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Lightning Performance of Transmission Line with and without Surge Arresters: Comparison between a Monte Carlo method and field experience

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ABSTRACT

This paper presents a study regarding the lightning flashover rates of transmission lines comparing results from calculation procedures and field experience. The proposed procedure is based on Monte Carlo method and allows the estimation of the lightning performance of lines equipped or not with surge arresters. The procedure has been implemented in Delphi and linked to Alternative Transients Program—ATP. The calculation is done using simple engineering models for each component. Nevertheless, the overall modeling led to reliable results, concerning the comparison with the reported field data. With this respect, the comparative study of lightning performance of transmission lines, the paper presents results for three lines: a line without surge arrester, in Tennessee—USA, for which the performance was estimated using both IEEE FLASH and the proposed procedure, and two transmission lines equipped with surge arresters, in Minas Gerais—Brazil, calculated solely using the proposed methodology. These three lines have been monitored for more than 7 years, without significant layout/design changes in this period, favoring the statistical relevance of the reported data.

1. Introduction

The lightning performance of transmission lines is very important for electric utilities around the world, since lightning is a major cause of outages of overhead lines [1]. In transmission systems up to 138 kV, in Brazil, lightning is especially damaging, even in regions with both average lightning density and soil resistivity, since most tripouts are caused by backflashover [2–4].

The available methodologies and input data for calculating the lightning performance of transmission lines share some common ground. These data usually consider the characterization of return stroke current (peak, front time, time to half value and waveform), lightning striking point on the line, as well as the proper modeling of the electrical system and its response to surge propagation. The lightning performance of transmission lines is widely discussed in literature, with papers presenting either results for specific lines or numerical comparisons of lightning performance, which are calculated using different methodologies or including variation on the component modeling [5–11]. Despite this comprehensive discussion, there are few studies presenting real transmission line performance data, facilitating the validation of proposed methodologies. In fact, there are not many papers comparing calculated values with results obtained from field experience.

This paper aims to introduce and detail a procedure for calculating the lightning flashover rate of transmission lines that accounts for the use of surge arresters. The calculation results are compared with lightning performances observed in the field for two transmission lines with a nominal voltage of 138 kV, both owned by CEMIG, and a transmission line of 161 kV owned by TVA. Section 2 presents the adopted modeling for each component. The backflashover rate calculation procedure is detailed in Section 3, while the study cases are shown in Section 4. Finally, the conclusions are stated in Section 5.

2. Component modeling for lightning overvoltage calculations

Several documents have been published regarding modeling guidelines for power systems components aimed to lightning overvoltage simulations [2–4,6,12–14]. The goal of following sub-

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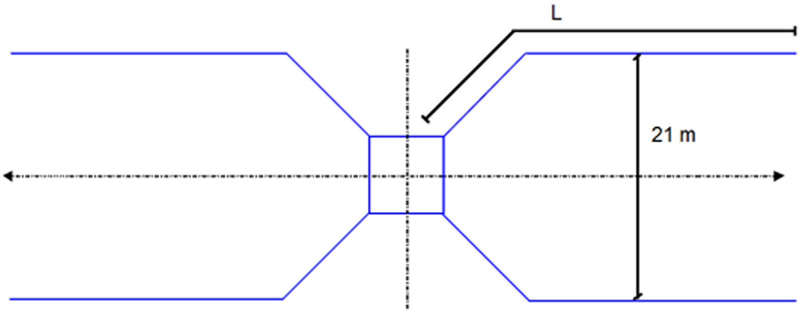

Fig. 1. Tower-footing arrangement consisting of four counterpoise-wires (radius 2.59 mm) of length L, from 20 m to 90 m, buried 0.5 m deep in soil.

sections is to provide a summary of the available models and general guidelines for modeling such components, while indicating the modeling adopted in this work.

2.1. *Overhead transmission line*

Lightning overvoltages are fast transients, whose magnitudes are influenced by traveling waves on the adjacent spans. Then, the line should be modeled to consider 3 or 4 spans at each side of the point of impact. Each span is properly represented by a multi-phase untransposed distributed parameter line section. The electrical parameters of these line sections may be modeled considering either frequency-dependent or constant parameters, calculated at 500 kHz [14]. Constant parameter modeling is chosen for this work. Corona effect is not simulated.

To avoid reflections that would affect the simulated overvoltages around the point of impact, the line terminations at each side is represented by means of a long-enough line section, adopted in this work, or by inserting an impedance matrix at each termination, matching the line surge impedance.

2.2. *Transmission line towers*

The transmission lines towers may be modeled as a vertical transmission lines with distributed parameters, characterized by a surge impedance associated with an electromagnetic wave travel time. There are several studies seeking to characterize the models for towers [3,15–21]. The value for the tower surge impedance is calculated according to Eq. (1) [21] and the electromagnetic wave velocity of propagation in towers is considered to be equal to 80% of the velocity of light (240 m/μs). The following equation, derived considering the tower as an equivalent cylinder, gives the surge impedance value:

$$Z = 60\left(\ln\left(2\sqrt{2}\frac{h}{r}\right) - 1\right), \tag{1}$$

where h is the tower height in meters, r is the tower base radius in meters and Z is the surge impedance in Ω.

2.3. *Tower grounding impedance*

The tower grounding impedance is very important for determining the occurrence of backflashover [22–24]. For transmission lines with rated voltage up to 230 kV, backflashover is the main cause of the outages. Tower grounding is generally modeled by a lumped resistance whose value is equal to the one obtained either from low frequency measurements (upon which a correcting factor may be used) or calculations. In large grounding systems, as those used in high voltage transmission lines installed in high resistivity soil, which may be composed by long counterpoises, soil ionization may be disregarded, as it occurs only when injecting very high lightning currents. In these cases, the tower-footing electrodes generally consist of the counterpoise arrangement indicated in Fig. 1.

Considering the high frequency involved in lightning analysis, the behavior of a grounding system may be described by its impulse impedance Z_P, which is given by the ratio between the peak values of the grounding potential rise (GPR) and the injected current ($Z_P = V_P/I_P$). As an alternative, that is adopted in this work, the ground system is modeled as a lumped resistance with value equal to impulse impedance, but calculated in a different way. The impulse impedance value is obtained by multiplying the low frequency resistance (R_{LF}) by the impulse coefficient (I_C). The impulse coefficient is calculated using Eq. (2), as described in Ref. [25]:

$$I_C = k\left(\alpha L + \beta\right), \tag{2}$$

where L is the electrode length in meters, k is a correction factor that depends on the electrode arrangement, and it is equal to 1 for the horizontal electrode and α and β are coefficients dependent on the soil resistivity and lightning current waveform. Considering the parameters for the first stroke, α and β are calculated by Eqs. (3) and (4) [25]:

$$\alpha_{1st} = 0.002 + \exp\left(-1.55\rho_0^{0.162}\right), \tag{3}$$

$$\beta_{1st} = -0.5 + \exp\left(-0.00046\rho_0^{0.83}\right), \tag{4}$$

where ρ_0 is the soil resistivity at 100 Hz.

Thus, the impulse grounding impedance Z_P is a function of the soil resistivity, the current waveform, primarily its front-time, and counterpoises length. Therefore, a long counterpoise cable may present a low resistance value for industrial frequency currents, but a high value for lightning currents.

2.4. *Surge arrester model*

Only gapless surge arresters are considered and a typical nonlinear resistance (V–I characteristic curve for ZnO arrester) has been adopted. Additionally, a lumped inductance of 1 μH/m representing the earth arrester lead was also included.

2.5. *Strength of insulation*

The insulation strength depends on the waveform of the applied voltage. Considering lightning, a flashover across the insulator string may be evaluated using the following approaches:

- Voltage–time curves
- Integration methods
- Physicals models