AN IMPROVED BACKFLASHOVER MODEL FOR ESTIMATING THE LIGHTNING PERFORMANCE OF TRANSMISSION LINES

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ABSTRACT

An improved backflashover model, which estimates the lightning performance of high voltage overhead transmission lines using Monte Carlo statistical technique, is presented based upon a previous study. In contrast to the earlier approach in which only mean values of design characteristics and meteorological data were considered, this method takes into consideration the characteristics of each one individual tower of the transmission line and the exact meteorological conditions for the particular geographic region where each one tower is located. Furthermore it gives the opportunity to use in the calculations, either the measured footing resistance of each tower, or to estimate the tower footing resistance by providing the resistivity of soil and the geometric characteristics of the grounding system. The improved method coded as a Visual Basic computer program, has been applied, on several operating Hellenic transmission lines, with different geometrical and geographical characteristics, showing much greater accuracy than this which has been shown using the earlier approach and results almost identical to the field observation data. The proposed method can be used as a useful tool in the design of electric power systems, aiding in a more effective protection of them against lightning strokes.

INTRODUCTION

The design of transmission lines for a predetermined lightning performance requires a method of predicting failure rates of the lines. A very important role in the lightning performance of high voltage transmission lines plays the backflashover phenomenon, where the lightning stroke terminates on the structure or on a shielding wire, changing the potential of the structure sufficiently to cause a flashover to a healthy, until to this moment, phase conductor.

Several methods around the globe, based on many different techniques such as analogue computers [1], geometrical models, travelling waves, and Monte-Carlo simulation [2], have been proposed in the last decades in order to predict lightning performance. The current work, extending a previous study, in which only mean values of design characteristics and meteorological data were considered [3], demonstrates an improved backflashover method in an effort to obtain more accurate results, almost identical to field observation data. In this method special attention is paid: a) to the monthly metereological conditions of the geographic region through which line is running, b) to the design characteristics of each one individual tower of the examined transmission line, and c) to the tower footing resistance, which can be measured directly, or can be easily estimated using the soil resistivity and the grounding system geometric characteristics. The proposed method coded in a l comprehensive Visual Basic computer program is applied on operating Hellenic lines of 150 kV and 400 kV, of known outage rate, in order to validate its accuracy.

CONCEPTS CONCERNING THE IMPROVED BACKFLASHOVER METHOD

Monte-Carlo simulation technique

The principle difficulty in modelling the lightning performance of any overhead transmission line is the genuine variability of the key model parameters. Monte-Carlo technique accommodates these variabilities by accumulating the results of repeated computer simulations made with randomly drawn parameter values [2]. The physical behaviour is accurately modelled by drawn each of the independent random variables from realistic probability density functions. Then the computed failure rate (i.e. the number of runs resulting in failure v.s. the total number of runs) constitutes a reasonable representation of the actual lightning performance of the modelled transmission line.

Lightning strokes to transmission lines

The lightning level, defined as the average number of days per year on which thunder is heard, can be evaluated from isokeraunic maps. Figure 1 presents the isokeraunic map of Hellas. Using the lightning level, an approximation to the number of strokes to earth, that intercepted by a transmission line, is calculated using the equation (1) [4]:

$$N_L = 0.004 \cdot T^{1.35} \cdot \left(b + 4 \cdot h^{1.09}\right) \qquad (1)$$

where, N_L is the number of lightning strokes to a line per 100km per year, T is the lightning level in the vicinity of the line, h is the average height in meters of the shielding wires and b is the horizontal spacing, in meters, between the shielding wires.

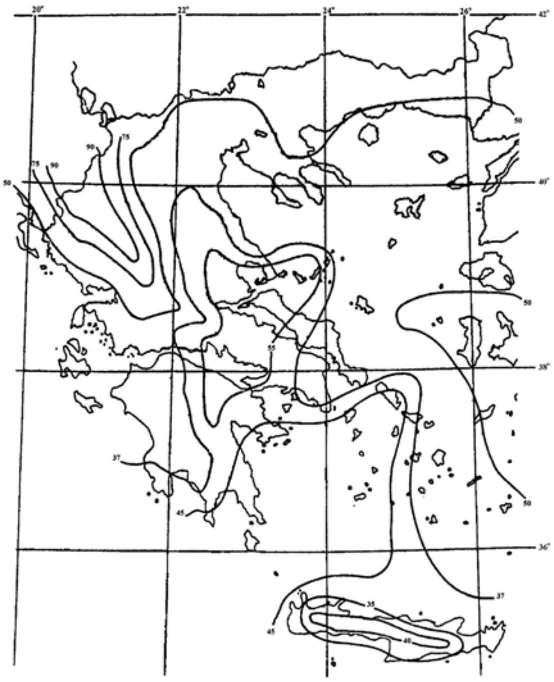

Figure 1: The Isokeraunic Map of Hellas [5]

Lightning parameters

The lightning parameters, i.e. the peak value and the slope of lightning current, are randomly selected from statistical distributions based on the measurements performed by Berger in Monte San Salvatore [6]. According to Berger's measurements the 85% of the lightning strokes are considered negative while the 15% of the lightning strokes are considered positive with the characteristics of Figs. 2 and 3.

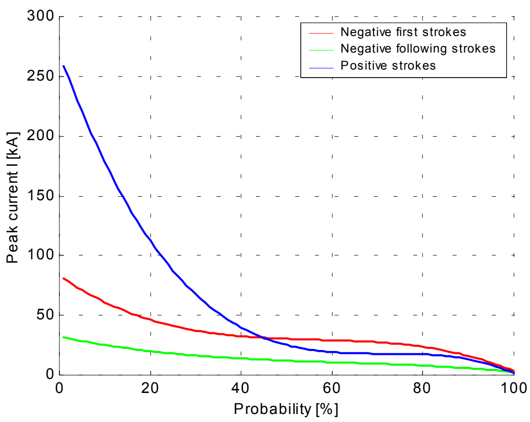

Figure 2. Lightning current peak value distribution

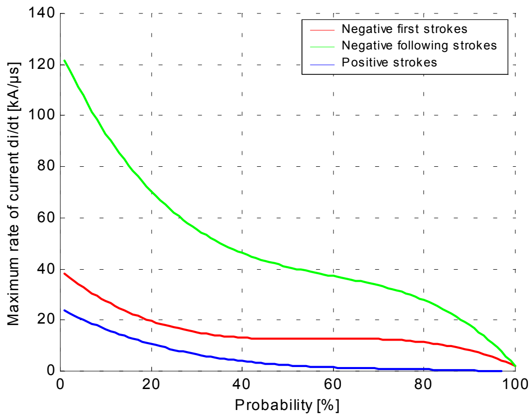

Figure 3. Lightning current slope distribution

Tower footing resistance

The lightning performance of transmission lines is strongly related to the tower footing resistance. The individual characteristics of the towers, rather than the average characteristics of all the towers are considered in this study, since even a few towers located in high resistivity soil can degrade the overall line performance.

Wenner method [7] has been used in order the soil resistivity of the ground to be measured. The distance α between two sequential electrodes was continuously varied in order the structure and the lack of homogeneity of the ground to be recorded. It is obvious that the soil resistivity of the ground has significantly higher values during summer months, where high temperatures and low rainfalls dry up at least the upper layer of the ground, than winter months.

The calculation of the parameters of a two-layer structure of the ground is an optimization problem. For the computation of the three parameters (soil resistivity of the upper layer ρ_1, soil resistivity of the lower layer ρ_2 and the thickness h of the upper layer) the minimization of the function F_g is necessary:

$$F_g = \sum_{i=1}^{N} \frac{\left|\rho_{ai}^{m} - \rho_{\alpha i}^{c}\right|}{\rho_{\alpha i}^{m}} \tag{2}$$

where ρ_{ai}^{m} is the *i-th* measurement of the soil resistivity when the distance between two sequential probes is α, while ρ_{ai}^{c} is the computed value of the soil resistivity for the same distance. The soil resistivity is calculated using the equations (3-6) [8-9]:

$$\rho_a^c = \rho_1 \cdot \left(1 + 4 \cdot \sum_{n=1}^{\infty} \left(\frac{1}{\sqrt{A}} - \frac{1}{\sqrt{B}}\right)\right) \tag{3}$$

where k is the reflection coefficient, which is given by equation (4):

$$k = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \qquad (4)$$

$$A = 1 + \left(\frac{2 \cdot n \cdot h}{a} \right)^2 \qquad (5)$$

$$B = A + 3 \qquad (6)$$

Although there are several techniques [8-9] in order to analyze the structure of the ground and to calculate the parameters of soil resistivity, in this study a genetic algorithm method has been used [10].

Using the resistivity of the soil and the geometric characteristics of the grounding grid, the tower footing resistance can be calculated, either for uniform or two-layer soil, through equations (7) and (8) respectively [11].

$$R = \frac{\rho}{4} \cdot \sqrt{\frac{\pi}{A}} + \frac{\rho}{L} \qquad (7)$$

$$R = 1.6 \cdot \frac{\rho_2}{P} + 0.6 \cdot \frac{\rho_1}{L} + \rho_1 \cdot \frac{h}{A} \qquad (8)$$

where: R is the tower footing resistance (in Ω), ρ, ρ_1 and ρ_2 are the soil resistivities (in Ωm), A is the area occupied by the grid (in m^2), P is the grid perimeter (in m), h is the depth of the upper soil layer (in m) and L is the total length of grid conductors (in m).

ESTIMATING BACKFLASHOVER METHOD

The proposed improved method is an extention of a previous backflashover method in which only mean values of design characteristics and meteorological data were considered, in an effort to obtain more accurate results [3]. It is coded as a Visual Basic computer program, simple in use, in order to facilitate all the necessary calculations. The method is capable to estimate the average number of backflashover faults which may occur in a transmission line, with or without shielding wires, dividing them also in single phase and three phase faults.

The improvements of the method, lead to more accurate results almost identical to the field observation data are owned to the following:

a) The average lightning level in the vicinity of the examined line is considered for each one individual month of the year [5].

b) Transmission line characteristics such as: heigths of phase conductors and shielding wires, sags and tower dimensions are considered for each one individual tower of the examined line.

c) The tower footing resistance is either considered: as the actual measured value [12] or as the monthly value estimated using the soil resistivity and the geometric characteristics of the tower's grounding system.

APPLICATION TO REAL CASES

Transmission lines characteristics

The method presented in this paper has been applied and tested on 150 kV and 400 kV operating transmission lines of the Hellenic interconnected system. These two lines were carefully selected among others, due to: a) their high failure rates during lightning thunderstorms [12], b) their consistent construction for at least 90 present of their length and c) their sufficient length and their sufficient time in service in order to present a reasonable exposure to lightning.

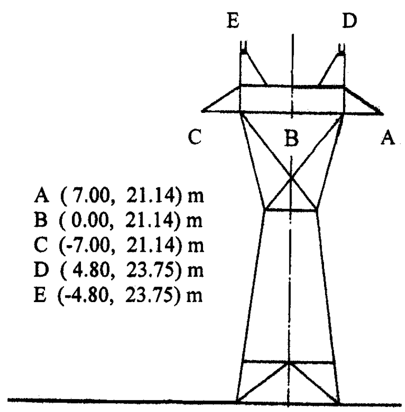

Figure 4: Typical tower of the analyzed 150kV Hellenic transmission line

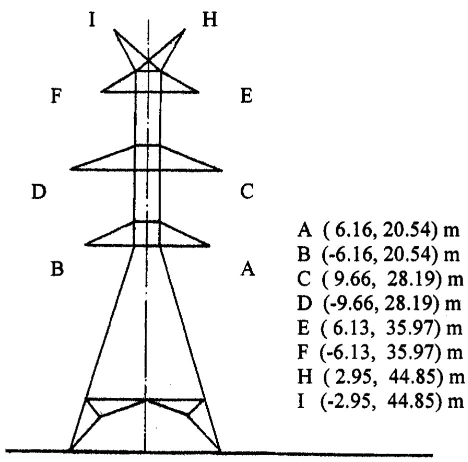

Figure 5: Typical tower of the analyzed 400kV Hellenic transmission line

The first line called Kilkis - Serres is a 150kV line having a length of 58.068km. It comprises a three phase single circuit, with two shielding wires (Figure 4). The line has got 162 towers with an average span of 358m. The line's insulation level is 750kV and the phase conductor dimensions are ACSR 336.4 MCM.

The second line called Thessaloniki - Kardia is a 400kV line having a length of 109.908km. It comprises a three phase double circuit, with two shielding wires (Figure 5). The line has got 305 towers with an average span of 360m. The line's insulation level is 1550kV and the phase conductor dimensions are ACSR 954 MCM.

Simulation results of the improved method

Table 1 presents the recorded field observation data of the two examined transmission lines and results obtained according to the old backflashover method and the proposed improved backflashover method [12].

It is clear that the results obtained by means of the improved method are much more accurate than these obtained by the old method and almost identical to the actual ones, something, which obvious implies the necessity of the method's improvement.

Table 1: Field Observation Data versus Simulated Results

Line	Predicted Lightning Failures by the Old Method [3]	Predicted Lightning Failures by the Improved Method	Average Lightning Failures from 1997 to 2002
Kilkis - Serres	3.78	3.52	3.29
Thessaloniki - Kardia	3.91	3.75	3.56

CONCLUSIONS

The paper describes in detail an improved backflashover method, which evaluates the lightning performance of high voltage overhead transmission lines based upon a previous study. The method is applied on operating Hellenic transmission lines of 150 kV and 400 kV giving results much more accurate than these obtained from the old method and almost identical to the actual ones. Special attention has paid to the design characteristics of each one individual tower of the examined transmission line, to the monthly metereological conditions of the geographic region that line is running, and to the tower footing resistance which can be easily estimated using the soil resistivity and the grounding system geometric characteristics. The proposed method can be used as a useful tool in the design of electric power systems, aiding in a more effective protection of them against lightning strokes.

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