URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Cable Conduits with Non-linear Permeabilities

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This paper discusses an electrical model for estimating the effects of magnetic field saturation in a ferromagnetic conduit, or shield. Starting with Maxwell's equations, a diffusion equation describing the magnetic field within the conduit material is developed. While this diffusion equation cannot be solved analytically for the general nonlinear case, it may be solved numerically using a finite difference time domain (FDTD) method. The steps in performing this analysis are described and several sample results are illustrated. The representation of the nonlinear behavior of the magnetic permeability of the conduit material is important in conducting such an analysis. A relatively simple functional form for the material magnetization curve is suggested and used in the sample analysis.

A sample calculation is performed for the iron conduit, which has been discussed in previous reports. An earlier analysis suggested that a linear relative permeability of $\mu_r = 200$ is appropriate for this material. Using this value, a hypothetical nonlinear magnetization curve is developed and a calculation of the per unit-length excitation voltage of shielded wires within the conduit is conducted. Additional calculations for this cable conduit will require a more accurate determination of the material magnetization properties.

In previous reports detailing the effects of a direct lightning strike to a building with a buried cable conduit, a transfer impedance model was used to estimate the excitation of signal wires within the protective conduit [1], [2]. A portion of the direct lightning strike to the building can flow along the conduit, and due to the resistance of the conduit, there is a voltage drop along the conduit. This voltage excites the wires inside the conduit and the resulting current flow may cause problems in the equipment connected to the end of the cables. For non-magnetic conduit materials, such as aluminum or copper, the transfer impedance model is straightforward due to the inherent linearity in the electrical properties of the material. However, for the case of the iron tube, it is recognized that the permeability (μ) of the material is usually a nonlinear function of the magnetic field intensity (H). This implies that the shielding provided by the iron tube and other magnetic type conductors is not easily described by the linear transfer impedance concept discussed in [1]. The study of electromagnetic shielding by materials with nonlinear permeability is not a new subject. An early report on electromagnetic pulse (EMP) shielding and relationships to the physical properties of the material (iron in this case) was described by Young [3]. Later, Merewether studied the EMP shielding effects of a planar and cylindrical magnetic shields [4.5]. This paper reviews the development of a procedure for computing the shielding of a magnetic tubular shield, or conduit. In this discussion, we will define a diffusion equation for the magnetic field penetrating into the conduit material and indicate how the internal E-field can be calculated. A numerical example for the results of this calculation will be provided. Key in conducting this solution is the representation of the magnetization (B-H) curve of the ferromagnetic material. A simple representation of this property is suggested.

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