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Modification of IEEE Model for Metal Oxide Arresters Against Transient Impulses Using Genetic Algorithms

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Abstract: Dynamic characteristics of zinc oxide arresters are of great importance in studies related to steep front impulse currents. Several models are suggested up to now for frequency analysis simulations with acceptable validity. In this paper, different electrical models which are represented for analysis of transient states, are investigated and then using simulations and comparison between experimental and simulation wave forms, a model is tried to obtain which is more similar to the reality in quantity (number of elements) and in quality (wave form). Within existing models, IEEE model is very suitable in quantity and quality but it loses its efficiency because of absence of residue voltage caused by switching current in most producers' catalogue (the test is very complex) and therefore troubles modeling of this type. In this paper, a special genetic algorithm is represented to correct IEEE model. Considering that the mentioned method represents very acceptable results in the range of current surge wave front time from 0.5 $\mu\sec$ to 45 $\mu\sec$, it is possible to reach a model with appropriate parameter values using a standard impulse (8/20 $\mu\sec$) and one other arbitrary wave with try and error method and finally by stating correcting method for IEEE model, related results are investigated and compared with other models.

Key words: Metal oxide arresters, Dynamic characteristic, residue voltage, Genetic algorithm.

INTRODUCTION

Usage of metal oxide arresters (or zinc oxide ZnO) in today's technological world is very common to protect capacitor banks and transformers against over voltages. For this reason, correct and accurate understanding about zinc oxide arresters' treatment in the grid requires correct simulations in simulator software's. There have been represented so many papers about arresters modeling (Danielm 2001; Ravinda and T.V.P. Singh, 2002; Dr. Ahmad Zahedi, 1994; Meshkatoddini *et al.*, 1993; Popov *et al.*, 2002; Diaz *et al.*, 2001; IEEE Working Group, 1992; Li *et al.*, 2002; Fernandez and Diaz, 2001) and (Pinceti and Giannettoni, 1999; Ikmo Kim *et al.*, 1996), which each of them have used different parameters for simulation. Initially, the modeling was done just by one nonlinear resistor because of completely nonlinear characteristic of varistor disc. Then high frequency spectrums in transient state analysis caused leakage capacitors to be under attention. This point confirmed by crystal structure of varistors. In investigation about the waveforms of the residue voltage and arrester current, delay between the peaks of voltage and discharge current lead to an inductance series to the system. This inductance resulted correct answers only in a limited range of transient waves, therefore other models were developed by D.W. Durbak and IEEE work team. IEEE model is an appropriate model which loses its applicability greatly by absence of the switching voltage in the most of producers' catalogues (caused by hardness of testing) and troubles modeling of this type. So other models which are based on it are represented (Diaz *et al.*, 2001; Pinceti and Giannettoni, 1999; Ikmo Kim *et al.*, 1996). In this paper, a solution is represented to solve this problem based on IEEE W.G. 3.4.11 work group claims. Considering the acceptable results of this model for transient waves with time to crest 0.5 to 45 $\mu\sec$, it is possible to obtain a model with suitable parameters by try and error method using a standard impulse (8/20 $\mu\sec$) with an arbitrary wave form.

The Model Represented by IEEE W.G.3.4.11:
Frequency Model for Lightening Waves and Steep Front Impulse Currents:

IEEE Work Group 3.4.11 has revised some methods of modeling metal oxide arresters to model arrester. Discharge voltage's experimental data and accessible currents of metal oxide arresters showed work group that the metal oxide arresters has dynamic characteristics similar to what can be seen in Figure 1 which is interesting for studies about lightening and other steep front waves. The model investigated by the group was a frequency dependent one in a way that the arrester was composed of two nonlinear parts A_0 and A_1 which were detached by a RL filter. For impulse waves with slow front waves, this RL filter had very low impedance and two parts was getting parallel to each other and for steep front waves the RL filter impedance was getting highlighted and in a way that the current passing through A_0 was greater than the other one. Therefore characteristic for A_0 has higher voltage than A_1 for a constant current. This can be seen in Figure 2.

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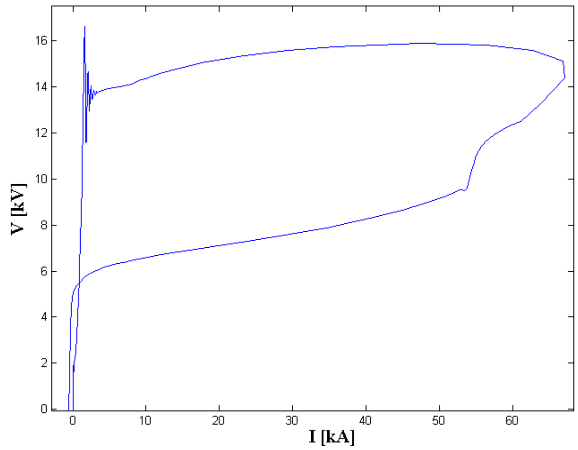
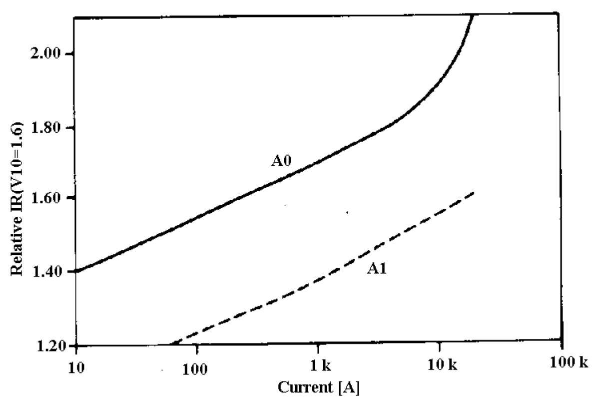
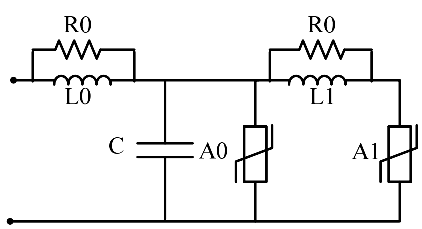


Fig. 1: Dynamic characteristic of zinc oxide arresters.



(I)

Fig. 2: V-I characteristic for nonlinear resistors part of the model.



(II)

Fig. 3: Frequency characteristic of metal oxide arrester.

Represented model is completely symphonic with the treatment of a metal oxide arrester which shows much more discharge voltage for the steep front waves. Even it is possible to construct more advanced parts using RL filters. Having these altogether, just two-part models was investigated by work group because of great relation of it with experimental data. This model represents very satisfying results for waves with time to crest of 0.5 to 45 $\mu \sec$.

Choosing Frequency Model Parameters:

d : Approximate height of the arrester.

n : Number of parallel shafts of discs.

L_1, R_1 : RL filter parameters.

L_0 : Inductance of magnetic field around arrester.

R_0 : For convergence guarantee of calculations.

C : External capacitor between two arrester terminals.

$$L_1 = 15\, d/n \qquad R_1 = 65\, d/n$$
$$L_0 = 0.2\, d/n \qquad R_0 = 100\, d/n \tag{1}$$
$$c = 100\, n/d$$

Step 1: Using stated formulas to obtain initial values.

Step 2: Adaptation of per-unit values for curves A_0 and A_1 to reach to an acceptable adaptation with discharge voltages represented by producer for current switching waves with rise time more than 45 $\mu\sec$.

Step 3: Adaptation of L_1 to reach adaptation between arrester discharge voltage for impulse current 8/20 $\mu\sec$. This adaptation is done using a repeat and interpolation with acceptable error percentage.

Curves in the Fig.5 are used to determine initial values for nonlinear resistors A_0 and A_1. To do so, first discharge voltage (V_d) is obtained using the equation below for each nonlinear resistor.

$$V_d\ [\text{kV}] = \text{IR} \times \text{V10} / 1.6 \tag{2}$$

Correction of IEEE Modeling Method:

Based on what mentioned, IEEE model is a very appropriate model in quality and quantity, but loses its efficiency in the absence of switching voltage in most producers catalogues. In this paper, a solution is represented to solve this problem based on IEEE 3.4.11 Work Group claims. Considering the acceptable results of this model for transient waves with time to crest of 0.5 to 45 $\mu\sec$, it is possible to reach a model with suitable parameters by try and error method using a 8/20 $\mu\sec$ wave form with another wave form different of 8/20 $\mu\sec$ with arbitrary amplitude and front and tail time. First using previous formulas, values for parameters are being determined. Then L_1 is being adjusted for 8/20 $\mu\sec$ wave and finally nominal voltages of nonlinear resistors A_0 and A_1 are being determined based on arbitrary waveform. Two cases are possible to happen:

1) Values for L_1 are increasing and for U_n are decreasing or Vice-Versa. It means that one has negative error percentage and the other has positive one. In this case, the loop is convergent. We continue L_1 adjustment loop and nominal voltage adjustment in order to reach appropriate values. One percent error value seems to be acceptable.
2) Values for L_1 and U_n are both increasing or are both decreasing. In this case error percentage for both of them has the same sign and related loop is divergent. This confirms that the nominal voltage is suitable. Then U_n is being accepted and L_1 is being determined for both waves and appropriate value is being defined using interpolation in a way that the residue voltage of both waves bears the least error.

Try and error method may be time consuming somehow and in some cases leads to divergence. To solve this, a special genetic algorithm is being used in this case.

Used Genetic Algorithm for Model Correction:

In the applied genetic algorithm, all existing operators such as cross over, mutation and elitism are assumed. Diagram for the algorithm is shown in Figure 4. Related simulations are done by Simulink as Figure 5. For simulation validity, negative and zero values are denied.

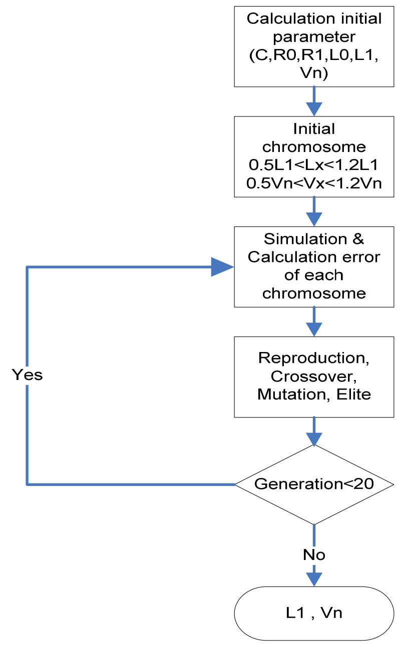


Fig. 4: Diagram for used algorithm.

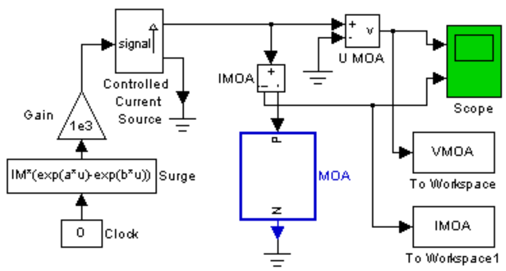


Fig. 5: Imposing impulse wave to determine model parameters.

Simulation Results:

Here simulation results done using Matlab and PSCAD and also experimental real wave forms for discharge voltage test done on a varistor of Tous Co. based on IEEE C62.11 are represented and compared in quality and quantity. Related experimental circuit and experimental results are shown in Figures 6 and 7.
Then a comparison between complete arresters is done only based on residue voltage peak. The varistor which is used to be modeled has general characteristics as below:

- Nominal Current: 10 kA.
- Dimensions[$^{m}m^{2}$](Diameter$\times$Height):30$\times$50.
- Residual voltage at 10 kA current surge with a 8/20 μsec shape is equal to 11.47 kV.
- Residual voltage at 10 kA current surge with a 4/10 μsec shape is equal to 12.14 kV.
- Residual voltage at switching current with a 250/2500 μsec shape is equal to 6.8 kV

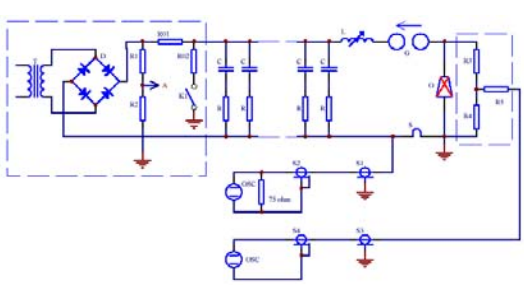


Fig. 6: Experimental circuit.

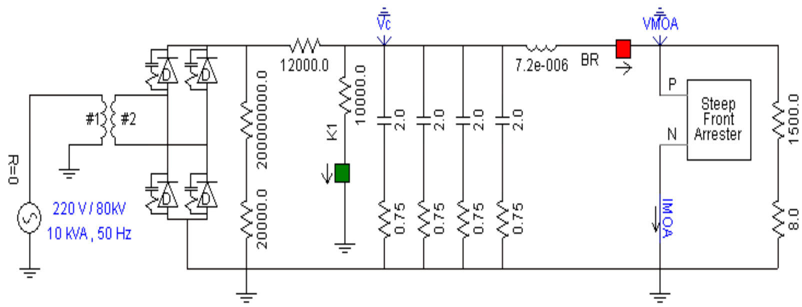


Fig. 7: Simulation of the circuit in PSCAD.

Results of experiments and simulations are shown in Fig.8 and Fig.9. In the obtained wave form from experiment, time scale for the current is two times more than the voltage. (2.5 against 5 $\mu s/Div$).

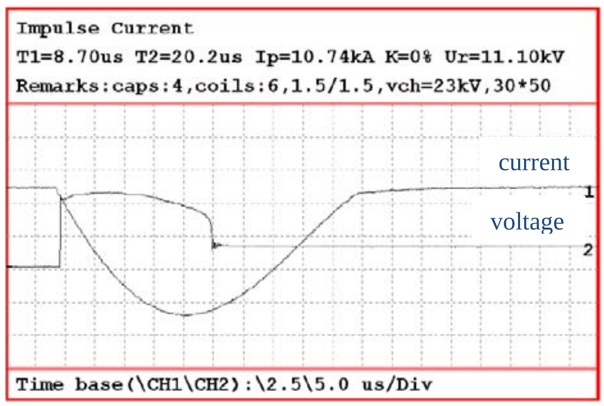


Fig. 8: Resulted experimental curves.

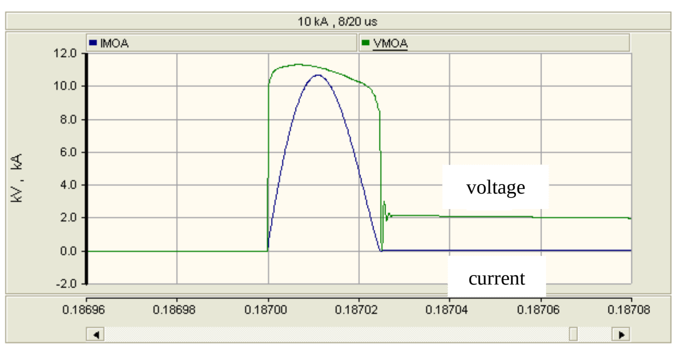


Fig. 9: Resulted simulation waveforms using PSCAD for IEEE model.

Table 1: Comparing real wave values with the values resulted from simulating corrected model

Model	U_r[kV]	Voltage Wave		$\Delta t[\mu s]$	t_d[μs]	Er%
		t_1[μs]	t_2[μs]			
IEEE (8/20)	11.30	7.5	25	3.5	2.5	1.05
w × e%	1.80	1.18	0.2	1.67	-0.01	
Modified (8/20)	11.33	6.5	25	4	3	1.75
w × e%	1.8	2.35	-0.2	3.33	0.01	
IEEE (4/10)	15.79	3	9	2	1	4.2
w × e%	-6.7	1.43	3.33	3.33	0	
Modified (4/10)	15.83	3	9	2	1	4.13
w × e%	-6.67	1.43	3.33	3.33	0	

We investigate resulted waveforms in quality and quantity using definitions below:

$Ur[kV]$: Residual voltage peak.
$t_1[\mu s]$: Voltage wave front time.
$t_2[\mu s]$: Voltage wave tail time.
Δt : Time delay of current peak to voltage peak.
$t_d[\mu s]$: Damping time for voltage wave oscillations.
$e\%$: Error percentage for each parameter.
w : Special weight of error which is assumed 1 for voltage and current peak and is assumed 0.001 for damping time and oscillation frequency and 0.1 for all residues.

$Er\%$: General error percentage which is similar to a definition in (Data taken from the PSCAD(EMTDC) default Surge Arrester, 2003) and could be calculated as below:

$$Er\% = \sqrt{\frac{1}{N}\sum_{j=1}^{N}(w \times e_j)^2} \tag{3}$$

Investigation on Discharge Energy of Each Model:

In this part, all models are being compared based on discharge energy or in other words the era under voltage or current curves.

Calculation of the surface is complex; therefore the experimental formula mentioned in (Penchenat, 1992) is used:

$$W = k \times V_{\max} \times I_{\max} \qquad [Joules] \tag{4}$$

In which $I_{\max}$ and $V_{\max}$ are discharge current peak (KA) and residue voltage peak (KV) respectively and constant K is assumed 20.8 for 8/20 $\mu\sec$ wave and 10.4 for 4/10 $\mu\sec$ wave.

Table 2: Unloaded energy into the earth by each model (Joule).

Model	8/20 $\mu\sec$	4/10 $\mu\sec$	*Er%*
IEEE	2512	10779	0.94
e%	1.33	-0.05	
Modified IEEE	2512	10783	0.94
e%	1.33	-0.01	
Real Value	2479	10784	

Conclusion:

The model represented by IEEE 3.4.11 Work Group is a very good model which results acceptable current and voltage waveforms in quality and quantity. In the case that the residue voltage caused by switching current is not determined accurately, IEEE model loses its efficiency. Based on the obtained tables and acceptable results, it can be seen that the modeling via corrected method is applicable.

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