01 Jan 2004

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Recommended Citation

R. Papazyan et al., "Modeling the Wave Propagation Properties of Power Cables Using Numerical Simulations," *Proceedings of the 2004 Conference on Precision Electromagnetic Measurements Digest*, Institute of Electrical and Electronics Engineers (IEEE), Jan 2004.
The definitive version is available at https://doi.org/10.1109/CPEM.2004.305283

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MODELING THE WAVE PROPAGATION PROPERTIES OF POWER CABLES USING NUMERICAL SIMULATIONS

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Abstract

The high frequency properties of coaxial power cables are modeled using time- and frequency-domain numerical simulations. This is required due to the complex helical structure of the outer metallic screen. It is established that this screen design causes a dependence of the cable characteristics on the surrounding medium.

Introduction

Crosslinked polyethylene (XLPE) cables were introduced in the 1960's. A specific degradation of the insulation, called "water treeing", necessitated the creation of diagnostic methods for its detection [1]. A further development constitutes the localisation of water treeing along the cable length, which requires the knowledge of the high frequency properties of the power cables.

Previous work, [2], has established the basis for the frequency domain measurement methods of the cable's wave propagation characteristics. This article investigates, experimentally and numerically, the influence of the metallic screen design and the surrounding medium on the measured properties. Identifying all effects on the precision of the measured dielectric data becomes essential since water trees increase the high frequency cable losses by approximately 10% [3].

Analytical analysis could not be carried out in this investigation due to the complexity of the helical wires screen. Therefore, two electromagnetic numerical solvers were implemented – frequency-domain finite element method (FEM) [4] and finite difference time-domain method (FDTD) [5].

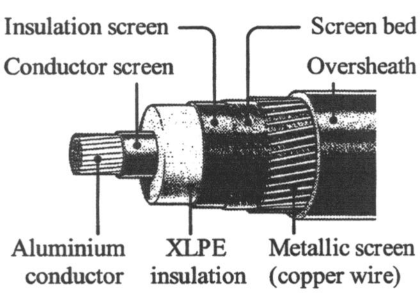

Figure 1. Typical XLPE power cable design. The metallic screen consists of 44 separate helical wires.

Investigated Power Cable

A typical design of XLPE insulated power cables can be seen in Fig. 1. In this paper simulations and measurements were conducted on a 12/7 kV 95mm^2 cable manufactured in 1995, which has not been in service.

Measurements

The objective of the experiment is to estimate the effect of two different types of surrounding media – air and water. The cable is placed in a plastic tube that is filled either with air or water to control the surrounding medium.

A Network Analyzer (NA) is used to measure the *S*-parameters, from which the cable propagation constant (γ) is extracted with its real and imaginary parts: attenuation constant α, (Np/m) and phase constant β, (rad/m), respectively. In Fig. 2 a noticeable increase in the measured losses can be observed above 70 MHz when the surrounding medium is water.

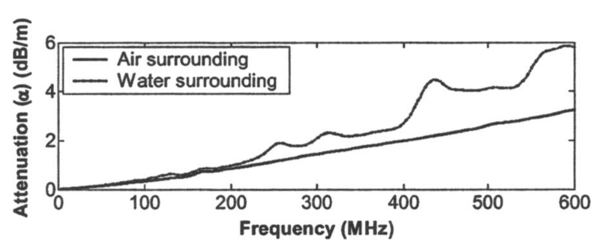

Figure 2. Measured attenuation constant (α) for the two types of surrounding media – air and water.

Numerical Simulations

Results from the two numerical solvers were initially compared to an analytical transmission line model [6] to assure the credibility of the subsequent simulations (see Table 1).

Table 1. Comparison of measurement and model results for the attenuation constant (α) at 100MHz. The numerical cable models assume a solid metallic screen.

@ 100 MHz	Measurement	Analytical model	Numerical models	
			FEM	FDTD
Attenuation constant (dB/m)	0.335	0.358	0.359	0.433

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Table 1 reveals marked agreement between the analytical and FEM model results, both matching the measurement result closely. The FDTD result contains relatively higher error, which is attributable mainly to volume discretizing (gridding) and the finite length of the used cable model [7]. However, the FDTD code has the distinct advantage of simpler graphical user interface (GUI) for input of the helical screen and was therefore chosen for the following studies (Fig. 3).

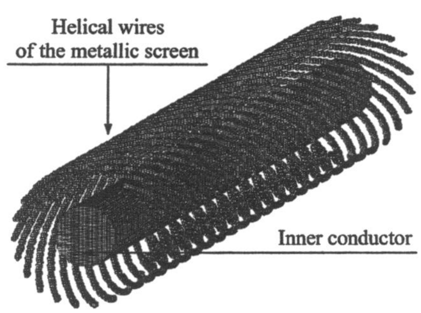

Figure 3. FDTD model of the inner conductor and metallic screen of the power cable.

Influence of the helical wires screen. To investigate its effect on the cable properties two other types of screen designs were studied and compared - solid screen and straight wires screen. For the latter the number and dimensions of the wires, running parallel to the inner conductor, are equal to those used in the helical screen. The inner conductor and all dielectric layers in the cable construction are identical for all three models.

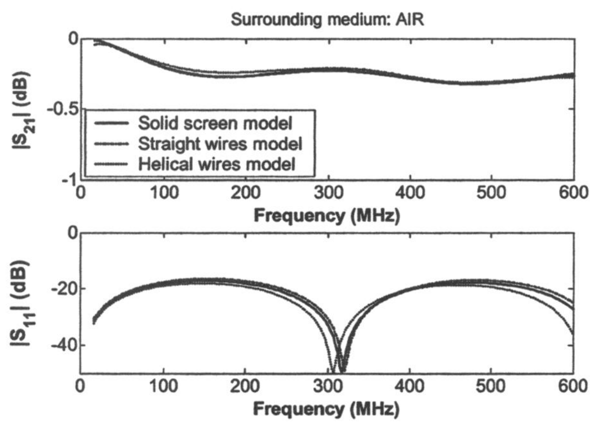

Figure 4. S-parameters normalized to the cable port impedance. The dielectric parameters used in the models are valid at 100 MHz [7].

Fig. 4 shows that the screen design does not significantly affect cable losses at microwave frequencies. However, judging by the position of the minimums in the S_{11} reading, helical screens cause an increase in the electrical length. Compared to the physical cable length the influence is 2% for this specific type of helix.

Influence of the surrounding medium. Water ($\varepsilon_r = 80$, $\sigma=0.001$ *S/m*) and air were modeled as surrounding media. Fig. 5 shows that the surrounding medium effects can be represented only using the helical wire screen model. The propagating wave in the helical screen case has a unique longitudinal component of the H-field, which could be an explanation for this modeling requirement.

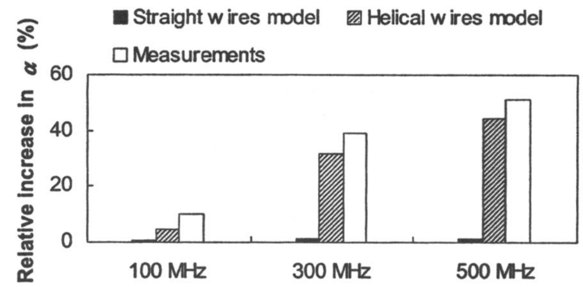

Figure 5. Effect on the attenuation constant when changing the surrounding medium from air to water.

Conclusions

- The cable wave propagation characteristics above approximately 70 MHz can notably be affected by the surrounding medium. This effect is mainly attributed to the helical structure of the metallic screen and can successfully be modeled numerically.
- When the surrounding medium is not of interest, cable losses in the investigated frequency region can be modeled analytically with sufficient precision. The increase in the electrical length caused by the helical screen should be considered in this case.

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