Effects of coaxial cables on high-voltage lightning impulse measured parameters: A comparative between measurements and simulations

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***Abstract* — Effects of the measuring cable on a lightning impulse measured by high-voltage dividers have not been usually considered in the common practice of high-voltage measurements. An analysis of these effects for different types of high-voltage dividers has been done, by comparing results obtained from lab measurements and those obtained from simulations when accurate models are used for measuring cables.**

***Index Terms*— Measuring cables, high-voltage dividers, high-voltage measurement techniques, modelling.**

I. INTRODUCTION

Common practice for high-voltage lightning impulse (LI) measurements is based on voltage dividers whose output is a low voltage signal related to the high voltage impulse to be measured. This output is connected to a measuring instrument (e.g. a digital recorder) by a coaxial measuring cable [1]. The selection of this coaxial measuring cable is usually done according to their characteristic impedance, attenuation and shielding effectiveness. To cover the distance between the voltage divider and the control room, in which the digital recorder is located, several meters or some tens of meters long measuring cables could be used. As a general practice, little attention is paid to the effect of cable length on the measured signal at the output of the divider; however, cable characteristics, such as attenuation or capacitance, can differ significantly between different cables, even though they have the same characteristic impedance. Consequently, the length of the cable can affect the signal waveform depending on the characteristics of the cable.

Effects caused by measuring cable in lightning impulse measurements has been treated in the literature [2], in which only cable unitary capacitance is considered, but attenuation is neglected. In the last years new analysis based on measurements were done about this matter [3], [4].

Attenuation and distortion caused by a coaxial measuring cable can be determined accurately by modelling and by software simulation. The coaxial measuring cable is a special case of a transmission line, whose model is based essentially on a series impedance and a parallel admittance that are frequency dependent functions, being the series impedance the one that has a strong variation with the frequency. These frequency dependent functions for coaxial cables can be determined from the equations proposed by Schelkunoff [5].

This paper presents the comparison between measured and simulated results obtained for a capacitive damped divider, when different measuring cable lengths are considered. The comparison is focused on the front time parameter T_1, as defined in [1].

II. THEORETICAL BASIS

Conventional damped-capacitive lightning impulse measuring systems, as the one shown in Fig. 1, are composed by five different elements: a high-voltage arm Z_1, a low-voltage arm Z_2, a matching impedance Z_3 adjusted according to the characteristic impedance Z_c of the coaxial measuring cable, and a measuring instrument with input impedance of Z_4.

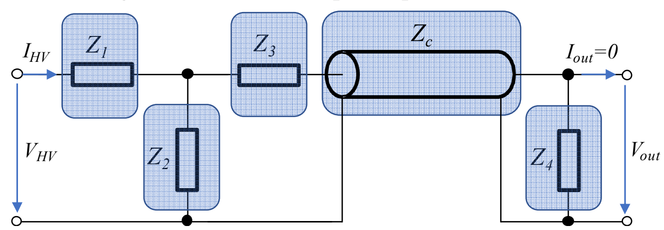

Fig. 1. Conventional lightning impulse measuring system represented by its main circuit elements.

The frequency behaviour of this equivalent circuit can be analysed as a two-port network or quadrupole. The frequency domain output voltage and current in the digital recorder input, $V_{out}(s)$ and $I_{out}(s)$, are related to the input voltage and current Laplace functions at the high voltage side ($V_{HV}(s)$ and $I_{HV}(s)$) through the ABCD transmission matrix, according to

$$\begin{bmatrix} V_{out}(s) \\ I_{out}(s) \end{bmatrix} = \begin{bmatrix} A(s) & B(s) \\ C(s) & D(s) \end{bmatrix} \cdot \begin{bmatrix} V_{HV}(s) \\ I_{HV}(s) \end{bmatrix}, \qquad (1)$$

where the transmission parameters $A(s)$, $B(s)$, $C(s)$ and $D(s)$ are expressed using Laplace variable, s. To determine the $A(s)$, $B(s)$, $C(s)$ and $D(s)$, individual quadrupoles of the five different elements shown in Fig. 1 are considered. The *ABCD* matrix of (1) can be obtained as it is described in [6]. For an applied high voltage $V_{HV}(s)$, the output voltage function $V_{out}(s)$ can be determined by the following equations, by considering the boundary condition $I_{out}=0$:

$$I_{out}(s)=0 \rightarrow I_{HV}(s)=-\frac{C(s)}{D(s)}\cdot V_{HV}(s) \quad (3)$$

$$V_{out}(s)=A(s)\cdot V_{HV}(s)+B(s)\cdot I_{HV}(s) \quad (4)$$

where $I_{HV}(s)$ is the frequency function of the current at the high-voltage side.

For obtaining the time function $u_{out}(t)$ corresponding to $V_{out}(s)$ a dedicated numerical inversion of Laplace transform has been used [6].

III. Example

The error on the front time parameter, T_1, is analyzed by varying the measuring cable length. This analysis is carried out by measurements and by simulation. Fig. 2 shows the schematics and the values of the different elements for a considered capacitive damped divider, (see Fig.2).

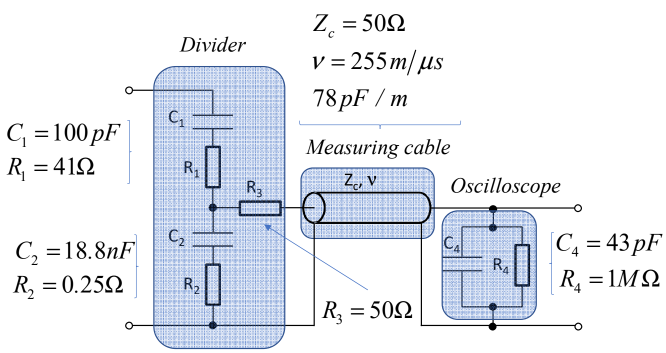

Fig. 2. Schematics for the considered capacitive damped divider.

A reference scenario with no cable connected (cable length = 0 m) has been considered, when a high voltage lightning impulse is applied with time parameters of 0.84/60 µs.

In the simulation the C_1 to C_4, R_1 to R_4 and cable capacitance and conductance were assumed to be frequency independent. The frequency dependencies of cable resistance and inductance were estimated using formulae from [5].

Comparative results for the measurements and for the simulations are shown in Fig. 3. Simulation results achieve a good fitting to the measurement. The obtained results show an increasing error when the cable length is increased.

IV. Conclusion

The results of this work show that the cable length has clear influence on measured lightning impulse voltage, especially on its front time. Measurements with resistive divider and analysis for other lightning impulse parameters are ongoing. Additionally, an accurate model that can be used to estimate measurement errors is available to simulate measuring coaxial cables applied to high voltage measuring systems.

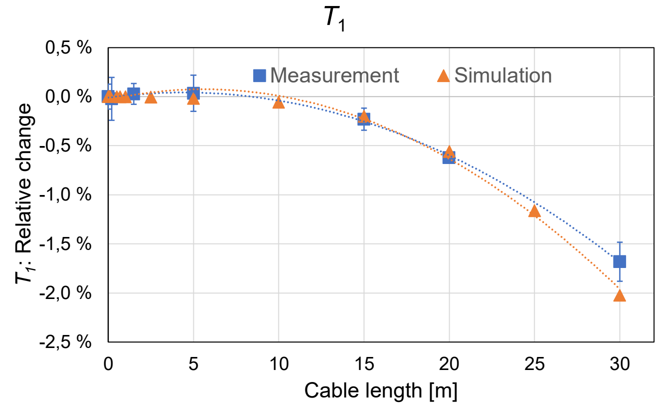

Fig. 3. Comparative results for the measurements and for the simulation.

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References

[1] IEC 60060-2: 'High-Voltage Test Techniques - Part 2: Measuring systems', 2010.

[2] Zaengl, W.: 'Ein Beitrag zur Schrittantwort kapazitiver Spannungsteiler mit langen Messkabeln', etz-a Bd. 98 (1977), S. 792–795.

[3] J. Havunen; S. Passon; J. Hällström; J. Meisner; T.-C. Schlüterbusch, "Characterization of Cable Effects on a Reference Lightning Impulse Voltage Divider" 2020 Conference on Precision Electromagnetic Measurements (CPEM), Denver, CO, USA, 24-28 August 2020.

[4] A. Bergman, M. Nordlund, Alf-Peter Elg, J. Havunen, J. Hällström, J. Meisner.: 'Influence of coaxial cable on response of high-voltage resistive dividers', The 20th International Symposium on High Voltage Engineering, Buenos Aires, Argentina, August 27 – September 01, 2017.

[5] S. A. Schelkunoff: 'The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields', Bell System Technical Journal, Volume 13, Issue 4, October 1934, pp. 532–579.

[6] A. Khamlichi, F. Garnacho, J. Rovira, P. Simón. "Signal attenuation and distortion in coaxial cables for high voltage measurements". The 22nd International Symposium on High Voltage Engineering, Xi'an, China, November 21-25, 2021.