A Computational Model For The Energy Distribution Network In Broadband Over Power Line Communications

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Abstract— Recently, the Brazilian Telecommunications Agency (ANATEL) has issued a recommendation for the establishment of Broadband over Power Line (BPL) operation by the electricity utility companies. However, Brazil has a very heterogeneous energy distribution network, comprised by both legacy and modern recently built subsystems. In this scenario, the previous to installation knowledge of the behavior of a Power Line Communication (PLC) system is paramount to the success to this technology in the country. This article describes the development of a Matlab computational model for the simulation and performance evaluation of BPL/PLC signal transmission in distribution networks. This model is based on the physical distributed parameter characteristics of the network and a subsequent mathematical modeling of PLC channel under the constraint of a modulated signal. The model was tested with Gaussian minimum shift keying (GMSK) and orthogonal frequency division multiplex (OFDM) modulated signals. The results indicate the correctness of the model for both cases.

Keywords - PLC; BPL; channel characterization and modeling

I. INTRODUCTION

The transmission of digital data, voice and image signals through the energy distribution network is significantly affected by the characteristics of these networks. The media is electromagnetically open and insufficiently protected against interferences [1]. The physical structure of the cabling was not designed to support the propagation of high frequency signals. For this reason, PLC technology faces several challenges originated by problems (frequency selectivity dependent on the size of the trunk, variable impedance, non linear phase response, multiple reflections, different kind of induced and irradiated noises, etc) originated in the infrastructure [2,3].

During the planning phase of a PLC system, it is necessary to consider the parameters of the medium voltage (MV) and low voltage (LV) networks in order to guarantee a minimal level of quality of service (QOS), according to a service level agreement (SLA) with the prospective users.

The objective of this work is to develop a computational model that supports the evaluation the performance of BPL/PLC signal transmission in a real energy distribution environment. For this matter, the proposed model was based in both the physical characterization of real electricity systems and the mathematical simulation of modulated channels. The proposed model was applied to Gaussian minimum shift keying (GMSK) and orthogonal frequency division multiplex (OFDM) signal transmissions and the results corroborate its correctness

The physical characterization of the electricity system is obtained from parameters obtained from the software Alternative Transients Program (ATP) [3]. The input for this stage is comprised of data about posts, cables; short-circuit impedances, ground resistance, etc. The output is the distributed parameters (line resistance, inductance and capacitance values) of the physical network.

These parameters are used to derive a continuous time transfer function in the domain of the Laplace transform. This rational function is "discretized" through the application of the bilinear transformation, originating a z domain equivalent transfer function. This represents the data transmission channel theoretical model of the electricity network.

Computationally, the Matlab program was used to implement the model. First, the physical parameters of the distributed model are input to the SimPower module. Then, the Simulink tool is used to perform the remaining simulation through its Communications Blockset.

Finally, the model was employed to evaluate the performance of transmission of OFDM and GMSK signals through the network.

II. DEVELOPMENT OF THE MODEL

As reported before, the development of the mathematical/computational model was accomplished in two stages. First, the physical network was simulated to originate a distributed parameter characterization. Then, the parameters obtained in the first stage were employed to build a Communication System model in Simulink.

ANATEL has established the frequency range from 1.705 to 50 MHz for the operation of PLC networks. In this work, the frequency of 1.705 MHz was chosen for simulation without

any loss in generality as the results can be readily extended to other frequencies.

A. Modeling the Physical Nwtwork

The elements of the electrical systems may be modeled as a circuit formed by distributed capacitive (C), inductive (L) and resistive (R) elements. The derived model will be similar to the one shown in figure 1 below.
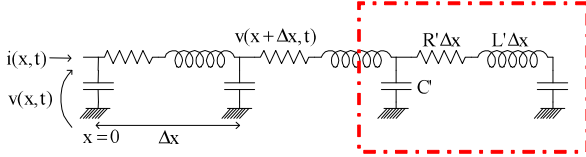

Figure 1. Example of a simplified distributed model for a TL

A distribution line can also be represented by a simplified unifilar diagram in which the loads are fed by a substation bus. The equivalent circuit for a circuit with 2 loads spaced 1 km from each other in a 2 km extension is shown in figure 2. This circuit will be used as an example of the development of the model proposed in this work.
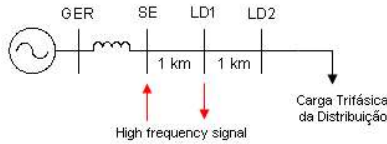

Figure 2. Unifilar diagram of a 2 km distribution circuit

The required data to characterize a feeder are: short circuit Power (Scc), the nominal medium voltage (MV) at the primary, the short circuit impedance (Zcc) and the nominal low voltage (LV) value. Other parameters of the structure of the feeder such as posts and cables are also necessary. For this example, the parameters in Table 1 were used for the feeder circuit.

TABLE I.   PARAMETERS OF A TYPICAL FEEDER CIRCUIT [5]

Parameter	Value
Scc	500 MVA
Nominal MV	23kVrms
Zcc	0,3809 Ω
Nominal LV	220Vrms

The parameters in Table II and Table III were used for the secondary in an untransposed configuration.

TABLE II.   PARAMETERS FOR THE SECONDARY CIRCUIT - PHASE CONDUCTOR

Parameter	Value
Length	2 km
Aerial cable	477 CAA
Rcc (20°C)	0.1194Ω /km
Diameter	2.180cm
Conductor Height	6.8m
Conductor Sag	1 m
Soil resistivity	1000 Ω.m

TABLE III.   PARAMETERS FOR THE SECONDARY CIRCUIT - NEUTRAL CONDUCTOR

Parameter	Value
Length	2 km
Aerial cable	1/0 AWG
Rcc (20o C)	0.5349 Ω /km
Diameter	0.936cm
Conductor height	7 m
Condutor Sag	1 m
Soil resistivity	1000 Ω.m

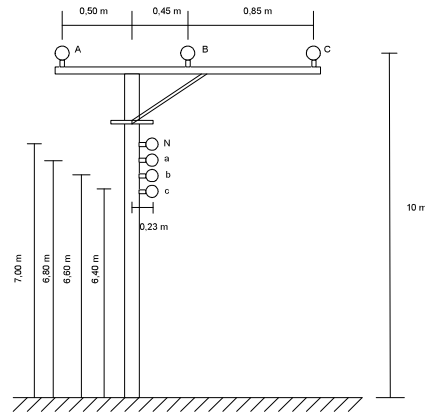In addition, the posts and cable characteristics are depicted in figure 3.

Figure 3. Posts and cable characteristics of the simulated circuit

It is important to observe that these parameters were obtained from a real circuit.

The distributed parameter equivalent circuit is obtained through the use of the Line Constants routine of the ATP program. The resulting values are shown in Tables IV and V.

TABLE IV.   VALUES OF THE DISTRIBUTED CIRCUIT FOR THE SECONDARY NETWORK EXTRACTED FROM ATP

SEQUENCE	RESISTANCE (ohm/km)	REACTANCE (ohm/km)	SUSCEPTANCE (Siemens/km)
POSITIVE	R1=2.58321e-01	XL1=2.65408e-01	BC1=6.68110e-06
ZERO	R0=4.35086e-01	XL0=2.36441	BC0=2.21569e-06

TABLE V.   VALUES OF THE DISTRIBUTED CIRCUIT FOR THE PRIMARY NETWORK EXTRACTED FROM ATP IN 60 Hz

	RESISTANCE	INDUCTANCE	CAPACITANCE
/ km	R1=2.58321e-01	L1=7.04017e-04	C1=1.77222e-08
/ m	R1=2.58321e-04	L1=7.04017e-07	C1=1.77222e-11
/ km	R0=4.35086e-01	L0=6.2716e-03	C0=5.8772e-09
/ m	R0=4.35086e-04	L0=6.2716e-06	C0=5.8772e-12

These parameters define the distribution line from a Circuit Theory perspective and will be used to determine the channel model for BPL signals in the second phase of this work.

B. Modeling the Communication Channel

In order to get a better insight of the electric circuit to be modeled, the section running from SE to LD1 in the unifilar

diagram of figure 2 will be analyzed as an example. The block diagram in figure 4 represents this section.

A very important factor of this model is the determination of the values of the secondary circuit in 60 Hz used as parameter for the transmission line. These values were derived from the physical characterization performed in ATP. It is interesting to note tat the values of inductance and capacitance were obtained by dividing the reactance and susceptance by the angular frequency in 60 Hz.

In this diagram, the following blocks are used:

- The Three Phases Source was set up as 60 Hz 220 Vrms sinusoidal triphasic source to emulate the LV source in the secondary of the transformer

- The 2 RLC e RLC1 parallel circuits represent the blocking coils for the high frequency signals, protecting the characteristics of the generating source and of the receiver in 60 Hz.

- The components of the PI section of the distributing line have the same values to represent different sections of the line.

- The transmission line parameters were also obtained from ATP program characterization. This block of the model is used to emulate the effect of the transmission line in the high frequency signal.

- The consumer block at the end of the line is used to verify the influence of the high frequency signal in the quality of the supplied electricity.

- The AC Voltage Source is used to inject a 1.705 MHz 20V signal with the purpose to evaluate the attenuation properties of the transmission line at this frequency

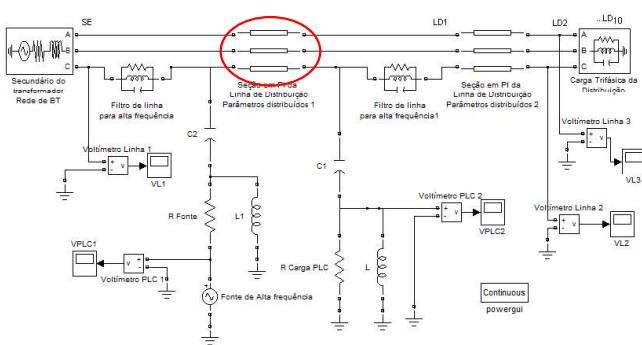- Filters were introduced to block out the high frequency signals.

Figure 4. SimPower implementation of the BPL channel model

In order to simulate this model in Simulink, it needs to be "discretized". For this matter, the analog transfer functions of the SimPower module are submitted to the bilinear transform, [6] originating an equivalent discrete time module.

This discrete time parameters are implemented as digital filters in Simulink, completing the development of the model for simulation of PLC signals in distribution networks.

The circled PI circuit in figure 4 has a transfer function that is equivalent to the BPL channel. This block is simulated as a digital filter in the diagram shown in figure 5.

III. SIMULATION RESULTS

In order to validate the proposed simulation model, two different modulated signals were submitted as prototypes for the PLC transmission: a GMSK and an OFDM signals.

Both signals were generated in the Matlab environment using the Simulink module and transmitted through a digital filter whose coefficients were obtained from the model developed in section II. The figure 5 shows the configuration.
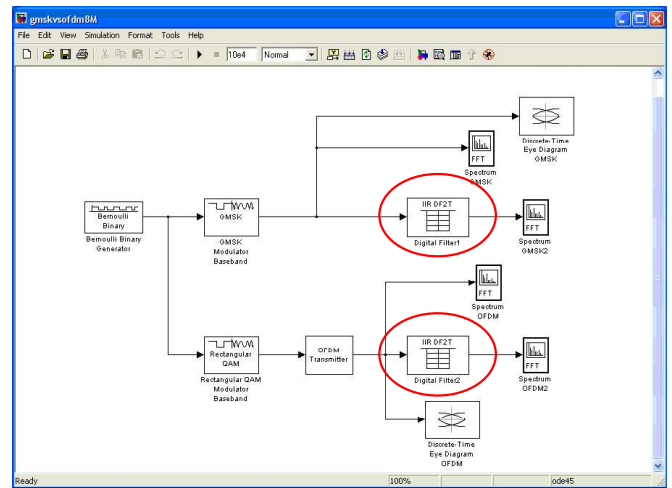

Figure 5. Simulink model of the BPL channel with modulated signals

It was found that the many filters used to block signals in the simulated model added a resonance effect just below 1 MHz. for this reason the spectrum of the GMSK signal was reshaped as it was transmitted across the line as shown in figure 6 and 7.
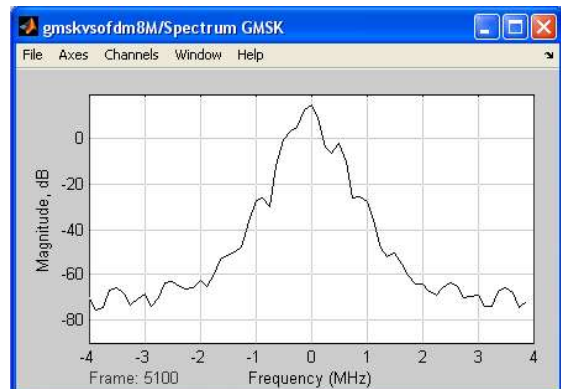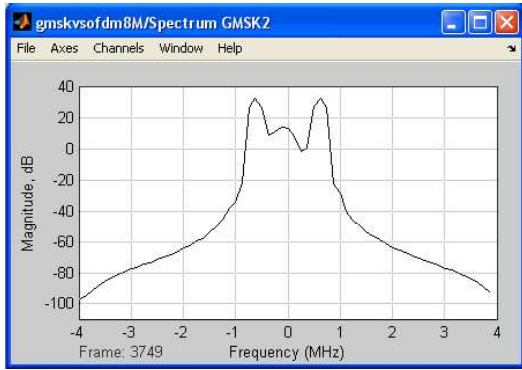

Figure 6. Spectrum of transmitted GMSK Signal

Figure 7. Spectrum of received GMSK Signal

As the above figures indicate, the simulation model is a useful tool to predict the behavior of the energy distribution network as a channel for communication signals in BPL applications.
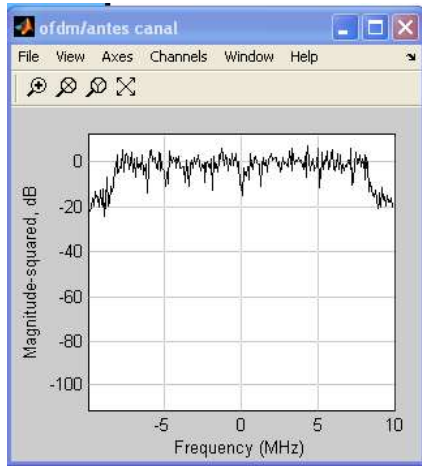

Figure 8. The transmitted spectrum for OFDM signal

Similar results were obtained for an OFDM signal. The spectra for this signal are shown in Figure 9 and 10 for the transmitted and received signal, respectively. Again, the resonance due to the diverse LC elements in the line causes a distortion in the frequency content of the signal.
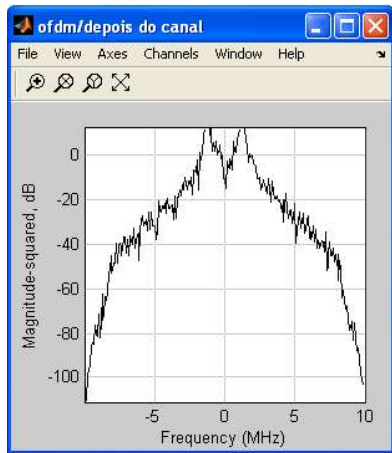

Figure 9. The received spectrum for OFDM signal

IV. CONCLUSIONS

Simulation models for electricity distribution networks in communication applications can be derived by the use of the method reported in this article by first modeling as a distributed parameter system and then converting it to a digital network.

The results can be used to predict the behavior of the network before the installation of BPL equipment.

Simulation results were present to corroborate the application of the method.

Although, the main purpose of this work is to model the typical channel of a BPL channel in the Brazilian electricity distribution network, it can be readily extend to the typical lines of other regions.

There were several parameters such as impedance variability and impulsive noise that were not modeled. This is left pending for a future continuation of this research.

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