Ground Effects on Electrical Fields around Power Line Carrier Channels

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Abstract — **Results obtained by simulation and measurement of the electrical fields generated by carrier channels on high voltage transmission lines above lossy ground are presented. The ground proprieties are modeled and their effects are taken into account in the calculation of the radiated electrical field. Real ground samples situated beneath the transmission line corridor are analyzed in laboratory regarding their relative complex permittivity by specific procedures. The electrical parameters are modeled for the specific value of the operating frequency of the PLC system.**

Index Terms — **Electromagnetic fields, Electromagnetic radiation and interference.**

I. INTRODUCTION

Among the main aspects to be analyzed in the Power Line Communication System (PLC), the electromagnetic compatibility phenomenon has been investigated on various aspects [1]-[2]. It is important to know that the radiated electrical field by a PLC system depends on, first of all, how the circuit is set up. Vertical or horizontal circuits have their own electrical parameter in the wave propagation study. Another aspect is the fact that the earth presence does not have to be neglected in the electrical parameter model. In this way, PLC systems must incorporate both the ground impedance, and the admittance at electrical parameter models for high frequencies [3]. As the ground proprieties change with the PLC operation frequency, a priori ground sample analysis should be done in laboratory with the collected samples underneath the cables where the measurements are carried out. In this way, the calculated electrical field reflects the transmission line settings with the ground effects. The work shows the electrical field calculation taking into account the specific characteristics of the ground and compares the results with the obtained measurements.

II. ELECTRICAL FIELD - FORMULATION

The electrical field can be expressed as a function of *Hertz* potentials. Equation (1) shows the electrical field $\mathbf{E}$ (V/m) as a function of the electrical *Hertz* potential $\mathbf{\Pi}_e$ (V/m) and the magnetic *Hertz* potential $\mathbf{\Pi}_h$ (A/m).

$$\mathbf{E} = -\gamma_m^2 \mathbf{\Pi}_e + \nabla(\nabla \cdot \mathbf{\Pi}_e) - i\mu_m \omega \nabla \times \mathbf{\Pi}_h \quad (1)$$

It should be said that γ_m (m^{-1}) represent the complex propagation constant and μ_m (H/m) the permeability of the medium. Considering the conductors cables as thin wires of indefinite length located at a height *h* over a lossy ground, it is possible express the *Hertz* potentials as a function of the geometrical and electrical characteristics. The Fig. 1 shows a general configuration for a transmission line above a lossy ground.

In the power line model, the ground has permittivity ε_g (F/m) and conductivity σ_g $(\Omega \cdot m)^{-1}$.

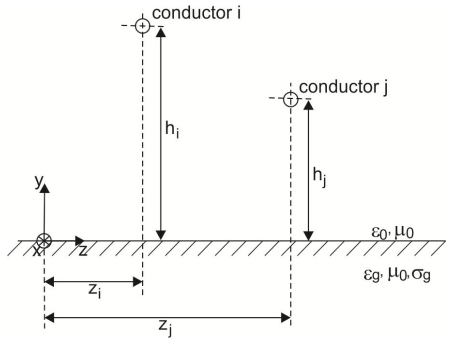

Fig. 1. General configuration of a transmission line

Equation (2) shows the electrical *Hertz* and magnetic *Hertz* potentials [4].

$$\mathbf{\Pi}_e = -\frac{j\omega\mu_0}{4\pi k_0^2} I_0 e^{-j\gamma_m x} \int_{-\infty}^{\infty} \{e^{-u_0|y-h|} + R_E(\lambda) e^{-u_0(y+h)}\} \frac{e^{-jz\lambda}}{u_0} d\lambda$$

$$\mathbf{\Pi}_h = -\frac{j\omega\mu_0}{4\pi k_0^2} I_0 e^{-j\gamma_m x} \int_{-\infty}^{\infty} R_H(\lambda) e^{-u_0(y+h)} \frac{e^{-jz\lambda}}{u_0} d\lambda \quad (2)$$

The constants R_E and R_H represent the ground reflection coefficients for the electrical *Hertz* potential and magnetic respectively. Using (2) in (1) is possible to find the solution for the electrical field taking into account the effects of the lossy ground. Since R_E and R_H incorporate the ground conductivity, it is necessary to analyze the ground proprieties.

In the present study, the currents are obtained as a function of the modal currents. In this way, the *Hertz* potentials are calculated as a sum of the *n* contributions related to the *n* propagation modes. For a three phase power system, there will be 3 propagation modes for each one of the 3 existent conductors [5].

III. GROUND ANALYSIS

Using the transmission line theory is possible to obtain the complex permittivity $\varepsilon_g = \varepsilon_r' - j\varepsilon_r''$ of the dielectric in a coaxial cable operating in TEM mode, where ε_r' and ε_r'' represent the real and the imaginary components respectively. Relating the scattering and the transmission (*ABCD*) matrixes is possible to develop conversion expressions for the parameters of a two-port network [6]. Equation (3) shows the relationships.

$$B = Z\frac{(1+S_{11})(1+S_{22}) - S_{12}S_{21}}{2S_{21}} \quad C = \frac{1}{Z}\frac{(1-S_{11})(1-S_{22}) - S_{12}S_{21}}{2S_{21}} \quad (3)$$

The Z (Ω) variable can represent both the source as the load impedance in the network analyzer. For a two-port network, the transmission (*ABCD*) matrix can be obtained by (4).

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{bmatrix} \cosh(\gamma L) & Z_c \sinh(\gamma L) \\ \frac{1}{Z_c}\sinh(\gamma L) & \cosh(\gamma L) \end{bmatrix} \quad (4)$$

In (5) γ (m^{-1}) represents the homogeneous propagation constant in the coaxial line and L (m) the length of the transmission line. In the laboratory, the medium inside the coaxial line is the collected ground beneath the transmission line. In this way, the experiment can analyze as the ground permittivity changes in the PLC spectrum. The product of the *B* and *C* elements in the matrix (4) results in (5).

$$\gamma = \frac{\operatorname{asinh}(\sqrt{BC})}{L} \quad (5)$$

The attenuation constant $\alpha = \alpha_c + \alpha_d$ (Np/m) is composed of the attenuation constant in conductor α_c and the attenuation constant in the dielectric α_d. Their values are obtained in (6) [7].

$$\alpha_c = \left(\frac{0.014272\sqrt{f}}{Z_c}\right)\left(\frac{1}{d} + \frac{1}{D}\right) \quad \alpha_d = 0{,}091207 f \sqrt{\varepsilon_r'} \tan(\delta) \quad (6)$$

After the necessary manipulations, the real and imaginary complex permittivity can be obtained. The Fig. 2 shows the real part of the complex permittivity obtained in laboratory for the collected ground.

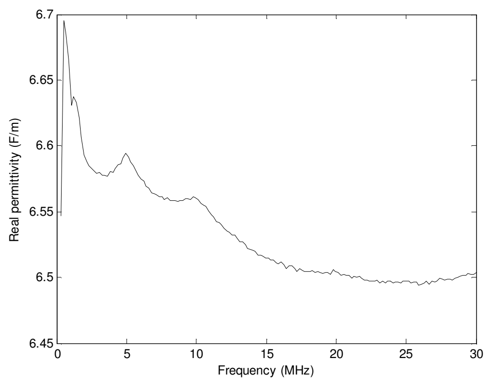

Fig. 2. Real permittivity for the ground sample in the PLC spectrum

IV. PLC System - Measurements

The frequencies of the PLC signals in the operating systems correspond to 364, 332 and 308 kHz and the associated values of the complex permittivity are incorporated in the electrical parameter calculation. The Fig. 3 shows the sketch of the transmission line corridor where the measurements were carried out. Each tower has its own carrier channel operating in the own frequency. The measurements were done in middle of the span of the transmission line.

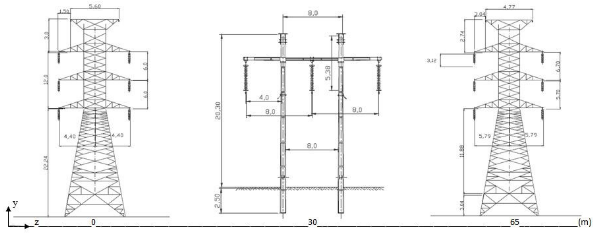

Fig. 3. Sketch of the supports of the transmission line corridor

The Fig. 4 presents the radiated electrical field for the PLC systems obtained by measurements and by simulations. The simulating model results are considering both the mean and the specific value data of the dielectric permittivity shown in the Fig. 2.

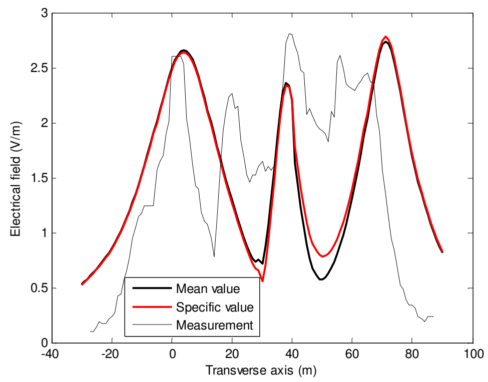

Fig. 4. Radiated electrical field – Simulation and Measurement

The obtained values by simulations are promising as for BPLC. The main peaks agree in their positions. It can be noted that the simulation presents own results for the mean and the specific value of ground dielectric permittivity. These promising results can help the PLC designer in critical places, as far as the regulatory agencies are concerned with the electromagnetic emission.

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