Electric Power Systems Research 80 (2010) 1160–1170

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

A generalized model for the calculation of the impedances and admittances of overhead power lines above stratified earth

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ARTICLE INFO

Article history:
Received 1 September 2008
Received in revised form 10 January 2010
Accepted 20 March 2010
Available online 24 April 2010

Keywords:
Earth return admittance
Earth return impedance
Multiconductor lines
Nonhomogeneous earth
Transient analysis

ABSTRACT

A general formulation for the determination of the influence of imperfect earth on overhead transmission line impedances and admittances is presented in this paper. The resulting model can be used in the simulation of electromagnetic transients in cases of two-layer earth over a wide frequency range, covering most fast transient phenomena of power engineering interest. The propagation characteristics of an overhead transmission line over homogeneous and two-layer earth are investigated using the proposed model. A systematic comparison of the proposed model with other approaches is also presented and the differences due to earth stratification are reported. Finally, the transmission line parameters calculated by the proposed formulation are used in the simulation of fast transient surges in a transmission line excited by double exponential sources.

1. Introduction

Overhead transmission line (TL) modelling in electromagnetic (EM) transient simulations requires the detailed representation of the influence of the imperfect earth on the conductor parameters. Although several approaches have been used since many years, the accurate modelling of earth conduction effects on transmission lines is still an appealing research topic, especially in the high frequency region for the simulation of fast transients.

Historically, the first approach is the Carson's homogeneous earth model [1]. Carson proposed the use of earth correction terms for the series impedances, which are derived using the following assumptions:

- The relative permeability of the homogeneous earth is considered to be equal to unity.
- The axial displacement currents in the air and in the earth are neglected.
- The influence of the imperfect homogeneous earth on the shunt admittances is neglected.
- Quasi-TEM (Transverse ElectroMagnetic) field propagation is assumed.

Carson's approach has been intensively used in the calculation of the series impedances of transmission lines. It provided a useful tool for TL modelling, especially in simulations where the displacement currents and the influence of the imperfect earth on shunt admittances can be neglected.

Many efforts to develop more accurate models, mainly for the earth return impedance calculation in high frequency region are reported in the literature, in these approaches the axial displacement currents are taken into account either using analytical formulas [2,3] or approximations. Among the latter are the asymptotic approach of Semlyen [4] and the logarithmic evaluation, originally proposed by Sunde [5] and extended in [6]. Discrepancies and limitations of these approximate models are discussed in [7,8].

A different approach, aiming at the calculation of the earth conduction effects on both the series impedances and the shunt admittances was proposed by Wise; the Herzian vector has been used to develop proper earth correction terms for both series impedances [9,10] and shunt admittances [11] for a single conductor. This semi-infinite homogeneous earth model was further improved by Nakagawa, who extended the formulas for the series impedances earth correction terms for cases of multiconductor lines and for earth configurations consisting of several horizontal layers with different EM properties, taking also into account the displacement currents in the earth [14]. The multi-layered earth model of Nakagawa is implemented in the Electromagnetic Transients Program (ATP-EMTP) [15]. Additionally Nakagawa proposed formulas for shunt admittances but only for the homogeneous earth case [12,13]. The shunt admittance formulation has been extended

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doi:10.1016/j.epsr.2010.03.009