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Analysis of MOV Surge Arrester Models by using Alternative Transient Program ATP/EMTP

Vishal R. Rakholiya
PG Scholar
Department of Power System Engineering
UBDTCE, Davangere, India

Dr. H. R. Sudarshana Reddy
Professor
Department of Electrical & Electronics Engineering
UBDTCE, Davangere, India

Abstract

Transient over voltages that happen in the power system are the major factor of equipment harm in the electrical system. One of defensive device which can diminish the lightning impact, protect high and medium voltages of system device under switching overvoltage or lighting is metal oxide surge arrester (MOSA). Frequency-dependent characteristic of arrester have been simulated by IEEE, Pinceti and Fernandez & Diaz models. The models parameters were calculated by using trial and error method in the ATP/EMTP software. Results suggest that the Pinceti model gives better residual voltage responses compared to other models. In addition, the Fernandez & Diaz model is the best surge arrester model particularly with respect to the quenching time.

Keywords: Transient over voltages, Metal Oxide Surge Arrester and Alternative Transient Program (ATP/EMTP)

I. INTRODUCTION

Metal Oxide Surge Arrester (MOSA) is a basic device which can be used to protect equipment against lightning or internal and external overvoltage condition. Overvoltage may damage and failure of electrical equipment or cause supply disturbance and other serious damages in the power system. Sometimes overvoltage occurs on system because of lightning strikes which may then give the difficulty to the functioning of equipment. So, it's very important thing to know about overvoltage protection. Sudden changes in operating conditions of the electrical network can produce switching and temporary overvoltage. Transient which is occurs when the electrical network is changed because of switching of fault conditions cause switching overvoltage. These phenomena will usually cause high oscillation and damped sinusoidal of response in the network. The overvoltage range of frequency varies from a few hundred Hz to kHz. Disconnection of the load may cause temporary overvoltage or steady-state overvoltage power frequency in steady-state voltages of power system frequency. The detail study of overvoltage may include the study of its shape, magnitude and frequency, duration.

By Here this work is depends on main causes of over voltages in power system which are switching and lightning. The occurrence of over voltages in system may damage the insulation of lines and equipment's. To protect insulations and equipment from the damaging effect because of overvoltage, metal oxide surge arresters have been used. Because of dynamic performance of the surge arresters, we cannot simulate by using non-linear resistors. Therefore, different models are introduced for simulate the dynamic behaviour of surge arresters. In this literature, to determine surge arrester parameters, a novel algorithm has been proposed and then a comparison of IEEE and Pinceti model done. IEEE and Pinceti models are the main models which used to simulate surge arrester's dynamic performance [1].

Metal oxide surge arrester is fundamental element of protecting device that can protect against overvoltages. In developing models to represent the behaviour of a metal oxide surge arrester to lightning current, it is important to take into account the dynamic behaviour of metal oxide surge arrester. It is called accurate non- linear V-I curve. Even though several models have been analysed, the model with improved accuracy is still sought after. In this paper, an approach is to analyse models that can characterize the behaviour metal oxide surge arrester with series gap. To carry out simulation of metal oxide surge arrester using ATP/EMTP and to evaluate the performance of metal oxide surge arrester models.

II. METHODOLOGY

Some of previously published models which are IEEE, Pinceti and Fernandez and Diaz model will be discussed in this section.

A. IEEE Model

Figure 1 shows the surge arrester model proposed by the IEEE Working Group 3.4.11 [2]. It has two nonlinear elements known as A_0 and A_1 separated by R_1-L filter. A capacitor gives the external capacitance related with the height of the arrester. The stability can be improved by adding an inductance Lo (connected in parallel with resistance R_0). For the fast rising current, the impedance of RL filter becomes more significant which means current passes through the non-linear branch A_0.

So, A_0 has a higher voltage than A_0. The model of arrester will generate higher voltages which then match the dynamic behaviour of metal oxide surge arrester. This model is shown in figure 1.

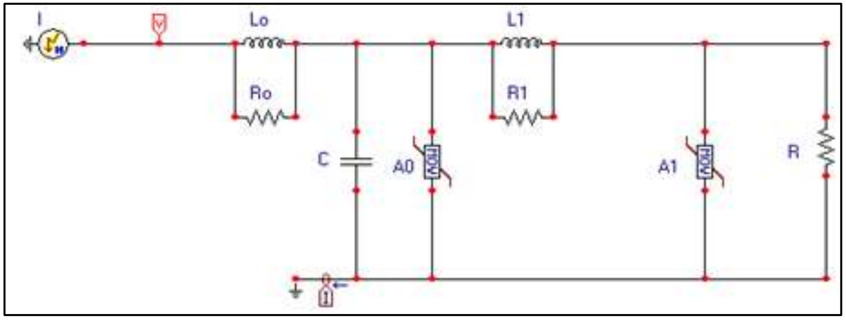

Fig. 1: IEEE Working Group model

Equations (1-5) show the parameter and V-I characteristic of varistor given in ref. [2]. The A_0 and A_1 nonlinear characteristic of V-I characteristic is shown in figure 2.

$$L_0 = \frac{0.2d}{n} \ \mu H \tag{1}$$

$$R_0 = \frac{100d}{n} \Omega \tag{2}$$

$$L_1 = \frac{15d}{n} \ \mu H \tag{3}$$

$$R_1 = \frac{65d}{n} \Omega \tag{4}$$

$$C = \frac{100d}{n} \ pF \tag{5}$$

Where;
n = Total number of parallel columns in metal-oxide (MO) disks.
d = Length of arrester columns in metre (m).

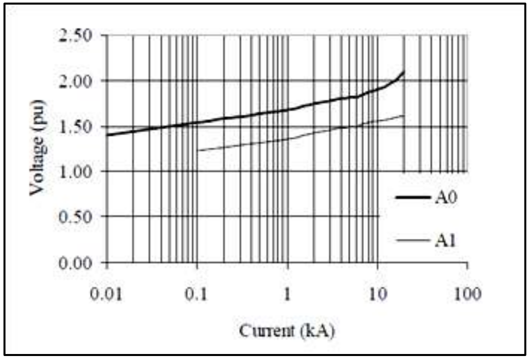

Fig. 2: Nonlinear V-I characteristic for A_0 and A_1

B. Pinceti Model

Here pinceti model is related to IEEE model, but a few modifications are done in model [3]. The difference is that no capacitance between the one terminal to other terminal and nonlinear resistance A_0. As shown in figure 3 at input terminal; R is replaced by nearly about 1MΩ resistance. The higher value of R is used to avoid numerical oscillation. Nonlinear resistance values are based on [2]. Inductances L_0 and L_1 are calculated using equation (6, 7).

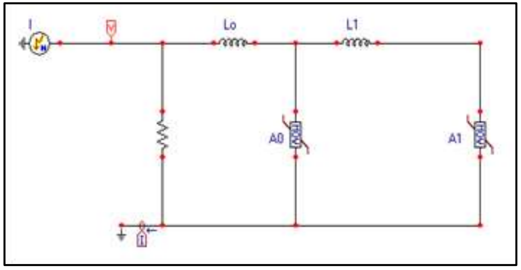

Fig. 3: Pinceti Model

$$\mathrm{L_0} = \frac{1}{12} \cdot \frac{\mathrm{V_{r1/T2}} - \mathrm{V_{r8/20}}}{\mathrm{V_{8/20}}} \mathrm{V_n}\ \ \mu\mathrm{H} \qquad (6)$$

$$\mathrm{L_1} = \frac{1}{4} \cdot \frac{\mathrm{V_{r1/T2}} - \mathrm{V_{r8/20}}}{\mathrm{V_{8/20}}} \mathrm{V_n}\ \ \mu\mathrm{H} \qquad (7)$$

Where;
V_n= Arrester’s rated voltage
V_{r1/T_2} = Residual voltage at 10kA fast front current surge ($1/T_2\ \mu s$)
$V_{8/20}$ = Residual voltage value at 10kA current impulse surge with $8/20\ \mu s$ shape
The advantage of this model is there is no need to consider any physical characteristic but only manufacturer datasheet required. For equations (6) and (7) are based on the fact that parameter L_0 and L_1 are related to the model. The importance of the inductance is to characterize the model behaviour on fast front surge.

C. *Fernandez and Diaz*

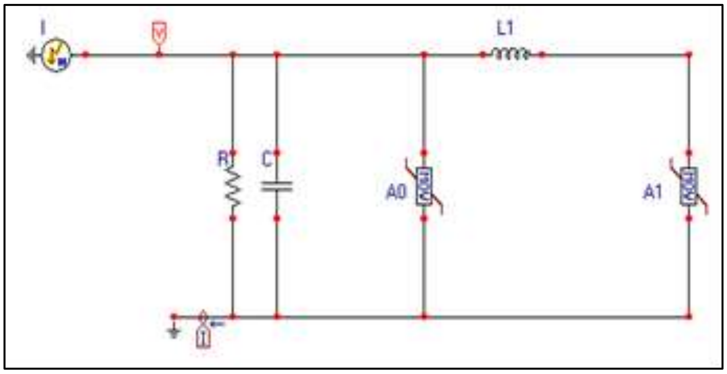

Fig. 4: Fernandez and Diaz model

Fernandez and Diaz model is also based on the IEEE model. In Fernandez and Diaz model A_0 and A_1 are separated by L_1 and L_0 is neglected. This figure is shown in figure 4. Capacitance is included in this model and it represents terminal to terminal capacitance of arrester [4].

The advantage of this model is that it does not need the iterative procedure. V-I (curve) characteristic for A_0 and A_1 are calculated using manufacturer’s datasheet. For the resistance, it is assume as 1MΩ to avoid numerical oscillation or to limit the current in circuit. Computation of parameter for procedure is given in ref. [5]. Inductance L_1 and capacitor is given as:

$$\mathrm{L_1} = \frac{1}{5} \cdot \frac{\mathrm{V_{r8/20}} - \mathrm{V_{30/60}}}{\mathrm{V_{8/20}}} \mathrm{V_n}\ \ \mu\mathrm{H} \qquad (8)$$

$$\mathrm{C} = \frac{1}{55} \cdot \frac{\mathrm{V_{r8/20}} - \mathrm{V_{30/60}}}{\mathrm{V_{8/20}}} \mathrm{V_n}\ \mathrm{pF} \qquad (9)$$

Where;
V_n = Arrester rated voltage.
$V_{r8/20}$ = Residual voltage at 10kA current surge.
$V_{30/60}$ = Residual voltage at 1kA.

III. DETERMINING V-I CHARACTERISTIC DATA FOR ALL MODELS

The data on surge arrester V-I characteristic was provided by IEEE working group 3.4.11 [2]. This dissertation is to calculate V-I characteristic from the sample of the IEEE working group. The manufacturer datasheet with Pexlim-P96 was chosen to simulate the nonlinear V-I characteristic. Table 1 shows the manufacturer datasheet of Pexlim-P96 with various lightning surge currents.

Table - 1
Residual voltage for surge arrester in manufacturer datasheet

Type of surge arrester	*Rated voltage (kV)*	*Residual Voltage With Different Waveforms for Discharge Current Values in kV*					
		1/5µs	*8/20µs*			*30/60µs*	
		10 kA	*5 kA*	*10 kA*	*20 kA*	*1 kA*	*2 kA*
Pexlim P96	*96*	*232*	*208*	*219*	*240*	*188*	*194*

Selected current was chosen from non-linear resistor V-I characteristics point with reading of IR in per-unit (pu). Then, this value was multiplied with ($V_{10}/1.6$) to calculate the discharge voltage of the arrester. Conversion from pu to actual voltage can be done by following formula (10, 11) is shown in table 2.

For A0, voltage kV= (Voltage in pu) × ($\mathrm{V_{10}}/1.6$) (10)
Same with A_1, voltage kV= (Voltage in pu) × ($\mathrm{V_{10}}/1.6$) (11)

Table - 2
Voltage Current (V-I) values for nonlinear resistor A_0 and A_1 in IEEE, Pinceti and Fernandez & Diaz model

Curve A_0			*Curve A_1*		
I (kA)	*V (PU)*	*V (kV)*	*I (kA)*	*V (PU)*	*V (kV)*
0.01	*1.40*	*191.62500*	*0.1*	*1.23*	*168.35625*
0.1	*1.54*	*210.78750*	*1*	*1.36*	*186.15000*
1	*1.68*	*229.95000*	*2*	*1.43*	*195.73125*
2	*1.74*	*238.16250*	*4*	*1.48*	*202.57500*
4	*1.80*	*246.37500*	*6*	*1.50*	*205.31250*
6	*1.82*	*249.11250*	*8*	*1.53*	*209.41875*
8	*1.87*	*255.95625*	*10*	*1.55*	*212.15625*
10	*1.90*	*260.06250*	*12*	*1.56*	*213.52500*
12	*1.93*	*264.16875*	*14*	*1.58*	*216.26250*
14	*1.97*	*269.64375*	*16*	*1.59*	*217.63125*
16	*2.00*	*273.75000*	*18*	*1.60*	*219.00000*
18	*2.05*	*280.59375*	*20*	*1.61*	*220.36875*
20	*2.10*	*287.43750*			

A. Final Parameters of Each Model

The modelling and selecting parameter of metal oxide surge arrester model for one column arrester and 96 kV rated voltage with an overall length of arrester of 1 meter. The discharge voltage, V_{10}, for this arrester is 219 kV and switching discharge voltage, V_{SS} for 1kA, $30/60\ \mu sec$ is 188kV. The final parameter of the surge arrester model is shown in table 3.

Table – 3
Final parameter of each model

Model	*L_0 (μH)*	*L_1 (μH)*	*R_0 (Ω)*	*R_1 (Ω)*	*C (pF)*
IEEE	*0.2*	*15*	*100*	*65*	*100*
Pinceti	*0.475*	*1.425*	*100000*	*-*	*-*
Fernandez and Diaz	*-*	*2.178*	*100000*	*-*	*0.247*

IV. RESULTS

Simulation results for IEEE, Pinceti and Fernandez & Diaz model were analysed. Two important things are the peak of residual voltage and the quenching time for each model. The absolute error for each model is based on peak residual voltage simulation result and manufacturer datasheet. Simulations of the behaviour of lightning arrester by various magnitude current surges were done. Results are compared with manufacturer datasheet.

The simulation results calculated for each model are compared with the data provided by manufacturer. The relative error is calculated (Table 4) by using equation (12):

$$\text{Error(e)} = \frac{\text{V}_{\text{r simulation}} - \text{V}_{\text{r manufacturer}}}{\text{V}_{\text{r manufacturer}}} \times 100\ \% \qquad (12)$$

Where; $V_{r\ simulation}$ is the residual voltage value from the simulation and $V_{r\ manufacturer}$ is the residual voltage value provided in the manufacturer's datasheet.

Figure 5 shows residual voltage for 10kA steep current impulse ($1/5\mu s$) and figure 6, 7, 8 shows residual voltage for lightning current impulse ($8/20\mu s$) at different magnitude current surge that 5 kA, 10 kA and 20 kA. Table 4 shows residual voltage with absolute error for each model. All simulated models seem to be efficient and produce almost same residual voltage.

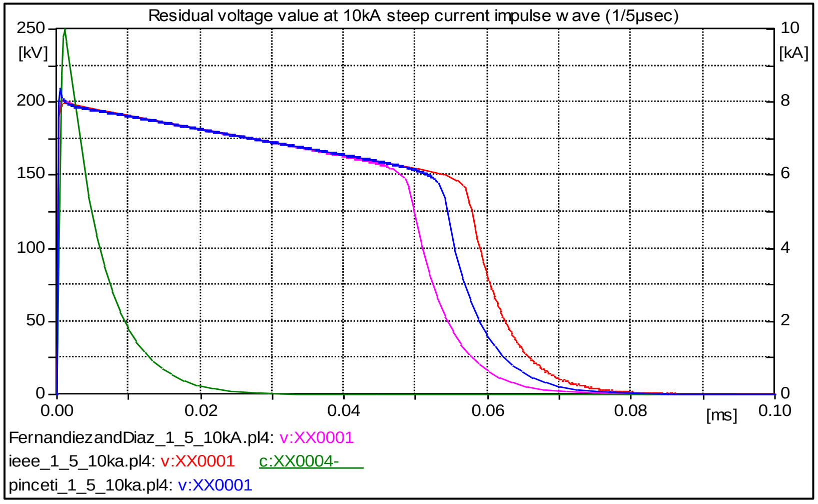

Fig. 5: Residual voltage value at 10kA steep current impulse wave (1/5µsec)

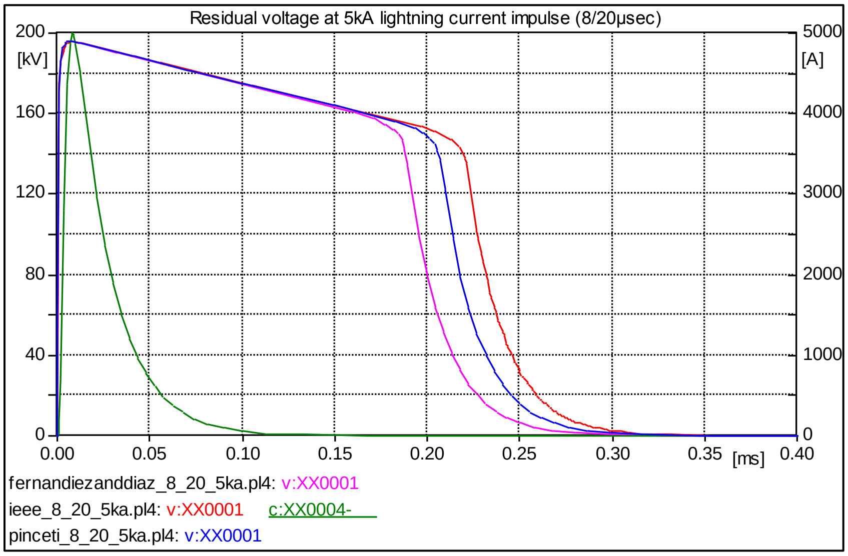

Fig. 6: Residual voltage at 5kA lightning current impulse (8/20µsec) in all models

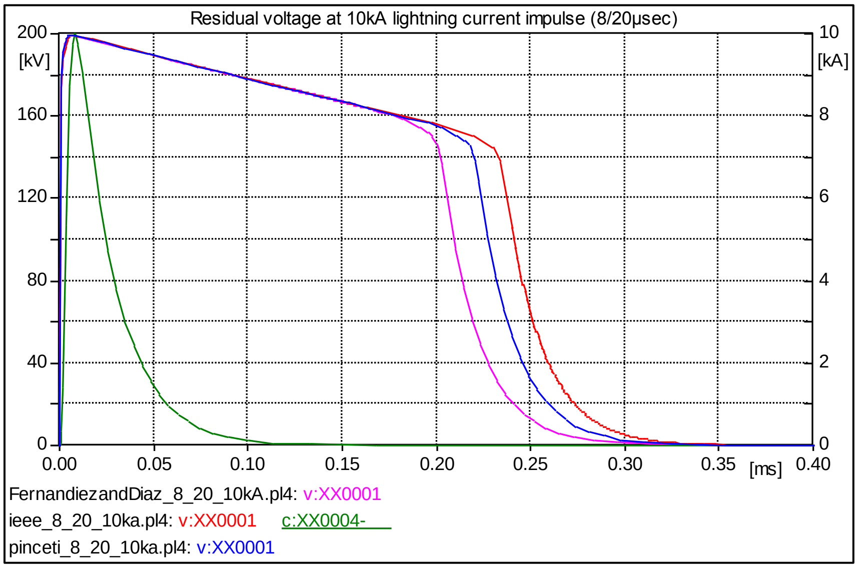

Fig. 7: Residual voltage at 10kA lightning current impulse (8/20µsec) in all models

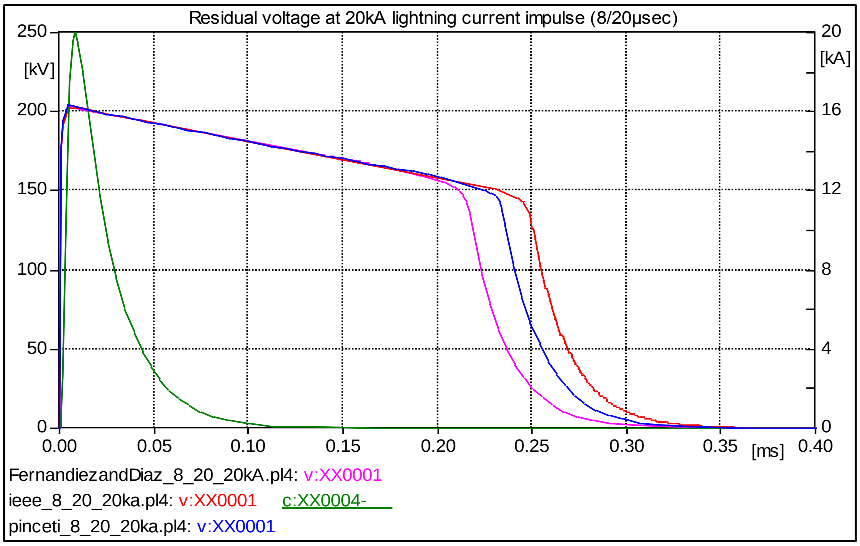

Fig. 8: Residual voltage at 20kA lightning current impulse (8/20µsec) in all models

Table – 4
Residual voltage with absolute errors for each model

Model	*Residual Voltage With Different Waveforms for Discharge Current Value and Absolute Errors*							
	1/5μs		*8/20μs*					
	10 kA		*5 kA*		*10 kA*		*20 kA*	
	Voltage (kV)	*Error (%)*	*Voltage (kV)*	*Error (%)*	*Voltage (kV)*	*Error (%)*	*Voltage (kV)*	*Error (%)*
IEEE	*199.141*	*14.163*	*195.718*	*5.905*	*199.136*	*9.070*	*202.619*	*15.575*
Pinceti	*202.285*	*12.808*	*195.803*	*5.863*	*199.549*	*8.881*	*204.047*	*14.980*
Fernandez and Diaz	*201.197*	*13.277*	*195.798*	*5.866*	*199.456*	*8.924*	*203.441*	*15.232*

Figure 5 shows residual voltage for 10kA steep current impulse (1/5μs) and figure 6, 7, 8 shows residual voltage for lightning current impulse (8/20μs) at different magnitude current surge that 5 kA, 10 kA and 20 kA. Table 4 or figure 9 shows residual voltage with absolute error for each model. All simulated models seem to be efficient and produce almost same residual voltage.

From table 4 or figure 9, error in each model is nearly same for different lightning surge current. From figure 9, it is notable that the error between the residual voltage of simulation and manufacturer datasheet with different lightning current were reduced mainly during lightning current impulse 5 kA and 10 kA. For a lightning current of 5 kA, it shows the IEEE, Pinceti and Fernandez & Diaz model give an error of 5.905, 5.863 and 5.866 percent.

Furthermore, in steep front, all models have the higher error compare with other current impulse. In steep front, time step in software ATP-EMTP should be chosen properly for minimizing the error.

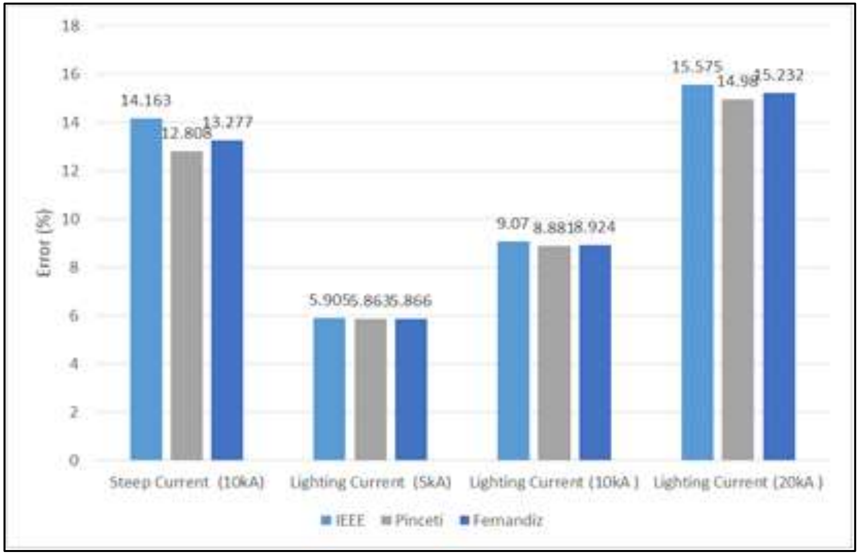

Fig. 9: Error of each model with various lightning surge current.

From figures 5, 6, 7, 8, we can show that the quenching times at the end of lightning arrester are different for each model. The Fernandez & Diaz model provides the shortest quenching time compared with other models. To give lightning arrester more reliability, the quenching time requires being as small as possible. When the voltage is directly eliminated, less energy absorption and thermal stress occur. Based on Modrusan and R. Diaz [7], the optimal real value of quenching time of lightning current is almost the same with the quenching time of the residual voltage of the measurement through experiment. Besides, the residual voltage is dependent on the rise time. The voltage will increase when the rise time decreases and the residual voltage reaches its peak before the current reaches its peak.

V. CONCLUSION

In this work, by using different impulse test a simulation of the dynamic behaviour of zinc oxide surge arrester model was done. The simulation was performed by using ATP/EMTP software. A procedure of selecting the parameter and the correlation of simulation and manufacturer datasheet to assess the models are displayed. Metal oxide surge arresters have their notable dynamic properties:

- When the front time decreases; the voltage across surge arrester increases.
- The residual voltage reaches its peak before the current reaches its crest.
- At higher amplitude current, the surge arrester exhibit shorter time to peak than at higher amplitude.

From the outcome and perception, the Fernandez and Diaz model gives profoundly agreeable results will all dynamic properties and show shortest quenching time contrasted with different models. More simulations ought to be completed toward characteristic of surge arrester to get the best metal oxide surge arrester.

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