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COMPARISON OF SURGE ARRESTERS MODELS TO OVERVOLTAGES STUDIES IN ELECTRICAL NETWORKS

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Abstract: Overvoltages occurring in electrical power networks are caused by changes of power network operation conditions (e.g. faults, lightning strikes or switching operations). In order to limitation of overvoltages, Metal Oxide Surge Arresters (MOSA) are installed in electrical networks. To analyze and determine overvoltages values in electrical power systems, dedicated simulations are necessary. This paper deals with frequency-dependent surge arresters models utilized for overvoltages studies by means of EMTP/ATP simulation software. Various surge arresters models have been presented in this article. In order to compare simulation results, each surge arrester model has been used to perform lightning overvoltages simulations occurring in the analyzed electrical network. Simulation results show influence of surge arrester model type on obtained simulation results and estimated overvoltages observed in electrical network.

Keywords: frequency-dependent models, GIS substations, lightning overvoltages, surge arresters

1. INTRODUCTION

Increase voltage over the nominal value is very dangerous for insulating system of electrical devices installed in electrical power network. These phenomena are able to damage electrical equipment installed in power network or even may cause power outage. For purpose reduce overvoltages, metal oxide surge arresters are installed in electrical network. Performing simulations by means of specialized software is necessary to determine overvoltages values occurring in electrical network during transient states. Thus, for this purpose, equivalent mathematical models of surge arresters are indispensable. Frequency-dependent models provide more accurate representation of real surge arresters for transient states analyses. Three various frequency-dependent surge arresters models have been presented in this paper: IEEE Working Group 3.4.11 model, Pinceti and Giannettoni model, as well as Fernandez and Diaz model. Each of above mentioned models has been modeled and used to perform lightning overvoltages simulations in electrical power network. Calculations presented in this paper have been performed in high voltage power system containing SF_6 Gas Insulation Substation (GIS). Thus, simulation results presented in this paper show practical comparison of various frequency-dependent surge arresters models for insulation coordination studies in electrical power systems. Lightning overvoltages calculations for analyzed surge arresters model presented in this paper have been performed in EMTP/ATP software.

2. SURGE ARRESTERS MODELS

2.1. The IEEE Working Group 3.4.11 model

The frequency-dependent surge arrester model recommended by IEEE Working Group 3.4.11 [1] has been presented in Figure 1.

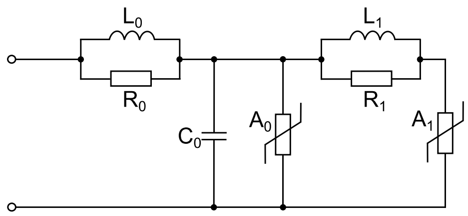

Fig. 1. The IEEE Working Group 3.4.11 model for MOSA [1]

IEEE Working Group 3.4.11 MOSA model contains non-linear I-V characteristics represented by two non-linear elements A_0 and A_1 connected in parallel by R_1-L_1 filter. For slow front surges, the R_1-L_1 impedance is very small, thus elements A_0 and A_1 are connected practically in parallel. In turn, for fast front surges the R_1-L_1 impedance increases and causes current distribution between elements A_0 and A_1. Due to inductance L_1 effect, current flowing through A_0 increases when the surge front decreases.

L_0, R_0, L_1, R_1, C_0 parameters, and characteristics of non-linear elements A_0 and A_1 are calculated according to description contained in [1]. Parameters calculations for linear components are related to MOSA dimensions, whereas characteristics of non-linear elements A_0 and A_1 are calculated according to MOSA data provided by manufacturer.

2.2. The Pinceti and Giannettoni model

The frequency-dependent surge arrester model elaborated by Pinceti and Giannettoni derives from the standard IEEE Working Group 3.4.11 presented in Figure 1. In contrast to standard model, the Pinceti and Giannettoni model does not contain capacitor C_0 (according to [2], its effect on model behavior is negligible), as well as resistors

R_0 and R_1 (it have been replaced by large resistance R – about 1 MΩ). The Pinceti and Giannettoni model has been presented in Figure 2.

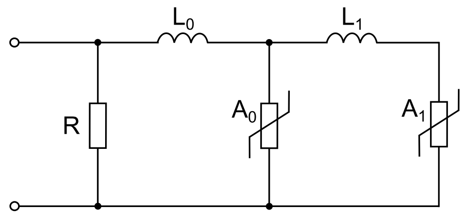

Fig. 2. The Pinceti and Giannettoni model for MOSA [2]

In contrast to IEEE Working Group 3.4.11 model, parameters of L_0 and L_1 elements are based on non-linear I-V characteristics provided by MOSA manufacturer. Parameters of elements A_0 and A_1 are calculated similarly to the standard IEEE Working Group 3.4.11 model. The way of L_0, L_1, A_0 and A_1 elements calculations is presented in [2].

2.3. The Fernandez and Diaz model

The Fernandez and Diaz model is also based on frequency-dependent model developed by IEEE Working Group 3.4.11 (presented in Figure 1). The Fernandez and Diaz model has been showed in Figure 3. It consists of two non-linear elements A_0 and A_1 connected only by inductance L_1, capacitor C_0 and resistor R_0 (R_0 resistance value is large, similarly to model presented in Figure 2).

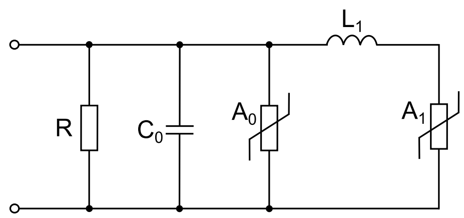

Fig. 3. The Fernandez and Diaz model for MOSA [3]

Characteristics for nonlinear resistors A_0 and A_1 are calculated according to I-V MOSA characteristic provided by manufacturer according to the following assumption: the ratio of the currents flowing through A_0 and A_1 non-linear elements is constants and equals 0.02. Inductance L_1 is fabricated according to MOSA characteristic, whereas capacitance C_0 is calculated according to MOSA dimensions. The resistor R has been applied to avoid numerical oscillations during simulations. The procedure of Fernandez and Diaz model parameters calculations is presented in [3].

3. PARAMETERS CALCULATIONS FOR SURGE ARRESTERS MODELS

To analyze surge arresters models described in this article, two types of MOSA have been taken into account: air type surge arrester and GIS dedicated surge arrester used for switchgear protection, transformers and other equipment in HV system. For this purpose, ABB PEXLIM P-Y air surge arrester, and ABB AZ32 GIS surge arrester installed in GISs substations have been chosen. Both types of MOSA have been implemented into EMTP/ATP calculations. Input data for both surge arresters types have been taken from manufacturer catalog. Data for ABB AZ32 GIS surge arrester have been listed in Table 1.

Table 1. Performance Data Sheet from the manufacturer catalog for ABB AZ32 surge arrester (U_R = 360 kV) [4]

Residual voltages for wave						Height
impulse surge (1/… μs)	lightning surge (8/20 μs)					
	2 kA	5 kA	10 kA	20 kA	40 kA	
[kV]						[mm]
944	733	768	800	864	944	2949

Manufacturer data used to parameters calculations of ABB PEXLIM P-Y air surge arrester model have been listed in Table 2.

Table 2. Performance Data Sheet from the manufacturer catalog for ABB PEXLIM P-Y surge arrester (U_R = 342 kV) [5, 6]

Residual voltages for wave					Height
impulse surge (1/… μs)	lightning surge (8/20 μs)				
	5 kA	10 kA	20 kA	40 kA	
[kV]					[mm]
904	740	779	852	934	3225

According to description contained in this paper and in references [1, 2, 3], all parameters of analyzed sure arresters models have been calculated and implemented into EMTP/ATP program.

4. RESIDUAL VOLTAGES CALCULATIONS FOR MOSA MODELS IN EMTP/ATP PROGRAM

In order to compare residual voltages obtained from simulations for MOSA models (for 20 kA nominal discharge current) and residual voltages from manufacturer catalog data, surge arresters models developed in EMTP/ATP program have been tested by means of 8/20 μs current source. In this way, residual voltage of each surge arrester model has been determined. The current source has been modeled in EMTP/ATP by using following formula [7]:

$$I(t) = A \cdot I_p \cdot t^3 \cdot e^{-\left(\frac{t}{T}\right)} \qquad (1)$$

where: A – constant (0.01243), I_P – desired peak current magnitude, T – time constant (T = 3.911 μs)

The 8/20 μs current surge waveform calculated in EMTP/ATP program according to formula (1) has been showed in Figure 4.

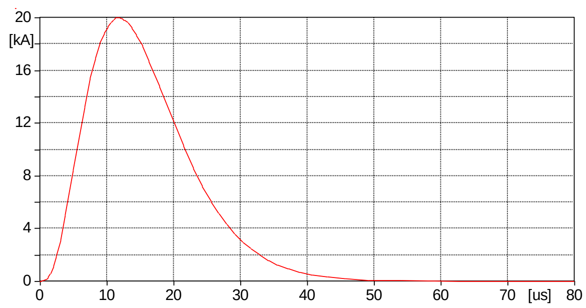

Fig. 4. Current impulse of 8/20 μs used to residual voltages calculations for analyzed surge arresters models

Circuit diagram used to residual voltages calculations of analyzed MOSA models in EMTP/ATP program has been presented in Figure 5.

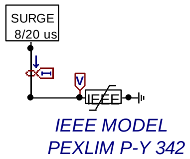

Fig. 5. EMTP/ATP circuit diagram to verification of MOSA models

Calculations of residual voltages waveforms have been performed for each analyzed MOSA model (according to EMTP/ATP circuit diagram presented in Figure 5). Simulation results for ABB PEXLIM P-Y surge arresters models have been presented in Figure 6.

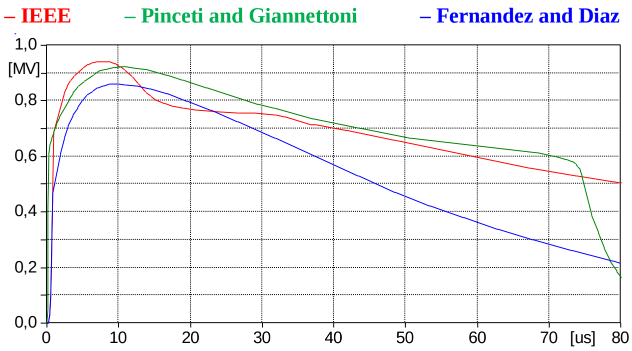

Fig. 6. Calculations of residual voltage for ABB PEXLIM P-Y surge arresters models

As shown in Figure 6, waveforms calculated for various models are comparable. Waveforms shapes calculated for Pinceti and Giannettoni and Fernandez and Diaz are very similar in shape. Waveform simulated for IEEE Working Group model reaches peak value and decreases immediately after it faster in comparison to other waveforms. Maximum values of residual voltages for ABB PEXLIM P-Y sure arrester have been listed in Table 3.

Table 3. Residual voltages for calculated ABB PEXLIM P-Y surge arresters models (20 kA, 8/20 μs wave)

	Calculated data in EMTP/ATP	Data manufacturer catalog	Difference
	[kV]	[kV]	[%]
The IEEE model	942	852	10.56
The Pinceti and Giannettoni model	922		8.22
The Fernandez and Diaz model	861		1.06

Table 3 contains also residual voltage for ABB PEXLIM P-Y according to manufacturer catalog data. The differences between calculated and manufacturer data have been calculated – the largest difference between both values is observed in case IEEE Working Group and it equals more-less 10%. According to simulation results, the Fernandez and Diaz model provides the highest calculations accuracy.

Simulation results for ABB AZ32 GIS surge arresters models have been presented in Figure 7.

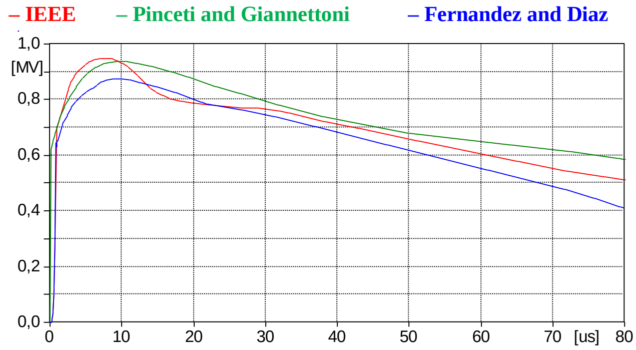

Fig. 7. Calculations of residual voltage for ABB AZ32 surge arresters models

Waveforms shapes presented in Figure 7 are very similar to waveforms showed in Figure 6. In this case, differences in waveforms shapes are comparable. Peak values of residual voltages for ABB AZ32 MOSA have been presented in Table 4.

Table 4. Residual voltages for calculated ABB AZ32 surge arresters models (20 kA, 8/20 μs wave)

	Calculated data in EMTP/ATP	Data manufacturer catalog	Difference
	[kV]	[kV]	[%]
The IEEE model	950	864	9.95
The Pinceti and Giannettoni model	937		8.45
The Fernandez and Diaz model	874		1.16

As shown in Table 4, differences for calculated overvoltages are very like to differences listed in Table 3.

5. INSULATION COORDINATION STUDY

To analyze various surge arresters models presented in this article, insulation coordination study has been performed. Analyzed 380 kV power system contains: overhead line, air surge arresters, cable, GIS with connected surge arresters, and power transformer connected by cable. Circuit diagram of analyzed network modeled in EMTP/ATP has been presented in Figure 9. Calculations have been performed for 30 kA 8/20 μs lightning direct stroke in overhead line (50 m from air surge arresters). Waveforms calculated at power transformer terminal for various MOSA models have been presented in Figure 8.

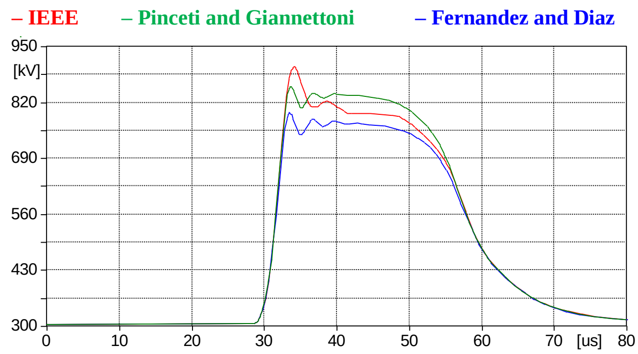

Fig. 8. Simulation results in analyzed power system – voltage at power transformer terminal

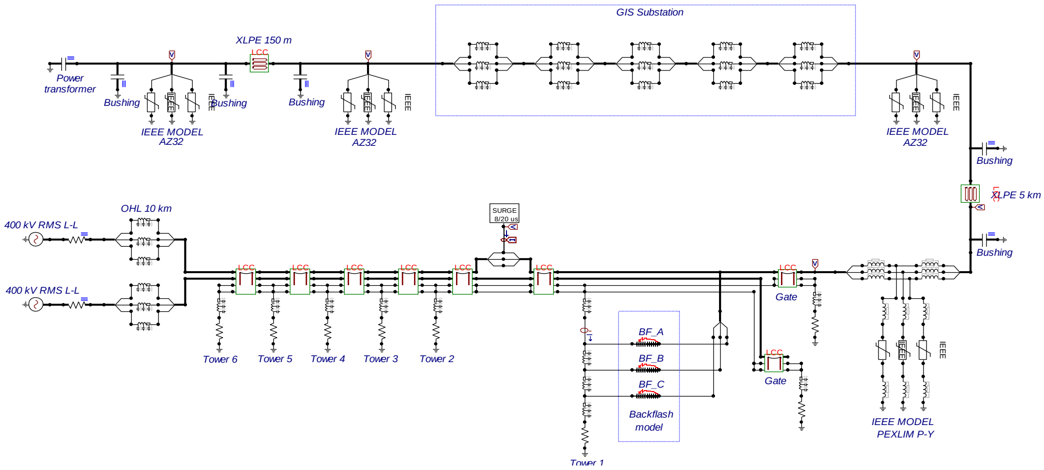

Fig. 9. Circuit diagram of analyzed power system into EMTP/ATP program used for investigation MOSA models

Voltages in analyzed power system have been measured also for two different localizations: at air surge arresters, and GIS entrance. Simulation results have been presented in Table 5.

Table 5. Simulation results for various surge arresters models in analyzed power system

	PEXLIM P-Y Surge arrester	GIS entrance	Power transformer
	[kV]		
The IEEE model	877	916	904
The Pinceti and Giannettoni model	852	862	857
The Fernandez and Diaz model	800	800	796

As shown in Table 5, simulation results obtained for the IEEE model have the largest values, while voltages values are the smallest for the Fernandez and Diaz model.

4. CONCLUSIONS

Simulation results show insignificant differences between analyzed MOSA models. The smallest difference in comparison to manufacturer data is for the Fernandez and Diaz model (≈1%), while the greatest difference (≈10%) is for IEEE Working Group model. For insulation coordination analysis, differences in simulation results for analyzed power system are most significant – voltage at power transformer terminal is greater about over 100 kV for IEEE Working Group model in comparison to the Fernandez and Diaz model. Waveforms shapes at terminal power transformer for various MOSA models corresponding to each MOSA model type. According to simulation results, the Fernandez and Diaz model provides the greatest calculations accuracy for overvoltages analysis.

5. LITERATURE

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PORÓWNANIE MODELI OGRANICZNIKÓW PRZEPIĘĆ WYKORZYSTYWANYCH DO ANALIZ PRZEPIĘCIOWYCH W SYSTEMACH ELEKTROENERGETYCZNYCH

Słowa kluczowe: modele zmienno-częstotliwościowe ograniczników przepięć, rozdzielnice izolowane gazem (GIS), przepięcia atmosferyczne

Przepięcia występujące w sieciach elektroenergetycznych powodowane są przez zmianę warunków pracy obwodu – m. in. przez zwarcia, wyładowania atmosferyczne do linii przesyłowych, czy też operacje łączeniowe. W celu ograniczenia przepięć w sieciach elektroenergetycznych stosowane są ograniczniki przepięć z tlenków metali. Aby określić wartości przepięć podczas trwania stanów nieustalonych, konieczne jest przeprowadzanie symulacji komputerowych. Niniejszy artykuł zawiera opis zmienno-częstotliwościowych modeli ograniczników przepięć, wykorzystywanych do symulacji komputerowych. W celu porównania poszczególnych model, opracowano ich schematy zastępcze w programie EMTP/ATP, a także wykonano z ich użyciem analizę przepięć atmosferycznych w sieci elektroenergetycznej.