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Comparison of Different Metal Oxide Surge Arrester Models

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Abstract. Two methods for modeling metal oxide surge arresters are presented and compared: the surge arrester model proposed by IEEE Working Group 3.4.11 and the simplified surge arrester model proposed by Pinceti and Giannettoni. The comparison of model performances and accuracy is conducted in the program package EMTP – RV. Detailed instructions describing the implementation of both models into EMTP – RV environment are also provided. It is demonstrated that the simplified model proposed by Pinceti and Giannettoni yields highly satisfactory results especially taking into consideration a much easier implementation of that model in the EMTP – RV environment in relation to the IEEE model.

Keywords: Comparison, EMTP-RV, Metal oxide surge arrester, Modeling.

1 INTRODUCTION

The nonlinear feature of the metal oxide surge arrester requires careful consideration of how to incorporate this nonlinearity into a surge arrester model accurately. The most frequently used surge arrester model is that proposed by the IEEE Working Group 3.4.11 [1]. This model was further tested, validated and compared to measurements from laboratory tests by various scientists [2, 3].

Although the IEEE model provided an accurate approximation of the surge arrester behavior, its main draw-back was the complexity of using this model to approximate the surge arrester characteristic using data provided by the manufacturer. To counter this, a simplified model has been proposed by Pinceti and Giannettoni [4, 5] which makes the modeling of the surge arrester considerably easier. Since surge arrester models are essential in a variety of power sys-tem analyses [5-11], it is important to determine the accuracy degree of the models developed.

To achieve this, the IEEE model and the simplified model proposed by Pinceti and Giannettoni will be implemented into the program package EMTP – RV where their accuracy will be analyzed for three surge arresters of different rated voltage. In addition, the process of model implementation into the EMTP – RV program package will be described in detail.

2 MODEL RECOMMENDED BY IEEE WORKING GROUP 3.4.11

The model recommended by the IEEE Working Group 3.4.11 [1] is a frequency – dependent model which combines the characteristics of two nonlinear resistors A_0 and A_1 (Fig. 1) to approximate the data provided by the manufacturer effectively.

Other elements that are used in the IEEE model are inductance L_0 associated with magnetic fields in the immediate vicinity of the surge arrester, stabilizing element R_0 used to circumvent possible numerical instabilities, the filter between the two nonlinear resistances consisting of L_1 and R_1 and, finally, terminal – to – terminal capacitance C of the surge arrester [1].

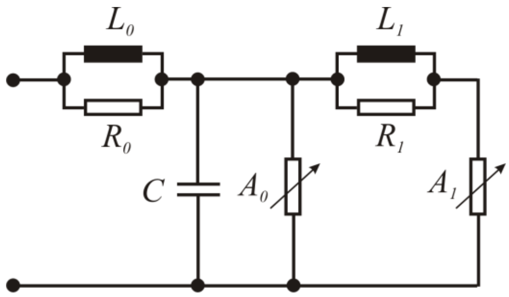

Figure. 1. IEEE model [1].

These elements are computed from:

$$R_0 = 100 \cdot \frac{d}{n} [\Omega], \tag{1}$$

$$L_0 = 0.2 \cdot \frac{d}{n} [\mu H], \tag{2}$$

$$R_1 = 65 \cdot \frac{d}{n} [\Omega], \tag{3}$$

$$L_1 = 15 \cdot \frac{d}{n} [\mu H], \tag{4}$$

$$C = 100 \cdot \frac{n}{d} [pF]. \tag{5}$$

where d is the estimated height of the surge arrester in meters and n is the number of parallel columns of metal oxide in the arrester [1].

The $R_1 – L_1$ filter has a low impedance for slow front surges which implies that the two nonlinear resistances A_0 and A_1 are connected essentially in parallel. On the other hand, for fast front surges, this filter has a high impedance which implies that the majority of current will pass through the A_0 nonlinear resistance.

The nonlinear characteristics of the A_0 and A_1 resistors in per unit (p.u.) values are presented in Table I [1].

Table 1. U-I characteristics for A_0 and A_1

I (kA)	U (p.u.)	
	A_0	A_1
0.01	0.875	-
0.1	0.963	0.769
1	1.050	0.850
2	1.088	0.894
4	1.125	0.925
6	1.138	0.938
8	1.169	0.956
10	1.188	0.969
12	1.206	0.975
14	1.231	0.988
16	1.250	0.994
18	1.281	1.000
20	1.313	1.006

2.1 IEEE Model in EMTP-RV

The implementation of the IEEE surge arrester model into the EMTP – RV environment (Fig. 2) requires the following steps:

- formation of the A_0 and A_1 nonlinear resistances (Table 1) using the EMTP – RV functions ZnO and ZnO Data Function,
- calculation of element values given by equations (1-5) and connection of the elements according to Fig. 1,
- adjustment of the referent voltage (V_{ref}) in A_0 and A_1 nonlinear resistances to match the switching surge voltages (wave shapes such as 30/60 μs),
- adjustment of L_1 to match the residual voltage at 10 kA current surge with a 8/20 μs shape.

In the ZnO Data Function the following values must be entered: a) Data Voltage Rating must equal 1, b) V_{ref} must equal the residual voltage at 10 kA current surge with 8/20 μs shape, and c) Desired Voltage Rating must be half the value of V_{ref}. Initially, V_{ref} in A_0 and A_1 nonlinear resistances must equal twice the value of the residual voltage for a 10 kA current surge with 8/20 μs shape.

The procedure for implementing the IEEE model is relatively complicated and time consuming compared to the Pinceti and Giannettoni simplified model [4, 5].

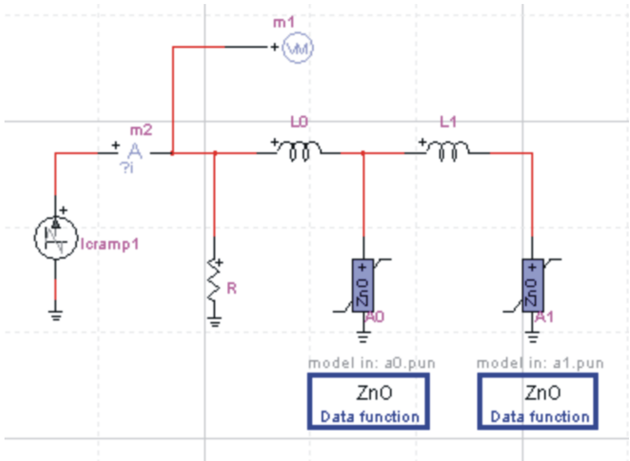

Figure. 2. IEEE model in EMTP-RV.

3 SIMPLIFIED MODEL RECOMMENDED BY PINCETI AND GIANNETTONI

The model recommended by Pinceti and Giannettoni [4, 5] is a simplified version of the IEEE model (Fig. 3). In this simplified version the capacitance C has been removed due to its negligible influence [4]. Furthermore, the resistances R_0 and R_1 have been replaced by one resistance R to counter possible numerical instabilities.

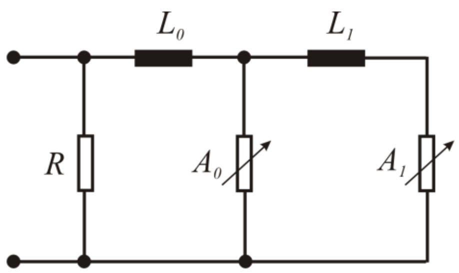

Figure. 3. Simplified surge arrester model [4, 5].

The characteristics of the A_0 and A_1 nonlinear resistors are identical to that of the IEEE model (Table 1). The parameters L_0 and L_1 of this simplified surge arrester model are computed from:

$$L_0 = \frac{1}{12} \cdot \frac{U_{r1/T_2} - U_{r8/20}}{U_{r8/20}} \cdot U_r \,, \tag{6}$$

$$L_1 = \frac{1}{4} \cdot \frac{U_{r1/T_2} - U_{r8/20}}{U_{r8/20}} \cdot U_r \,. \tag{7}$$

where U_r represents the surge arrester rated voltage, $U_{r1/T2}$ is the residual voltage for a 10 kA fast front current surge ($1/T_2$) and $U_{r8/20}$ is the residual voltage for a 10 kA current surge with 8/20 μs shape. As mentioned, the resistance R = 1 MΩ is introduced to avoid numerical instabilities

3.1 Simplified Model in EMTP-RV

The implementation of the simplified surge arrester into the EMTP – RV environment (Fig. 4) requires considerably less effort than the IEEE model. The following steps are required:

- formation of the A_0 and A_1 nonlinear resistances (Table 1) using the functions ZnO and ZnO Data Function,
- calculation of elements values given by equations (6-7) and connecting the elements according to Fig. 3.

In A_0 and A_1, V_{ref} is twice the value of the residual voltage for a 10 kA current surge with 8/20 μs shape.

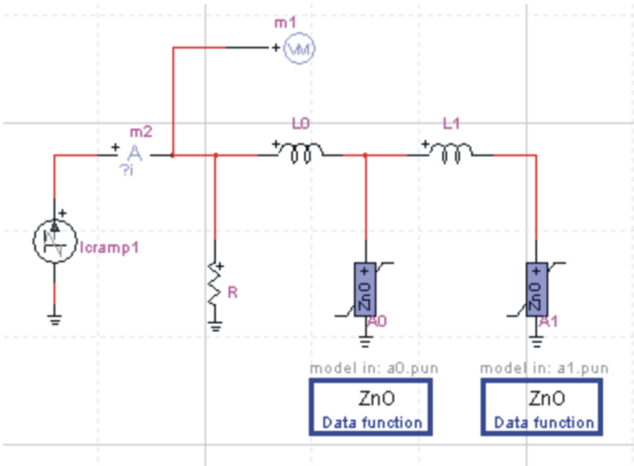

Figure. 4. Simplified model in EMTP-RV.

4 EXAMPLE OF PARAMETER SELECTION FOR METAL OXIDE SURGE ARRESTERS

In this section the accuracy of the presented models will be analyzed relative to the manufacturer's data [12]. Three metal oxide surge arresters of different rated voltages will be observed. The manufacturer's data of these surge arresters are presented in Table 2, Table 3 and Table 4 [12]. The number of parallel columns n = 1.

Table 2. Manufacturer's data of the metal oxide surge arrester U_r = 10 kV

U_r = 10 kV, d = 0.187 m		**Wave 1/5 µs**			
	I [kA]	1	5		10
	U [kV]	29	25.6		29
		Wave 8/20 µs			
	I [kA]	1	5	10	20
	U [kV]	20.8	23.2	24.6	27.2
		Wave 30/60 µs			
	I [kA]	0.125	0.25	0.5	1
	U [kV]	18.1	19	19.7	20.5

Table 3. Manufacturer's data of the metal oxide surge arrester U_r = 30 kV

U_r = 30 kV, d = 0.347 m		**Wave 1/5 µs**			
	I [kA]	1	5		10
	U [kV]	62.9	76.9		86.9
		Wave 8/20 µs			
	I [kA]	1	5	10	20
	U [kV]	62.4	69.6	73.7	81.6
		Wave 30/60 µs			
	I [kA]	0.125	0.25	0.5	1
	U [kV]	54.3	57.1	59.1	61.4

Table 4. Manufacturer's data of the metal oxide surge arrester U_r = 50 kV

U_r = 50 kV, d = 0.507 m		**Wave 1/5 µs**			
	I [kA]	1	5		10
	U [kV]	104.8	128.2		144.8
		Wave 8/20 µs			
	I [kA]	1	5	10	20
	U [kV]	104	116	122.8	135.9
		Wave 30/60 µs			
	I [kA]	0.125	0.25	0.5	1
	U [kV]	90.4	95.2	98.4	102.4

4.1 Comparison for surge arrester U_r = 10 kV

For the IEEE model, introduction of d and n into equations (1-5) yields: R_0 = 18.7 Ω, L_0 = 0.0374 μH, R_1 = 12.155 Ω, L_1 = 2.805 μH and C = 534.7594 pF. The value of V_{ref} in A_0 and A_1 was iteratively changed in order to obtain the best approximation of the residual voltage for the slow front wave shape 30/60 μs for 1 kA current amplitude. This resulted in V_{ref} = 48.025 kV. As mentioned, to adequately approximate fast front surges, the parameter L_1 must be altered in order to obtain a better approximation. The residual voltages produced by the model are then compared to the residual voltages at 10 kA current surge with an 8/20 μs shape. The best agreement was found for L_1 = 1.2 μH (Table 5).

As for the simplified model, substituting the manufacturer's data from Table 2 into equations (6-7) the following values of inductances were found: L_0 = 0.149051 μH and L_1 = 0.447154 μH. Again, it is important to emphasize that unlike the IEEE model, the computation of the required parameters for the simplified model is a great deal easier.

By connecting a current source in EMTP – RV to the surge arrester model in order to simulate the various current surge waves (Table 2) the residual voltages for both models were obtained and are presented in Table 5.

Furthermore, the percent errors (p.e.) of the two presented models are computed relative to the manufacturer's data and are also given in Table 5.

Table 5. Residual voltages and percent errors of the IEEE and the simplified model for surge arrester U_r = 10 kV

	I (kA)	IEEE		Pinceti and Giannettoni	
		U [kV]	**p.e. [%]**	**U [kV]**	**p.e. [%]**
1/5 μs	**1**	21.6098	2.90	21.495	2.36
	5	26.0781	1.87	25.6742	0.29
	10	27.6525	-4.65	28.42	-2.00
8/20 μs	**1**	20.5591	-1.16	20.9794	0.86
	5	23.129	-0.31	23.2907	0.39
	10	24.5991	0.00	24.4913	-0.44
	20	26.6279	-2.10	26.0806	-4.12
30/60 μs	**0.125**	18.647	3.02	19.1005	5.53
	0.25	19.2226	1.17	19.6874	3.62
	0.5	19.8207	0.61	20.2946	3.02
	1	20.447	-0.26	20.9252	2.07

4.2 Comparison for surge arrester U_r = 30 kV

For the IEEE model, introduction of d and n into equations (1-5) yields: R_0 = 34.7 Ω, L_0 = 0.0694 μH, R_1 = 22.555 Ω, L_1 = 5.205 μH and C = 288.1844 pF. The value of V_{ref} in the A_0 and A_1 was found to be 144.05 kV whereas the parameter L_1 was altered to obtain the best agreement to L_1 = 3.57 μH (Table 6).

As for the simplified model, substituting the manufacturer's data from Table 2 into equations (6-7) the following values of inductances were found: $L_0 = 0.447761$ µH and $L_1 = 1.343284$ µH. As previously, the residual voltages as well as percent errors for this surge arrester is presented in Table 6.

Table 6. Residual voltages and percent errors of the IEEE and the simplified model for surge arrester $U_r = 30$ kV

	I (kA)	IEEE		Pinceti and Giannettoni	
		U [kV]	p.e. [%]	U [kV]	p.e. [%]
1/5 µs	**1**	64.752	2.94	64.4022	2.39
	5	77.8944	1.29	76.9373	0.05
	10	82.4676	-5.10	85.1711	-1.99
8/20 µs	**1**	61.6575	-1.19	62.8534	0.73
	5	69.3307	-0.39	69.7804	0.26
	10	73.7028	0.00	73.3799	-0.43
	20	79.7204	-2.30	78.2531	-4.10
30/60 µs	**0.125**	55.9309	3.00	57.223	5.38
	0.25	57.6572	0.98	58.9818	3.30
	0.5	59.4507	0.59	60.8012	2.88
	1	61.328	-0.12	62.6905	2.10

4.3 Comparison for surge arrester $U_r = 50$ kV

For the IEEE model, introduction of d and n into equations (1-5) yields: $R_0 = 50.7$ Ω, $L_0 = 0.1014$ µH, $R_1 = 32.955$ Ω, $L_1 = 7.605$ µH and C = 197.239 pF. The value of V_{ref} in A_0 and A_1 was found to be 240.4 kV whereas the parameter L_1 was altered to obtain the best agreement to $L_1 = 5.775$ µH (Table 7).

As for the simplified model, substituting the manufacturer's data from Table 2 into equations (6-7) the following values of inductances were found: $L_0 = 2.23941$ µH and $L_1 = 0.74647$ µH. As previously, the residual voltages as well as percent errors for this surge arrester is presented in Table 7.

4.4 Accuracy analysis

For fast front surges of a 1/5 µs wave shape, it is evident that the simplified model yields more accurate results then the IEEE model in all cases.

For fast front surges of an 8/20 µs wave shape, both models display similar accuracy degrees although, for these wave shapes, the simplified model has the highest percent error always for the 20 kA amplitude.

For slow front surges of a 30/60 µs wave shape, the IEEE model displays a greater accuracy degree than the simplified model for all cases.

Table 7. Residual voltages and percent errors of the IEEE and the simplified model for surge arrester U_r = 50 kV

	I (kA)	IEEE		Pinceti and Giannettoni	
		U [kV]	**p.e. [%]**	**U [kV]**	**p.e. [%]**
1/5 µs	**1**	107.879	2.94	107.309	2.39
	5	129.678	1.15	128.2	0.00
	10	137.393	-5.12	141.922	-1.99
8/20 µs	**1**	102.874	-1.08	104.727	0.70
	5	115.585	-0.36	116.27	0.23
	10	122.799	0.00	122.269	-0.43
	20	132.735	-2.33	130.39	-4.05
30/60 µs	**0.125**	93.3403	3.25	95.3446	5.47
	0.25	96.2204	1.07	98.2756	3.23
	0.5	99.2118	0.82	101.308	2.96
	1	102.342	-0.06	104.456	2.01

The highest percent errors of 5.53 % (U_r = 10 kV), 5.38 % (U_r = 30 kV) and 5.47 % (U_r = 50 kV) is displayed by the simplified model always at a 0.125 kA amplitude of the 30/60 µs current wave shape.

5 CONCLUSION

In this paper, two models were compared with respect to the accuracy of their approximation of the manufacturer‘s data. The comparison was performed in the program package EMTP – RV. The accuracy of the two models was analyzed on three surge arresters of different rated voltage.

In summary, the simplified model proposed by Pinceti and Giannettoni [4] yields highly satisfactory results especially taking into consideration a much easier implementation of the model in the EMTP – RV environment.

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