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The Lightning Arrester Modeling Using ATP-EMTP

Trin Saengsuwan* and Wichet Thipprasert

ABSTRACT

This paper describes operating analysis of metal oxide surge arrester, IEEE Model, Pinceti Model and the new model proposed, using ATP-EMTP. Nowadays the utilities in Thailand such as the Provincial Electricity Authority (PEA) and the Metropolitan Electricity Authority (MEA) mostly use lightning arrester from Ohio Brass and Precise brands. The lightning arrester models are based on the Ohio Brass: PDV-100, 9 kV and Precise: Precise PAZ-A09_1 10 kA. Class 1, 30 kV. The tests are performed by applying standard impulse current wave (8/20). It is found that the models can predict the operation of the metal oxide surge arrester in the system with error of less than 1% at 10 kA. The percentages of error developed by the model using ATP-EMTP show that it can be use to predict or calculate energy consumption in each type of surge arresters. The percentage of error of this model is less than that of the other two models. From this reason, the result of prediction or estimation will be close to the real value of surge arrester in the normal condition of system.

Key words: lightning arrester modeling, zinc oxide, EMTP, metal oxide surge arrester, overvoltage, frequency-dependent model

INTRODUCTION

Metal Oxide Surge Arrester has been in service since 1976. They protect major electrical equipment from damage by limiting overvoltage and dissipating the associated energy (Ikmo *et al.*,1996). Metal Oxide surge Arrester should be highly reliable in most application because the metal oxide surge arresters are less likely to fail than silicon carbide arrester due to moisture ingress and contamination.

Metal Oxide Surge Arresters have been designed for the protection of overhead distribution equipment, and these arresters are replacing silicon carbide arrester on many systems. Experience has shown that most failures of silicon carbide arrester occur because of gap sparkover. These failures due to moisture ingress or contamination have been reduced by using Metal oxide surge arrester, to a level low enough to permit repetitive sparkover at or near normal operating voltage. Because metal oxide valve elements are much more non-linear than silicon carbide elements, gaps are not required in metal oxide surge arrester designed with protective characteristics that are approximately the same as silicon carbide arresters. Elimination of gaps, the arrester element most likely to fail, should result in a significant improvement in reliability. On the other hand, the elimination of gaps results in an increased probability of failure of metal oxide surge arrester on system overvoltage that is lower than normally required to cause the sparkover of gapped arresters. Another aspect of reliability that

Department of Electrical Engineering, Faculty of Engineering, Kasetsart University, Bangkok 10900, Thailand.
* Corresponding author, e-mail: fengtss@ku.ac.th

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has not been examined is the relative surge current discharge capacity of metal oxide and silicon carbide valve elements. Because the experience with metal oxide distribution arresters is limited, the most realistic method available for estimating the long-run frequency of surge failures of metal oxide surge arrester is to compare their surge discharge capability to that of silicon carbide arresters. Consideration of published test data on both kinds of arresters leads to the conclusion that metal oxide surge arresters might be more vulnerable to high energy lightning surge than silicon carbide arresters. Although a conclusion frequently reached in failure studies of silicon carbide arresters is that lightning surges account for a relatively small percentage of total failures, surge failures of metal oxide surge arresters could be significant in areas of high lightning intensity. (Pinceti and Giannttoni, 1999)

The advantages of the metal oxide surge arrester in comparison with the silicon carbide gapped arrester are:-

1. Simplicity of design, which improves overall quality and decreases moisture ingress.

2. Easier for maintenance especially to clear arc.

3. Increased energy absorption capability.

The disadvantage of the metal oxide surge arrester occurs at the normal power frequency. Voltage is continually resident across the metal oxide and produces a current of about one milliampere. While this low-magnitude current is not detrimental, higher currents, resulting from excursions of the normal power frequency voltage or from temporary over- voltages such as from faults or ferroresonance, produce heating in the metal oxide. If the temporary overvoltage is sufficiently large in magnitude and long in duration, temperatures may increase sufficiently so that thermal runaway and failure occur. (Andrew, 1999)

This paper describes operating analysis of metal oxide surge arrester, IEEE and Pinceti model, using ATP-EMTP. The lightning arrester models are designed based on the Ohio Brass :PVR 221617 21kV and Precise: Precise PAZ-P09-1 9 kV 10kA class 1, by applying standard impulse current wave (8/20 μs). The models can predict the operation of the metal oxide surge arrester in the system within 10% errors.

MATERIALS AND METHODS

IEEE model

The model recommended by IEEE W.G 3.4.11(IEEE Working Group 3.4.11, 1992) is shown in Figure 1. In this model, the non-linear V-I characteristic is obtained by means of two non-linear resistors (tagged A_0 and A_1) separated by a R-L filter. For slow surges the filter impedance is extremely low and A_0 and A_1 are practically connected in parallel.

On the contrary, during fast surges, the impedance of the filter becomes significant, and causes a current distribution between the two branches. For precision sake, the current through the branch A_0 rises when the front duration decreases. Since A_0 resistance is greater than A_1 resistance for any given current, the faster the current surge, the higher the residual voltage. This is because high frequency current are forced by the L_1 inductance to flow more in the A_0 resistance than in the A_1 resistance.

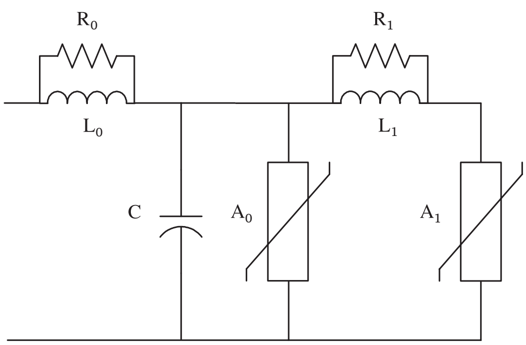

Figure 1 IEEE frequency-dependent model.

The comparison of the calculated peak values with the measured values shows that the frequency dependent model gives accurate results for discharge currents with times to crest between about 0.5 μs and 45 μs.

The main problem of this model is how to identify its parameters. The W.G.3.4.11 suggests an iterative procedure where corrections on different elements are necessary until a satisfactory behaviour is obtained. The starting values can be obtained through formulas that take into account both the electrical data (residual voltages), and the physical parameters (overall height, block diameter, columns number). (Sakshaug *et al*., 1989)

The inductance L_1 and the resistance R_1 of the model comprise the filter between the two non-linear resistances. The formulas for these two parameters are :-

$$L_1 = 15d/n \quad \mu H. \qquad (1)$$

$$R_1 = 65d/n \quad \Omega \qquad (2)$$

where d is the estimated height of the arrester in meters (use overall diamensions from catalog data)

n is the number of parallel columns of metal oxide in the arrester

The inductance L_0 in the model represents the inductance associated with magnetic fields in the immediate vicinity of the arrester. The resistor R_0 is used to stabilize the numerical integration where the model is implemented on a digital computer program. The capacitance C represents the terminal-to-terminal capacitance of the arrester.

$$L_0 = 0.2d/n \quad \mu H. \qquad (3)$$

$$R_0 = 100d/n \quad \Omega \qquad (4)$$

$$C = 100n/d \quad pF. \qquad (5)$$

The non-linear V-I characteristics A_0 and A_1 can be estimated from the per unitized curves given in Figure 4.

The efforts of the working group in trying to match model results to the laboratory test data have indicated that these formulas do not always give the best parameters for the frequency-dependent model. However, they do provide a good starting point for picking the parameters. An investigation was made by the working group into which parameters of the model had the most impact on the results. To accomplish this, a model based on the preceeding formulas was set up on the Electromagnetic Transients Program. (Ikmo *et al*., 1996)

PINCETI model (Pinceti AND Gianttoni, 1999)

The model presented here is derived from the standard model, with some minor differences. By comparing the models in Figure 1 and Figure 2, it can be noted that:

1. The capacitance is eliminated, since its effects on model behavior is negligible.

2. The two resistances in parallel with the inductances are replaced by one resistance R (about 1 MΩ) between the input terminals, with the only scope to avoid numerical troubles.

The operating principle is quite similar to that of the IEEE frequency-dependent model.

The definition of non-linear resistors characteristics (A_0 and A_1) is based on the curve shown in Figure 4. These curves are derived from the curves proposed by IEEE W.G.3.4.11, and are referred to the peak value of the residual voltage measured using a discharge test with a 10 kA lightning current impulse ($V_{r8/20}$);

To define the inductances, the following equations can be used:-

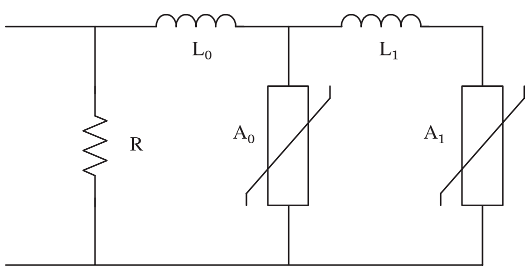

Figure 2 Pinceti model.

$$L_1 = \frac{1}{4} \cdot \frac{V_{r1/T2} - V_{r8/20}}{V_{r8/20}} \cdot V_n \quad \mu H. \quad (6)$$

$$L_0 = \frac{1}{12} \cdot \frac{V_{r1/T2} - V_{r8/20}}{V_{r8/20}} \cdot V_n \quad \mu H. \quad (7)$$

where

Vn is the arrester rated voltage

$V_{r1/T2}$ is the residual voltage at 10 kA fast front current surge ($1/_{T\,2}$ μs). The decrease time is not explicitly written because different manufacturers may use different values. This fact does not cause any trouble, since the peak value of the residual voltage appears on the rising front of the impulse, and

$V_{r8/20}$ is the residual voltage at 10 kA current surge with a 8/20 shape.

The proposed criterion does not take into consideration any physical characteristics of the arrester, only electrical data are needed.

The equations (6) and (7) are based on the fact that parameters L_0 and L_1 are related to the roles that these elements have in the model. In other words, since the function of the inductive elements is to characterize the model behaviour with respect to fast surges, it seemed logical to define these elements by means of data related to arrester behaviour during fast surges.

PROPOSED model

Proposed model has recently been developed which is recommended by IEEE W.G. 3.4.11 and Pinceti model. This model consists of non linear resistance connected in parallel and separated by inductance L_1. The principle of surge arrester varies from surge current. And by comparing the model with simulation result from ATP-EMTP program in case of varying values of inductance L_0, found that the effect is insignificant even it is in the condition of fast front surge. For this reason, the proposed model will not concern L_0 inductance, in contrast to inductance L_1 as the filter has the effect only when the surge comes into the system. It could be mentioned that in case of slow front surge, the impedance of filter is low, but for fast front surge, the value of the impedance will increase. Capacitane C is the value of terminal to terminal of capacitor and the resistor represents of arrester which has the value of the whole resistance of 1 M0hm. In real condition of installation, the high impedance and parameters calculation will not be as complex as the Pinceti model.

The process for finding the parameters of Proposed model followed the method to build model similar to IEEE model and Pinceti model by using ATP-EMTP program. The model is made different from Pinceti model by adding the parallel capacitance it. It seems that the surge's capacitance is installed to the system without considering the value of L_0 (value of the electromagnetic's effect). According to the experiment in IEEE model and Pinceti model from ATP-EMTP program, the surge voltage has a little change when affected by L_0. For this reason, L_0 can be neglected from this model calculation. To define the inductances, the following equations can be used

$$L_1 = \frac{2}{5} \cdot \frac{V_{r8/20} - V_{ss}}{V_{r8/20}} \cdot V_n \quad \mu H \quad (8)$$

$$C = \frac{1}{55} \cdot \frac{V_{r8/20} - V_{ss}}{V_{r8/20}} \cdot V_n \quad pF \quad (9)$$

Where

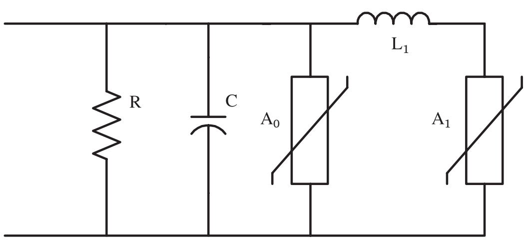

Figure 3 Proposed model.

Vn is the arrester rated voltage,

$V_{r8/20}$ is the residual voltage at 10 kA current surge with a 8/20 μs shape in kV,

V_{ss} is the residual voltage at 500 A. current surge switching 60/2000 μs or 30/70 μs in kV.

Define parameters A_0 and A_1

To define non-linear parameter resistors, A_1 and A_0 the reference from the committee of IEEE W.G. 3.4.11 will be used. The experiments obtain the characteristic curves of current and voltage of both non-linear resistors. In the three models experimentation will use non linear resistor from the curves below

Examples of experiment

1. Product from Precise company, Data used in model : Precise PAZ-P09-1 9 kV 10 kA class 1

IEEE model

Table 1 Parameters used in the IEEE model.

Pinceti model

Table 2 Parameters using in the Pinceti model.

2. Product from Ohio brass

Data using in model : Ohio brass PVR 221617, 21 kV.

IEEE model

Table 3 Parameters used in the IEEE model.

Pinceti model

Table 4 Parameters used in the Pinceti model.

Table 1 Parameters used in the IEEE model.

	A0		A1	
A.	V(pu.)	V(kV.)	V(pu.)	V(kV.)
10	0.875	48.65	0	0
100	0.936	53.543	0.769	42.756
1000	1.05	58.38	0.85	47.26
2000	1.088	60.493	0.894	49.706
4000	1.125	62.55	0.925	51.43
6000	1.138	63.273	0.938	52.153
8000	1.169	64.996	0.956	53.154
10000	1.188	66.053	0.969	53.876
12000	1.206	67.054	0.975	64.21
14000	1.231	68.444	0.988	54.933
16000	1.25	69.5	0.994	55.266
18000	1.281	71.224	1	55.6
20000	1.313	73.003	1.006	55.934

d (High)	0.302	m.
n	1	Numer of Columne
L1	4.53	microHen.
R1	19.63	Ohm
L0	0.0604	microHen.
R0	30.2	Ohm
C	331.126	pF.
Vref(A0)	33.6204	kV.
Vref(A1)	27.4227	kV.

Table 2 Parameters using in the Pinceti model.

	A0		A1	
A.	V(pu.)	V(kV.)	V(pu.)	V(kV.)
10	0.875	48.65	0	0
100	0.936	53.543	0.769	42.756
1000	1.05	58.38	0.85	47.26
2000	1.088	60.493	0.894	49.706
4000	1.125	62.55	0.925	51.43
6000	1.138	63.273	0.938	52.153
8000	1.169	64.996	0.956	53.154
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12000	1.206	67.054	0.975	64.21
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16000	1.25	69.5	0.994	55.266
18000	1.281	71.224	1	55.6
20000	1.313	73.003	1.006	55.934

Steep front	30.2	kV.
Arrester Rating	9	kV.
L1	0.15106	microHen.
L0	0.050353	microHen.
R0	1	MegaOhm

Table 3 Parameters used in the IEEE model.

	A0		A1	
A.	V(pu.)	V(kV.)	V(pu.)	V(kV.)
10	0.875	48.65	0	0
100	0.936	53.543	0.769	42.756
1000	1.05	58.38	0.85	47.26
2000	1.088	60.493	0.894	49.706
4000	1.125	62.55	0.925	51.43
6000	1.138	63.273	0.938	52.153
8000	1.169	64.996	0.956	53.154
10000	1.188	66.053	0.969	53.876
12000	1.206	67.054	0.975	64.21
14000	1.231	68.444	0.988	54.933
16000	1.25	69.5	0.994	55.266
18000	1.281	71.224	1	55.6
20000	1.313	73.003	1.006	55.934

d (High)	0.316	m.
n	1	Numer of Columne
L1	4.74	microHen.
R1	20.54	Ohm
L0	0.0632	microHen.
R0	31.6	Ohm
C	316.456	pF.
Vref(A0)	66.053	kV.
Vref(A1)	53.876	kV.

Table 4 Parameters used in the Pinceti model.

	A0		A1	
A.	V(pu.)	V(kV.)	V(pu.)	V(kV.)
10	0.875	48.65	0	0
100	0.936	53.543	0.769	42.756
1000	1.05	58.38	0.85	47.26
2000	1.088	60.493	0.894	49.706
4000	1.125	62.55	0.925	51.43
6000	1.138	63.273	0.938	52.153
8000	1.169	64.996	0.956	53.154
10000	1.188	66.053	0.969	53.876
12000	1.206	67.054	0.975	64.21
14000	1.231	68.444	0.988	54.933
16000	1.25	69.5	0.994	55.266
18000	1.281	71.224	1	55.6
20000	1.313	73.003	1.006	55.934

Steep front	134	kV.
Arrester Rating	36	kV.
L1	12.6906	microHen.
L0	4.23022	microHen.
R0	1	MegaOhm

Examples of testing waveform

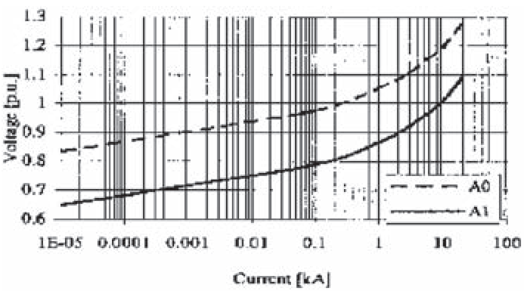

Figure 4 Static characteristics of the non-linear elements. The Voltage is in p.u. referred to the $V_{r8/20}$.

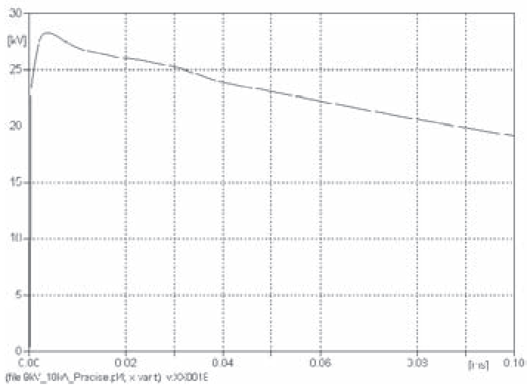

Figure 5 voltage waveform from IEEE model : Precise PAZ-A09_1 10 kA Class 1 30 kV.

RESULTS AND DISCUSSION

1. Comparison of deviation between surge model in case of IEEE model, Pinceti model and the proposed model are shown in Table 5.

CONCLUSION

The analysis and comparsion of the simulation results of Metal oxide surge arrester when the over voltage occurs in power system is done on ATP-EMTP program by using IEEE model, Pinceti model and Proposed model. The modeling result of the operation of surge arrester under the condition of current impulse in different front wave.

1. For the effect of current impulse at steep front wave, the percentage deviation of

model is almost equal to the other models.

2. For the effect of current impulse at standard front wave (8/20 μs), the percentage deviation of the proposed model (Proposed model) is less than the IEEE model and Pinceti model. Especially at current impulse larger than 10 kA, the percentage deviation of the model is less than both models.

3. For the Effect of current impulse in case of on-off switch or over voltage switching, the results from the three models are similar.

The percentage deviation developed by using ATP-EMTP can be used to predict or calculate the energy consumption in each type of surge arresters, The percentage deviations of the Proposed model are less than that of the other two models. From this reason, the result of prediction or estimation will be close to the real value of surge arrester in the normal condition of system.

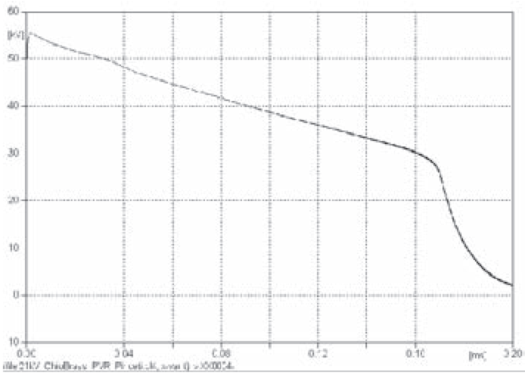

Figure 6 voltage waveform from Pinceti model : Ohio brass PDV-100, 9 kV, Heavy duty.

Table 5 Percent deviation of surge from the product of Ohio brass type PDV-100, 9 kV, Heavy duty.

Impulse test (Ohio Brass PDV-100,9 kV, Heavy Duty)		Data sheet (kV.)	Test (kV.) Proposed model	IEEE model	Pinceti model	%Deviations Proposed model	IEEE model	Pinceti model
Steep current 0.5/1 uS.	10 kA.	34	34.579	34.528	33.637	-1.703	-1.553	1.068
Lightning impulse 8/20 (kV Crest)	1.5 kA.	24.5	26.261	26.268	26.26	-7.188	-7.216	-7.184
	3.0 kA.	27.5	28.277	28.389	28.28	-2.825	-3.233	-2.836
	10 kA.	30	29.995	30.008	30.014	0.017	-0.027	-0.047
	20 kA.	35	32.611	32.566	32.642	6.826	6.954	6.737
	40 kA.	41	35.97	35.624	35.743	12.268	13.112	12.822
Switching impulse 60/2000	500 A.	22.5	24.737	24.737	24.62	-9.942	-9.942	-9.422

Table 6 Percentage deviation of surge from the product of Precise PAZ-A09_1 10 kA. Class 1, 30 kV.

Impulse test (Precise PAZ-A09_1,10 kA. Class 1,30kV)		Data sheet (kV.)	Test (kV.) Proposed model	IEEE model	Pinceti model	% Deviations Proposed model	IEEE model	Pinceti model
Steep current 1/3 uS.	10 kA.	100.6	108.229	108.637	108.622	-7.583	-7.989	-7.974
Lightning impulse 8/20 (kV creast)	5 kA.	86.9	89.071	89.112	89.066	-2.798	-2.545	-2.493
	10 kA.	94.5	94.497	94.496	94.492	0.010	0.004	0.005
	20 kA.	104.6	102.714	102.583	102.737	1.803	1.928	1.781
Switching impulse 60/2000	500 A.	74.2	77.922	77.923	77.922	-5.016	-5.018	-5.016

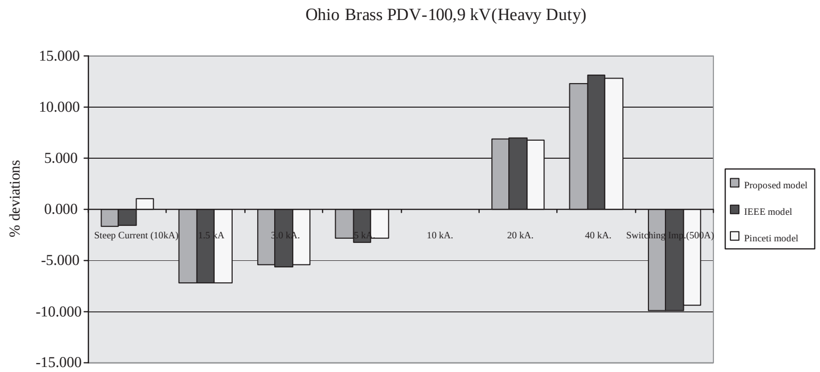

Figure 7 Percentage deviation of surge from the product of Ohio brass PDV- 100, 9 kV, Heavy duty.

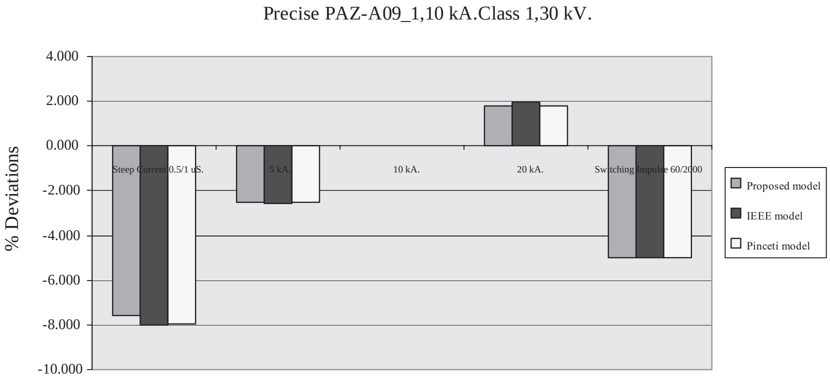

Figure 8 Percentage deviation of surge from the product of Ohio brass PAZ- A09_1 10 kA. Class 1, 30 kV.

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