MODELLING OF LONG GROUND ELECTRODES FOR LIGHTNING STUDIES

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Abstract - For evaluating the lightning performance of transmission lines by computer simulation, the accurate modelling of tower footing is very important. Considering the high frequencies and magnitudes characteristics of lightning currents, an adequate representation of earth electrodes must take into account the distributed nature of their parameters, as well as its non-linear behaviour, due to soil ionisation phenomena. The purpose of this paper is to study the non-linear behaviour of long ground electrodes, based on a finite-differences transmission line model able to take non-linearities into account [1]. Results obtained show the influence of soil ionisation process at the voltage and current distributions along the electrode and the important role played by the lightning current rise time.

1. Introduction

Computer simulation is an important tool for evaluating the lightning performance of transmission lines and the adequate modelling techniques for the different system's components have to be established. In particular, it has been emphasised by different authors that the predicted lightning backflashover rates are very sensitive to the tower footing behaviour, thus being essential an adequate ground electrode model.

Considering the high frequencies and magnitudes characteristic of lightning currents, the influence of these parameters have to be taken into account in tower footing modelling. In order to reproduce accurately the high frequency behaviour, a distributed model may be needed, depending on the length of the ground electrode.

In high resistivity soils it is often required to install long horizontally buried conductors, *counterpoises*, in the tower footing. The accurate modelling of counterpoises for lightning currents requires their representation by a distributed parameters model [2-5].

If high magnitude currents flow from the tower footing into the soil, the critical field strength of the soil can be exceeded, and its partial breakdown occurs. Then, the conductor is surrounded by a corona-type discharge pattern. The ionised area occupies a confined space in which the conductivity becomes much greater than in the rest of the soil. In this situation, the ground electrodes display a non-linear transient behaviour and present a lower resistance to ground.

Different models have been developed to describe the non-linear behaviour, due to soil ionisation process, of concentrated ground electrodes. These models can be classified in three categories: empirical models [6-7], variable geometry models [2-5][8] and variable resistivity models [9-11]. The same approaches can also be used for long ground electrodes.

In this paper the counterpoise distributed nature and non-linear behaviour is taken into account using a transmission line model, based on a finite-differences algorithm [1].

2. Non-Linear Counterpoise Distributed Model

A) Calculation of linear distributed counterpoise parameters: L', G' and C'.

According to *Dwight* [12], the resistance to ground of a cylindrical electrode, of length ℓ_r, radius r_0, buried horizontally in an homogeneous soil at the depth *s*, can be determined by image theory. The author determines the resistance of the equivalent system formed by the earth electrode and its image, represented in fig. 1, using the same equations derived for two parallel vertical rods of length 2ℓ, at distanced *D*.

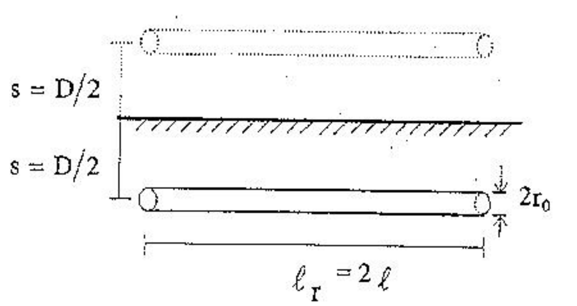

Fig. 1 Counterpoise geometry.

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According to Dwight, and considering that $2\ell >> D$, the counterpoise ground electrode resistance is given by:

$$R = \frac{\rho_0}{\pi \ell_r}\left(\ln\left(\frac{2\ell_r}{\sqrt{2r_0 s}}\right) - 1\right) \qquad (1)$$

being ρ_0 the soil resistivity.

The distributed transversal conductance, per unit length, is obtained from equation (1),

$$G' = \frac{\pi}{\rho_0}\frac{1}{\ln\left(\frac{2\ell_r}{\sqrt{2r_0 s}}\right) - 1} \qquad (2)$$

Considering the relation between resistance and capacitance, the distributed counterpoise capacitance is given by:

$$C' = \frac{\varepsilon_0 \varepsilon_r \pi}{\ln\left(\frac{2\ell_r}{\sqrt{2r_0 s}}\right) - 1} \qquad (3)$$

Then, the inductance, per unit length, is given by:

$$L' = \frac{\mu_0}{\pi}\left[\ln\left(\frac{2\ell_r}{\sqrt{2r_0 s}}\right) - 1\right] \qquad (4)$$

In this model the electrode is considered a perfect conductor, being the longitudinal resistance $R' = 0$.

These parameters have been included in a general purpose transmission line model developed by the authors [1]. The basic algorithm used for solving the wave propagation equations is based on a finite-differences approximation to the partial derivatives, considering the line divided into N equal segments. This type of algorithm is most adequate for representing the non-linear distributed behaviour of the counterpoise.

B) Characterisation of the non-linearity, using a variable geometry approach.

To describe the counterpoise non-linear behaviour, due to soil ionisation process, a variable geometry model is chosen [2-5][8]. Thus, the ground electrode is discretized into N segments, with Δx length, being each segment radius dependent on the electrical field value. A critical current value I_c is defined, associated to the soil ionisation threshold field E_c:

$$I_c = \frac{E_c}{\rho_0} A \qquad (5)$$

being A the segment lateral cylindric area,

$$A = 2\pi r_j \Delta x \qquad (6)$$

When the transversal current in segment j exceeds the critical value, the equivalent segment electrode radius, r_j, is evaluated using the equation:

$$r_j = \frac{\rho_0 I_j}{2\pi \Delta x E_c} \qquad (7)$$

3. Simulation Results

In this paper two different lengths counterpoises are used ($\ell_r = 8$ *and* $80\ m$), being kept constant the remaining electrode parameters: $r_0 = 5\ mm$ and $s = 0.6\ m$. The counterpoises are embedded in a soil with the following characteristics: $\rho_0 = 100\ \Omega m$, $\varepsilon_r = 30$ and $E_c = 2.8\ kV/cm$.

In order to evaluate the electrodes behaviour when a lightning current is injected, the current and voltage distributions along the counterpoises are computed for two different values of the current rise time. In order to evaluate the soil ionisation, the linear as well as non-linear models described above are considered.

Figs. 1 and 2 show the computed voltage and current distributions, along the *8 m* electrode, using two different double-exponential lightning currents, *5 kA/10 μs/50 μs* and *5 kA/1 μs/50 μs*, respectively.

Figs. 3 and 4 show the computed voltage and current distributions, along the *80 m* electrode, using two different double-exponential lightning currents, *5 kA/10 μs/50 μs* and *5 kA/1 μs/50 μs*, respectively.

The results presented in fig. 1 show that the *8 m* counterpoise behaves as a lumped conductance for the *10 μs* front current. For the same electrode and considering a *1 μs* rise time current, fig. 2 shows an increasing on the peak value of the voltage at the injection point ($x = 0\ m$), which occur before the current peak value, corresponding to an inductive behaviour. Both in figs. 1 and 2 the effect of soil ionisation can be observed. As expected, it acts to reduce the voltage at the different points along the electrode.

The results presented in figs. 3 and 4 show that the *80 m* counterpoise has an inductive behaviour even for the *10 μs* rise time current. The soil ionisation process, in spite of reducing the voltage at the different points along the electrode, has an irrelevant effect on the voltage curves obtained. This may be explained by the strong inductive character presented by the electrode.

The results obtained with de *10 μs* front current and using the linear counterpoise model show that when the electrode length is increased from *8 m* to *80 m* the voltage peak at the injection point is reduced about *46%*. For the *1 μs* front lightning current the electrode length increase originate, although, a voltage maximum increase at the injection point.

4. Conclusions

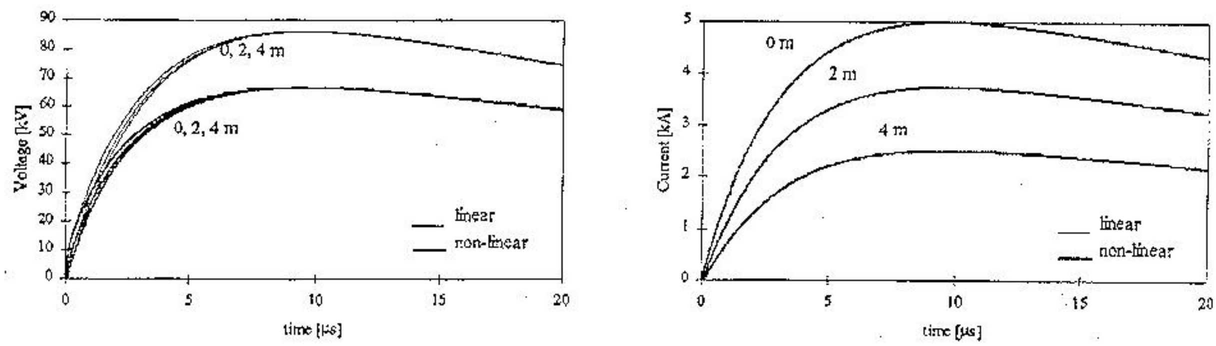
A non-linear counterpoise distributed model is presented. This model is based on a finite-differences transmission line model [1]. This type of algorithm is most adequate for representing the counterpoise non-linear distributed behaviour, due to soil ionisation phenomena, and has the advantage to allow the investigation of the voltage and current evolution along the electrode.

The behaviour of the voltage and current along the counterpoise are studied, considering two different electrode lengths (*8 m* and *80 m*) and two different lightning injected current rise times (*1 μs* and *10 μs*).

The results obtained show that the *8 m* counterpoise behaves as a lumped parameter conductance for the *10 μs* current wave, but for the *1 μs* front current presents, at the injection point, an inductive behaviour. On the other hand, the inductive behaviour of the *80 m* counterpoise appears even for the *10 μs* front current.

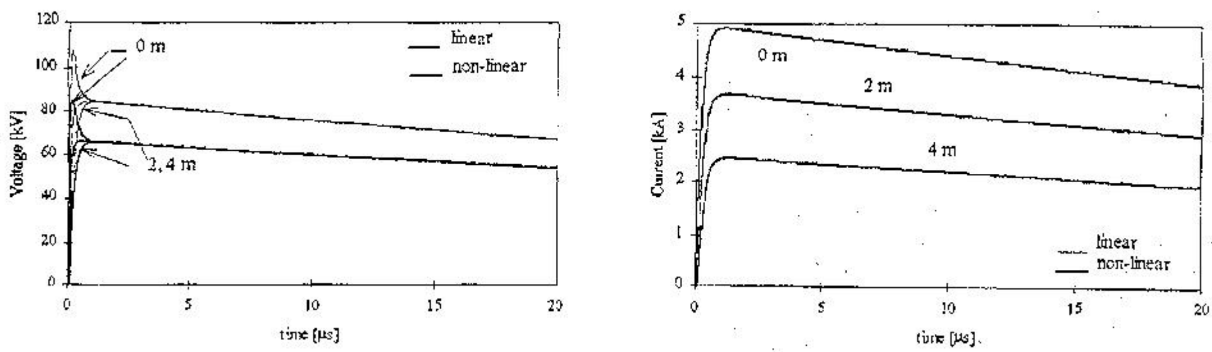
The ground electrode non-linear behaviour acts to increase the transversal conductance, reducing consequently the voltage at the different points along the electrode. However, for the *80 m* electrode this effect is irrelevant on the voltage curves obtained, explained by the strong inductive character presented by the electrode.

The results obtained for the *10 μs* current also show that when the counterpoise length is increased from *8 m* to *80 m* the voltage peak is reduced, but for the *1 μs* lightning current the voltage peak increase.



(a) (b)

Fig. 1 Voltage (a) and current (b) in different sections of the *8 m* counterpoise, for a *5 kA/10 μs/50 μs* injected current. Comparision between linear and non-linear counterpoise models.



(a) (b)

Fig. 2 Voltage (a) and current (b) in different sections of the *8 m* counterpoise, for a *5 kA/1 μs/50 μs* injected current. Comparision between linear and non-linear counterpoise models.

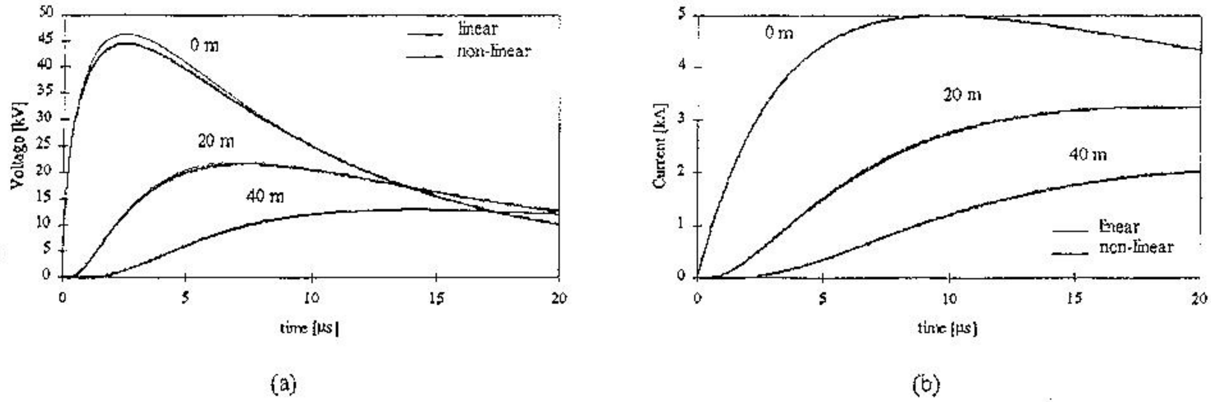


Fig. 3 Voltage (a) and current (b) in different sections of the *80 m* counterpoise, for a *5 kA/10 μs/50 μs* injected current. Comparision between linear and non-linear counterpoise models.

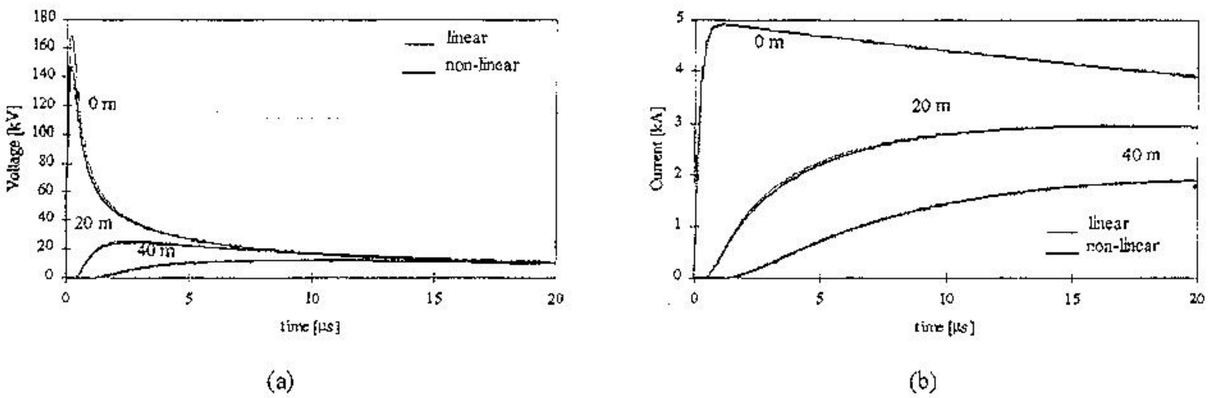


Fig. 4 Voltage (a) and current (b) in different sections of the *80 m* counterpoise, for a *5 kA/1 μs/50 μs* injected current. Comparision between linear and non-linear counterpoise models.

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