A Review Paper on Study and Analysis of Dynamic Behavior of Surge Arrester

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Abstract — *Surge Arresters are used as protective device against lightning strokes and high voltage switching surges in power system. Dynamic behavior of various surge arrester are analyzed by modelling in ATP Draw and by selecting various system parameters. By analyzing the simulation results mainly the peak of residual voltage and the quenching time for each model is calculated. The metal oxide surge arresters cannot be modeled by only a non-linear resistance, since its response depends on the magnitude and the rate of rise of the surge pulse because the residual voltage increases as the current front time descends and the residual voltage reaches its maximum before the arrester current reaches its peak. In the current work three modes – IEEE, Pinceti-Gianettoni and Fernandez- Diaz – are examined using ATP. The residual voltage of each model, implying 5kA, 10kA and 20kA 8/20µs impulse current and 1.2 /50µs compared with the manufacturers' datasheet.*

Keywords-*ATP, MOSA, Residual voltage, Dynamic behavior, Lightning stroke*

I. INTRODUCTION

Metal oxide surge arrester is the basic element to protect equipment from overvoltage. The main purpose of the paper is to study and analyze the dynamic behavior of various surge arrester models like IEEE, Pinceti, Fernandez and Diaz with the help of software like ATP/EMTP.The parameters of the models are calculated from the manufacturer datasheet. The dynamic behavior is important for the surge arrester location and insulation coordination study.Generally, cause of damage in electrical equipment and the network occurs when lightning strike happens. The overvoltage is very dangerous for any equipment and it may cause damage or failure, unless some protective steps against this overvoltage are being taken. The overvoltage may cause many interruptions like: supply interruption, or even equipment damage.

When equipment damage cause waste of money with time. To make certain convenience with safety, we required some device which can protect devices against overvoltage in the system. Metal oxide surge arrester is fundamental crucial part of protecting device that can protect against overvoltage. Some of the important to be count into account is dynamic behavior of metal oxide surge arrester while in progressing models to represent the performance of a metal oxide surge arrester to lightning current. It is called accurate non-linear V-I curve. [9]

Different types of surge arrester like gapped silicon carbide (SiC), gapped or non-gapped metal oxide surge arrester are also used. Gapped surge arresters with silicon carbide are still in use in several countries. However, surge arresters used today are generally gapless metal oxide surge arresters (MOSA) and it has a very simple structure. It has a series connection of ZnO elements with high nonlinear resistance. The elements are in cylindrical blocks with single or multiple columns. The cylindrical block type metal oxide varistor are shown in figure 2.2. The energy absorption was calculated based on the block diameter. Generally, in distribution a system, the diameter has varies in a range within 30 mm to 100 mm in high or ultra-high voltage system or in special applications.

Metal oxide resistors have a height from 20 mm to 45 mm. During a lightning surge (e.g. current 10kA), the residual voltage per millimeter of height are 450 V/mm for distribution surge arresters down to 270 V/mm for arrester in 420kV system. The elements are stack on top of each other for metal oxide surge arrester has to be mechanically fixed in the housing. It is sure that the active part cannot be moved from original position during arrester installation. Moreover, contact pressure for a certain axis is necessary to make current stress easy to handle.

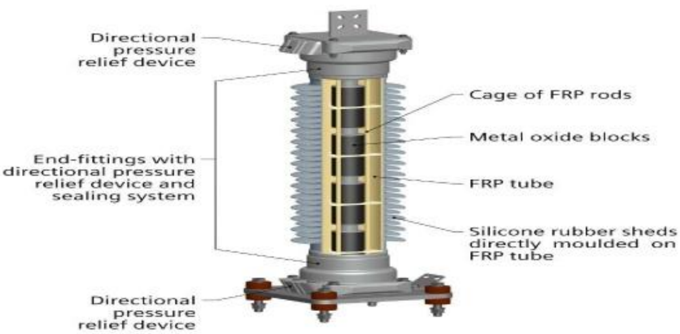

Figure 1. Metal oxide Surge Arrester Design [16]

II. V-I Characteristics of MO Surge Arresters

Dynamic effect inclines effect to become momentous to current waves which peak in the range of 8µs and faster. To obtain a certain test for faster rate of rise impulse currents, it is so difficult. Then, IEEE working group 3.4.11 [9] has restrained its effort to metal oxide surge arrester model to the current amplitude with rise times of greater than 0.5.There are three dynamic properties of metal oxide surge arrester in which voltage value across surge arrester increase as time increase; and peak of the arrester current decrease. Based on IEEE working group, the arrester can increase the residual voltage by around 6% when time to crest of discharge current is decreased from 8 µs to 1.3 µs. Second is the arrester voltage will reaches its peak before the arrester current reaches its peak [15]. Time depends zinc oxide nonlinearity is caused by decrease in time potential barrier height. It has been implies that trapping of either electron or holes in the barrier region could reason such change in barrier height. Third property is time to peak of arrester discharge current which is depending on amplitude of current.

For higher amplitude of current, the arrester achieves shorter time to peaks than low amplitude. At lower amplitude, in the high conduction region, the number of current path will be more and decreased path length compare to low conduction region. At the higher amplitude, the difficulty voltages across terminal metal oxide surge arrester (MOSA) for tending to break down intergranular layers are easy.

Usually, V-I characteristic will affect by temperature. This is because with increase in the current at given applied voltage will increase temperature since its principal lead to thermal runaway. In order to be high for thermal mass, effective field must be sufficiently low. Besides, the low effective field will cause costing are increasing because of the large quantities material is used like diameter and height of the blocks. In the lightning application, it has very large energies should be discharged through the blocks which rising temperature quickly (microsecond). This application, we can see at length at transmission line. Figure 3 shows V-I curves represent by several exponential segments by equation (2.1). Data on metal oxide varistor (MOV) can be calculated from impulse current 8/20µs wave shape. It is done to avoid the effect of heating varistor. Figure 3 shown non-linear V-I characteristic curve.

$$I=KV^{\alpha},\ \alpha < 1 \tag{2.1}$$

Where;
I = Discharge current via Metal Oxide (MO) varistor
V= Residual voltage across metal oxide varistor
k=Ceramic constant
α =Non-linearity exponent

III. The IEEE Model

Figure 2 shows the surge arrester model proposed by the IEEE Working Group 3.4.11 [9]. It has two nonlinear elements known as A_0 and A_1 separated by R_1 -L filter. A capacitor give the external capacitance related with the height of the arrester. The stability can be improved by adding an inductance Lo (connected in parallel with resistanceR_0). For the fast rising current, the impedance of R L filter becomes more significant which means current passes through the non-linear branch A_0. So, A_0 has a higher voltage than A_1.The model of arrester will generate higher voltages which then match the dynamic behavior of metal oxide surge arrester. This model is shown in figure.

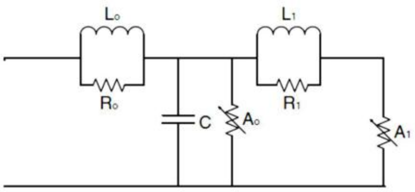

Figure 2: IEEE Working Group model

In this model, the parameters are dependents on the physical characteristic. It is based on the number of parallel columns of metal disk and the height of the lightning arrester. Equations show the parameter and V-I characteristic of varistor given in ref. [9]. The $A0$ and $A1$ nonlinear characteristic of V-I characteristic is shown in figure 3 or table 1.

$$L_0 = 0.2\frac{d}{n}\mu H \tag{2.2}$$
$$R_0 = 100\frac{d}{n}\Omega \tag{2.3}$$
$$L_1 = 15\frac{d}{n}\mu H \tag{2.4}$$
$$R_1 = 65\frac{d}{n}\Omega \tag{2.5}$$
$$C = 100\frac{n}{d}pF \tag{2.6}$$

Where;

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

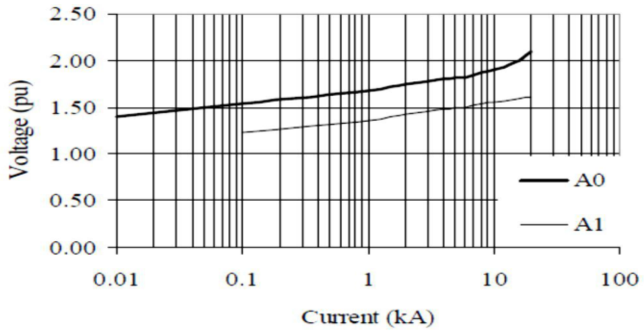

Figure 3 Nonlinear V-I characteristic for ***A0*** *and* ***A1***

Table 1: Current Voltage (V-I) value for both non-linear resistor

Curve(A_0)		Curve(A_1)	
I(kA)	**V(PU)**	**I(kA)**	**V(PU)**
0.01	1.40	0.1	1.23
0.1	1.54	1	1.36
1	1.67	2	1.43
2	1.74	4	1.48
4	1.80	6	1.50
6	1.82	8	1.53
8	1.88	10	1.55
10	1.90	12	1.56
12	1.93	14	1.57
14	1.97	16	1.59
16	2.00	17	1.60
17	2.05	20	1.61
20	2.10		

IV. THE PINCETI MODEL

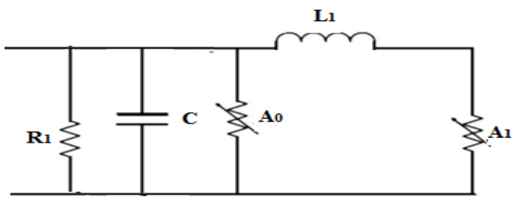

Figure 4: Pinceti Model

Here Pinceti model is related to IEEE model, but a few modifications are done in model [20]. The difference is that no capacitance between the one terminal to other terminal and nonlinear resistance. As shown in figure 4 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 [9]. Inductances $L1$ and $L0$ are calculated using equation (2.7,2.8).

$$L_1 = \frac{1}{4}\frac{[U_{r1/T_2} - U_{r8/T_2}]\,U_r}{U_{r8/T_2}}\mu H \quad (2.7)$$

$$L_0 = \frac{1}{12}\frac{[U_{r1/T_2} - U_{r8/T_2}]\,U_r}{U_{r8/T_2}}\mu H \quad (2.8)$$

Where,
Ur1/$\boldsymbol{T2}$is the residual voltage at 10 K a fast front current surge (1/T2 s)
Ur8/20 is the residual voltage at 10 kA current surge with 8/20µ s shape
R = 1 MΩ is introduced to avoid numerical instabilities.
The advantage of this model is there is no need to consider any physical characteristic but only manufacturer datasheet required.

V. FERNANDEZ AND DIAZ MODEL

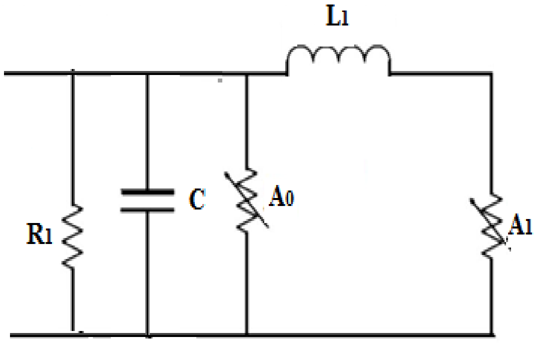

Figure 5: Fernandez and Diaz Model

Fernandez and Diaz model is also based on the IEEE model. In Fernandez and Diaz model and are separated by R and L is neglected. This figure is shown in figure 5. Capacitance is included in this model and it represents terminal to terminal capacitance of arrester [17]. The advantage of this model is that it does not need the iterative procedure. V-I (curve) characteristic for and 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. [7].
Inductance L and capacitor is given as:

$$L_1 = \frac{2/5[U_{r8/T_2} - U_{SS}]\,U_r}{U_{r8/T_2}} \text{ H} \qquad (2.9)$$

$$C = \frac{1}{55}\frac{[U_{r8/T_2} - U_{SS}]\,U_r}{U_{r8/T_2}} \text{ pf} \qquad (2.10)$$

Ur is the rated voltage
Ur8/20 is the residual voltage at 10 KA current surge with 8/20µs shape in kV
Uss is the residual voltage at 500 A current surge switching 60/2000µs or 30/60µs in kV
R1 = 1 MΩ

VI. DETERMINING V-I CHARACTERISTIC DATA FOR ALL MODELS

Table 2: Residual voltage for surge arrester in manufacturer datasheet [21]

Type of surge arrester	Rated voltage (kV)	Residual Voltage With Different Waveforms For Discharge Current Values in kV					
		1.2/50µs	8/20µs			30/60 µs	
		10 kA	5 kA	10 kA	20 kA	1 kA	2 kA
Pexlim P96	96	213	207	219	240	188	194

Selected current was chosen from non-linear resistor V-I characteristics point with reading of IR in per-unit (p.u). Then, this value was multiplied with (V_{10} ⁄1.6) to calculate the discharge voltage of the arrester.

A_0, voltage kV= (Voltage in p.u) *(V_{10} ⁄1.6) (3.1)

A_1, voltage kV= (Voltage in p.u)*(V_{10} ⁄1.6) (3.2)

Table 3: Voltage Current (V-I) values for nonlinear resistor A0 and A1 in IEEE, Pinceti and Fernandez & Diaz model

Curve A0			Curve A1		
I (kA)	V(PU)	V(kV)	I (kA)	V (PU)	V (kV)
0.01	1.40	191.62500	0.1	1.23	167.35625
0.1	1.54	210.77750	1	1.36	176.15000
1	1.67	229.95000	2	1.43	195.73125
2	1.74	237.16250	4	1.47	202.57500
4	1.70	246.37500	6	1.50	205.31250
6	1.72	249.11250	7	1.53	209.41775
7	1.77	255.95625	10	1.55	212.15625
10	1.90	260.06250	12	1.56	213.52500
12	1.93	264.16775	14	1.57	216.26250
14	1.97	269.64375	16	1.59	217.63125
16	2.00	273.75000	17	1.60	219.00000
17	2.05	270.59375	20	1.61	220.36775
20	2.10	277.43750			

Step1: Initial value of R_0, L_0, R_1, L_1 and C.
Step2: Scaling factor of V_{10} from the manufacturer datasheet are applied to metal oxide varistor of A_0 and R_1 component.
Step3: Adjustment of Voltage reference for A_0 and A_1 to matching switching surge voltage. This matching can be done trial and error until it has good match switching surge voltage of manufacturer datasheet.
Step4: The model with accurate non-linear resistor A_0 and A_1 must be tested to obtain a good match between the model $8/20$ µs injected current with manufacturer datasheet. So, Inductance L is adjusted until it has good match with datasheet.

Table 4: Final parameter of each model

Model	L0(µH)	L1(µH)	R0(Ω)	R1(Ω)	C(pF)
IEEE	0.2	15	100	65	100
Pinceti	0.475	1.425	100000	-	-
Fernandez and Diaz	-	2.177	100000	-	0.247

VII. SIMULATION AND RESULTS

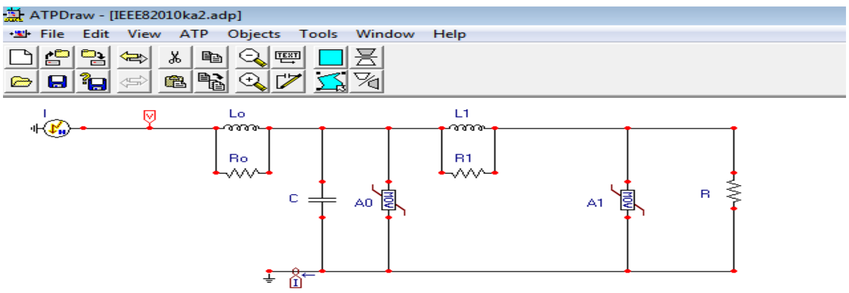

Figure 6: Test circuit of IEEE model in ATP-EMTP

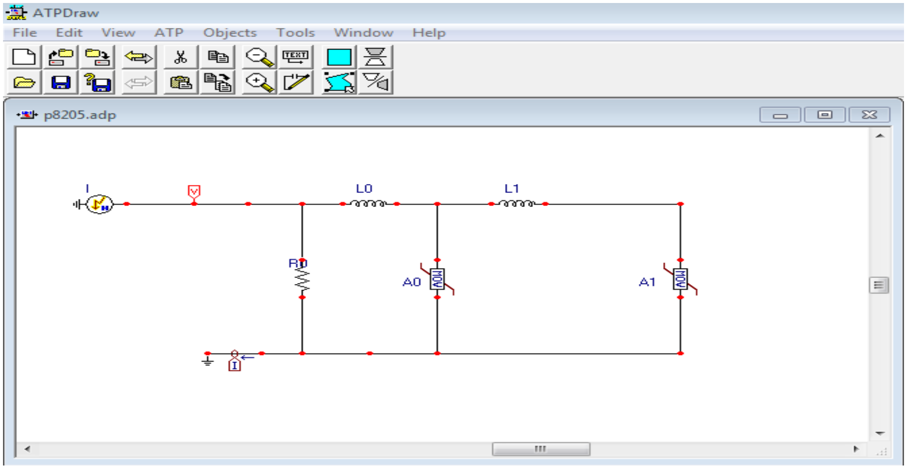

Figure 7: Test circuit of Pinceti model in ATP-EMTP

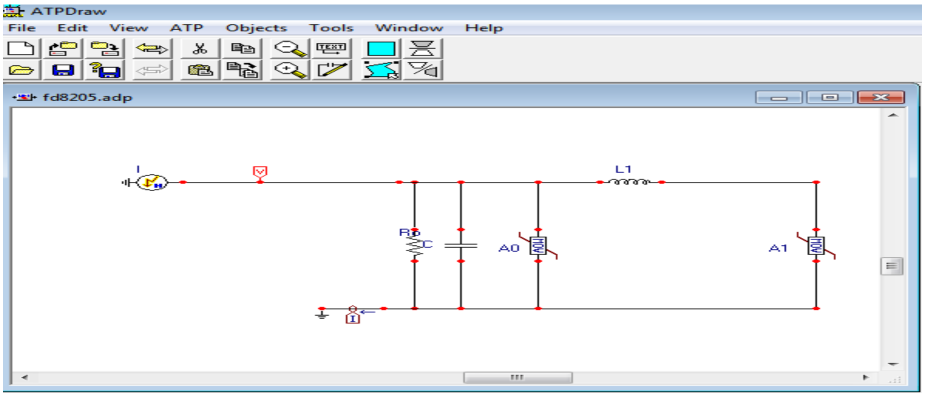

Figure 8: Test circuit of Fernandez and Diaz model in ATP EMTP

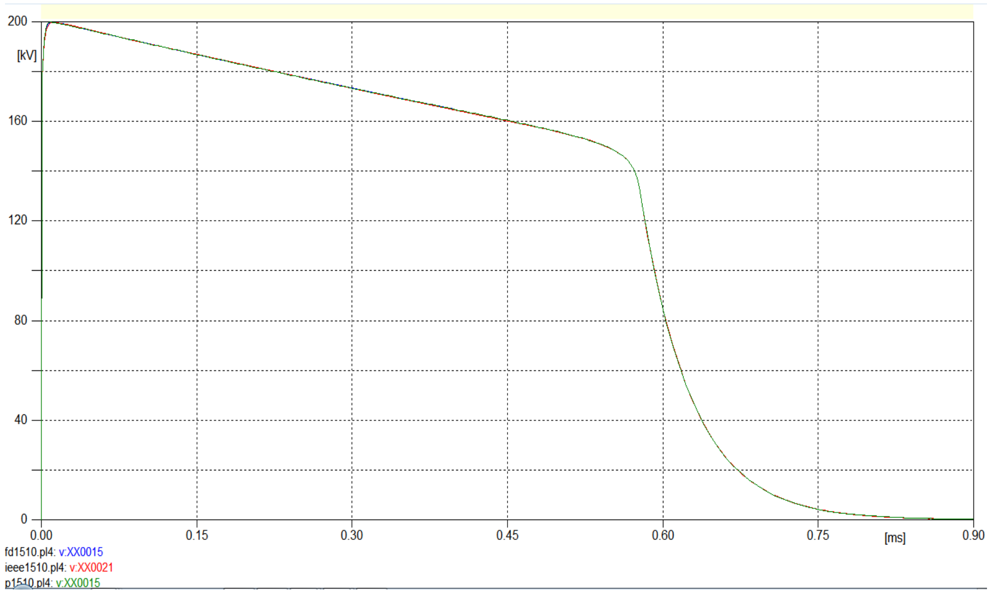

Figure 9 .Residual voltage at 10kA lightning current impulse (1.2/50μsec)

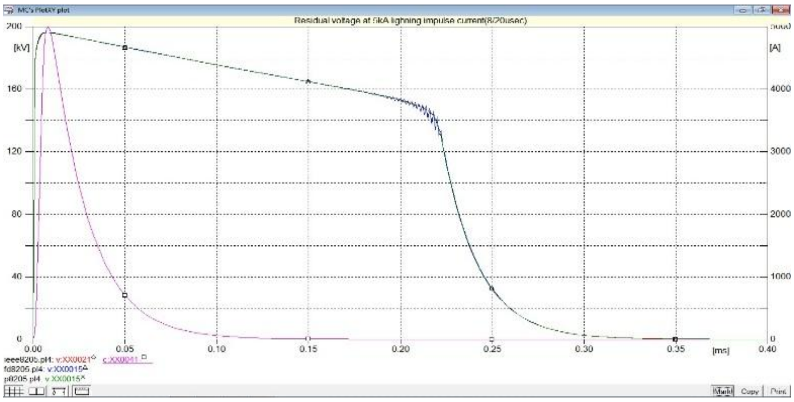

Figure 10 Residual voltage at 5kA lightning current impulse (8/20μsec)

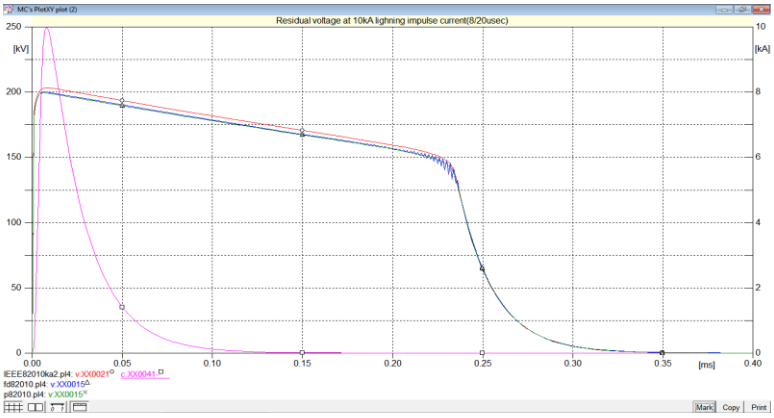

Figure 11 Residual voltage at 10kA lightning current impulse (8/20μsec)

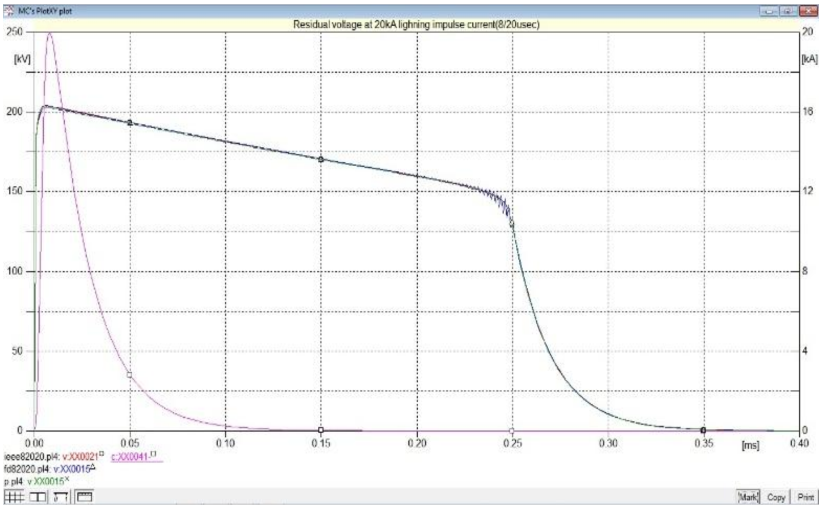

Figure 12 Residual voltage at 20kA lightning current impulse (8/20μsec)

The simulation results calculated for each model are compared with the data provided by manufacturer. The relative error is calculated (Table 5) by using equation 5.1:

$$ERROR\ (e) = \frac{V_r \text{simulation} - V_r \text{manufacturer}}{V_r \text{manufacturer}} * 100 \qquad (5.1)$$

Where;

Vrsimulation is the residual voltage value from the simulation

Vrmanufacturer is the residual voltage value provided in the manufacturer's datasheet.

Table 5: Residual voltage with absolute errors for each model

Model	Residual Voltage With Different Waveforms for Discharge Current Value and Absolute Errors							
	1.2/50µs		8/20µs					
	10 kA		5 kA		10 kA		20 kA	
	Voltage (kV)	Error (%)	Voltage (kV)	Error (%)	Voltage (kV)	Error (%)	Voltage (kV)	Error (%)
IEEE	199.76	13.91	196.30	5.16	203.24	7.19	203.26	15.30
Pinceti	199.88	8.88	196.36	5.14	199.50	8.90	203.62	15.15
Fernandez Diaz	199.87	12.81	196.39	5.12	200.06	8.64	204.04	14.98

VIII. CONCLUSION

In this work, by using different impulse test a simulation of the dynamic behavior 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.

1. When the front time decreases; the voltage across surge arrester increases.
2. The residual voltage reaches its peak before the current reaches its crest.
3. 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.

The Fernandez & Diaz model provides the shortest quenching time compared with other models. To give lightning arrester more reliability, the quenching time requires to be as small as possible. 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.

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