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Analysis of Lightning-Induced Voltages in Overhead Transmission Lines

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Abstract

In this work we study the coupling of lightning induced voltages in Overhead Transmission Lines .The study is led directly in the time domain with hold in account the effect of a finite conductivity of the soil. After discretization by the method so-called FDTD (Finite Difference Time Domain) of the lines equations excited by a lightning wave and the application in every node of the network in current and voltage, we deduct a equations system, of which the resolution permits us to deduct the induced electric quantities in every node of the network. . In order to confirm our theoretical work, we present a set of applications that allows validating this study.

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Keywords: lightning; electromagnetic field; Transmission line; transient ground resistance; Induced voltage;

1. Introduction

The induced voltages generated by lightning in the transmission of electrical energy are nowadays one of the main causes of poor quality of energy supplied to consume and electromagnetic compatibility. Due to growing a better quality of electricity demand, protection against disturbances caused by lightning has become of paramount importance. Therefore, the evaluation of induced voltages has become essential for the effective protection of electrical and electronic systems. In this work we interested on the calculation of currents and voltages induced by lightning channel on an overhead line, which is usually responsible for the transmission of the disturbance by conduction. In this several works are devoted to this subject [1, 2], [3,4], antenna theory is the most rigorous [5] but implementation remains inadequate and heavy work for long wire frames. Drawing on the work of C.R Paul [6]. We model the coupling lightning-line by the method of transmission line. For the electromagnetic excitation, which is the second of the equations of the lines, we use the formalism of the dipoles for the calculation of the electromagnetic field radiated by the lightning channel.

2. Modelling retourn stroke channel

To calculate the lightning electromagnetic field, a straight vertical channel over a perfectly conducting ground is assumed. Figure 1 shows the geometry for the calculation nearby overhead line. The electric and magnetic fields generated by the lightning return stroke can be obtained if the spatial temporal distribution of the lightning return stroke current i(z0, t) and its velocity along the channel are known. There are several return stroke models that have been

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proposed by earlier researchers that specify these parameters [7]. In the present study the modified transmission line (MTL) model has been adopted. According to this model, the
lightning current is allowed to decrease with height while propagating upward along the channel and is described as follows:

$$i(z',t) = i\left(0, t - \frac{z'}{v}\right) exp\left(-\frac{z'}{\lambda}\right) u\left(t - \frac{z'}{v}\right) \quad (1)$$

Where *v* is the velocity of the return stroke and l is the decay constant that accounts for the effect of the vertical distribution of charge stored in the corona sheath of the leader and subsequent discharge during the return stroke phase.

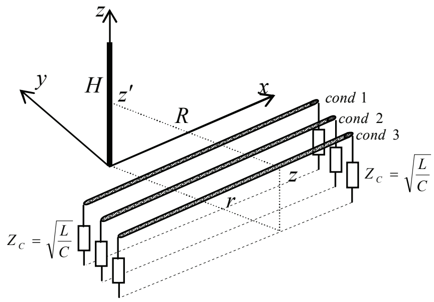

Fig.1. Geometry of the line.

magnetic field is required when using the Cooray– Rubinstein formula. For a current element of length *dz'* at a height *z'* and carrying a current *i(z', t),* the vertical electric field $dE_z(r, z, t)$, the horizontal electric field
$dE_r(r, z, t)$ and the magnetic field $dH_\phi(r, z, t)$ at a point
$P(r, \phi, z)$ over a perfectly conducting ground in cylindrical co-ordinates in the time domain are given by the following expressions :

$$dE_r(r,z,t) = \frac{dz}{4\pi\varepsilon_0 R^2}\left[\frac{3r(z-z')}{R^3}\int_0^t i(z',\tau - R/c)d\tau + \frac{3r(z-z')}{cR^2} i(z', t - R/c) - \frac{r(z-z')}{c^2 R}\frac{\partial i(z', t-R/c)}{\partial t}\right] \quad (2)$$

$$dE_z(r,z,t) = \frac{dz}{4\pi\varepsilon_0 R^2}\left[\frac{2(z-z')^2 - r^2}{R^3}\int_0^t i(z',\tau - R/c)d\tau + \frac{2(z-z')^2 - r^2}{cR^2} i(z', t - R/c) - \frac{r^2}{c^2 R}\frac{\partial i(z', t-R/c)}{\partial t}\right] \quad (3)$$

$$dH_\Phi(r,z,t) = \frac{dz}{4\pi R}\left[\frac{r}{R^2} i(z', t - R/c) + \frac{r}{cR}\frac{\partial i(z', t-R/c)}{\partial t}\right] \quad (4)$$

where ε_0 is the permittivity of free space and c is the velocity of light. $R = \sqrt{r^2 + (z-z')^2}$ is the distance from the current element to the observation point. The above equations use the MTL lightning return stroke model discussed in the previous Section. The total vertical and horizontal electric field and magnetic field are obtained by integrating along the lightning return stroke channel and its image. The horizontal component of the electric field with the finite conductivity of the ground is calculated using the Cooray–Rubinstein formula [8]. The horizontal electric field $E_{rg}(z = h, r)$ as per the above formula is given by

$$E_{rg}(z = h, r) = E_r(z = h, r) - H_\varphi(z = 0, r) \cdot \frac{\sqrt{\mu_0}}{\sqrt{\varepsilon_g + \sigma_g / j\omega}} \quad (5)$$

where $E_{rg}(z = h, r)$ is the Fourier-transform of the horizontal electric field at height *h*, $H_{\varphi p}(z = 0, r)$ is the Fourier transform of the azimuthal component of the magnetic field at ground level,μ_0 is the permeability of air, and ε and σ_g are the permittivity and conductivity of the ground, respectively. Both $E_{rg}(z = h, r)$ and $H_{\varphi p}(z = 0, r)$ are calculated assuming a perfect conducting ground using (2) and (4).