Immunity of power line communications (PLC) in disturbed networks

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Abstract - This paper presents an analysis of electromagnetic immunity of energy metering devices, using broadband power line communications (PLC) in low voltage (LV) supply networks with high levels of disturbance. Several tests have been carried out to characterize the behavior of PLC modems and couplers in presence of the most common types of disturbances and electromagnetic interferences (EMI) which can be expected in LV distribution networks.
The method exposed allows repeat the tests with different modems, communications wires and couplers. Thus it is possible to compare different elements between them and choose the best for every occasion.

Keywords – Power line communications, PLC. Electromagnetic Interferences, EMI.

I. INTRODUCTION

There is an increasing interest on the implementation of remote energy metering, power quality monitoring, power demand management and supply network safety. The basis to implement all the mentioned functions in the electrical supply systems is the possibility of networking different electronic devices performing such functions and link them to a central computer [1] [2] [3]. Therefore, there is a growing interest on reliable and cheaper communications methods. Power Line Communications (PLC) through the supply networks themselves, seems to be the preferred solution to implement such communications systems, because of its availability and the relative low cost of the solution. Nowadays, the existing low voltage (LV) or medium voltage (MV) networks [4] [5] [6].

PLC communications systems operate by impressing a modulated carrier signal on the supply wiring system by means of a modem and a coupling interface. There are different types modems, using different frequency bands, depending on the signal transmission characteristics. Since the power wiring system was originally intended for transmission of AC power, the power wire circuits have only a limited ability to carry high frequencies and therefore, the propagation problem becomes a limiting factor for each type of power line communications. Data rates over a power line communication system vary widely from low-frequency carriers (about 100-200 kHz) which can be impressed on high and medium voltage (HV, MV) lines allowing equivalent data rates of a few hundred bits per second. However, these circuits may be many kilometers long. Higher data rates generally imply shorter transmission lengths. For example, local area networks may operate at several MHz. Depending on the frequency band and the type of modulation used, it’s possible to obtain different speeds. For example, using 50 kHz bandwidth the data rate may reach up to 130 kbps, while using 30 MHz bandwidth, Fig. 2, the raw data rate may reach up to 200 Mbps. The broadband (speeds over 1 Mbps) and the newest arrow band communications use OFDM modulations (Orthogonal Frequency Division Multiplexing) [7] [8].

At present, the more extended standards for Broadband over Power Lines (BPL) in the market have been developed in the frame of two projects: OPERA (Open PLC European Research Alliance) [9] and Home Plug Power-line Alliance [10] [11] [12]. Both projects have finished with some proposed standards which seems to converge to a common agreement based on IEEE standard P1901 [13]. Also in the frame of such projects and beside them, many studies and analysis have been done in order to know better the effect of electrical noise and Electromagnetic Interferences (EMI) on PLC communications [14] [15].

In this paper, several tests are performed to determine the robustness of PLC communications in presence of EMI will be presented. Beside the distortion of the signal, owing to cable losses and multipath propagation, one of the main problems for PLC communications are the disturbances in the physical channel. In contrast to other telecommunications channels, PLC does not introduce Additive White Gaussian Noise (AWGN). In LV power lines, the source of noise can be generated inside or outside the power network.

In power lines we may identify five types of noise, usually superposed and independently overlaid to each other [16].

a) Background noise with a relatively low power spectral density (PSD). This can be usually neglected.
b) Narrowband noise. Mostly formed by amplitude modulated sinusoidal signals, caused by the coupling of radio frequency (RF) signals (broadcasting stations, Wi- Fi, etc.)
c) Periodic impulsive noise, asynchronous to the mains frequency, which is mostly caused by switched-mode power supplies (SMPS).
d) Periodic impulsive noise, synchronous to the mains frequency, which is mainly caused by commutation of rectifiers.
e) Asynchronous impulsive noise, which is caused by switching transients in the power network (arcing). The paper is organized as follows, in section II the materials and methods are presented with a description of the different test performed, while in section III, the results of EMI tests are showed. Finally, the conclusions are presented in section IV.

II. MATERIALS AND METHODS

Two PLC modems connected each one to a PC (computer B and computer C in Fig. 1) are used to send and receive the data packets. Another PC (computer A in Fig. 1) acts as a front-end controller of the computers B and C and monitors the whole system. This PC also extracts the Simple Network Management Protocol (SNMP) information from PLC modems and executes the scripts.

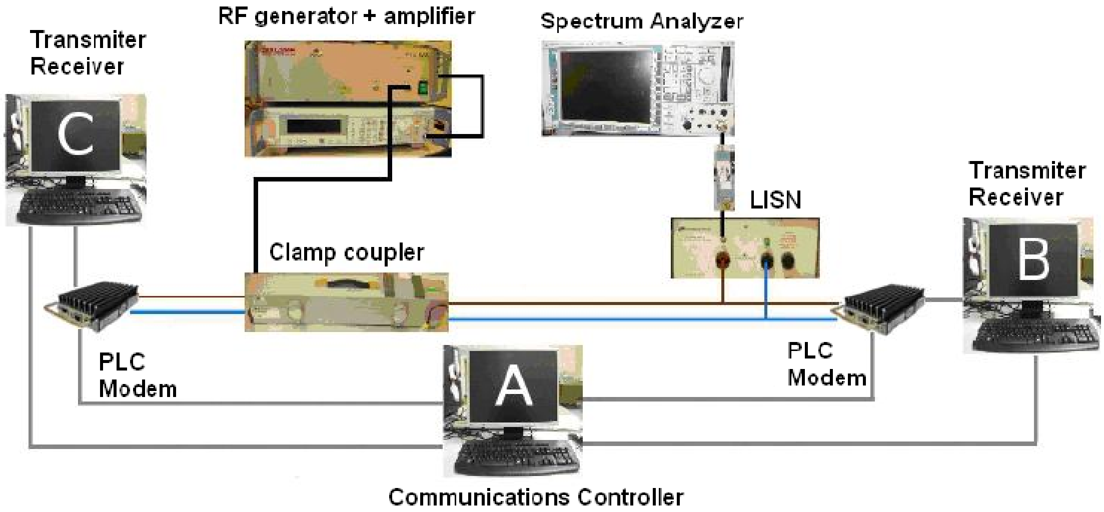

Fig. 1.- Test setup

The modems used for the test are model DR200 from DESE, with DS2 chipset [17]. This chipset use the OPERA specifications using a bandwidth of 30 MHz (from 4 MHz to 34 MHz) as can be seen in Fig. 2.

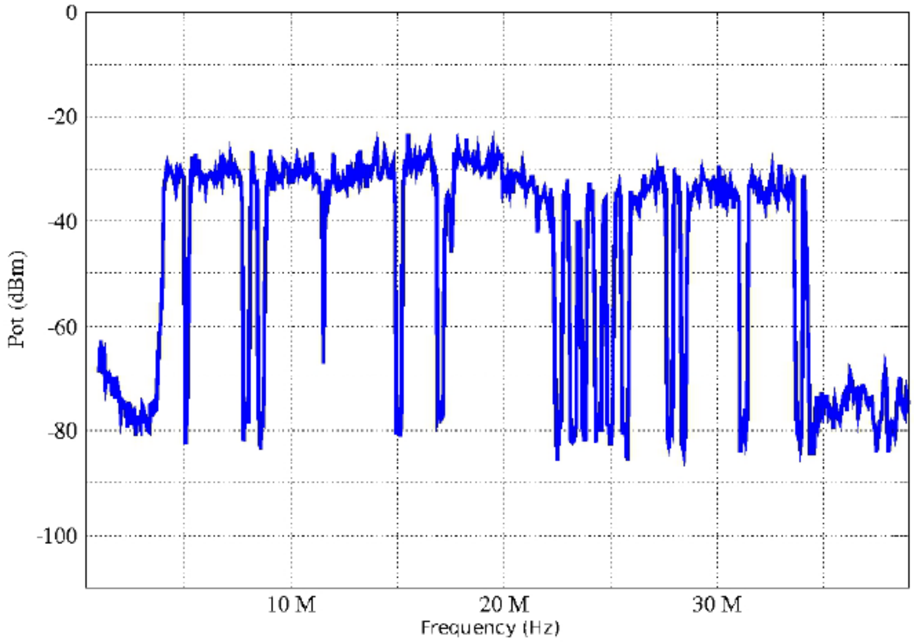

Fig. 2.- Spectral signal of the PLC modems used during a data transmission

Errors on the data communications are used to monitor the EMI susceptibility when the interferences are injected on the power line. The errors are analyzed using the Distributed Internet Generator (D-ITG) [19]. This software has been enhanced by adding some self-made scripts using SNMP protocol [20], to obtain a deeper knowledge of communications parameters, like Signal to Noise Ratio (SNR), bits allocated in each sub-carrier, etc.

To generate the RF test signals, types a) and b), explained in section I, a signal generator, type SMBV100A from Rohde&Schwarz, connected to a RF amplifier, was used. The amplifier output was connected to an injection clamp, type EM101 from Lüthi Elektronik-Feinmechanik.

The impulsive noise, types c) to e) as described in section I, were generated by a burst generator type CEMaster from KeyTek. EMI were coupled to cables by using a capacitive clamp type CM-CCL from KeyTek.

The power line was monitored by using an EMI receiver, ESPI from Rohde&Schwarz, connected to a Line Stabilization Network (LISN), type EM-7820 from Electro-Metrics. The measurements were done with a resolution bandwidth (RBW) of 9 kHz, with an average detector and a -6 dB filter.

The test method allows an easy change of modems and coupling clamps in order to compare the behavior with different test setups.

III. EXPERIMENTAL RESULTS

To check the robustness of PLC communications we performed the following tests

1) RF tests, with different test parameters.
2) EFT/Burst test, according to IEC 61000-4-4
3) Tests for capacitive and inductive coupler comparison.

Before the tests were performed, the maximum transmission data rate was found to be 87.9 Mbps. We set this as the reference in order to compare the incidence of each type of noise on the communications. We measured the total error rate (TER), defined as the ratio between non received packets and the number of packets to be sent. In some tests this ratio was split up in two parts:

a) The ratio between the discarded packets (caused by overflow) and the total packets to be sent.
b) The ratio between the non received packets and sent packets.

A. Interference level for RF Tests.

For RF tests, the interference signal was placed at 17 MHz, with a bandwidth of 26 MHz in order to overlap the maximum number of communication bands. The interference signal was a sinus wave FM modulated. The power level of the interference signal was selected to be higher than the power level of a normal transmission, which is around -30 dBm, see Fig. 2. Actually we choose three levels of interference signal: -30, -25 and -20 dBm.
With an interference power level of -20 dBm the total error rate in the communications reached the 37.2%, see Table I, which is too high to obtain any conclusion from the tests. For interference power level below -25 dBm the TER was similar to that of a normal transmission, therefore we decided to continue the tests with an interference value of -25 dBm which is slightly above the normal transmission level.

B. RF Tests interfering the whole bandwidth.

RF tests with interfering signal covering the whole bandwidth have been carried out. Table I shows a summary of transmission error rates at different power levels of interfering signal. The meaning of different parameters in Table I are as follows: SNMP TER is the modem to modem error rate, while the D-ITG TER is the terminal to terminal error rate. The table also shows the average bit rate and the response time of the modems when noise is started and stopped.

TABLE I
COMMUNICATIONS PARAMETERS OBTAINED WITH DIFFERENT INTERFERENCE POWER LEVELS.

Inteference power level	Without noise	-20 dBm	-25 dBm	-30 dBm
SNMP TER	0.69%	35.69%	27.99%	27.01%
D-ITG TER	0.81%	37.20%	29.79%	31.99%
SNMP Average bit rate	87.9 Mbps	56.6 Mbps	63.4 Mbps	61.0 Mbps
D-ITG Average bit rate	87.3 Mbps	55.2 Mbps	61.7 Mbps	59.7 Mbps
Set up time after noise addition	-	1 seconds	1 seconds	1 seconds
Recovery time after noise removed	-	15 seconds	12 seconds	9 seconds

C. RF Tests partially interfering the bandwidth

These tests were designed so that the interfering frequencies covered only a part of the communication bandwidth. The transmission bandwidth (4 to 34MHz) was divided into three sub-bands, each one of 10 MHz, i.e. three tests were performed covering from 4 to 14 MHz, 14 to 24 MHz and 24 to 34 MHz. Therefore the interference signal was again a sinus wave FM modulated, of 10 MHz bandwidth centered at 9, 19 and 29 MHz.

From Table II, it can be seen that interfering in the 4 to 14 MHz produced a TER value of 12.78%. Interfering the 14 to 24 MHz and the 24 to 34 MHz causes TER values of 24.62% and 27.69% respectively. From those measures we can conclude that the data was mainly sent on high frequencies.

TABLE II
COMMUNICATIONS PARAMETERS OBTAINED WITH PARTIALLY BANDWIDTH INTERFERED.

Bandwidth	4-14 MHz	14-24 MHz	24-34 MHz
SNMP TER	10.23%	21.50%	26.59%
D-ITG TER	12.78%	24.62%	27.69%
SNMP Average bit rate	79.0 Mbps	69.1 Mbps	64.6 Mbps
D-ITG Average bit rate	76.6 Mbps	66.2 Mbps	63.5 Mbps

D. RF Tests partially interfering the bandwidth with carrier sweep across the bandwidth

To know the effect the modem reaction when a random part of the communication band is interfered, we applied a sinus wave sweeping from 5 MHz to 33 MHz in 1 MHz steps, FM modulated covering a 2 MHz bandwidth. Several tests were performed where the carrier frequency was held for one, five and ten seconds at each frequency, see Fig. 3.

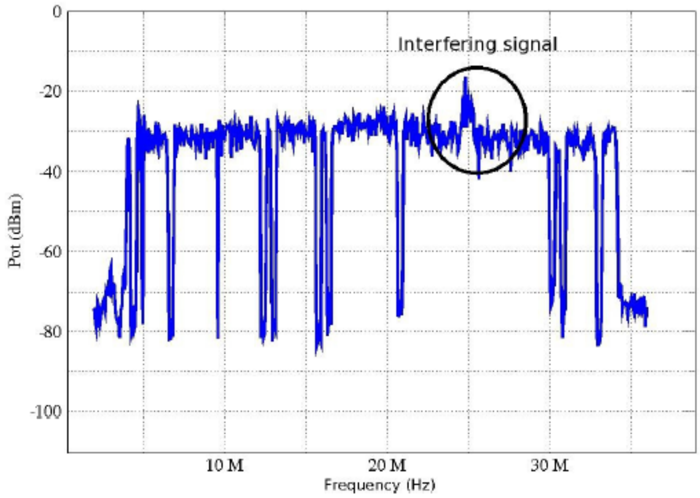

Fig. 3.- Communications signal with the frequency sweep.

From Table III it can be seen that if the interference remains one second at each frequency, the 39.3% of the packets were not received and the 13.8% of packets were discarded from the transmission buffer of the modem. When the interference remained for longer time, the 3.0% of the packets were not received and the 52.8% of the packets were discarded.

One explanation for that is that when the interference remains during a short time in a frequency slot, the modem can't reduce the speed, neither use the bands not affected by the interference, Fig. 4 and Fig. 5. As the interference remains for longer time in a specific frequency slot, the modem reduces the transmission speed to a minimum and therefore increases the number of packets discarded, Fig. .

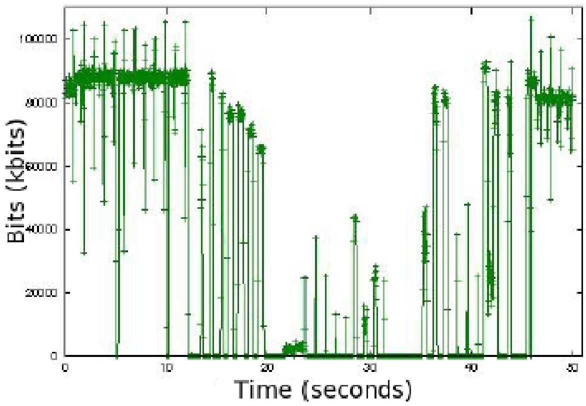

Fig. 4.- Average bit rate in a 1s frequency sweep speed.

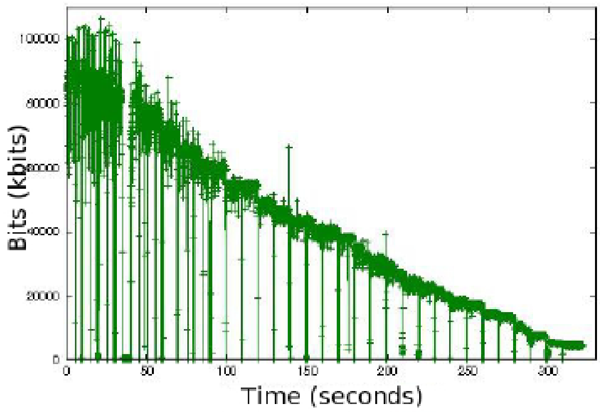

Fig. 5.- Average bit rate in a 10s frequency sweep speed.

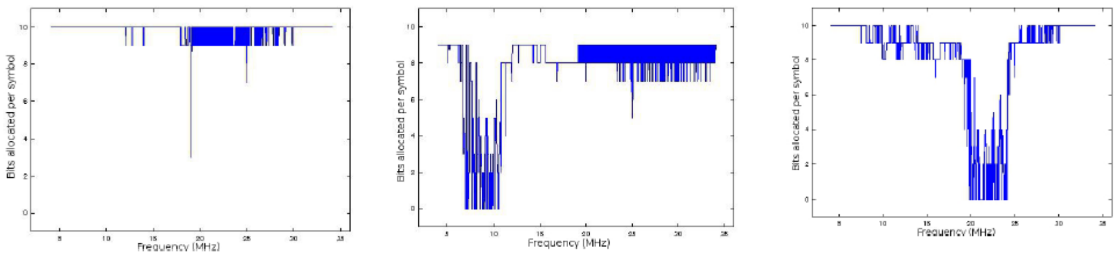

Fig. 6.- Bits per symbol allocated at different instants of a all band frequency sweep, lasting 10s.

Notice from Fig. 6 , that the modem tries to send more bits in the band with best SNR, increasing the bits per symbol rate (BPS) in the interference free gaps. Table III shows also the average delay of received packets, the discarded packets and not received packets. As the interference remains longer time in a certain frequency slot, the delay and the discarded packets increased and the not received packets decreased. The TER remains approximately constant with the permanence time of interference in each frequency slot.

TABLE III
COMMUNICATIONS PARAMETERS OBTAINED WITH FREQUENCY SWEEP ACROSS THE BANDWIDTH.

Variable Time	One second	Five seconds	Ten seconds
SNMP TER	53.40%	54.58%	55.92%
D-ITG TER	58.45%	55.78%	56.81%
Average delay	0.040983 s	0.158558 s	0.184716 s
Discarded packets	13.79%	47.65%	52.84%
Channel lost	39.3%	6.89%	3.06%

E. EFT/Burst tests

The impulsive noise coupled to the power line was simulated using the EFT/Burst tests defined in the IEC 61000-4-4. The EFT signal was coupled in common mode (CM) to the power line. The voltage levels used in the test were: 200 V, 1 kV and 2 kV. Results are presented in Table IV, where all given parameters are the average of five consecutive measurements. From Table IV it's clear that increasing the voltage of the EFT, the TER increases.

TABLE IV
COMMUNICATION PARAMETERS FOR CM EFT TESTS

Voltage level	No EFT	200 V	1000 V	2000 V
SNMP TER	6.13%	24.25%	29.85%	38.41%
D-ITG TER	9.52%	26.34%	31.14%	36.23%
SNMP Average bit rate	82.6 Mbps	66.5 Mbps	61.7 Mbps	54.2Mbps
D-ITG Average bit rate	79.5 Mbps	64.7 Mbps	60.5 Mbps	55.4 Mbps

Table V shows the results of an EFT test comparing the response in common mode (CM) and differential mode (DM). For this test, the signal level was set at 1 kV. Notice that, as expected, the resulting communication parameters are very similar, since PLC signal is applied in CM to both live conductors against ground.

TABLE V
CM AND DM PARAMETERS COMPARISON FOR EFT TESTS AT 1 KV

Cable	2 cables	Blue cable	Black cable
SNMP TER	29,85%	26,65%	33,42%
D-ITG TER	31,14%	28,78%	34,08%
SNMP Average bit rate	61,7 Mbps	64,3 Mbps	58,4 Mbps
D-ITG Average bit rate	60,5 Mbps	62,6 Mbps	58 Mbps

F. Couplers comparison tests

To test the influence of the couplers in the communication parameters, two EFT/Burst tests were performed using a medium voltage (MV) capacitive coupler, see Fig. 4, and a MV inductive coupler, see Fig. 5. The power line used for the tests was a 30 kV cable.
As it can be seen in Table VI, the inductive coupler causes bigger delays and higher TER than the capacitive coupler. More precisely, the TER for inductive coupler reached 24.5% while the TER for the capacitive coupling was 18.1%.

Fig. 4.- Capacitive coupler

Fig. 5.- Inductive coupler

TABLE VI
COMMUNICATION PARAMETERS OBTAINED WITH COUPLERS

Test	Inductive		Capacitive	
	No EFT	EFT	No EFT	EFT
SNMP TER	6.56%	24.21%	0.34%	18.09%
D-ITG TER	7.38%	24.53%	0.92%	18.13%
SNMP Average bit rate	67.3 Mbps	54.6 Mbps	71.7 Mbps	58.9 Mbps
D-ITG Average bit rate	66.6 Mbps	54.2 Mbps	71.3 Mbps	58.8 Mbps
delay	130.95 ms	153.40 ms	2.72 ms	98.83 ms

IV. CONCLUSIONS

The PLC technology has demonstrated its validity to build communications systems addressed to monitor the electrical distribution system. More precisely PLC is used for remote energy metering, energy management, demand control and safety monitoring. Furthermore, the broadband PLC technology is capable to establish communications over the power grid at data rates of more than 200 Mbps. Up to 88 Mbps were measured in our setup tests.
Tests made in this work have shown that EMI susceptibility of the PLC modems, using OFDM, in front of typical electromagnetic interferences, is low. Only in the case that the interferences covered the whole transmission bandwidth, the communications were completely lost. When the communications bandwidth was only partially interfered, the wide band OFDM modems, manage to maintain the communication, either by reducing the transmission speed and/or by re-allocating the transmission channel, thus giving a high electromagnetic immunity.

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