A Methodology for modeling a power cable in frequency domian

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***Abstract*—Extracting the Circuit parameters model of the power cable at high frequency is very difficult process. In this paper a proposed methodology to obtain the input impedance of a power cable with any load. The obtained circuit parameters can be represented as SPICE circuit model. The methodology appears a good agrement by comparing its results with the experimental results.**

I. Introduction

In order to study the influence of the characteristics of the power cables on the high frequency levels of the transient currents, it is necessary to use precise models of the power cables that take into account skin effects, proximity effects and dielectric losses. for example A PWM drive-to-motor output cable is often a costly system item, especially if long length is required. Also special cable geometry and voltage rating concerns need to be addressed when using a PWM drive, to control common mode (CM) leakage current that leads to system EMI problems, and differential mode (DM) reflected wave over-voltage leading to cable/motor failures at cable end termination [1], [2].

The popular method to model the power cable as a transmission line (TL) is a distributed parameter model [3], [4]. In this method The simulation was carried out using various numbers of the elementary cells (classical TL which composed of R, L, G and C). The choice of the number of cells in this method is the first challenge and has to do by a tedious iterative way until to meet the first resonance. The second challenge is to model the skin effect and proximity effect. The modeling of the skin effect and proximity effect is achieved by additional complex ladder circuit has to add to each cell [3].

This paper proposes a method to synthesize the network of the power cable as a passive lumped element with prescribed set of S-parameters in the Laplace domain. The synthesis network has a small number of parallel branches to model a power cable in a big range of the high frequencies. As most synthesis methods, my Methodology is derived from the transfer function of the system (power cable in my case) basic on Foster synthesis [5]. The used S-parameter models are not necessarily to be reciprocal or even stable. The synthesis network may contain a negative value for the resistance or the conductance, nevertheless it is applicable in all SPICE circuit software.

II. Methodology

Consider a linear system

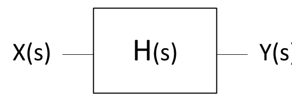


Fig. 1.

that consists of an input X(s) and output Y(s). The output is related to the input through a transfer function

$$H(s) = \frac{Y(s)}{X(s)} \tag{1}$$

The scattering parameters capture the H(s) behavior of any Transmission line (TL), which can then be represented as a black box in a SPICE simulation. To synthesize the passive network of the TL, the scattering parameters should to be represented in Laplace plane (s-plane). The representation needs special fitting function to fit the measured data with transfer function or rational function. The rational function is the polynomial function in the numerator and polynomial function in the denominator must satisfy the following conditions for a passive circuit [6]:

1) All the coefficients of the polynomials must be real.
2) All the poles of the polynomial function must be located on the left half plane.
3) The order of the numerator polynomial P must be less than or equal to the order of the denominator Q.
4) Rational function must be a positive real function.

So The format of the output rational function is :

$$Y(s) = \sum_{m=1}^{n} \frac{c_m}{s - a_m} + D + Cs \tag{2}$$

Each partial fraction, residues and an infinity pole in equation (2):

1) A constant D
2) An infinity pole Cs
3) A real pole fraction $\frac{c}{s-a}$
4) A pair of fractions with conjugate complex poles $\frac{c'+c''}{s-(a'+ja'')} + \frac{c'-c''}{s-(a'-ja'')}$

can be represented as a branch in an admittance of electrical circuit.

There are two possibility forms of electrical network (impedance and admittance) can be model from the rational function. In this paper, the admittance will be implemented.

III. Admittance Implementation

The admittance-parameters, each fraction or pair of fractions can be implemented as a parallel admittance branch:

- A constant D is implemented as a resistor with resistance value $R = \frac{1}{D}\,(\Omega)$
- A pole at infinity ks is implemented as a capacitance of value$C = C\,(F)$
- A real pole fraction $\frac{c}{s-a}$ is implemented by an RL series circuit with the inductor $L_1 = \frac{1}{c}\,(H)$ and the resistor $R_1 = \frac{-a}{c}\,(\Omega)$.
- A pair of fractions with conjugate complex poles $\frac{c'+c''}{s-(a'+ja'')} + \frac{c'-c''}{s-(a'-ja'')}$ is implemented as an LRC series resonance circuit as depicted in Fig 2. Each element can be calculated as the following [7]:

$$L_2 = \frac{1}{2c'} \tag{3}$$

$$R_2 = \left(-2a' + 2\left(c'a' + c''a''\right)L_2\right)L_2 \tag{4}$$

$$C_2 = \frac{1}{\left(a'^2 + a''^2 + 2\left(c'a' + c''a''\right)R_2\right)L_2} \tag{5}$$

$$G_2 = -2C_2L_2\left(c'a' + c''a''\right) \tag{6}$$

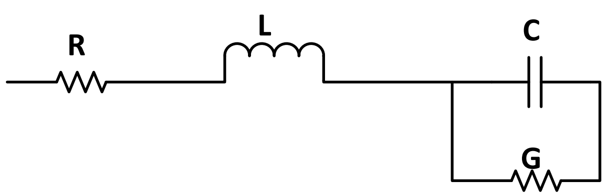


Fig. 2. Complex pole pair as admittance element realization.

IV. Validation of the methodology

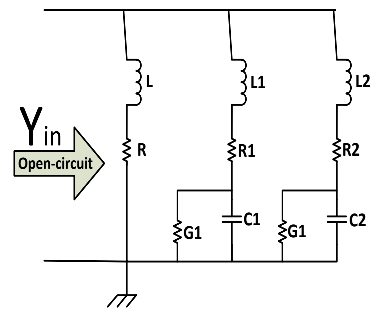
In order to apply this methodology, one meter shielded cable with three conductors is used. The cross sectional area of each conductor is 2.85mm.

Open circuit has been done for the power cable to get The reflection coefficient $S11$. after applying this methodology on these data, the synthesization of the admittance as an electrical network has been achieved in Fig3. After that the comparison between the synthesized network and measured value is achieved in Fig 4.

It is clear that there is a good agrement between the calculated and measurement results.

V. Conclusion

To analyze the behavior of any phenomena like electromagnetic interference inside power cable, the accuracy model is desired. This methodology proved that the power cable can be model with small number of branches of a simple network for a big frequency band [10 KHz - 100 MHz]. The accuracy of the output network is very high especially at resonance frequencies. also the skin effect and proximity effect have been taken in the calculation of the output network. Only one disadvantage is the negative value of the conductance. Nevertheless the model is applicable in Spice simulation and realisability is irrelevant.



Element	Open circuit
R	5.2001(μΩ/m)
R_1	42(mΩ/m)
R_2	6.8(mΩ/m)
L	0.83738(nH/m)
L_1	0.31813(nH/m)
L_2	0.31644(nH/m)
C_1	2.6854(nF/m)
C_2	10.913(nF/m)
G_1	-0.2832(S/m)
G_2	-0.0658(S/m)

Fig. 3. Synthesization open circuit admittance by electrical network.

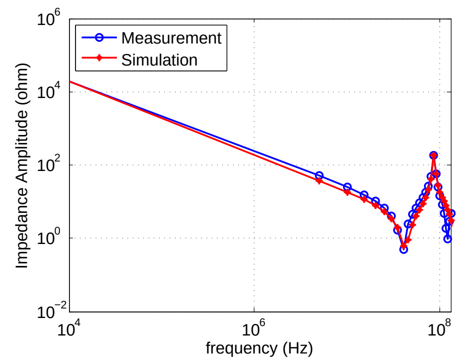


Fig. 4. Evolution of open circuit impedance for the 1 m long cable.

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