MODELING OF POWER CABLES USING CLN METHOD

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Abstract

The Cauer Ladder Network (CLN) method can generate a reduced model based on an equivalent electrical circuit from a finite element magnetoquasistatic problem. In this study, the CLN method has been used to construct a cascaded pi model of a system composed of two HVDC cables. A comparison of the generated model with ElectroMagnetic Transient (EMT) software shows that the proposed method leads to accurate results and seems to be more stable at low frequencies.

1 Introduction

The accurate modelling of electromagnetic transients related to power transmission cables such as HVDC cables becomes essential for the design of power networks. To study the system under fault case, the earth-return impedance should be considered. Usually, this impedance is evaluated using some analytical formulas [1] and is used to couple the admittance of cables with the transmission line (TL) based approach, which would generate coupled equations in the frequency domain. In case time domain analysis is needed, the Vector fitting method can be applied leading to a wideband model. The wideband model can be used to carry out transient analysis, like in ElectroMagnetic Transient (EMT) software. However, the system derived from the Vector Fitting method can sometimes fail because it doesn't guarantee the passivity of the system of equations [2]. The wideband model is thus prone to instability when applying the Vector Fitting technique for transient analysis in the time domain. Ongoing research aims to fix this issue. Meanwhile, the ground-return impedance obtained by analytical formulas is less accurate than the value given by the finite element (FE) method.

For transient analyses, the lumped parameters models can also be used. The standard lumped parameters (LP) models are based on standard pi-equivalent form, which fail to represent the frequency-dependent characteristics of impedance like the eddy current effect. Additionally, It has been shown in [3] that Vector fitting methods can be also used to generate Frequency-dependent cascaded pi model. In this communication, the Cauer Ladder Network is used to generate an equivalent circuit of HVDC cables which consider the magnetoquasistatic (MQS) effects. The equivalent electrical circuit obtained by the CLN method can be used to construct a frequency-dependent cascaded pi model of a HVDC transmission system. The results obtained are compared with the ones obtained from Electromagnetic Transients Program (EMTP [4]).

2 Cauer Ladder Network

Consider the HVDC cable system shown in Figure 1. The two cables are buried underground. Under nominal case, the current flows through the cores. However, under fault case, the current can be returned through the earth. To account for the earth-return impedance, a FE model is used based on the two buried cables which leads to the following equation system:

$$\boldsymbol{KX} + \mathrm{j}\omega\boldsymbol{NX} = \boldsymbol{FI} \tag{1}$$

Where the vector $\boldsymbol{X} \in R^N$ is solution vector and N is the degree of freedom of vector potential $\boldsymbol{A}$. $\boldsymbol{K}$ and $\boldsymbol{N}$ are two matrices depending on the magnetic permeability and electric conductivity. The source term $\boldsymbol{F} \in R^{N\times 4}$ is generated by solving 4 electro-kinetic problems. The current vector has the following structure:

$$\boldsymbol{I} = \left[i_{0,1}\; i_{0,2}\; i_{0,3}\; i_{0,4}\right]^T \tag{2}$$

If the current vector $\boldsymbol{I}$ is equal to $[1\;0\;0\;0]^T$, it means that the current $i_{0,1}$ flowing through core of cable 1 is equal to 1 A, the current returning through the ground is also equal to 1 A (see Figure 2) and the current passing through the rest of the conductive domain is zero.

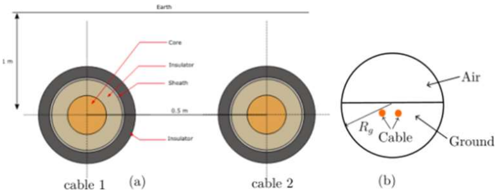

Figure 1: (a) Spatial distribution of cables (b) Simulated domain for the MQS model.

The equation system (1) is a multi-inputs and multi-outputs system of $\mathrm{M} = 4$ ports. By applying the CLN method [5], we can generate a reduced system of unknows n which is much smaller than N and an equivalent circuit of $\mathrm{M} = 4$ ports made with resistances and inductances considering mutual effect. It should be mentioned that the equivalent circuit components have physical meanings and is passive and stable, since the

CLN method leads to an equivalent electrical circuit with passive components.

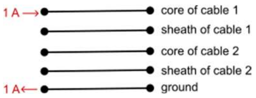

Figure 2: The boundary conditions correspond to the first column of source matrix $\boldsymbol{F}$, i.e. $\boldsymbol{F}[1\ 0\ 0\ 0]^T$.

3 Cascaded pi model composed with the equivalent circuit of the CLN method

The standard LP model uses the constant series impedance $\mathbf{Z}$ and admittance $\mathbf{Y}$ to form an interconnected circuit, as shown in Figure 3 for the cable system in the single input and single output case. If we replace the constant series impedance $\mathbf{Z}$ with an equivalent circuit of the CLN method and if we represent the constant admittance $\mathbf{Y}$ with a capacitor, we can obtain an interconnected circuit composed of the inductances, resistances and capacitances which can represent the behaviour of the cables (see Figure 4).

4 Result

In the following, we consider the cable system in Figure 1 with a length of 100 km and calculate the input impedance of the two cores under normal case (the sheaths are both grounded at both ends). Figure 5 shows the evolution in function of the frequency of the input impedances obtained by the EMTP and the LP model constructed using the equivalent circuit of the CLN method. We have considered $n = 60$ for the CLN model and $n_\pi = 100$ sections. This figure shows that the LP model approximates well the wideband model. Nevertheless, the wideband model leads to unphysical low oscillation in the low-frequency domain ($f < 1$ Hz) compared with the LP model. However, we can see a clear divergence at high frequency showing that more pi-sections are needed to make the pi model converging in the high frequency domain. If the LP model is used in the time domain, we need to solve the transient problem of a large interconnect circuit of size $n \times n_\pi \times 4$. Since both n_π and n need to be increased to guarantee a good precision in the high frequency domain, the pi model is not effective when considering high dynamics unless a further reduction method is applied. However, if the system dynamic is low, the interconnect system obtained by the small-size LP model (n_π and n small) can be used advantageously.

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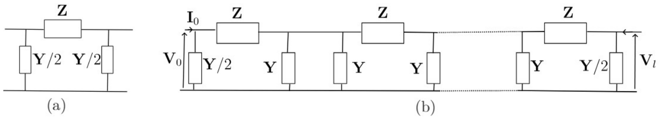

Figure 3: (a) Pi circuit, (b) LP model with n_π sections.

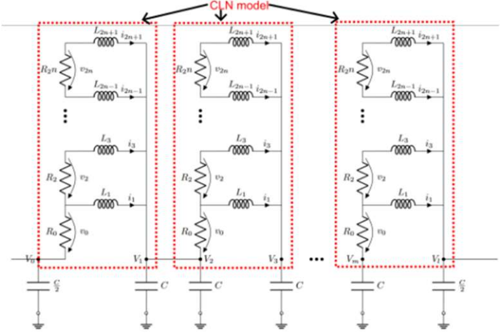

Figure 4: cascaded pi model composed of the equivalent circuit of the CLN method.

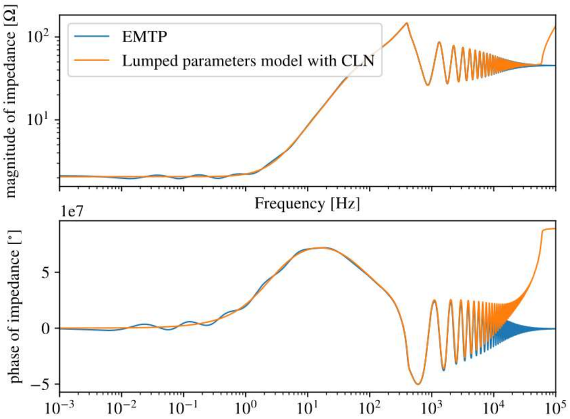

Figure 5: Input impedance calculated with the EMTP model and LP model with the CLN equivalent circuit with $n = 60$ and $n_\pi = 100$.

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