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ON THE MODEL OF MV POWER LINE COMMUNICATION SYSTEM IN THE CASE OF LINE TO LINE TRANSMISSION

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Abstract – In this paper a complete model of Medium Voltage (MV) power system for PLC communications, in the frequency domain, is presented. A simple and friendly Simulink® software is used to develop the model. A distributed parameters MV cables model in line-line configuration is considered. Also the signal coupling networks with the generation and receiving systems are included. The performances of the complete PLC communication system are evaluated introducing the attenuation constant computed as ratio between the received and transmitted voltage signals. The signal losses produced by the complete system in the CENELEC frequency band and for different cable lengths are also considered.

Keywords: medium voltage, power line communication, attenuation constant

1. INTRODUCTION

In recent years, near to the huge development of the power line communication (PLC) for low voltage (LV) system the application of PLC to medium voltage (MV) power networks has had an increasing interest [1-2].

The network management optimization, the monitoring of the system and the operational services are the most important PLC applications for the MV networks [3]. In Europe, the available frequency intervals for communication systems on LV and MV power networks are settled by CENELEC EN 50065-1 [4]. The standard specifies five different bandwidths from 3 kHz to 148 kHz. In Northern America and in Japan the regulation is more permissive because it allows one to use frequencies up to 525 kHz, i.e. up to the AM broadcast threshold [5]. A further reference for PLC systems is the IEEE standard 643 – 2004 [6]. In the case of cable lines, two configurations are mainly used, line-ground and line-line configuration. In the line-ground configuration the signal is injected between a phase and cable shield. The shield is normally connected to the ground at the ends of the line. In the line-line configuration, the signal is injected between two phases of a three-phase power system, or between the phase and the neutral conductor of a single-phase power system. In both cases the signal can be injected by capacitive couplers or inductive couplers [6]. In literature, different studies have been presented on the behaviour both of high voltage (HV) and MV overhead lines and on LV cables at high frequency. On the other hand, there are few studies on the behaviour of MV cable lines [7-8]. The models proposed are mainly based on Bergeron's model, used also in this work [1-9].

In previous works the authors have presented a model to simulate the signal transmission through a MV cables in the line-ground and line-line configurations [10][11][12]. In this paper a complete model of MV power system for PLC communications, in the frequency domain, is presented in nthe case of a line to line configuration. The model requires the knowledge of the per unit length parameters of the transmission lines [10][11][12]. Moreover the coupling system for the signal injection, the signal generator and the signal receiver are considered.

In this paper, firstly the system under study is presented. Secondly, a description of the complete model with all the single components are reported. Finally, the simulation results in term of attenuation constant are illustrated by comparing the results for different line lengths.

2. SYSTEM UNDER STUDY

The system under study is composed by three unipolar MV shielded cables type RG7H1R with aluminum core and 185 mm^2 cross-section. The transmission system is based on line-line configuration in which the signal is injected in the cores of two cables and the external conductor of each cable are connected together to ground. The signal are injected and received by two commercial coupling networks (CN) whereas the signal generator and the receiver are connected by two isolation transformers. In Fig.1 a simplified schematic representation of the system under study is sketched.

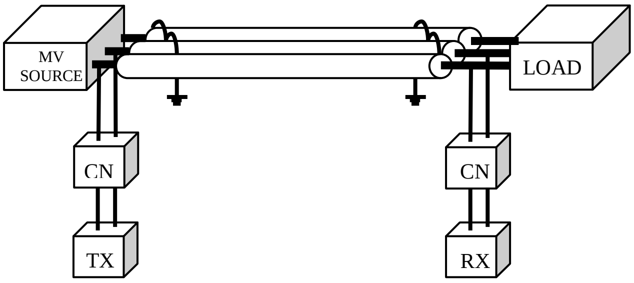

Fig.1. Schematization of the system under study

3. SIMULINK® MODEL

The complete model of the MV system for power line communication is developed in Simulink® environment. The schematic circuital representation is shown in Fig. 2. The blocks named TX and RX represent two functional blocks for the generation and receiving signal respectively.

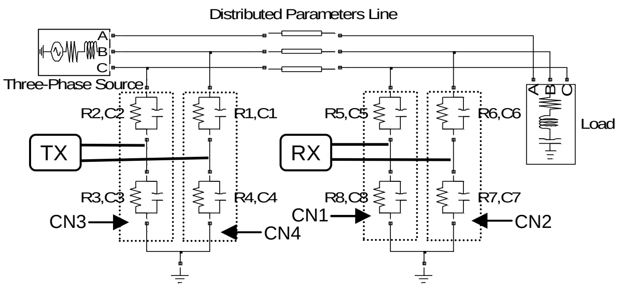

Fig. 2. Model of the MV system for power line communication developed in Simulink®.

3.1. Cable model

In literature the methods used to simulate and to study the transmission line behavior are different [1-9]. Most of them are obtained from the time dependent telegrapher's equations which are for the elementary line transmission cell, shown in Fig.3, the following:

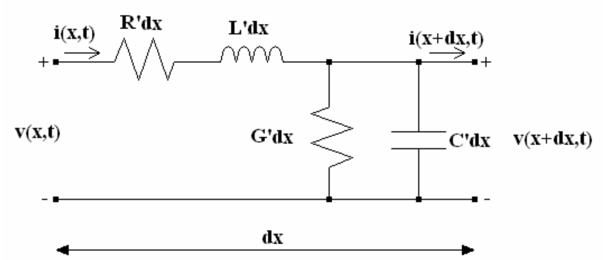

Fig. 3. Elementary cell of a transmission line.

$$\frac{\partial v(x,t)}{\partial x} + R' i(x,t) + L' \frac{\partial i(x,t)}{\partial t} = 0 \qquad (1)$$

$$\frac{\partial i(x,t)}{\partial x} + G' v(x,t) + C' \frac{\partial v(x,t)}{\partial t} = 0 \qquad (2)$$

In these equations x denotes the longitudinal direction of the line and *R'*, *L'*, *G'* and *C'* are the per unit length resistance (Ω/m), inductance (H/m), conductance (S/m) and capacitance (F/m) respectively.

In the time domain the most numerical method applied to solve the telegrapher's equations is the Bergeron one [1]. Usually, *G'* is neglected and only the distributed series resistance *R'* is considered to take into account losses in the line. Therefore, the input parameters required by the model are the reference frequency, the resistance *R'*, the inductance *L'* and the capacitance *C'*. The electric quantities are dependent by the geometric and constitutive parameters. Besides a variation law versus frequency for all electric parameters can be obtained by experimental measurements [11]. The per unit length resistance *R'* versus frequency trend is independent by the geometric and constitutive characteristics of the cable and it was fitted by the following second-order polynomial function:

$$R'(f) = A_R f^2 + B_R f + C_R \qquad (3)$$

In the case of two unipolar MV shielded cables type RG7H1R, of 185 mm^2 and 95 mm^2 cross-section with aluminum core and copper shielded the second order polynomial function coefficients are reported in Table 1.

Cable	A_R [Ω/(m*Hz^2)]	B_R [Ω/(m*Hz)]	C_R [Ω/m]
1 x 95 Al	-3.000*E-13	2.000 *E-7	0.0023
1 x 185 Al	-9.000*E-15	2.000*E-8	0.0055

Table 1. *R'* coefficients for two different cable typologies

As for the per unit length parameters *L'* and *C'* versus frequency trends a fitting with constant values dependent by cable typologies was obtained, as shown in Table 2.

Cable	*L* [H/m]	*C* [F/m]
1 x 95 Al	4.730*E-7	1.110*E-10
1 x 185 Al	2.680*E-7	1.550*E-10

Table 2. *L* and *C* coefficients for 185 and 95 mm^2 aluminum cables

3.2. Coupling Network

The signal injected and received in the MV cables is carried out by a commercial coupling network (CN) based on ohmic-capacitive divider. The frequency characterization of this network has been made by a vector network analyzer and the RC values are included in the model.

3.3. TX system

The signal generated by a RF generator with output impedance of 50Ω is connected to coupling network by a 1:1 isolation transformer. The parameters of this transformer are deduced by data sheet of the VAC T60403-K4096-X047 with isolation voltage of 6 kV and frequency operation from 1 kHz to 1 MHz; the inductance presented is 1,3 mH. As regard the signal generator is modelled by an ideal sinusoidal generator with a R_{tx}=50Ω resistance series. In Fig. 4 the circuital scheme of the TX model is sketched.

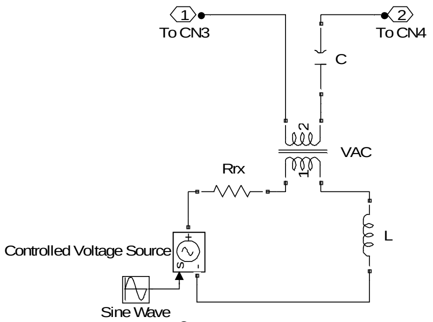

Fig. 4. Simulink® model of the TX system.

As shown in Fig. 4 in series to the sinusoidal generator is inserted an inductor L need to fit the generator output with the coupling network. Besides, in series to the secondary transformer a capacitor C to eliminate the residual 50 Hz voltage is introduced. The connectors 1 and 2 in Fig. 4 represent the connection point with the two coupling networks connected to the cable cores in MV source side.

3.4. RX system

Likewise to the TX system also in RX system the signal is picked up by the power cables through the CN, in load side, and transferred at the receiver through a 1:1 isolation transformer. In Fig. 5 the Simulink model of the RX system is represented. The receiver is modelled by a resistor Rrx=50Ω simulating the input impedance of the voltage measurement instrument.

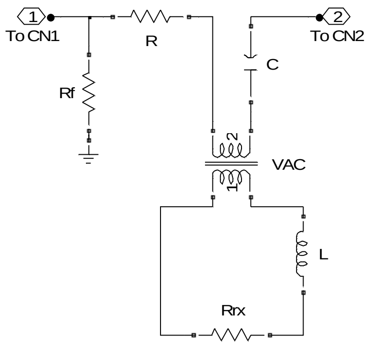

Fig. 5. Simulink® model of RX system.

Also in this case in series to the isolation transformer primary an inductor is connected and a resistor divider is connected to secondary transformer to fit the receiver impedance input to the coupling networks. Moreover, a series capacitor to the isolation transformer secondary is inserted to reduce the 50 Hz voltage residual present between the 1 and 2 connections.

The 1 and 2 connectors in Fig. 5 represent the connection points of the RX system to the coupling networks that shunt the signal from the power cables.

4. RESULTS

The distributed parameters model of the cable in line-line configuration has been verified considering the α attenuation constant as parameter to compare the model performance with the experimental measurements. In the case of a double cable configuration and for two different cables typologies the attenuation constant measured and simulated have been compared. The comparison results for 95 and 185 mm^2 cross-section aluminum cables are shown in Figures 6 and 7 respectively.

The simulation results obtained with a Simulink model are in good agreement with the experimental measurements showing a difference about 1 dB and lesser of 0.1 dB for 1 km cable length of 95 and 185 mm^2 cross section respectively.

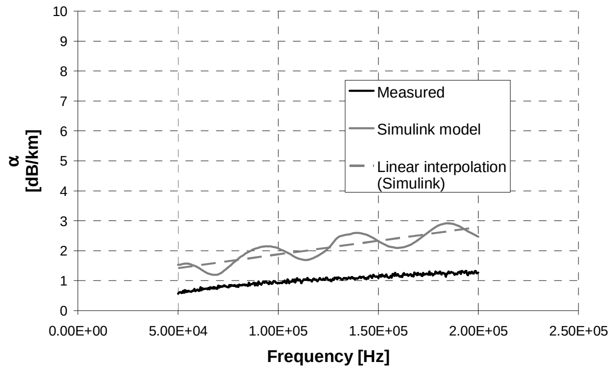

Fig. 6. Measurement and simulation results of the attenuation constant α vs frequency for the 95 mm^2 cross-section cable in the double cable configuration.

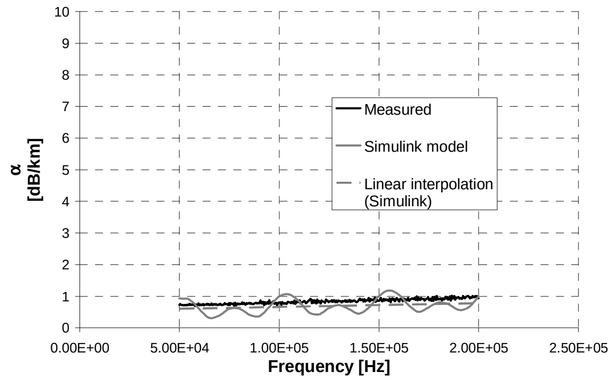

Fig. 7. Measurement and simulation results of the attenuation constant α vs frequency for the 185 mm^2 cross-section cable in the double cable configuration.

On the basis of the obtained results a complete MV power system model for PLC communications has been developed to verify the attenuation constant versus line length. Therefore, in the simulation model a transmission system in line to line configuration with 185 mm^2 cross section and aluminium core for different line lengths were considered. Preliminary, the attenuation constant versus frequency for 1 km long cable has been calculated, in the case of sinusoidal signal injection, and the results are shown in Fig. 8. The results shown a minimum attenuation value of 16.48 dB at the frequency of 86 kHz and its value it is lower than 40 dB in the frequency range of 86 ± 0.5 kHz.

For the frequency of 86 kHz corresponding to minimum attenuation value the variation of the constant α versus line length is considered and the simulation results are sketched in Fig. 9. For typical MV cable lengths of 0.8 and 2 km the attenuation constant assumes values between 16 and 20 dB.

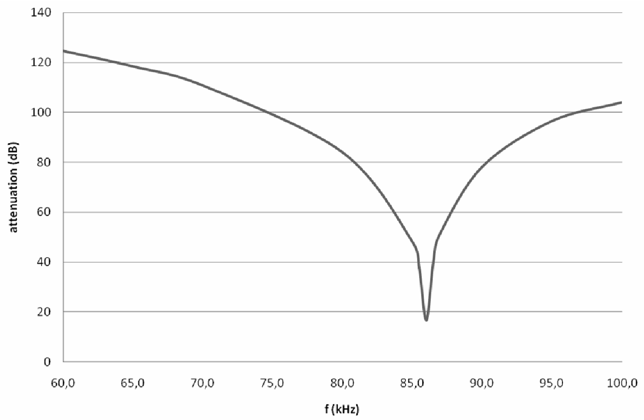

Fig. 8. Attenuation constant α versus frequency for 1km cable length in line to line configuration.

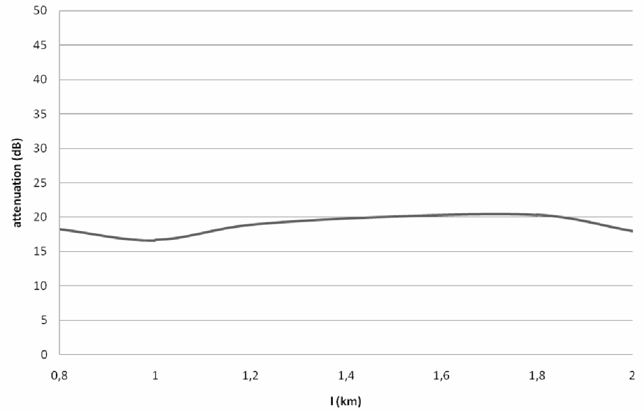

Fig. 9. Attenuation constant α versus line length simulated in line to line configuration for f =86 kHz.

The attenuation introduced by the complete system, in the line to line configuration, is about 15 dB higher respect to one of the cable and the principals losses are due to the coupling networks. As regard the attenuation constant function of the cable length, the maximum variation produced by different cable lengths is about 4 dB.

4. CONCLUSIONS

In this paper it has been proposed a simple and complete model of MV power system for PLC communications in the frequency domain. The system under study is composed by three unipolar MV shielded cables type RG7H1R with aluminum core and 185 mm^2 cross-section. The transmission system is based on line-line configuration in which the signal is injected in the cores of two cables and the external conductor of each cable are connected together to earth.

The main advantage of the proposed model is that it can be easily implemented in the Simulink® environment. The simulation results shown that the main losses in the transmission signal are due to the coupling networks and a minimum attenuation constant in the CENELEC frequency band it is possible to obtain. The attenuation introduced by the cable is negligible respect to one of the coupling networks considering a little contribution for different cable lengths.

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