

The Lightning Study of Overhead Transmission Lines

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Abstract: The focus of this paper is the analysis of lightning in Overhead Transmission Lines. By testing a real line of the Albanian transmission network, the paper treats the effect that modeling and the parameters of line can have on the lightning performance, especially on the peak currents during flashover phenomena. This is a very important aspect to evaluate the lightning protection and maintenance of power transmission lines.

Keywords: lightning, modeling, insulation coordination, transmission lines

I. Introduction

Based on insulation coordination guidelines [1], the procedure of evaluating the lightning performance of a power transmission line consists of the following steps: a) generation of random numbers to obtain the parameters of lightning strokes and the parameters of line, b) application of an incidence model to deduce the point of impact of the return stroke; c) calculation of the overvoltage generated by each stroke, depending on the point of impact; d) calculation of the flashover rate. The procedure must be performed with limitations and uncertainties, e.g. the knowledge of the lightning parameters is usually incomplete. These limitations can be partially overcome by performing a parametric study that could detect those parameters for which an accurate knowledge is required. This paper analyses the limitations related to the representation of an overhead transmission line in lightning calculations.

This paper presents a presentation at ATP program to a sensitive study whose main goal is to determine the effect that the model and the parameters selected for the presentation of the main parts of a transmission line can have on the flashover rate. The models whose effects are analyzed are those used to represent the tower, the grounding impedance and the insulator strings.

II. A summary of modeling the power transmission lines

The modeling guidelines for lightning transient analysis can be summarized as follows [2]:

- The transmission line has to be represented by means of several multi-phase untransposed distributed-parameters line spans at both side of the point of impact. This representation can be made by using either a frequency-dependent or a constant parameter model.
- A line termination is needed at each side of the above model to prevent reflections that could affect the simulated overvoltages. This can be realized by adding a long enough line section at each side.
- Tower models have been developed using a theoretical approach or an experimental work. They can be classified into the three groups described as below [3]:

a) *Single vertical lossless line models:* The tower is represented by means of a simple geometric form. The model that is implemented in the Flash program is based on the model recommended by CIGRE.

b) *Multi-conductor vertical line models:* Each segment of the tower between cross-arms is represented as a multi-conductor vertical line, which is reduced to a single conductor. The tower model is then a single-phase line whose section increases from top to ground, as shown in fig.1. The model shown in fig.2 includes the effect of bracings (represented as lossless lines in parallel to the main legs) and cross-arms (represented as a lossless line branched at junction points).

c) *Multistory model:* It is composed of four sections that represent the tower sections between cross-arms. Each section consists of a lossless line in series with a parallel R-L circuit, included for attenuation of the travelling waves, as shown in fig. 3. This model is especially appropriate for the overhead transmission lines with voltages over 400kV [4],[5].

- An accurate model of the grounding impedance has to account for a decrease of the resistance value as the discharge current value increases. It is accepted that the resistance value is greater for small lightning currents, and its variation with respect the low current and the low frequency values is only significant for large soil resistance. When the soil ionization is not incorporated, the grounding impedance model can be approximated by a nonlinear resistance:

$$R = \frac{R_0}{\sqrt{1 + \frac{I}{I_g}}} \quad (1)$$

Where: R_0 the grounding resistance at low current and low frequency; I_g the limited current to initiate the sufficient soil ionization; I the stroke current through the resistance.

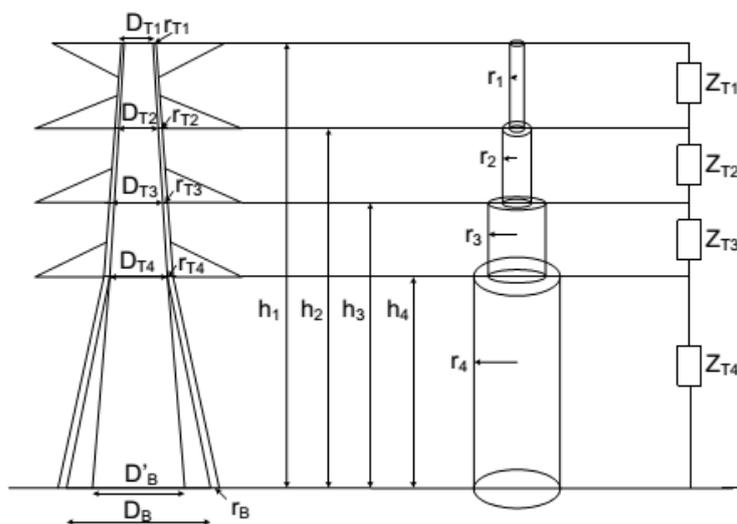


Fig.1 Multiconductor vertical line model

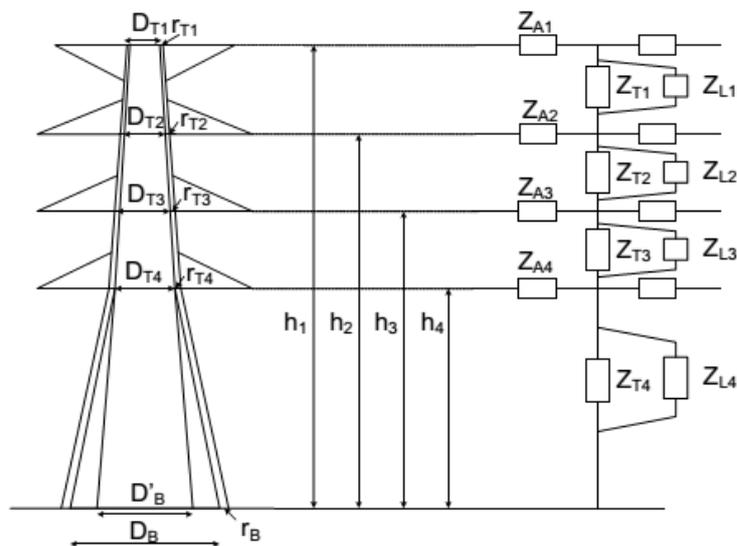


Fig.2 Multiconductor vertical line model including bracings and cross-arms

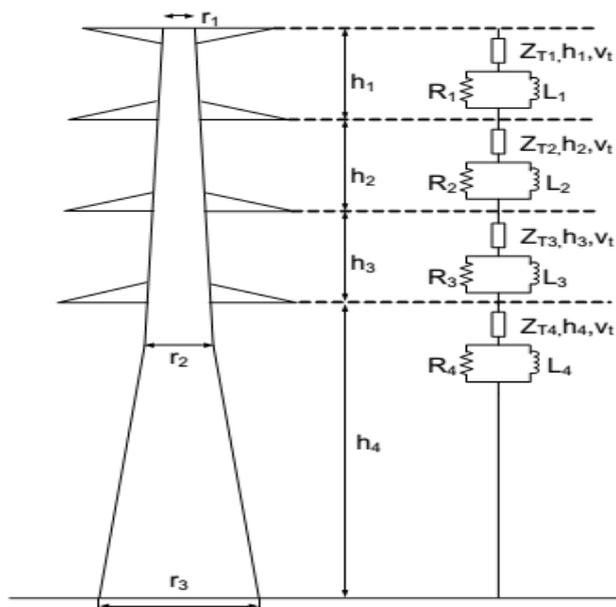


Fig.3 Multistory model

The limited current is calculated as follows:

$$I_g = \frac{E_0 \rho}{2 \pi R_0^2} \quad (2)$$

Where: ρ is the soil resistivity (ohm-m); E_0 the soil ionization gradient (about 400kV/m).

- The insulator string model can be based on the leader progression model or on a simple voltage-dependent flashover switch with a random behavior.

Using the first approach, streamers propagate along the insulator string when the applied voltage exceeds the corona inception voltage; if the voltage remains high enough, these streamers will become a leader channel. A flashover occurs when the leader crosses the gap between the cross-arm and the conductor.

The total time to flashover can be expressed as follows:

$$t_f = t_c + t_s + t_l \quad (3)$$

Where: t_c is the corona inception time; t_s the streamer propagation time; t_l the leader propagation time. Usually t_c is neglected, while t_s is calculated as follows:

$$t_s = \frac{E_{50}}{1.25 E - 0.95 E_{50}} \quad (4)$$

Where: E_{50} is the average gradient at the critical flashover voltage and E is the maximum gradient in the gap before breakdown. The leader propagation time t_l can be obtained from the following equation:

$$\frac{dl}{dt} = k_l v(t) \left[\frac{v(t)}{g - l} - E_{l0} \right] \quad (5)$$

Where: $v(t)$ is the voltage across the gap; g is the gap length; l is the leader length; E_{l0} is the critical leader inception gradient and k_l is the leader coefficient. The leader propagation stops if the gradient in the unbridged part of the gap falls below E_{l0} .

- The lightning stroke is represented as a current source. Fig.4 shows the concave form of standard impulse used for lightning study of transmission lines.

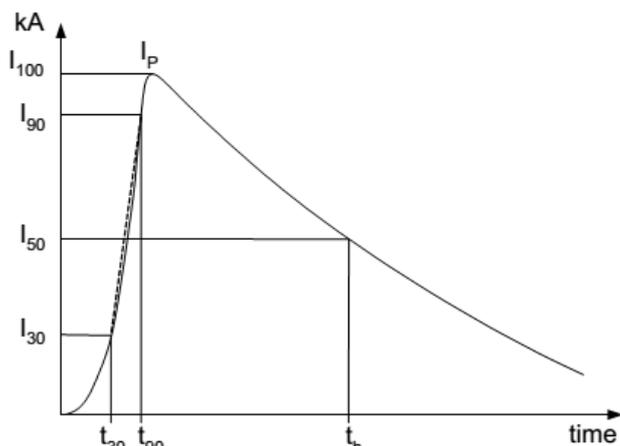


Fig.4 The standard impulse of lightning stroke

(I_{100} = peak current magnitude; $t_f = 1.67(t_{90}-t_{30})$ = rise time; t_h tail time

If lightning stroke parameters are assumed independently distributed, their statistical behavior can be approximated by a long-normal distribution with the following probability density function:

$$p(x) = \frac{1}{\sqrt{2\pi} x \sigma_{\ln x}} \exp \left[-0.5 \left(\frac{\ln x - \ln x_m}{\sigma_{\ln x}} \right)^2 \right] \quad (6)$$

Where: $\sigma_{\ln x}$ is the standard deviation of $\ln x$, and x_m is the average value of x .

III. The studied line

The object of the study is a line of the Albanian Transmission Network: the 400kV transmission line “Tirana-Podgorica”[7]. It is a line with two conductors per phase (with main characteristics as shown in Table I) and with tower design as shown in fig 5.

Table I :Characteristics of Phase Conductors and Shield Wires

	Type	Diameter (cm)	Resistance (Ω /km)
Phase Conductors	ACSR	3.06	0.01
Shield wires	OPGW	1.6	0.299

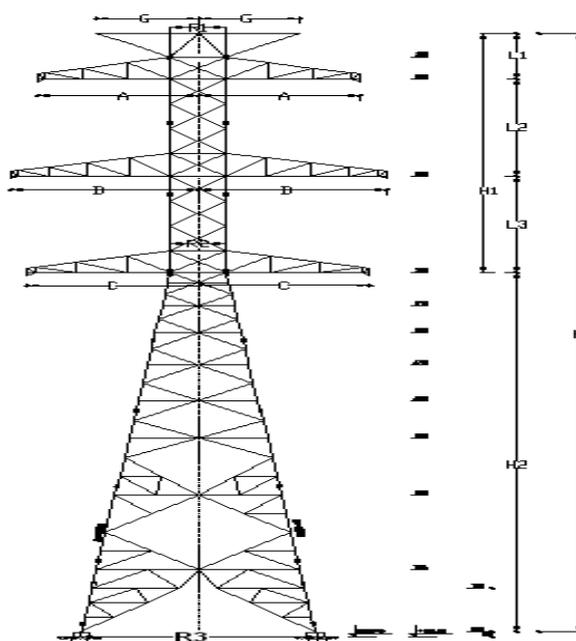


Fig.5 Tower configuration of 400kV line “Tirana-Podgorica”

IV. Modeling and simulating results

-Based on the real electro-geometrical data, a section of the overhead transmission line is modeled in ATP software with a constant distributed parameters model[6], [7], as shown in fig.6.

-The towers are represented by multistory model, which is chosen the most appropriate for the real case-study: based on the aim of lightning study, the linear voltage 400kV, and the height of towers which is higher than 30m.

-The representation of insulators string is modeled in FLASH program, based on their dimensions and characteristics (see fig.7).

-The soil resistivity is considered uniform 100 Ω m, and the soil gradient 400kV/m

-The line is simulated in different points of impact with different lightning impulses. The results of simulating are summarized in the table II: for every tower (with specific parameters), we have studied the peak current magnitudes depending on characteristic impedance and the grounding resistance. As can be noted from the charts shown in fig. 8 and fig.9, it can result that the lower peak current magnitude belongs to the towers with greater value of characteristic impedance and grounding resistance. Based on the real geometrical dimensions for the simulated towers, these characteristics belong to the towers with greater height and smaller perimeter.

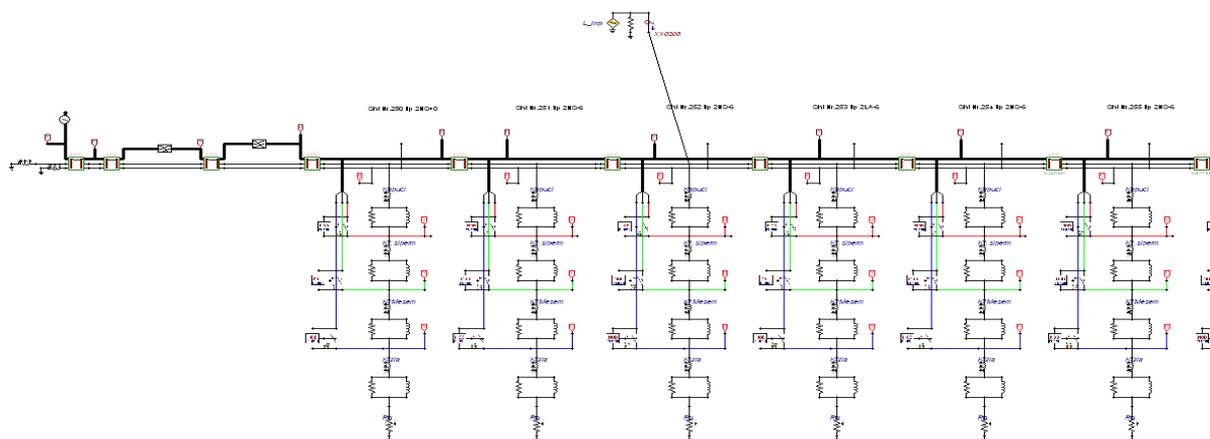


Fig.6 Modeling of the line tested in ATP software

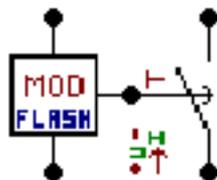


Fig.7 Insulators Model in FLASH program

TABLE II : A Summary of Simulating Results

Tower Type	Peak Current Magnitude (kA)	Tower No.	Characteristic impedance (Ω)	Grounding Resistance (Ω)
2NS+0	50	250	159.6	10.4
2NS-6	38.37	251	154	10.61
2NS-6	38.23	253	154	8.95
2LA-6	56	253	138.47	9.63
2NS-6	39.34	254	154	10.47
2NS-6	37.56	255	154	9.1
2HS+6	40	256	166.46	4.52
2HS+3+2	39	257	165.76	3.64
2HS-6	45	258	157.75	7.35
2HS-3	44	259	160	5.77
2LA+0	56	260	144.2	9.66
2NS+0	41	261	159.63	10.48
2HS+0	38	262	162.2	10.64
2MA+3	46	263	145	4.18
2HS-3	38	264	160	10.1

2HS+0	37	265	168.54	10.83
2LA+6-1	47	266a	148.66	7.8
2HS+9	36	266b	168.54	5.54
2HS+0	38	266c	162.2	4.54
2NS+3	39	266d	162.3	5.18
2LA-6	50	267	138.47	5.51
2NS+0	42	268	159.63	4.69
2NS+3	39	269	162.3	0.89
2NS+0	44	270	146.2	2.89
2NS-3	41	271	156.9	1.72
2NS-6	43	272	150.36	3.93
2LA-6	53	273	138.47	4.47

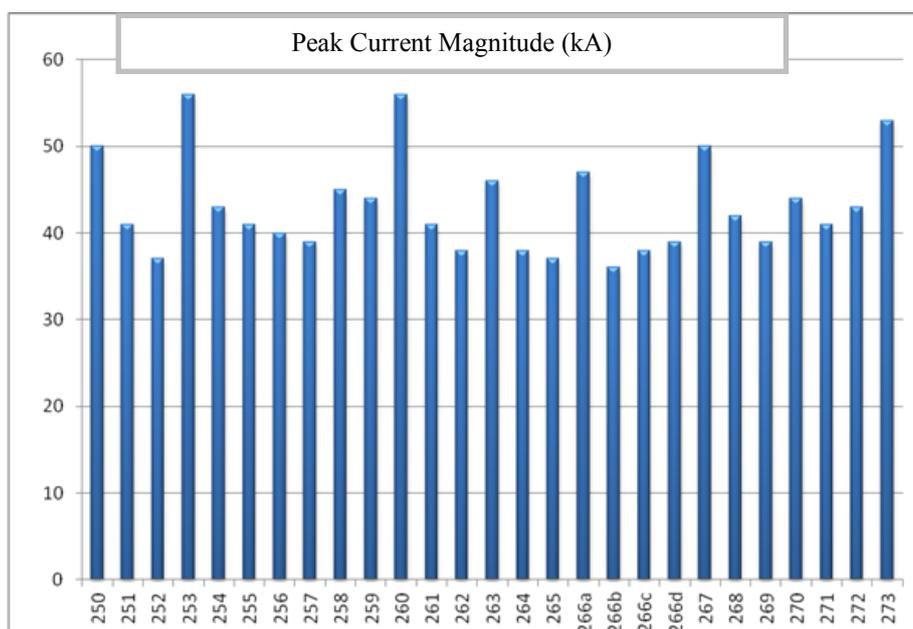


Fig.8 Peak Current Magnitude for the simulated towers

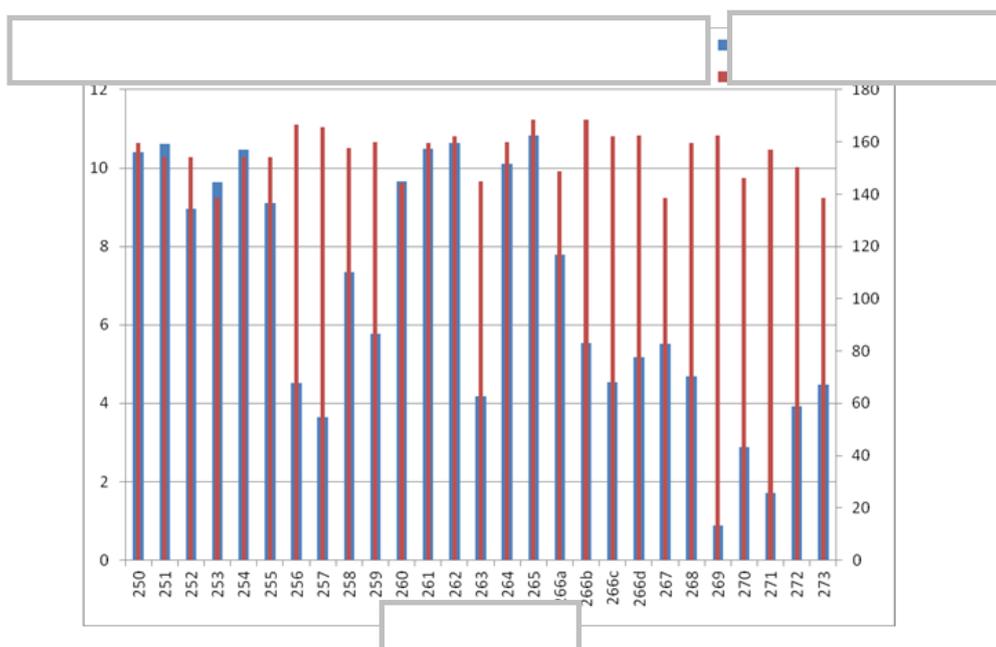


Fig.9 Characteristic impedance (with red color) and grounding resistance (with blue color) for the simulated towers

V. Conclusion

This paper presents a sensitive case of lightning study for overhead transmission line, which is very important for operation maintenance of this main component of power system.

The analysis of lightning transients requires an accurate modeling of line which is represented by towers, insulators and grounding impedance.

By modeling in ATP software a real overhead transmission line of the Albanian power system, the paper shows some interesting results about the relations between peak current magnitudes of lightning and towers parameters which are expressed through their characteristic impedance and grounding resistance.

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