European Association for the
Development of Renewable Energies, Environment
and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality
(ICREPQ'12)
Santiago de Compostela (Spain), 28th to 30th March, 2012

Evaluation of the Wire-Guard Arrangements in Overhead Distribution Feeders Against Lightning.

Roberto J. Cabral[1], Daniel S. Gazzana[1], Roberto C. Leborgne[1], Arturo S. Bretas[1], Guilherme A. D. Dias[1] and Marcos Telló[2]

[1] Department of Electrical Engineering
Federal University of Rio Grande do Sul - UFRGS
Av. Osvaldo Aranha, 103, CEP: 90035-190 Porto Alegre, RS (Brazil)
Phone:+55 51 3308-4291, e-mail: rjcabral@ece.ufrgs.br, dgazzana@ece.ufrgs.br, rcl@ece.ufrgs.br, abretas@ece.ufrgs.br, gaddias@terra.com.br

[2] Companhia Estadual de Energia Elétrica – CEEE-D
Av. Joaquim Porto Villanova, 8500, Prédio E2-A, Porto Alegre, RS (Brazil)
Phone: +55 3382–4421, e-mail: marcost@ceee.com.br

Abstract. This paper analyses the influence of wire-guard in distribution power systems subjected to a lightning surge. A real feeder was considered as a case study using ATP-EMTP software. The study compares the performance of the actual unprotected distribution line with a proposed shielded configuration. The simulation results show that the wire-guard can improve the immunity and power quality of distribution system against lightning.

Key words.

ATP-EMTP Software, Distribution Lines, Lightning Protection System, Flashover, Back-flashover, Modelling, Power Quality, Transient Analysis, Surge Atmospheric.

1. Introduction

One of the most important parameters used in the specification of the materials and devices that compose transmission and distribution networks, in the point of view of lightning protection, are the surge current, characterized by its peak value, and wave shape and the energy transferred to the electric network or equipment reached. The transient voltages in the electric power system (PES) are strongly dependent of the peak value and the rising time of the lightning current, with a significant influence in the equipment supportability [1].

Thus, during the planning and expansion stage of the electric power system, the project of the Lightning Protection System (LPS) has fundamental importance, providing great reliability to the PES and ensuring improvements in the quality and continuity of the power supply.

In other side, because of its random and stochastic nature, the correct knowledge of the characteristic and occurrence frequency of a lightning is a great challenge for the science yet. So, it can be verified the need of statistic and probabilistic methods to the representation of this phenomenon and its relation with the electric power system [2]-[3]. In this context, one of the parameters used to the project of a LPS and consequently performance analysis of the overhead distribution system is the flashover rate [4].

In order to improve the performance of a distribution feeder located in the south of Brazil, simulations will be performed considering the actual configuration (without wire-guard) in comparison with a protected topology.

In this context, the focus of this paper is to evaluate the performance of an overhead distribution feeder subjected to a direct lightning strike. ATP-EMPT software has been used for this purpose. The developed model is based on the feeder representation taken into account the frequency dependence of its electric parameters, wooden poles, insulators, cross-arm and grounding system.

2. Lightning Overvoltage Calculation

A. Discharge Lightning Current

The waveform and amplitude of lightning current are influenced by stochastic factors, including geographical location, geological conditions, climate, duration, etc. Researches show that, even considering a stochastic profile, lightning presents basic characteristics of a double exponential waveform, as shown in equation (1).

$$i(t) = I_0 \left(e^{-\alpha . t} - e^{-\beta . t} \right) \tag{1}$$

Where:

I_0 is the discharge peak current (kA);

α, β are the attenuation coefficients.

Currently, the Heidler equation (2) found greater acceptance to represent the behavior of the return current [5]. A conversion procedure has been performed to derive the parameters of the Heidler waveform [6].

$$i(t) = \frac{I_p}{\eta} \frac{k_s^n}{(1+k_s^n)} e^{-\frac{t}{\tau_2}} \qquad (2)$$

Where:

I_p is the discharge peak current (kA);

η is the correction factor of the peak current;

$k_s = t/\tau$, τ_1 and τ_2 are the time constants that define the rise and fall rate;

n is the growth factor of the current.

Nowadays, current discharge data are obtained from measurements on towers with current transducers and despite showing sources of error, this process is widely used.

B. Characterization of the discharge radius

The lightning current is defined by its shape and characteristic parameters. The current amplitude follows a probability law given by the cumulative probability of current I_0 exceeds the range i_0 as shown in equation (3), [1],[7].

$$P(I_0 \geq i_0) = \frac{1}{1+\left(\frac{i_0}{32}\right)^{2,6}} \qquad (3)$$

Where:

I_0 is the peak current (kA);

i_0 is the possible peak discharge current of return (kA);

P is the probability that I_0 is greater than a given value of i_0 (kA).

3. Component´s models using ATP/EMTP

The calculation of atmospheric overvoltage and therefore the evolution of the behavior in front of an airline radius, can be performed with good accuracy by using digital simulation and rigorous mathematical models for all components. ATP/EMTP does not have a single model line suitable for air on the calculation of stresses induced by atmospheric outbreak. However, it allows users to develop their own models.

ATP and other programs have been used in the calculation of voltages induced by lightning. Nevertheless, the model presented in this paper presents some differences in comparison with previous models and can still be used with distribution lines of any length.

Several studies have been published in recent years regarding the modeling of components in power system transient analysis [8],[9]. In the following sections, the models that have been used in the program ATP/EMTP to represent a distribution feeder will be presented.

A. *Network model*

1) Equivalent system

The simulated feeder is connected to the national grid at the Marmeleiro substation. The national grid is represented by an equivalent network modeled by an ideal voltage source type ACSOURSE [10] and the equivalent system impedance is modeled by a line type PI (RLC3) [11].

2) Line terminal

In order to reproduce the effect of length of the line, the affected pole is connected between two sections of 3 km feeder, that are modeled using model type LINEZT_3 [11].

One of the feeder´s sections is connected to the substation and the other with an array of resistances, which is equal to the characteristic impedance of the feeder to prevent the reflection of voltage waves [12].

3) 60 Hz Voltage

The maximum potential that appears on a line caused by a lightning depends of the produced voltages and mainly of its instantaneous value when the lightning happened. The value of the voltage in each phase can be calculated with a random uniform distribution of the phase angle between 0° and 360°. However, the contribution of the 60 Hz potential to the total voltage is negligible for distribution feeders [1].

B. Distribution Line

The feeder is represented considering the section between two consecutive poles. The Marmeleiro feeder is represented by distributed frequency-dependent parameters (type JMARTI), considered the most accurate model [13]. Since the highest voltages will be observed at the point of impact, it is only necessary to consider the poles near the affected one. In this study, the line is represented by three sections.

In the JMARTI's model, the feeder resistance and inductance are frequency-dependent, and this model is suitable to analyze the over-voltages of atmospheric origin. The equivalence of the PI model and the JMARTI model for a voltage frequency over 500 kHz is shown in fig. 1 [12], [13].

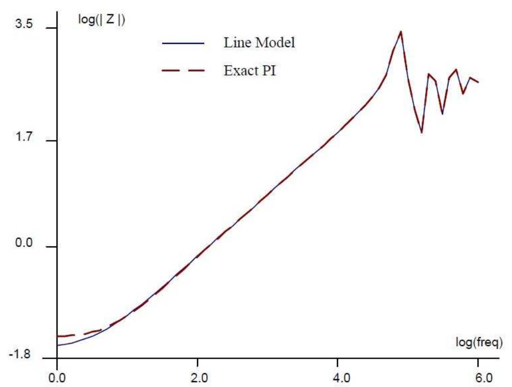

Fig. 1. Frequency response of the line model with distributed frequency-dependent parameters JMARTI [12].

C. Poles

The poles are simulated by series connected impedances, as shown in fig. 2 and 3. These impedances have the same value to avoid wave reflections. The poles are represented with only two impedances because all phase conductors are at the same level. The grounding resistance is also considered and it is connected in series with the pole impedances. The poles are modeled using distributed parameters LINEZT_1 [11] with values calculated according to the following equation (4) [14]:

$$Z_{Pole} = 60\ln\left(2\sqrt{2}\frac{H_c}{r_c}\right) - 60 \qquad (4)$$

Where:

H_c is the average height of the poles (m);
r_c is the radius of the base of the poles (m).

The pole grounding resistance R_g is modeled by a concentrated resistance of 10 Ω (same value estimated for all poles). This value can be changed according to the characteristics of the soil present in each site.

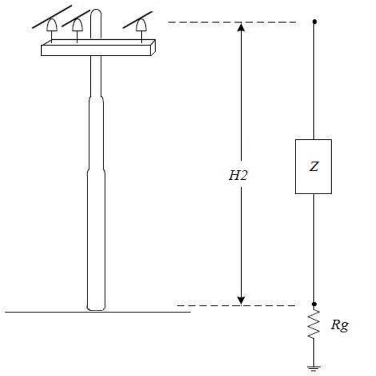

Fig. 2. Model representation of the wooden poles in distribution systems) – Pole without wire guard.

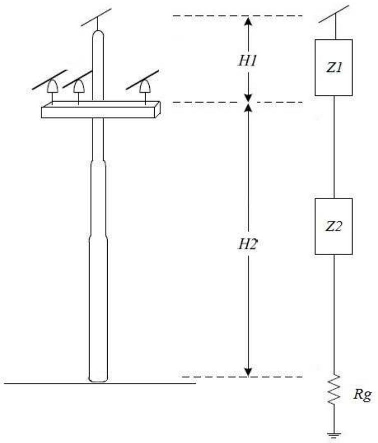

Fig. 3. Model representation of the wooden poles in distribution systems) – Pole with wire-guard.

D. Insulators

The failure of insulators occurs when the voltage exceeds the CFO (Critical flashover overvoltage). Therefore, the insulators can be modeled by voltage controlled switches [12]. The ability of electrical equipment to withstand transient over-voltages is not easily defined and depends to the exposure time. The flashover and backflashover discharge are represented using voltage-controlled switches, which are available in the library of ATP-Draw, as shown in Fig. 4 [10].

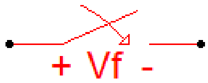

Fig. 4. Electrical insulator model in the ATP-Draw [12].

E. Lightning

The lightning can be simulated by an impulse current source type Heidler (Fig. 5), with a rising time of 1.2 μs and a decrease time of 50% of the peak value of 50 μs. These values correspond to the typical average values for discharge of negative polarity [15]. These parameters can also be changed randomly, representing the stochastic behavior of the lightning.

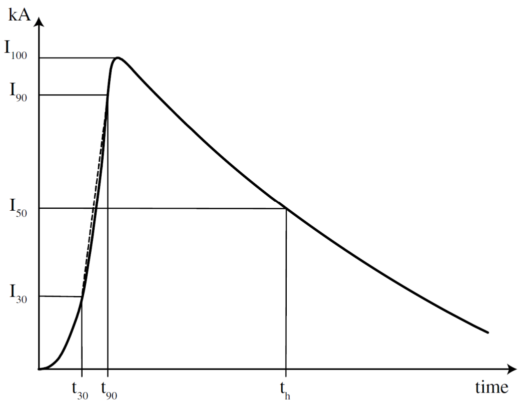

Fig. 5. Waveform of a discharge current of lightning surge [16].

F. System Model in ATP/EMTP

The representation of a lightning reaching the wire-guard is similar to the representation of a lightning in direct contact with a phase conductor. Fig. 6 and Fig. 7 show the equivalent diagrams for these cases. The differences between the cases are as follows:

• the representation of each section of the feeder include the wire-guard grounded at each pole;

• the grounding wire at each pole is modeled by an inductance.

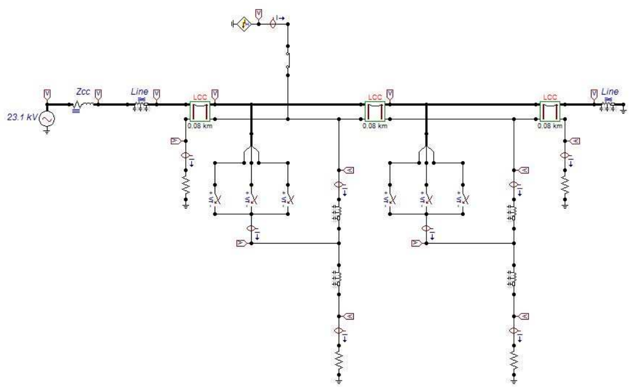

Fig. 6. Equivalent distribution system with wire-guard modeled in ATP-Draw.

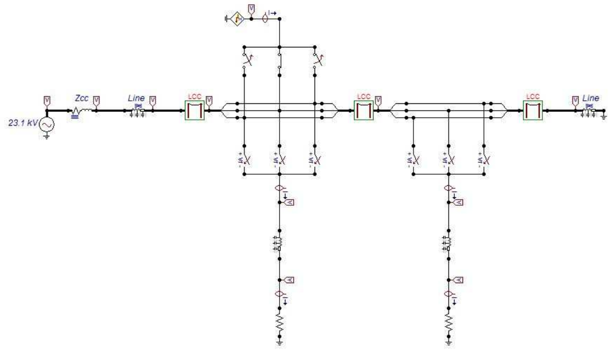

Fig. 7. Equivalent distribution system without wire-guard modeled in ATP-Draw.

4. Simulation results and analysis

The simulation was performed according to the two case studies, one considering the presence of wire-guard and other without this protection component. In both cases the peak current of the lightning was increased from 500 A until the occurrence of flashover or backflashover. The lightning was applied in the wire-guard (fig. 6) or in the phase conductor (fig. 7). The voltages on the insulators and on the lightning injection point, in this case with reference to the remote ground, were measured.

The influence of wire-guard can be analyzed in the fig. 8 to fig. 11 representing the transient voltages that are supported by the insulation present in the electric power system, being the pole insulators one important component when a lightning occurs.

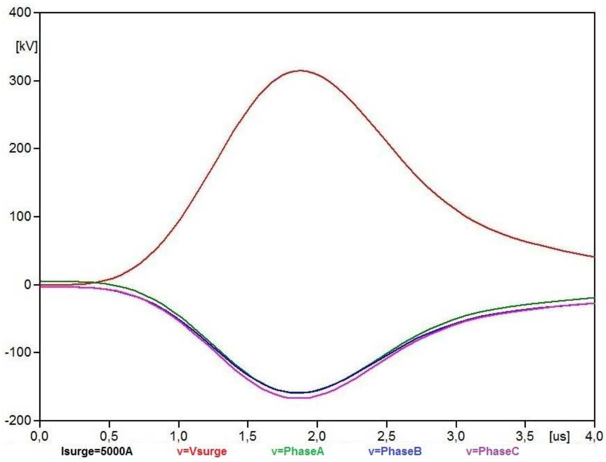

Fig. 8. Voltage at surge point and voltage over the insulators for Isurge = 5000A in the system with wire-guard.

Table I shows the maximum voltage that the insulators present in the distribution poles are submitted. The distribution systems in the studied region have a CFO = 180 kV. As commented previously, if the produced voltage exceeds this value, a discharge, both backflashover and flashover, can occur. Analyzing these results, it can be verified that the wire-guard allows a protection until a lightning with 5000 A of peak value (see phase C). For currents greater than 5500 A, a back-flashover occurs between the cross-arm and the phase conductors.

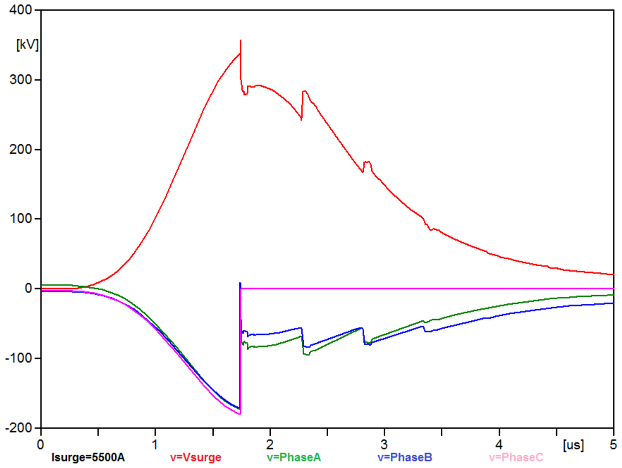

Fig. 9. Voltage at surge point and voltage over the insulators for Isurge = 5500A in the system with wire-guard.

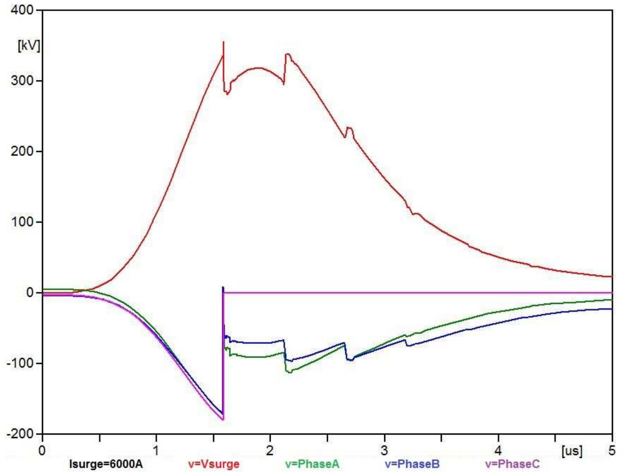

Fig. 10. Voltage at surge point and voltage over the insulators for Isurge = 6000A in the system with wire-guard.

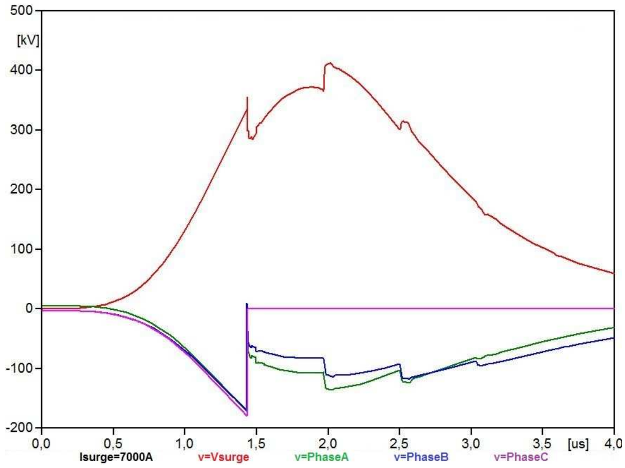

Fig. 11. Voltage at surge point and voltage over the insulators for Isurge = 7000A in the system with wire-guard.

Table 1. Voltage at surge point and voltage over the insulators due to lightning - system with wire-guard.

I_{surge} [A]	V_{surge} [kV]	$V_{phase\ A}$ [kV]	$V_{phase\ B}$ [kV]	$V_{phase\ C}$ [kV]
2500	157.5	-76.86	-80.78	-84.64
5000	314.94	-159.02	-158.4	-166.75
5500	337.61	-172.21	-170.84	**-179.95**
6000	335.72	-172.17	-170.8	**-179.97**
7000	336.41	-173.53	-171.9	**-179.98**

Considering the actual configuration without wire-guard the problem is more critic. Fig. 12 to fig. 14 shows the produced voltages considering different values of lightning peak current. It can be verified that current above 750 A produces flashover. Table II summarizes the maximum voltages produced over the insulators.

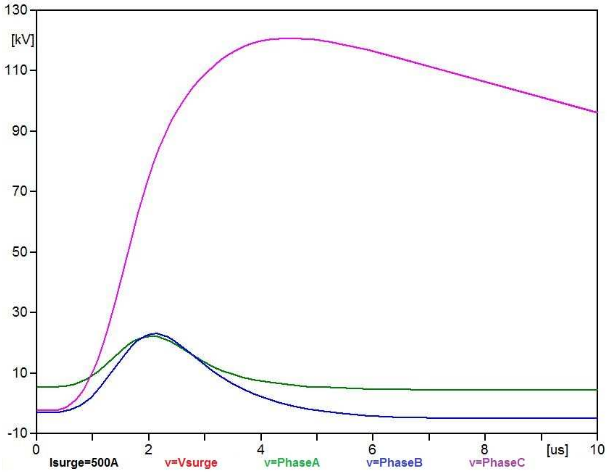

Fig. 12. Voltage at surge point and voltage over the insulators for Isurge = 500A in the system without wire-guard.

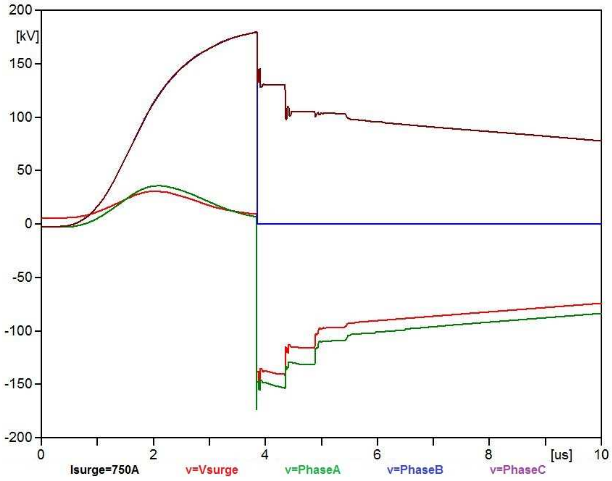

Fig. 13. Voltage at surge point and voltage over the insulators for Isurge = 750A in the system without wire-guard.

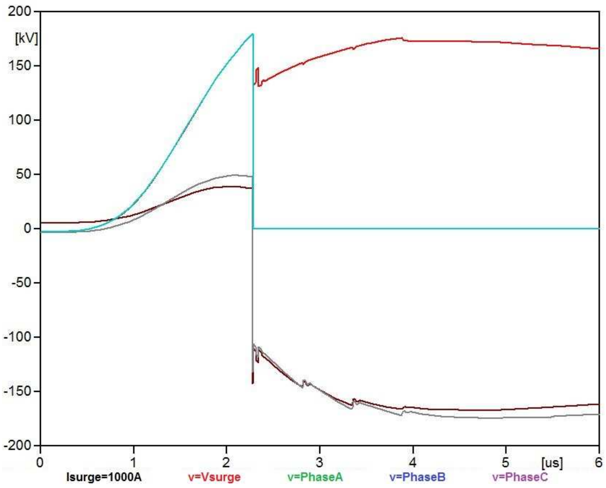

Fig. 14. Voltage at surge point and voltage over the insulators for Isurge = 1000A in the system without wire-guard.

Table II. Voltage at surge point and voltage over the insulators due to lightning - system without wire-guard.

I_{surge} [A]	V_{surge} [kV]	$V_{phase\ A}$ [kV]	$V_{phase\ B}$ [kV]	$V_{phase\ C}$ [kV]
500	120.86	6.217	-0.392	120.86
750	180.0	9.255	6.572	**179.95**
1000	179.89	37.236	47.916	**179.89**
2500	179.99	57.131	73.134	**179.99**

5. Conclusions

Lightning reaching a distribution line was simulated to find out the influence of the wire-guard inclusion in one existing feeder. Based on the simulations, it was verified that currents up to 5000 A can be supported considering this kind of shielding, in comparison with the 500 A in the actual unprotected system. Finally, the wire-guard can improves the performance of the feeder against lightning resulting in a better power quality supply.

Acknowledgement

The authors would like to thank CAPES, CNPQ and Companhia Estadual de Energia Eletrica (CEEE-D) by the assistance and financial support during the development of this research project.

References

[1] IEEE Std. 1410-2010: "IEEE Guide for Improving the Lightning Performance of Electric Power Overhead Distribution Lines", 2010.

[2] I.M. Dudurych; T.J. Gallagher,; M. Holly; "A Novel Stochastic Approach to the Assessment of the Lightning Performance of HV Transmission Lines Using EMTP", Proceedings IEEE Power Tech Conference, Italy, 2003.

[3] Li Zhina. "The Simulation and Analysis of the Lightning Back-flashover Protection Performance of the Medium Voltage distribution Network", International Conference of High Voltage Engineering and Application, China, 2008.

[4] J.A. Martinez and F. Castro-Aranda. "Lightning Performance Analysis of Overhead Transmission Lines Using the EMTP". IEEE Transactions on Power Delivery. Vol. 20 no. 3, pp. 2200-2210. July 2005.

[5] F. Heidler, M. Cvetic and B.V. Stanic. "Calculation of lightning current parameters". IEEE Trans. on Power Delivery. Vol. 14 No 2, pp. 399-404. April 1999.

[6] J.A. Martinez, F. Castro-Aranda and O.P. Hevia. "Generación aleatoria de los parámetros del rayo en el cálculo de sobretensiones atmosféricas". ALTAE 2003. San Jose, Costa Rica. August 18-23, 2003.

[7] J.G. Anderson. "Transmission Line Reference Book, 345 kV and Above". Palo Alto, CA: EPRI. 1982. pp. 545-597.

[8] IEEE TF on Fast Front Transients. "Modeling guidelines for fast transients," IEEE Transaction on Power Delivery, vol. 11, no. 1, Jan. 1996.

[9] A.M. Gole, J.A. Martínez-Velasco. "Modeling and analysis of system transients using digital programs", IEEE PES Special Publication, 1999.

[10] H.W. Dommel. "ElectroMagnetic Transients Program. Reference Manual (EMTP Theory Book)", Bonneville Power Administration, Portland, 1986.

[11] BPA - Bonneville Power Administration "Alternative Transients Program: ATP/EMTP". Site: http://www.emtp.org/

[12] J.A. Martinez-Velazco. "Análisis de sobretensiones de origen atmosférico en líneas aéreas de transporte. Parte I: Cálculo de sobretensiones. Revista Latinoamericana de Usuarios del EMTP/ATP. Buenos Aires, Argentina. Año 5, Vol. 4, Número 1, Abril, 2002.

[13] J. A. Martinez-Velasco. "Modelización de redes de distribución para el cálculo de sobretensiones." Revista Latinoamericana de

Usuarios del EMTP/ATP. Buenos Aires, Argentina. Año 2, Vol.1, Número 1, Março, 1999.
[14] A. Ametani et al., “Frequency-dependent impedance of vertical conductors and a multiconductor tower model,” IEE Proceedings Generation and Transmission Distribution, vol. 141, no. 4, pp. 339-345, July 1994.
[15] A. D´ALUZ et al., “Transitórios elétricos e coordenação de isolamentos. Aplicação em sistemas de alta tensão”. FURNAS Centrais Elétricas SA. 1987.
[16] J.A. Martinez-Velazco and F. Castro-Aranda. “Modeling of Overhead Transmission Lines for Lightning Overvoltage Calculations”. Ingeniare, Revista chilena de ingeniería, Vol. 18 no.1, pp120-131. 2010.