Circuit based implementation of the Universal Line Model

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ABSTRACT

This paper presents an improved version of the Universal Line Model (ULM) integrated into a graphical programming environment GPE (Simulink for example) for time domain transient simulations. The new model is based on an electrical circuit representation of the shunt line admittance and has improved efficiency using the Rational Krylov technique. The accuracy and performance of the new model are assessed through application examples and compared to results from electromagnetic transient software.

KEYWORDS

Electromagnetic transient, frequency dependency, transmission line model.

INTRODUCTION

The increasing integration of renewable energy sources into the transmission grid has led to a significant transformation in the grid's infrastructure, resulting in a growing number of high voltage direct current (HVDC) links that use power. The use of these technologies is crucial to achieving the goal of climate neutrality by 2050 [1]. Manufacturers of power converters face the challenge of developing solutions for multiterminal and multivendor HVDC and medium voltage DC (MVDC) systems, which require interoperability and protection strategies for reliable operation. Therefore, accurate and reliable simulation tools and models are essential for studying electrical systems.

Various commercial software tools and simulation environments are used to simulate electrical systems, such as EMTP, PSCAD, or MATLAB/Simulink. While EMTP and PSCAD provide comprehensive cable and power grid models [2], MATLAB/Simulink is widely used by power electronics manufacturers to model converters because of its low-level control. However, MATLAB/Simulink has less reliable and detailed models of cables and power grids compared to EMTP and PSCAD.

To address this issue, this article presents an improved version of the Universal Line Model (ULM) [3], also known as the Wide-Band (WB) model, that has been integrated into the MATLAB/Simulink environment for time-domain transient simulations of electrical networks based on power electronics. The ULM is based on an electrical circuit representation of the shunt line admittance and has been enhanced using the Rational Krylov technique to achieve improved efficiency with lower-order approximations [4]. For multiconductor modeling, the characteristic admittance is represented as an equivalent two-port Y parameter system.

This article reviews the frequency-dependent multiconductor transmission line modeling in the frequency and time domains, describes the new implementation step-by-step to reach the equivalent electrical circuit, and assesses the accuracy and numerical performance of the proposed implementation using representative application examples, comparing it to EMTP. The improved ULM combines the capability of reliable transient studies with similar performances to traditional grid simulation software.

UNIVERSAL LINE MODEL

Traveling wave formulation

Let us suppose a system of n parallel lines of length l above an infinite, perfectly conducting ground plane. Thus, the n line voltages and n line current in the frequency domain, in matrix form, are obtained as:

$$\frac{dV(s)}{dx} = Z(s).I(s) \tag{1}$$

$$\frac{dI(s)}{dx} = Y(s).V(s) \tag{2}$$

The per unit length series impedance $Z(s) \in \mathbb{C}^{N,N}$, and admittance $Y(s) \in \mathbb{C}^{N,N}$, matrices are given by: $Z(s) = R(s) + sL(s)$ and : $Y(s) = G(s) + sC(s)$. And contains the per-unit length resistance $R(s)$, inductance $L(s)$, conductance $G(s)$ and capacitance.

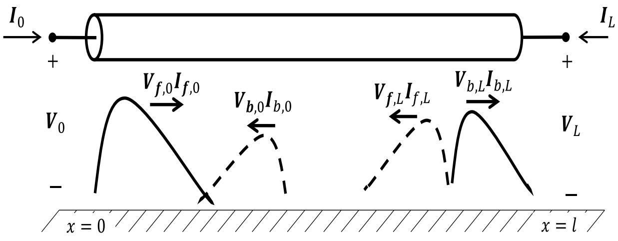

Figure 1: Illustration of the current and voltage waves for a multiconductor

Taking into consideration the terminal conditions at both ends, the currents and voltages can be expressed as forward and backward-traveling waves as shown in Figure 1. Subscripts f and b indicate the forward and backward traveling waves. The currents and voltages at both ends can be expressed as:

$$I_0(s) = Y_c(s)V_0(s) - H(s)[Y_c(s)V_L(s) + I_L(s)] \tag{3}$$

$$I_L(s) = Y_c(s)V_L(s) - H(s)[Y_c(s)V_0(s) + I_0(s)] \tag{4}$$

Where $Y_c(s) \in \mathbb{C}^{N,N}$ and $H(s) \in \mathbb{C}^{N,N}$ are matrices representing the characteristic admittance and the propagation function, respectively. Y_c and H being obtained by: