A BACKFLASHOVER MODEL FOR CALCULATING THE TRANSMISSION LINES' LIGHTNING PERFOMANCE

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Abstract: The paper presents a model, which determines the probability of backflashover in high voltage transmission lines due to lightning strokes, using Monte-Carlo simulation. The model can estimate the average number of faults which may occur in a transmission line by dividing them in single phase and three phase faults. Furthermore, the average grounding resistances of the transmission lines are calculated. The developed model was applied, on several operating Greek transmission lines, giving satisfactory results. The proposed model can be used as a useful tool in the design of electric power systems, aiding in the right insulation dimensioning of a transmission line.

Key words: Lightning stroke, backflashover, Monte-Carlo simulation, transmission lines, grounding resistance.

1. Introduction

There are two cases in the formation of backflashover. In the first case, lightning strikes directly a tower or a grounding wire, having an increase in the potential of the tower. In the second case, a lightning strikes an overhead phase-conductor, destroying the insulation, increasing the potential of the tower and giving the probability to appear a backflashover between the tower and a healthy, until to this moment, phase-conductor.

Therefore, it is obvious that the calculation of the potential increase of a grounding wire, as well as the potential increase of the neighbouring towers are necessary, in order to determine the distances between grounding wires and phase conductors, and the insulation between the neighbour towers and phase-conductors.

The potential increase of a tower can be maintained in low levels, if the tower's grounding resistance is low. According to this, there are two different methods in the design of a transmission line. The first method uses good grounding and relative low line insulation while the second one uses average grounding but relative high line insulation.

2. Method for estimating the lightning performance

It is well known that any method of estimating the lightning performance of transmission lines must cope with a variety of statistical and non-linear effects. It is also known that it is not useful to promote a method whose prediction accuracy exceeds the precision of knowledge of the constants and stimuli that enter the problem [1]. Several methods exist, which allow the yearly estimation of the line's faults caused by backflashover, giving results very close to the real ones. Such methods have been based in analogue computers [2], geometrical models, travelling waves, field theory methods and Monte-Carlo simulation [3, 4]. A relatively simple estimating method is presented below taking into consideration the following assumptions:

a) When lightning strikes a phase-conductor the discharge current is propagating in both directions from the point of the strike.

b) The tower, which is flowed by impulse current, is acting as an inductance with value approximately equal to 0.4μH [1]. Theoretical estimations give inductance values from 0.5μH to 0.7μH, while measurements give values below 0.3μH.

c) The tower's grounding consists of a resistance R and an inductance approximately equal to 5μH.

d) Backflashover appears in more than one phase-conductors. There is no relation between the peak value of the lightning current and its slope.

e) For every lightning current slope area, the voltages U_1, U_2 and U_3 are calculated using the following equations:

$$U_1 = 0.85 \cdot U_a - L\frac{di}{dt} \qquad (1)$$

$$U_2 = U_a - L\frac{di}{dt} \quad (2)$$

$$U_3 = 1.15 \cdot U_a - L\frac{di}{dt} \quad (3)$$

where U_a is the dielectric strength of the transmission line against lightning overvoltages

The total inductance L of the system will be the sum of the 0.4μH tower inductance and the 5μH ground system inductance. Thus, L is equal to 5.4μH.

A single-phase fault appears in a transmission line with grounding wire, for any lightning current I, if

$$U_3 > R \cdot \frac{I}{2} \geq U_1 \quad (4)$$

A multiphase fault appears, if

$$R \cdot \frac{I}{2} \geq U_3 \quad (5)$$

In case that the transmission line does not have a grounding wire, two cases are observed:
a) Stroke to a tower. In this case, a single-phase fault exists if

$$U_3 > R \cdot I \geq U_1 \quad (6)$$

and a multiphase fault exists if

$$R \cdot I \geq U_3 \quad (7)$$

b) Stroke to a phase-conductor: A backflashover occurs, after the initial single-phase fault, to one of the healthy phases, in case that

$$R \cdot I \geq U_2 \quad (8)$$

An approximation for the number of flashes to any line can be provided using the equation [1]:

$$N_L = 0.004 \cdot T^{1.35} \cdot \left(b + 4 \cdot h^{1.09}\right) \quad (9)$$

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

Based on the above method, a comprehensive computer program was developed to determine the lightning performance of transmission lines and to calculate their average grounding resistance.

3. Monte-Carlo simulation

The design of transmission lines for a predetermined lightning performance requires a method of predicting the failure rates of the lines during a prescribed period of time. Generally, the prediction methods are based on Monte-Carlo simulation [4].

Any approach using Monte-Carlo simulation requires the creation of a set of random numbers uniformly distributed, in the interval (0, 1), i.e., the numbers can take any value between 0 and 1 with equal likelihood [5].

The most effective algorithms for creating random numbers are the congruential generators from which a new number X_{i+1} in a sequence is calculated from the previous value X_i using the expression [5]:

$$X_{i+1} = (A X_i + C)(\mathrm{mod}\, B) \quad (10)$$

where A (the multiplier), B (the modulus) and C (the increment) are all non-negative integers.

The process is started by choosing the value X_0 known as the seed. The sequence is then produced automatically.

After deducing the sequence of random numbers X_i, a uniform random number u_i in the range (0,1) can be found [5]:

$$u_i = X_i / B \quad (11)$$

When a generator of random numbers is used, the constant value A, the initial value X_0, the increment C and modulus B must be given. In this paper the following values were randomly selected: B = 714025, A = 1366, C = 150889, X_0 = 2345 for the generation of the maximum lightning current, X_0 = 4567 for the generation of the slope of the lightning current and X_0 = 6789 for the generation of the nature and kind of the lightning.

In Monte-Carlo simulation the most important aspect is not only the generation of uniformly distributed random numbers, but also the conversion of them into other non-uniform distributions before the simulation process can begin [5].

In this paper, the generated numbers were chosen to follow the normal distribution with average value μ and standard deviation σ. In order to obtain this, the following transformation was used [6]:

$$X_1 = \mu + \sigma \cdot \sqrt{-2 \cdot \ln u_1} \cdot \cos(2 \cdot \pi \cdot u_2) \quad (12)$$

$$X_2 = \mu + \sigma \cdot \sqrt{-2 \cdot \ln u_1} \cdot \sin(2 \cdot \pi \cdot u_2) \quad (13)$$

where X_1, X_2 is a pair of random numbers following the normal distribution N (μ,σ).

4. Procedure and simulation results

The probability of existence of backflashover in a high voltage transmission line, having a grounding wire was studied. The developed computer program calculates backflashover using equations (1)-(8) and generates uniformly distributed random numbers in the interval 0-1 from equations (10), (11) using the already mentioned values. The peak value and the slope of the lightning current are calculated using equation (12), assuming that both follow the normal distribution and there is no relation between them. Finally, it is considered that the 80% of the lightnings are negative and 20% of them are positive with an average value μ and a standard deviation σ as it is shown in Table 1.

Table 1. Lightning parameters [7]

		μ	σ
Positive lightning	I_{max}	35 kA	15 kA
Positive lightning	di/dt	2.4 kA/μs	1.1 kA/μs
Negative lightning	I_{max}	30 kA	7.5 kA
Negative lightning	di/dt	40 kA/μs	14 kA/μs

Several tests were carried out varying the resistance from 1 to 20 Ω with the basic insulation level (BIL) constant at 750 kV. For the tests presented in this paper, a convergence of the simulation was achieved after two million repetitions. The backflashover probability for different values of grounding resistance is shown in Fig.1.

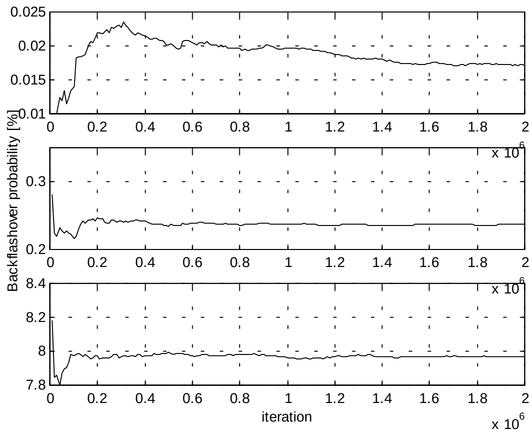

Fig. 1. Backflashover probability for different values of grounding resistances

The obtained simulation results are presented in Fig. 2, showing the percentage probability of having single phase and three phase faults for various grounding resistances.

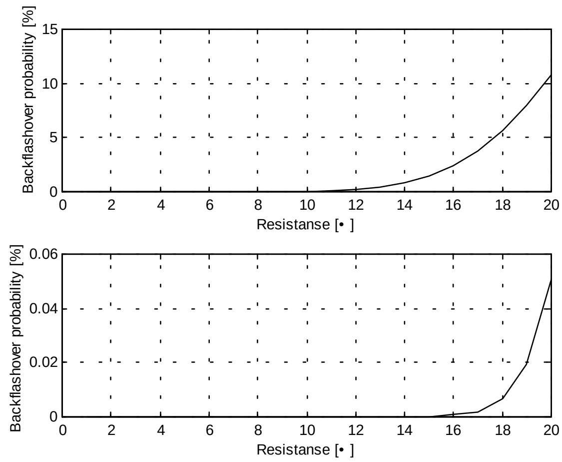

Fig. 2. Percentage probability of having single phase and three phase faults.

5. Transmission line study

The proposed model has been applied on three different 150 kV transmission lines which exist in the Greek interconnected transmission system. These lines were selected due to their high failure rates during lightning thunderstorms.

The line Tavropos-Lamia has a length of 75.384km, runs through a mountainous region and comprises of a three phase double circuit, 219 towers with average spans of 350m, 750kV BIL, phase conductor dimensions ACSR 636 MCM, average height of the grounding wires 19m and horizontal spacing between the grounding wires 9m. The average lightning level in the vicinity of the line for this area and the number of average failures occurred in this line from 1995 to 1999, were 22.2 and 6 respectively [8].

The line Kilkis-Serres has a length of 58.068km, runs through a plain region and comprises of a three phase single circuit, 162 towers with average spans of 360m, 750kV BIL, phase conductor dimensions ACSR 336.4 MCM, average height of the grounding wires 19m and horizontal spacing between the grounding wires 6.5m. The average lightning level in the vicinity of the line for this area and the yearly number of average failures occurred in this line from 1995 to 1999, were 27.2 and 3 respectively [8].

The line Igoumenitsa-Sagiada has a length of a 8.881km, runs through the coastline and comprises of a three phase single circuit, 41 towers with average spans of 220m, 750kV BIL, phase conductor dimensions ACSR 336.4 MCM, average height of the grounding wires 19m and horizontal spacing between the grounding wires 6.5m. The average lightning level in the vicinity of the line for this area and the yearly number of average failures occurred in this line from 1995 to 1999, were 41.6 and 3 respectively [8].

The lightning performance for each of the above three transmission lines has been predicted taking into account the characteristics of each line. Furthermore, the grounding resistance of each line was calculated, considering the percentage fault probabilities of Fig. 2, the number of lightning flashes N_L and the yearly average number of failure occurred in each line. The equation, which was used, is:

$$Av. Failure\ No. = N_L * Fault\ \ probability$$

The values of the calculated grounding resistances were very close to the actual ones, which implies that the proposed model has an acceptable accuracy.

Conclusions

The paper presents a model which estimates the lightning performance of high voltage transmission lines using backflashover calculations and a Monte-Carlo simulation method. The model has been applied on three different lines of the Greek interconnected transmission system and gives satisfactory results.

The model can also be used in another way. It has also the ability to compute the number of the backflashover failures occurred on a transmission line for a given grounding resistance.

The presented model can be used from electric power utilities in order to predict the lightning performance of any type of transmission and distribution line which means that it is a useful tool for the design of electric power systems.

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