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A conductor arrangement that overcomes the effective length issue in transmission line grounding

C.E.F. Caetano, A.B. Lima, J.O.S. Paulino, W.C. Boaventura*, E.N. Cardoso

Department of Electrical Engineering, Federal University of Minas Gerais, UFMG, Belo Horizonte, Brazil

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ABSTRACT

The reliability and availability of the electric power transmission system is severely influenced by lightning. In Brazil, roughly 65% of the overhead transmission lines outages are due to lightning, whereas the backflashover is the predominant phenomenon compared to shielding failure. Hence, obtaining a low value for the transmission line grounding impedance is an important issue when dealing with transmission lines backflashover performance. Usually, for high resistivity soils, increasing the grounding grid dimensions does not lead to low impedance due to the effective length issue. In this work, a special arrangement of ground electrodes is proposed in order to overcome the effective length problem in high resistivity soil. The transient voltage response of this low impedance ground arrangement is evaluated numerically using parametric modeling approach. Comparisons of numerical simulations results and measurements from a reduced model study are presented for validation purpose. Additionally, the quality of the results obtained using the reduced model elects it as a valuable tool for studies of electromagnetic transients involving interaction of lightning and grounding grids.

1. Introduction

Several efforts have been made to compute the transient behavior of the grounding electrodes [1] and important advances were achieved recently [2–16]. Achieving low impedance values through ground electrodes arrangements is important when dealing with the lightning performance of aerial transmission lines. In this paper, a special ground electrode arrangement is proposed and its transient response is analyzed. The main purpose is to obtain a low impedance value even for high resistivity soil.

In general, the performance of grounding electrodes is strongly influenced by the (i) lightning stroke current parameters, (ii) electrodes geometry and (iii) soil resistivity and permittivity values. Considering the stroke current, the important parameters are the peak value and waveform. In this study, soil parameters are considered as frequency invariant. The soil ionization phenomena are not treated in this work. This study uses the transmission line theory to calculate the ground electrode response with line parameters calculated using Sundeís equations [1] and Grcevís inductance formula [17]. The corresponding time-domain response is obtained using the parametric modeling approach described in Refs. [7,12], and in the simplified calculation method using the PSPICE described in Ref. [18].

The proposed arrangement is aimed to very high resistivity soil, as the case of the State of Minas Gerais, Brazil, where the median apparent resistivity is 1700 Ωm and the average is 2400 Ωm, as shown in Fig. 1 [19]. The proposed innovative arrangement, first analyzed and presented in Ref. [20] and then in Ref. [8], from which this paper is a sequel, permits the use of grounding arrangements where wire lengths are greater than the effective length while producing a reduction in the impedance value.

In this work, when compared to Ref. [8], the authors present a more detailed analysis of the proposed grounding arrangement. The reduced model was improved and specially developed to obtain new measurements, extending the validation of the theoretical results obtained through computational simulations. This new reduced model is composed of a hemispherical steel tank 3 m in diameter, filled with treated water (for fine resistivity control), a discharge channel model, a generator for simulating lightning current waveforms and a set of electrodes for the grounding simulation. As mentioned, the simulations considered soil parameters frequency invariant, since, in Ref. [8], a comparison showed that the behavior of the grounding presented little difference when considering or not the frequency dependence of the soil electrical parameters.

* Corresponding author.
E-mail address: wventura@ufmg.br (W.C. Boaventura).

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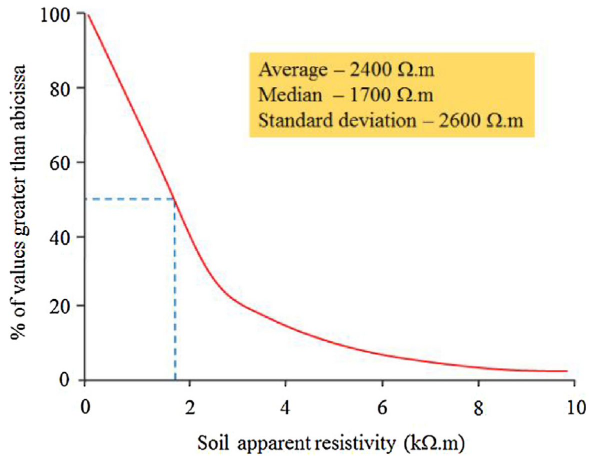

Fig. 1. Apparent soil resistivity in state of Minas Gerais of Brazil.

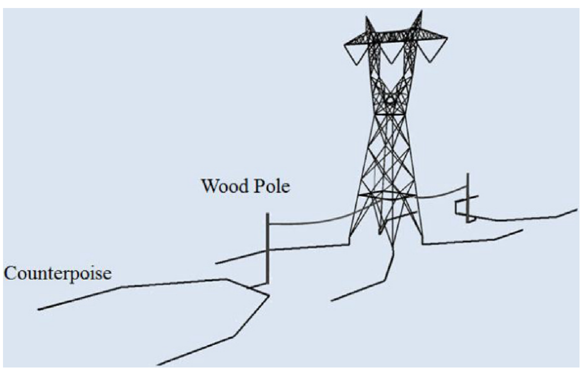

Fig. 2. Sketch of the proposed grounding arrangement aimed to a low impedance grounding electrode.

This paper is organized as follows. Section 2 presents the details of the proposed ground electrode configuration. Section 3 investigate the behavior of the proposed electrode arrangement through numerical simulations, whereas is field implementation is discussed in Section 4. The reduced model study is presented in Section 5. Discussion and conclusions are presented in Sections 6 and 7, respectively.

2. Proposed ground electrode configuration

The IEEE Guide for Improving the Lightning Performance of Transmission Lines [21] states that the use of additional guy wires on transmission towers improve the transmission line lightning performance: *This treatment should also improve lightning performance in two ways. First, each new guy anchor will behave as an additional ground electrode. The anchors may be grounded with low-resistivity material, such as concrete, and bonded to any existing counterpoise or structure, to maximize the benefit. Second, the guy wires will mitigate the tower surge response. Four widely separated guy wires may reduce the impedance of a tower from 100 Ω to 50 Ω. This factor alone may reduce the outage rate of a tall line by 30%.*

Using the basic concept from the IEEE Guide, a simple and innovative idea to reduce the impedance value of transmission tower grounding electrode is sketched in Fig. 2. This arrangement was initially proposed in Ref. [20]. Other approaches using the concept discussed in the IEEE Guide are shown in Refs. [22,23], where the lightning performance improvement is evaluated through the use of underbuilt cables.

The proposed concept is easy to implement and provides a technique that overcomes the effective length problem. It uses an aerial line to connect the tower basis to an extra set of counterpoises, which leads to an impedance reduction. In our estimate, it will increase about 20% in costs, mainly due to the pole and the aerial line, since the original buried conductor is split in two portions.

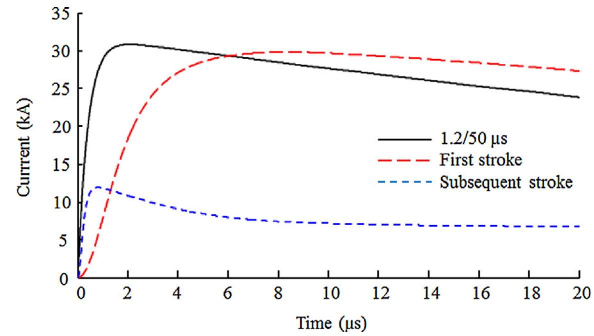

Fig. 3. Current waveforms used in this study: the classical 1.2/50 μs, the typical first and subsequent strokes proposed in Ref. [24].

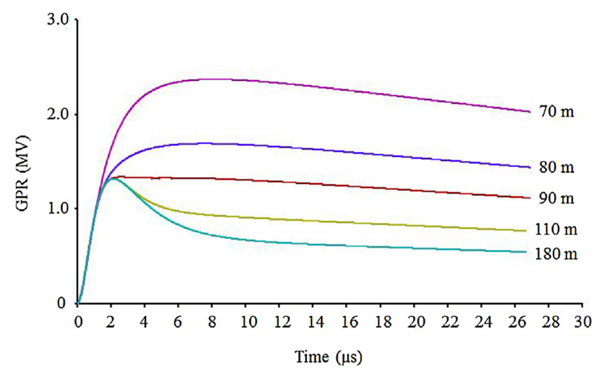

Fig. 4. The effective length problem for the case of a single electrode. Soil resistivity of 1700 Ωm. Typical first stroke current waveform.

3. Numerical simulations

Since the main objective is evaluating the grounding arrangement performance, the coupling between the phase conductors and the aerial part of the proposed arrangement is not considered. However, if the coupling was considered, probably, a better line performance would be achieved because the aerial part of the arrangement acts like an extra underbuilt shielding wire.

Three current waveforms were used for the simulations, Fig. 3: the classical current waveform of 1.2/50 μs, with a peak value of 30 kA, the typical first stroke current waveform, and the typical subsequent stroke current waveform, proposed by Rachidi et al. [24].

The ground electrical parameters considered are resistivity of 1700 Ωm and relative permittivity of 10. This resistivity value represents the median for Minas Gerais soil, according to Fig. 1. The buried grounding electrodes, 60–180 m long, are modeled as transmission lines with parameters calculated according to Sunde [1] and Grcev et al. [17].

Fig. 4 shows the ground potential rise (GPR) simulation for different electrode lengths, considering the soil parameters previously detailed, referring to the case of a single electrode, as shown in Fig. 5. For this soil parameters and a typical first stroke current waveform, the effective length is approximately 90 m. In this case, conventional grounding arrangements with lengths greater than 90 m will not contribute to the improvement of the system performance. Consequently, in the State of Minas Gerais, power utilities do not use counterpoises longer than 90 m [19].

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