Ingeniería Investigación y Tecnología, volumen XV (número 3), julio-septiembre 2014: 457-468
ISSN 1405-7743 FI-UNAM
(artículo arbitrado)

Ground-Wave Propagation Effects on Transmission Lines through Error Images

Efectos de la propagación de ondas en tierra en líneas de transmisión a través de imágenes de error

Uribe-Campos Felipe Alejandro
Departamento de Mecánica Eléctrica
División de Ingenierías
Universidad de Guadalajara,CUCEI
Correo: fauribe@ieee.org

Information on the article: received: March 2013, reevaluated: April 2013, accepted: June 2013

Abstract

Electromagnetic transient calculation of overhead transmission lines is strongly influenced by the natural resistivity of the ground. This varies from 1-10K (Ω·m) depending on several media factors and on the physical composition of the ground. The accuracy on the calculation of a system transient response depends in part in the ground return model, which should consider the line geometry, the electrical resistivity and the frequency dependence of the power source. Up to date, there are only a few reports on the specialized literature about analyzing the effects produced by the presence of an imperfectly conducting ground of transmission lines in a transient state. A broad range analysis of three of the most often used ground-return models for calculating electromagnetic transients of overhead transmission lines is performed in this paper. The behavior of modal propagation in ground is analyzed here into effects of first and second order. Finally, a numerical tool based on relative error images is proposed in this paper as an aid for the analyst engineer to estimate the incurred error by using approximate ground-return models when calculating transients of overhead transmission lines.

Keywords:

- ground-return effects
- earth impedances
- low frequency effects
- electromagnetic transients
- error images

Resumen

El cálculo de transitorios electromagnéticos en líneas aéreas de transmisión está fuertemente influenciado por la resistividad natural eléctrica del suelo. Esta puede variar de 1-10K (Ω·m) dependiendo de diversos factores en el medio y de la composición física del suelo. La precisión en el cálculo de la respuesta transitoria en un sistema depende en parte del modelo de retorno por tierra, el cual debe considerar la geometría de la línea, la resistividad eléctrica y la dependencia frecuencial de la fuente de alimentación. Hasta la fecha hay pocos reportes en la literatura especializada acerca del análisis de los efectos producidos por la presencia de un suelo conductor imperfecto de líneas de transmisión en estado transitorio. En este artículo se realiza un análisis de amplio rango a tres de los modelos de tierra actualmente más utilizados para cálculo de transitorios electromagnéticos en líneas aéreas de transmisión. El comportamiento de la propagación modal en tierra se analiza aquí en dos tipos de efectos de retorno por tierra. Finalmente, se propone en este artículo una herramienta numérica basada en imágenes de error relativo como una ayuda para que el ingeniero analista pueda estimar el error incurrido por utilizar modelos aproximados de tierra para el cálculo de transitorios en líneas aéreas de transmisión.

Descriptores:

- *efectos de retorno por tierra*
- *impedancias de tierra*
- *efectos de baja frecuencia*
- *transitorios electromagnéticos*
- *imágenes de error*

Introduction

The analysis of wave propagation effects on overhead transmission systems due to the presence of an imperfectly conducting ground, is critically important to assess the frequency dependent losses and phase delay of ground modes. By its own structure, the electric line parameters Z (series-impedance) and Y (shunt-admittance) characterize the ground-return effects on a first and second order, respectively.

First order effects arise when the influence of the ground prevails over the geometric influence of the line. This is the case when the characteristic impedance of the system, $Z_C = \sqrt{Z/Y}$, plays an important role in the simulation; *e. g.*, on transient short-circuit currents calculation (Marti and Uribe, 2002). In this case, the frequency dependence of Z_C is entirely due to the ground-return path (Wedepohl, 1965).

The second order effects arise in the calculation of the modal voltage propagation function of the line $e^{-\gamma \cdot \lambda}$ where $\gamma = \sqrt{Z \cdot Y}$ and l is the line length. In terms of propagation functions, when forming the product $Z \times Y$ the geometric effects tend to cancel out each other, except for the different influence of the ground (Marti and Uribe, 2002).

The problem here is that, up-to-date, there is no general criterion to evaluate the ground conduction effects on transmission line propagation. Another problem is the evaluation of how the ground-return conduction effects impact on transmission line systems when switching transients occur.

Thus, it is the main idea of this paper to perform a new algorithmic methodology to analyze the first and second order ground-return conduction effects on voltage and current transient waveforms of overhead transmission systems.

First, a broad range solution of the Carson's integral (Carson, 1926) is developed and implemented in this paper based on a previously established algorithmic technique published in (Uribe *et al*., 2004; Ramirez and Uribe, 2007). In addition, normalized dimensionless parameter comparisons with the Carson's series and complex-depth closed-form approximations (Gari, 1976; Kostenko, 1955; Deri *et al*., 1981; Alvarado and Betancourt, 1983) are obtained here through the relative error criterion. This methodology yields a new technique proposed here as an aid to estimate ground-return modeling error on transients calculation through error images.

Finally, the impact of ground-return modeling errors on transients calculation is identified here with an application example accurately solved via the Numerical Laplace Transform (Uribe *et al*., 2002).

Algorithmic solution of carson's integral

Figure 1 shows two overhead infinite thin perfect conductors over an imperfectly conducting ground $0 < \sigma_2 < \infty$. The series-impedances contribution (in Ω·m) is given by (Marti and Uribe, 2002)

$$Z = \frac{j\omega\mu_0}{2\pi} P_M + Z_{Con} + Z_E, \tag{1}$$