CONSIDERATION OF DER IN THE PLC COMMUNICATION CHANNEL

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ABSTRACT

Abstract—In the intend to use the transmission and distribution power lines as a communication channel, much attention has been provided in the modeling of the transmission media used for the propagation of the signals that transmit the information. Most of this effort has been applied in the broadband propagation characteristics, due to higher bandwidth and the use of higher frequencies that can avoid some interference [1]. In this paper a method is proposed to better understand parameter differences between line characterization in the different frequencies of interest for PLC (Power Line Communications) applicable to analytically determine the channel model, by analyzing the effects of reflections due to the nodes and branch lines impedance mismatches that are present at the distribution power lines. Nowadays such methodology is empirically determined, so this new approach intends to facilitate the modeling methodology prior to its implementation.

INTRODUCTION

The active distribution network requires advanced information, communication and control technology to be the basic support that depends on the reliability of data transmission via the information and communication network. In the intend to use the transmission and distribution power lines as a communication channel for the new interconnected active distribution power grid [2], it brings to the engineering community, a motivation to deeper analyze and model such channels for the transmission of not only energy but also communication signals.

One of the pillars of smart grids is the capability of collecting and managing data from meters in a remote way, using a bidirectional communication link. Smart metering is being deployed all over the world, and power line communications is frequently used to provide this communication over the existing power network, enabling Utilities to implement cost-effective AMI solutions.

PRIME standard is being widely used in Utilities for this purpose since the foundation of the PRIME Alliance, in 2009. It comprehends a non-proprietary, license free open standard, reducing the meter device cost (CAPEX), and the communication carrier cost (OPEX), as it uses powerline communication signals in the 3 to 148.5 kHz CENELEC or the 14 to 480 kHz FCC frequency bands.

A method is proposed to better understand parameter differences between line characterization in the different frequencies of interest for PLC to analytically determine the channel model, by analyzing the effects of reflections due to the nodes and branch lines impedance mismatches, that are present at the distribution power lines with DER. Nowadays such methodology is empirically determined, so this new approach intends to facilitate the modeling methodology prior to its implementation. When utilities deploy the NB-PLC system for AMI purposes, it is of much importance to understand the media where the signal will be propagated.

The methodology merges several analytical approaches, making particular emphasis on distributed impedances over distribution grids with impedance effects made by substation power transformer, DER units, and domestic power grids that might affect the PLC signal propagation,.

POWER LINE PARAMETER EXTRACTION

A typical power line cable consists of three conductors; phase, neutral and ground. Each neutral and phase cables are independently coated by an insulator and the set of three conductors can be surrounded by metal cover or mostly by another insulator. Two of the three conductors are sufficient to create a communication channel.

Transmission lines are characterized by a combination of series and parallel components that represent different physical aspects of the lines. When proposing the modeling of power lines for PLC communication, several approaches have been presented using parameter fitting approach [3] based on some measurements and adjusting the values based on such measurements, or the use a bottom-up approach, using physical properties of the cables in order to obtain cable models. In the case here presented, based on physical parameters of the cables, the electrical parameters are extracted.

USE CASE PRESENTATION

The proposed use case under study considers the interaction between part of a power distribution grid with local loads (LV_{dis}), and a domestic or internal power grid (LV_{dom}). The main grid connects the substation distribution transformer output feeder down to the end user.

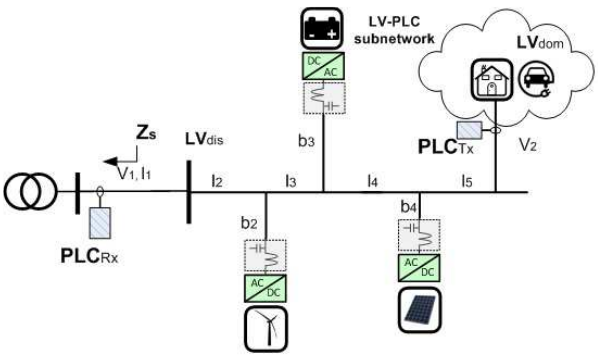

Fig.1 Power grid with the PLC devices

Such power grid is characterized by presenting a wide section cable, long distance, with few branch line connections that interface with the loads and the final users. These branch lines are responsible of reflections that will incur in signal attenuation. A residential distribution grid is deployed by means of more connections of internal branch lines, presenting much shorter distance and smaller cable section. The loads attached to such power lines present a higher level of impedance unpredictability due to its random nature of use and wide range of possible impedance values varying from few Ω to k Ω [4]. Even with short distances, the losses are very high, due to a dense number of branches and the absence of impedance matching. For certain frequency bands, the fluctuations observed in the channel transfer function within the same mains cycle can reach up to 5 dB.

Model for the LV distribution grid

The study performed of the PLC channel transfer function is based on *chain-matrix* (ABCD matrix) theory [5] very convenient for the calculation of channel transfer functions [6], including intermediate impedances and loads. In particular our distribution system can be implemented by means of modelling the following components represented in figure 2:

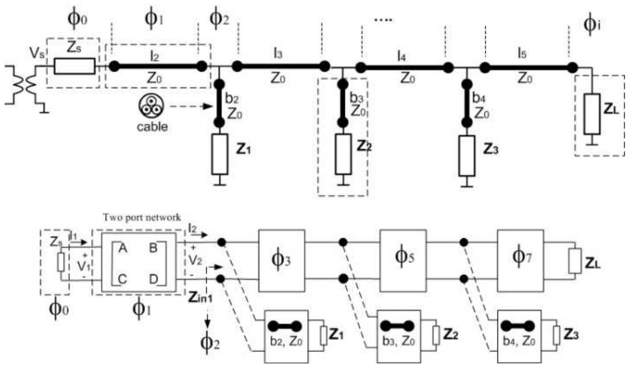

Fig.2 Equivalent model of the power grid for the PLC analysis

Source impedance

Expressed in terms of ABCD matrix in the following way

$$\emptyset_0 = \begin{bmatrix} 1 & Z_s \\ 0 & 1 \end{bmatrix} \qquad (1)$$

Parallel transmission line

Can be implemented by the ABCD matrix defined by Φ_i for the parallel cable with length l_i, characteristic impedance Z_0, and propagation constant γ:

$$\emptyset_1 = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cosh(\gamma_i l_i) & Z_c \sinh(\gamma_i l_i) \\ \frac{1}{Z_c}\sinh(\gamma_i l_i) & \cosh(\gamma_i l_i) \end{bmatrix} \qquad (2)$$

$$Z_0 = \sqrt{\frac{R_{LF} + j\omega L_{LF}}{G + j\omega C}} \qquad (3)$$

$$\gamma_i = \sqrt{(R_{LF} + j\omega L_{LF})(G + j\omega C)} \qquad (4)$$

Bridge tap

A transmission line with length b_i, ended with load impedance Z_i, that are represented by its equivalent input impedance from the main network by:

$$Z_{eq} = Z_0 \frac{Z_i + Z_0 \tanh(\gamma_i b_i)}{Z_0 + Z_i \tanh(\gamma_i b_i)} \qquad (5)$$

Terminal load

Is represented by the ABCD matrix expressed in the following manner

$$\emptyset_2 = \begin{bmatrix} 1 & 0 \\ \frac{1}{Z_L} & 1 \end{bmatrix} \qquad (6)$$

The use of the previous matrices will be applied to calculate the transfer function from the circuit, being able to represent the effects of the different loads and wiring from the input or output point of view. This is done by multiplication of the ABCD matrices (Φ_T), so the relation from PLC-concentrator voltage (V_1) to the voltage at PLC-meter (V_2) is:

$$H(f) = \frac{V_2}{V_1} = \frac{Z_L}{A_{\emptyset T} Z_L + B_{\emptyset T} + C_{\emptyset T} Z_S Z_L + D_{\emptyset T} Z_S} \qquad (7)$$

Model for the MV/LV distribution transformer

In addition to the model of power lines and loads, in the case presented, it is also necessary to develop a model of the power distribution transformer, where the PLC concentrator is connected to. In this study the model from [7] is used, and presented in Fig.3. The equivalent input impedance of the transformer for the frequency of interest in the LV side is extracted [7] (having a value of 20 Ohm with a phase of 50º . R = 12.8 Ω, L = 24.3 µH).

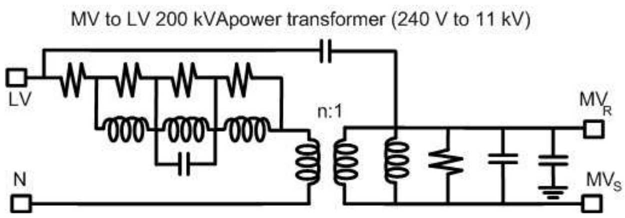

Fig.3 Equivalent circuit for the MV to LV power transformer considered from [7].

Model for DER's impedance

For the case of DER units, they are measured in a laboratory, in which the power converters define a microgrid environment (see Fig. 4), where different elements are configured as generation systems (PV or wind), storage (any kind of storage) and loads. In any case they are interface by means of back-to-back power converters with an output filter coil, that all of them present a similar impedance to the network, independently of the power level, absorbed or delivered into the grid.

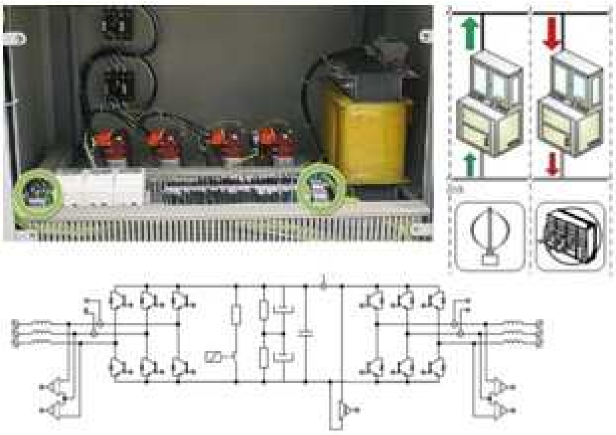

Fig.4 DER unit with VSC output filter coil.

In order to characterize the output filter behaviour (see Fig.5), it will be compared the equivalent inductor circuit and the experimental measurement of a real power electronic converter output filter. The resistance of the inductor's coils is considered a parasitic component of the inductor impedance and designated as R_{par}. The proximity of the adjacent inductor coils introduces a parasitic capacitance component into the inductor equivalent impedance. This parasitic capacitance, designated as C_{par}, increases significantly when space saving winding techniques (such as multiple layers of coils) are employed. the equivalent model can be expressed as a series combination of the element inductance and the parasitic resistance.

$$Z_{VSC} = \frac{j\omega L + R_{par}}{1 - \omega^2 L C_{par} + j\omega R_{par} C_{par}} \quad (8)$$

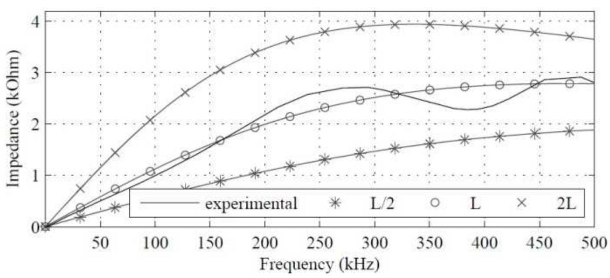

Fig.5 Measurements of the VSC output filter coil.

SIMULATION RESULTS

Two simulations are conducted, one for the domestic power grid, and another for the distribution grid, but using the previous obtained models of impedances from the domestic grid, and also the impedance presented by the distribution power transformer in the subestation.

Domestic distribution grid

A domestic LV power grid is simulated in order to obtain order of magnitude and variability of impedances and attenuation that will affect NB-PLC signal. Table I shows grid configuration. For the simulation, ABCD matrix method is used. In that case to show variability of the channel, three simulation setups have been considered for the case of having just one, two or three branch line ramifications from the main domestic distribution power line. Attenuation can reach -35 dB at 17 MHz. The cable in this case is thinner that in distribution grids. We use the same cable permeability (ε_r = 4.5), the main difference resides in having much shorter cable lengths. At this frequency range, the characteristic impedance will not vary as in the NB-PLC case, so it will keep constant for the frequency of interest ($|Z_{0A}|$ = 90 Ω, $|Z_{0B}|$ =180 Ω).

TABLE I. B-PLC channel layout values

	T.lines	Line (m)	Branch (m)	Terminal load
(a)	2	1, 5	2	ZLa=50+j100
(b)	3	1, 5, 7	1.5, 2.5	ZLb=150
(c)	4	1, 5, 7, 5	1.5, 2.5,1	ZLc=20-j100

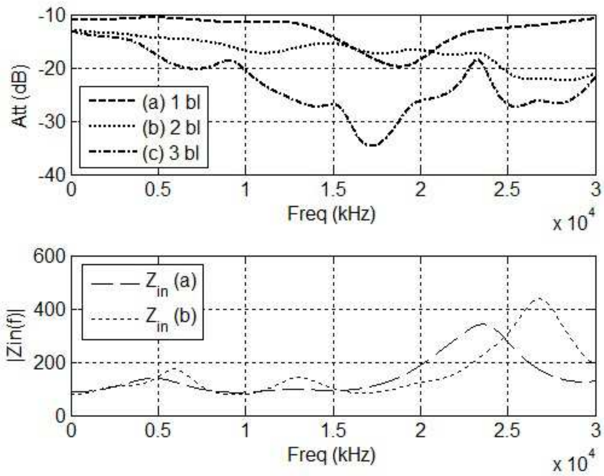

Fig.6 LV domestic grid (NB-PLC). Top. Attenuation for 1 to 3 bl. Bottom. Impedance at the bl.node.

For the prove of consistency with the aim of comparing with other methods, the attenuation is also computed by using the well known Zimmermann method [8-9-10], derived using similar concept as for multipath wireless channels, frequency response imposed to several multipath.

$$H(f) = \sum_{i=1}^{N} g_i e^{(-\alpha_0+\alpha_1 f^k)d_i} e^{(-j2\pi(d_i/v_p))} \quad (9)$$

with g_i is the i_{th} weighting factor from transmission and reflection, α_0 and α_{01} are the attenuation factor, d_i is the length of the i_{th} path, v_p is the speed of light transmitting in the insulating material, parameters to be empirically obtained (, α_0 = 1e-3, α_{01} = 2.5e-9, obtained from [10].

Distribution grid

The grid under study is described in figure 1. From the power distribution transformer, location where a PLC concentrator is located, until the terminal load, where a metering systems with PLC is plugged, the different models from the elements of the system are modelled according to the parameter values described in table II.

Attenuation of the channel for the frequencies of interest of NB-PLC are depicted in figure 8. The simulations have been reproduced for different LV_{dis} configurations, to represent that the attenuation is modified accordingly depending on the number of branches and length of the different wiring segments.

TABLE II. NB-PLC channel layout values (wire 4x95)

	T.lines	Line (m)	Branch (m)	Terminal load
(a)	2	20, 50	20	ZL1=50+j100
(b)	3	10	10	ZL2=150
(c)	4	40	30	ZL3=20-j100
(d)	5	15	10	ZL4=20-j20

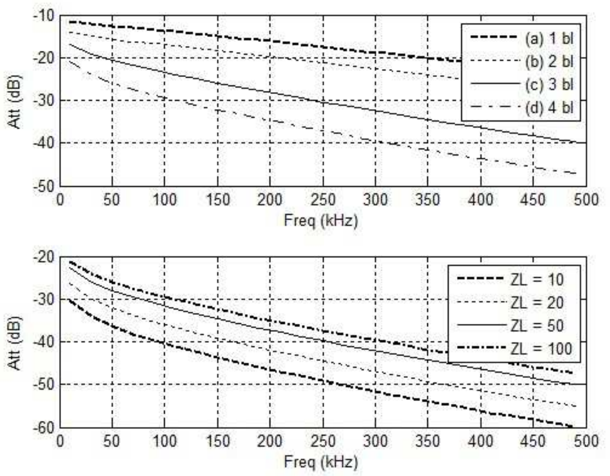

Fig.7 Attenuation of the distribution grid.

CONCLUSIONS

The work, shows a methodology that allows to present estimative results on the behaviour of communications signals in the CENELEC frequency band, taking as a premise, information on network topology, physical wire characteristics, DER impedance, distribution transformer and domestic grid. In reference to the terminal loads, it has been shown how useful can be the modelling of local domestic grid, and consider just its frequency variation.

The simulation methodology presented could be integrated in a global simulation that by including the noise sources from the different components. That would contribute to obtain an estimation on the quality of the communication link.

Acknowledgments

The research leading to these results has received funding from the European Union seventh framework program FP7-SMARTCITIES-2013 under grant agreement 608860 in the project IDE4L.

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