSES.

	Varistor			
	*A*1	*A*2	*B*1	*B*2
R^2	0.912	0.937	0.940	0.916

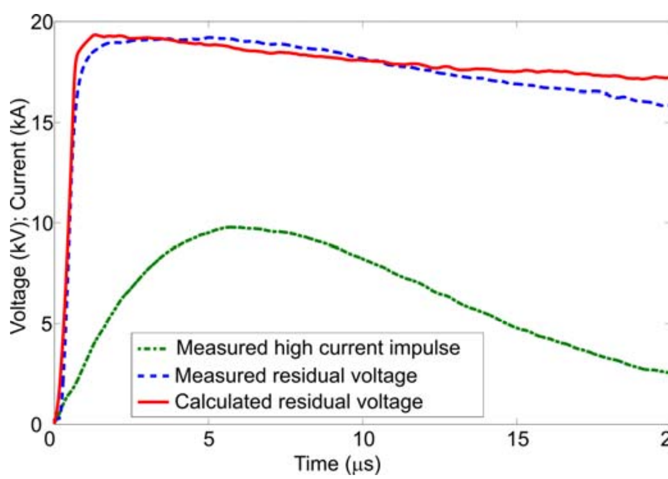

Fig. 9. Measured and computed residual voltage waveshapes for a high current impulse applied to the varistor *A*1.

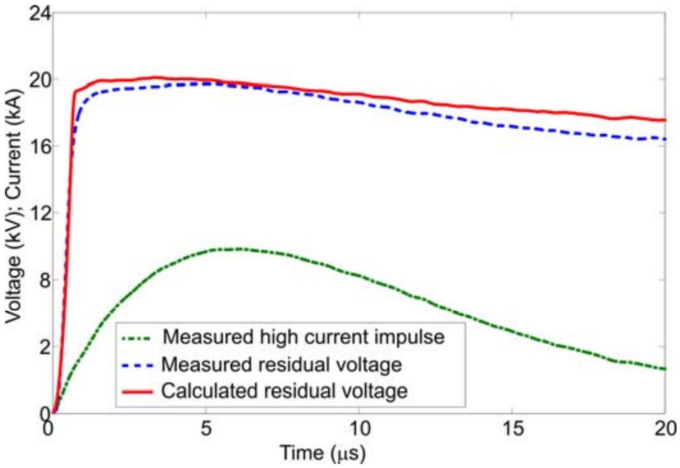

Fig. 10. Measured and computed residual voltage waveshapes for a high current impulse applied to the varistor *A*2.

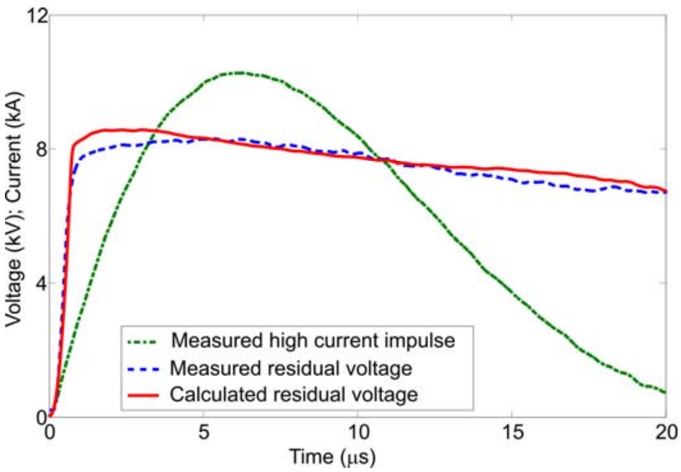

Fig. 11. Measured and computed residual voltage waveshapes for a high current impulse applied to the varistor *B*1.

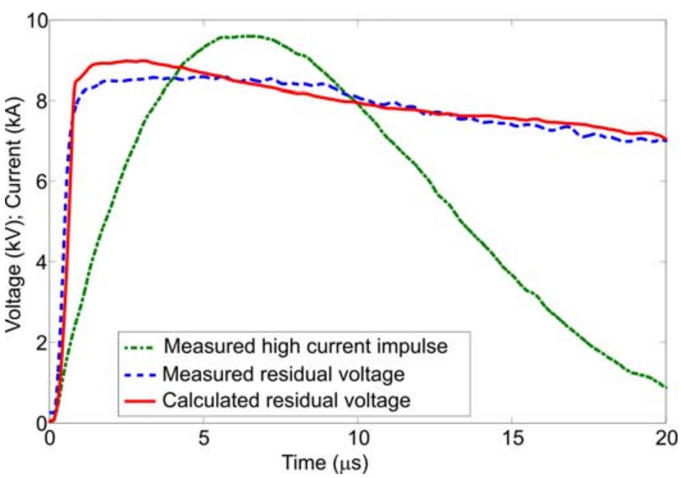

Fig. 12. Measured and computed residual voltage waveshapes for a high current impulse applied to the varistor *B*2.

Finally, it was performed a comparative study between the results obtained by the proposed technique with those obtained from the IEEE model with original adjustment procedure.

The IEEE model parameters were manually fitted for the four varistors (*A*1, *A*2, *B*1 and *B*2). In Table V and VI are shown, respectively, R^2 statistics for IEEE model with parameters identified by the original procedure, submitted to lighting current impulses and high current impulses. Comparing with the results of Tables III and IV, it is possible to verify that the parameter identification technique proposed in this paper yields more accuracy and reliable results, than the traditional adjustment procedure.

TABLE V
R^2 STATISTICS FOR THE IEEE MODEL MANUALLY FITTED WHEN SUBMITTED TO LIGHTING CURRENT IMPULSES.

	Varistor			
	*A*1	*A*2	*B*1	*B*2
R^2	0.255	0.403	0.352	0.329

TABLE VI
R^2 STATISTICS FOR THE IEEE MODEL MANUALLY FITTED WHEN SUBMITTED TO HIGH CURRENT IMPULSES.

	Varistor			
	*A*1	*A*2	*B*1	*B*2
R^2	0.395	0.304	0.517	0.673

VI. Response for Very Fast Transients

In order to test the estimated model parameters against very fast transients, the response of IEEE model was determined for a subsequent lightning return stroke. This impulsive signal was modeled by Heidler source, in ATP, with 0.5/30 μs waveshape and magnitude of 10 kA [20]. The impulse was applied to the IEEE model with the parameters obtained by the proposed technique for all the varistors. The responses of the fitted models are shown in Fig. 13.

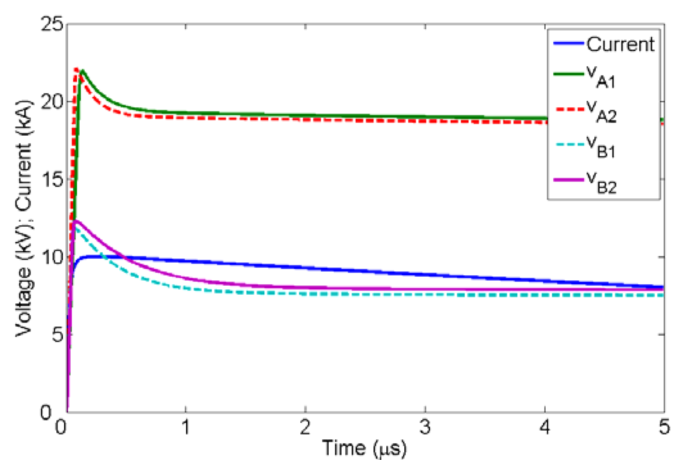

Fig. 13. Responses of the fitted models for a very fast transient.

As shown in Fig. 13, the behavior of the fitted models under a very fast transient was uniform, i.e., the waveshapes for the varistors of the same type have presented similar behavior. It was also observed an increase of the peak voltages in the obtained responses with relation to the residual voltages for lightning current impulse (shown in Figs. 5 to 8). This behavior is expected and desired for a dynamic MOSA model.

Comparisons of MOSA response for very fast transients with measured data were not yet carried out due to difficulties in reproduce this kind of transient in laboratory. However, the authors are working to supply data for studies related to the application of very fast transients in MOSA.

VII. Conclusions

In this work was presented a parameter identification technique for a dynamic metal oxide surge arrester model (IEEE model). The technique is based on the fitting of the residual voltage waveshapes measured and provided by the model for lighting current impulses (8/20 µs waveshape). The model was fitted for two kinds of metal oxide varistors. For all analyzed cases the parameter identification technique presented accurate and reliable results (R^2 statistics were greater than 0.96 in all cases).

It was evaluated the behavior of parameter identification for high current impulses (4/10 µs waveshape and amplitude of 10 kA), which are transients fastest than the lighting current impulses. Again, it was obtained good results for all the cases with R^2 statistics greater than 0.90. Therefore, it is possible to use the fitted model for lighting current impulses to other kinds of transients.

It was carrying out a comparative study between the results provided by the IEEE model with the original parameters adjustment procedure and the parameter identification technique proposed in this paper. The results obtained from the proposed technique were more accuracy and reliable than those obtained from original procedure. This was observed in the R^2 statistic values, which were between 0.25 and 0.68 for the manual parameters adjust procedure.

At last, it was simulated the response of the IEEE model with identified parameters under a very fast transient. The results obtained for the fitted model have presented an increase of the peak voltages in comparison with the residual voltages for lightning current impulse, as expected for a dynamic MOSA model.

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IX. Biographies

George R. S. Lira was born in Brazil in 1980. He received the B.Sc. and M.Sc. degrees in electrical engineering from Federal University of Campina Grande, Brazil, in 2005 and 2008, respectively. He is a Ph.D. student at the Federal University of Campina Grande, Brazil. His research interests are: high voltage, surge arresters, electromagnetic transients and optimization methods for power system applications.

Damásio Fernandes Jr. (M'05) was born in Brazil in 1973. He received the B.Sc. and M.Sc. degrees in electrical engineering from Federal University of Paraíba, Brazil, in 1997 and 1999, respectively, and the Ph.D. degree in electrical engineering from Federal University of Campina Grande, Brazil, in 2004. Since 2003, he is with the Department of Electrical Engineering of Federal University of Campina Grande. His research interests are electromagnetic transients and optimization methods for power system applications.

Edson G. Costa was born in Brazil in 1954. He received the B.Sc. and M.Sc. degrees in electrical engineering in 1978 and 1981, respectively, and the Ph.D. degree in 1999, all from the Federal University of Paraiba. Since 1978, he has been with the Department of Electrical Engineering, Federal University of Campina Grande, Campina Grande, PB, Brazil. His research interests include high voltage, surge arresters, insulators, partial discharge and electric fields.