Time Domain Modeling and Simulation of Partial Discharges on MV Cables by Vector Fitting Method

Tang Ming[1], Sun Jianyang[2], Guo Jianzhao[2], Li Hongjie[1], Zhang Wei[1], and Liang Deliang[1]
[1]State Key Laboratory of Electrical Insulation and Power Equipment, School of Electrical Engineering
Xian JiaoTong University, No.28 Xianning Road, 710049, China
[2]Quanzhou Power Supply Ltd., Wenlin Road, Quanzhou, 362000, China

***Abstract*—In this paper a transmission line model is developed based on lumped element representation and state-space techniques. A simple and efficient procedure to model medium voltage (MV) power cables directly in time domain is presented. The proposed methodology, considering both the skin effects and dielectric losses, takes into account the frequency-dependent parameters of the line. In order to incorporate this effect into the state matrices, a fitting method is applied. Based on the fitting method, a precise model of the medium voltage power cables is constructed. Using the estimated propagation speed of the presented model, the experimental results show that the accurate Partial Discharge (PD) location on medium voltage power cables can be achieved.**

***Index Terms* — Transmission line model, time domain, dielectric losses, power cables, vector fitting, partial discharge.**

I. INTRODUCTION

Poor design, degradation, aging processes and bad workmanship of insulation in medium voltage power cables result in localized electrical discharges known as partial discharges (PDs). Off-line and on-line distribution cable network PD diagnostic methods have been investigated and accepted over the past years. It is well recognized that these techniques are the effective method to assess the cable condition in a non-destructive way. For the past decades, some PD diagnostic commercial instruments, e.g. oscillating wave test system (OWTS), on-line PD detection system (PD-OL), have been developed and are in widespread use by utilities to detect and locate PDs on cables with a poor reliability performance history. In order to locate the defect point of the cable, knowledge on the propagation characteristics, especially the precise propagation speed of the cable, is vital.

The coaxial structure of a single phase power cable can be represented by transmission line model [1], [2]. The transmission line models, applied to simulate electromagnetic transients, are frequently classified as lumped or distributed parameters models. On the use of a lumped parameters model, it is possible to adequately simulate the distributed nature of the transmission line parameters in time domain, and then the detailed voltage and current profile is obtained [3], [4]. On the basis of vector fitting method, lumped parameters model is employed in this paper to estimate the accurate propagation speed. Different numbers of π sections are simulated and precise propagation speed is yielded. The experiment results confirm the accuracy of the presented model.

II. FITTING LONGITUDINAL PARAMETERS

A lossy transmission line can be represented by multiple π elements connected in cascades.

The per unit length (p.u.l.) series impedance $Z(\omega)$ of a lossy transmission line is an improper function. To fit $Z(\omega)$, a modified function $F(\omega)$ is necessary, as follows [6]

$$F(\omega)=\frac{Z(\omega)-R_{dc}}{j\omega}\,. \tag{1}$$

where R_{dc} is the asymptotic value of $Z(\omega)$ for $\omega = 0$.

Then the rational approximation of $F(\omega)$ can be written as

$$F'(\omega)=p+\sum_{n=1}^{N}\frac{c_n}{j\omega-a_n}\,. \tag{2}$$

where the poles a_n and residue c_n are a either real or conjugate pairs, and p is a real and positive residue.

Consider that $F(\omega)$ can be approximated by $F'(\omega)$

$$F(\omega)=F'(\omega)\,. \tag{3}$$

Substitute (1) and (2) into (3), $Z(\omega)$ can be written as

$$Z(\omega)=R_{dc}+j\omega\left[p+\sum_{i=1}^{N}\frac{c_i}{j\omega-a_i}\right]. \tag{4}$$

It is seen that $Z(\omega)$ may be approximated by a rational function. Once the function $Z(\omega)$ has been fitted, the equivalent R-L Ladder networks shown in Fig. 1 [6] can easily be associated.

In Fig. 1, Rn are resistances and Ln are inductances, n is the number of π sections. The corresponding equivalent circuit models with passive elements can be expressed as

$$Z(\omega)_{fit}=R_{dc}+j\omega L_0+\sum_{i=1}^{m}\frac{j\omega R_i}{j\omega+(R_i/L_i)}\,. \tag{5}$$

In this paper, R-L ladder circuits shown in Fig. 1, and G-C ladder network represented in Fig. 2, are used to model the skin effects and the dielectric losses respectively

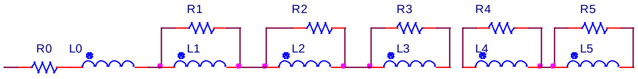

Fig. 1. Modeling of the skin effect by an R-L ladder network

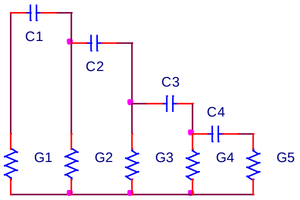

Fig. 2. Modeling of the dielectric losses by an G-C ladder network

Based on the methodology described above, a lumped parameters model of one cell of the medium voltage cable, taking into account the skin effects and the dielectric losses, is represented in Fig. 3. In Fig. 3, R_0, R_1, R_2, R_3, R_4, R_5 are resistances, whereas the L_0, L_1, L_2, L_3, L_4, L_5 are inductances. The terms Gi and Ci are the shunt conductance and shunt capacitance, respectively.

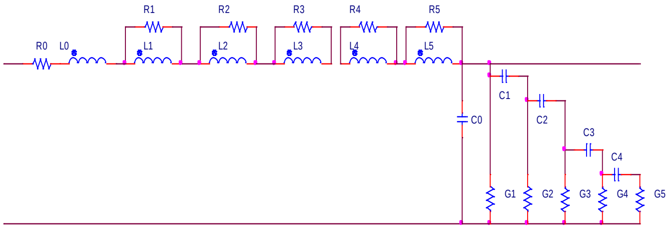

Fig. 3. Sketch of an elementary of the presented lumped parameters model

The fitting parameters p.u.l. of the cable model are presented in Table I and Table II respectively.

TABLE I
The p.u.l. parameters of the R-L ladder

Resistance (Ω/m)		Inductance (H/m)	
R_0	5.0644e-4	L_0	2.5859e-7
R_1	7.5865e-3	L_1	3.3572e-8
R_2	1.1835e-4	L_2	9.2228e-8
R_3	3.2917e-4	L_3	2.4174e-7
R_4	1.0342e-4	L_4	6.2368e-7
R_5	4.1080e-5	L_5	1.6588e-7

TABLE II
The p.u.l. parameters of the G-C ladder

Conductance (S/m)		Capacitance (F/m)	
G_1	1.9920e-9	C_0	4.1067e-10
G_2	7.1378e-7	C_1	7.1170e-09
G_3	2.1345e-6	C_2	1.6015e-06
G_4	5.2659e-6	C_3	5.1170e-08
G_5	1.2143e-5	C_4	1.9803e-04

III. MODELING AND SIMULATION ANALYSIS IN TIME DOMAIN

A. *Simulation and analysis*

To validate the model in time domain, voltage pulses are injected into the cable sending end, the rising time of which is about 8ns. In order to verify the accuracy of a lumped parameters model, a relative error is calculated as follows [5]

$$error = \frac{\left|\Delta t_D - \Delta t_\pi\right|}{\Delta t_D} . \qquad (6)$$

where Δt_D and Δt_π are respectively the time difference of the distributed parameters model and the lumped parameters model.

The cable model simulation results in the time domain are shown in Fig. 4, where the voltages on the sending and receiving ends are both included. It is verified that the lumped parameters model, constructed by a cascade with 128π sections, represents adequately transients for PD signal with a relative error of 2%. Thus, the accurate PD propagation speed of the medium voltage cable will be obtained.

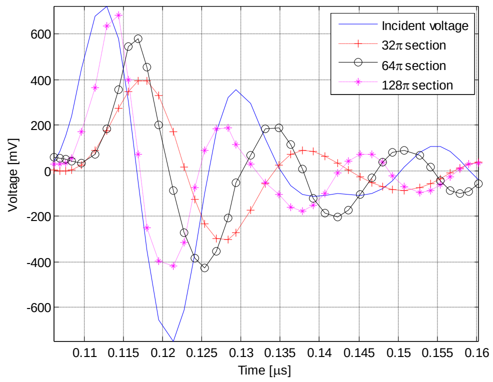

Fig. 4. Transient voltage at sending and receiving end with different π sections

B. *Experiment results*

The 300m PVC (Polyvinyl Chloride) cable with an artificial defect around 195m is employed in the experiment setup. The PD is captured by an HFCT (High Frequency Current Transformer) sensor and sampled data are stored in a digital storage oscilloscope. The PD location result using the estimated speed of the presented model is presented in Fig. 5.

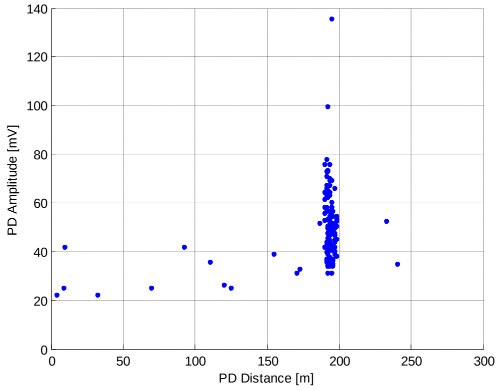

Fig. 5. PD location result

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