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Lightning Performance Evaluation of Hellenic High Voltage Transmission Lines

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Abstract: This paper describes a method for determining the lightning performance of high voltage transmission lines of the Hellenic interconnected system, taking into consideration both, shielding failures and backflashover rates. The method uses the electrogeometric model in order to estimate the incidence of lightning strokes on transmission lines. It also employs the Monte-Carlo statistical technique to select lightning and power system parameters and travelling waves techniques to calculate overvoltages on transmission line towers, resulting to the prediction of eventual faults. The method has been coded as a Visual Basic computer program, being able to be implemented on any type of transmission line and for various insulation levels. The developed method is applied on several operating Hellenic high voltage transmission lines, showing comparatively a quite satisfactory agreement between predicted and line experience results. The proposed method is a further development of a method, which relates only to the backflashover phenomenon and had been presented during the ISH 2001 in Bangalore.

1. Introduction

Lightning causes a significant part of the disturbances, damages and unscheduled supply interruptions in the modern power systems. This is the reason why over the last years, many lightning performance estimation procedures have been presented in the technical literature.

Clayton and Young [1] were from the first researchers, who tried to estimate the lightning performance of transmission lines introducing an analogue computer method based on generalized estimating curves. Anderson [2] in 1961, followed by Sargent and Daverniza [3], Darveniza, Popolansky and Whitehead [4], Bouquegneau, Dubois and Trekat [5] and many other researchers tried to solve the same problem using Monte-Carlo simulation techniques. Travelling wave method was introduced from Bewley [6] in order to calculate overvoltages on transmission line towers, while electrogeometric model, the technique used to determine the target point of a lightning stroke, was extensively studied, extended and modified from Young et.al. [7], Brown [8], Eriksson [9] and many others researchers.

This paper presents a method, which predicts the failure rate of the high voltage transmission lines of the Hellenic interconnected system. The method analyses both shielding failures, where the lightning stroke terminates directly on the phase conductor and backflashovers, where the lightning stroke terminates on structure or shield wire, changing the potential of the structure sufficiently to cause a flashover to a healthy, until to this moment, phase conductor. Several techniques have been utilized in the proposed approach. These techniques - travelling waves calculations, electrogeometric model, Monte-Carlo simulation technique - have been combined in a full comprehensive computer program coded in Visual Basic language to facilitate the calculations. The program uses real field data from operating Hellenic transmission lines of known lightning performance in order to check the developed method.

2. Shielding Failure Rates

An approximation for the number of flashes to any line can be provided using the equation [10]:

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

where, N_L is the number of lightning flashes to a line per 100km per year, T is the lightning level in the vicinity of the line - the average number of days per year on which thunder is heard, h is the average height in meters of the shielding wires and b is the horizontal spacing, in meters, between the shielding wires.

Lightning parameters such as: the crest value of stroke current, the time to crest, the steepness and time to half value and also power system parameters such as: tower footing resistance and tower surge impedance, are randomly selected from known statistical distributions published in the technical literature [11, 12], using the well known Monte-Carlo statistical technique [13].

The lightning stroke termination point on the transmission line, which can be a shield wire or a phase conductor is determined using the improved electrogeometric model proposed by Eriksson [9], considering the attractive (critical) radius around the shield wires and phase conductors equal to:

$$r = 0.67 \cdot H^{0.6} \cdot I^{0.74} \quad (2)$$

where, H is the structure high in meters and I is the prospective stroke current in kA.

Shielding failure flashover rate (SFFOR) is associated to a required minimum current I_{min} to cause a line insulation flashover [14]. SFFOR is defined as follows:

$$SFFOR = N_L \cdot \int_{I_{\min}}^{I} f(I)\, dI \qquad (3)$$

where *SFFOR* is the shielding flashover rate per 100km per year, N_L is the number of lightning flashes to a line per 100km per year, I_{min} is the minimum current equals to $2CFO / Z_{surge}$, *CFO* is the critical flashover voltage and Z_{surge} is the conductor line surge impedance. The critical flashover voltage *CFO* is defined as the crest voltage of an applied impulse wave that will cause flashover on the tail of the wave 50% of the time and will not flashover the other 50% of the time.

Travelling wave analysis can be used in order to calculate the overvoltages stressing the insulation of the system. The analysis takes into account the non-linearities in the system such as: the effects of corona, the effects of wave attenuation and tower footing behaviour including the effects of multiple flashovers in the phases and circuits [6]. In the analysis, the lightning stroke is assumed to be a constant current source, with surge impedance much greater than the impedance presented to it by the transmission system. As a simplifying assumption, the effect of charge in the stroke channel is ignored [13].

3. Backflashover Rates

Although there are several methods, which allow the yearly estimation of the line's faults caused by backflashover phenomenon, in this paper a relatively simple estimating method [15, 16] has been used. The method can estimate the average number of backflashover faults which may occur in a transmission line, with or without having shielding wires, dividing them also in single phase and three phase faults.

This simple method has been presented during the ISH 2001 in Bangalore and has been applied and tested on several operating Hellenic high voltage transmission lines, giving results very close to the real ones. In the current work, this backflashover method has been included in the developed Visual Basic computer program, which has also the ability to calculate shielding failures, resulting in a more sofisticated approach for evaluating the lightning performance of transmission lines.

4. Visual Basic Computer Program

A program coded in Visual Basic has been developed to facilitate all the necessary calculations in the evaluation of lightning performance of transmission lines. The program is user friendly, simple in use and very flexible in any modifications and changes in order to support any other different structures, insulation levels and parameters than these which are used in the Hellenic interconnected system (figure 1).

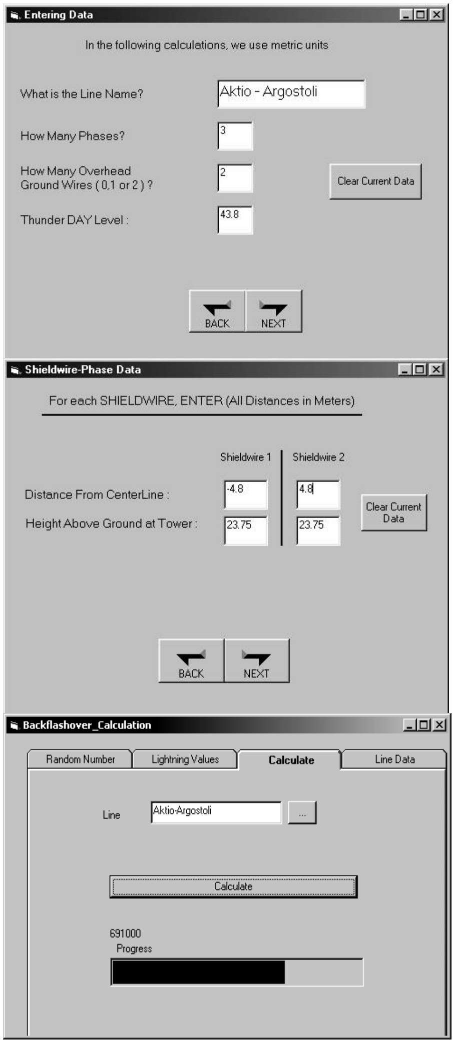

Figure 1: Characteristic forms of the developedVisual Basic program

The program is organised as follows:

a) Transmission line parameters (such as: tower dimensions, tower footing characteristics, span length, conductor heigths, sizes, sags etc) are introduced in the program
b) The number of strokes to the line is calculated for the lightning level in the vicinity of the line
c) Lightning parameters of a random stroke are determined randomly selected from known statistical distributions

d) The termination point of the stroke (i.e. phase conductor, shield wire or tower structure) is determined
e) Overvoltages stressing the line insulation are computed according to the travelling wave method
f) Shielding angles required for the phase conductors are calculated
g) Probability of backflashover is estimating
h) Backflashover rate and shielding failure flashover rate are calculated
i) Total flashover rate is calculated

5. 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 lines were carefully selected among others, due to:

a) their high failure rates during lightning thunderstorms [18],
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.

The first line called Arachthos-Acheloos is a 150kV line having a length of 70.300km. It is running through mountainous region and comprises a three phase double circuit. The line has got 192 towers with average spans of 370m The basic insulation level (BIL) of the line is 750kV and phase conductor dimensions are ACSR 636 MCM. The average measured tower footing recistance is 3.2 ohms. The average height of the shield wire is 32.5m while the average height of the phase conductors are 20.77m, 24.81m and 28.86m with average horizontal spacing between them 8.6m, 10.8m, and 6.8m respectively (figure 2a). Finally the average lightning level in the vicinity of the line from 1994 to 2002 was measured equal to 43.7 [17].

The second line called Thessaloniki-Kardia is a 400kV line having a length of 109.908km. It is running through a plain region and comprises a three phase double circuit. The line has got 305 towers with average spans of 360m. The line's BIL is 1550kV and the phase conductor dimensions are ACSR 954 MCM. The average height of the two shielding wires is 44.85m and the average horizontal spacing between them is 5.9m. The average height of the phase conductors are 20.54m, 28.19m and 35.97m with average horizontal spacing between them 12.31m, 19.38m, and 12.25m respectively (figure 2b). The average measured tower footing recistance is 5.9 ohms. Finally the average lightning level in the vicinity of the line from 1994 to 2002 was measured equal to 29.4 [17].

The third line called Aktio-Argostoli is 150kV line having a length of 81.409km. It is running through the coastline and comprises of a three phase single circuit. The line has got 224 towers with average spans of 365m The line's BIL is 750kV and phase conductor dimensions are ACSR 336.4 MCM. The average height of the two shielding wires is 23.75m and the average horizontal spacing between them is 9.6m. The average height of the phase conductors is 21.14m with average horizontal spacing between them 7m (figure 2c). The average measured tower footing recistance is 170 ohms. Finally the average lightning level in the vicinity of the line from 1994 to 2002 was measured equal to 43.8 [17].

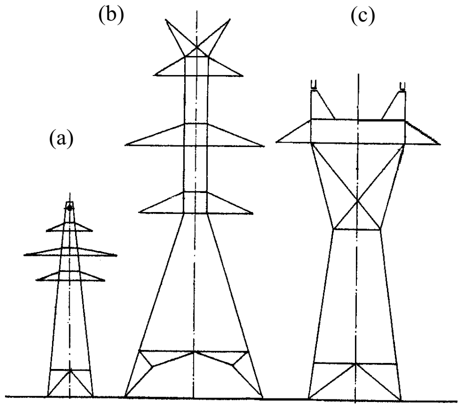

Figure 2: The structures of the analyzed 150kV and 400kV Hellenic Transmission Lines

6. Simulation Results

Table 1 clearly presents field observation data and the results obtained according to the proposed simulation method [18].

Table 1: Field Observation Data versus Simulated Results

Line	Average Lightning Failures from 1994 to 2002	Predicted Lightning Failures
Thessaloniki - Kardia	3.4	3.1
Arachthos - Acheloos	4.0	4.2
Aktio - Argostoli	2.9	3.3

The obtained results are very close to the actual ones something which implies that the proposed method has an acceptable accuracy.

7. Future Work

As a future work it would be the more extent implementation of the proposed method in the

Hellenic transmission lines and the comparison of the results with these of other methods published in the technical literature.

Furthermore it is believed, that the developed program could be a more effective tool in the evaluation of ligtning performance, by including in the calculations a surge arrester model, since the application of transmission line surge arresters to improve lightning performance has become worldwide a standard practice.

8. Conclusions

A method, which evaluates the lightning performance of the Hellenic high voltage transmission lines taking into consideration shielding failures and backflashover rates has been presented.

The method combines existing techniques such as: the Monte-Carlo statistical technique, the electrogeometric model and the travelling wave method. The method has been introduced in a Visual Basic computer program and has been applied in the Hellenic high voltage transmission lines. The computer program has been proved totally satisfactory, very simple in use and capable to be implemented to other types of structures and other insulation levels than these presented in the paper.

The presented method can be used by electric power utilities as a useful tool for the design of electric power systems.

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