Evaluation of the Impact of LED and Compact Fluorescent Lamps on the PLC Transmission with X-10 Technology

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***Abstract*—Power Line Communication (PLC) is a communication method that uses electrical wiring to carry both data and electric power simultaneously. A wide range of PLC technologies is used for different applications, ranging from home automation to internet access. Various data rates and frequencies are used in different situations. Records of transmitting commands using PLCs have been verified since 1838, and from 1913, technology has become commercial. Currently, communication in low voltage networks is a key technology for the automation of electrical distribution, also known as smart grids. PLC systems can be divided into groups according to the frequency bands and their architecture can be divided into three blocks: PLC, Outdoor and Indoor, which is the focus of this article. This article has the main objective of evaluating the impact of using the X-10 PLC communication protocol (developed by Pico Electronics) on the control of an incandescent lamp in the indoor environment, considering several scenarios of load and interference using several types of commercial light bulbs.**

***Index Terms*—Communications Technology; Protocols; Power Quality; Lighting Control.**

I. Introduction

Home automation, or domotics, a combination of the Latin word "Domus" (home) with "telematics" (electronics + computing) is considerably simplifying the lives of residents every day. A range of practical and economic possibilities are available that utilize automation, from the basic to the most comprehensive, in integration systems for various environments. The result is a more practical, comfortable, pleasant, charming, valued and safe environment, according to the user's interest.

The incorporation of domotics to the residential environment is carried out by a communication network that allows the interconnection of a series of devices, equipment and other systems, with the purpose of obtaining information about the residential and the inserted environment, making certain actions in order to supervise or manage it, thus allowing the use of devices to automate the routines and tasks of a home [1].

Figure 1. Example of a domotics network.

Many technologies are employed to communicate between devices and sensors in residential automation, among which we can highlight the X-10, Z-Wave, ZigBee, INSTEON, and EnOcean [2].

There are some works that analysis PLC technologies for indoor and outdoor environments. G3-PLC and PRIME are PLC widely used and tested in smart grids [3][4], including your use with a large number of nodes [5] for energy meter reading. Evaluations for indoor uses, with ethernet-to-powerline adapters [6], and the impact the impulses noise in several PLC communications modules for narrowband communications [7] was object of study in researches.

This work will analyze the operation of a set of modules of residential automation X-10, using the PLC technology, in the same electric circuit as of the feeding of lamps CFL and LED. Based on the manufacturer's manual, a standard load will be controlled through the X-10 device [8]. The intention is to verify the impact of the disturbances, usually triggered by the

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filters and sources of these lamps, in the transmission of PLC data and will analyze the waveforms, harmonic distortions, and system error rate.

This article is structured, in addition to this first introductory chapter, with a second chapter where a theoretical basis will be made on the technology studied. In the third chapter, the methodology will be described. In the fourth chapter, the results will be presented and in the last one the conclusion will be presented, is the closure of this work made with the references used.

II. Power Line Communication - PLC

PLC is a telecommunications system that uses the electrical network as a means of transport for digital or analog signal communication, such as internet, video, voice, among others, including Broadband over Power Line – BPL [4].

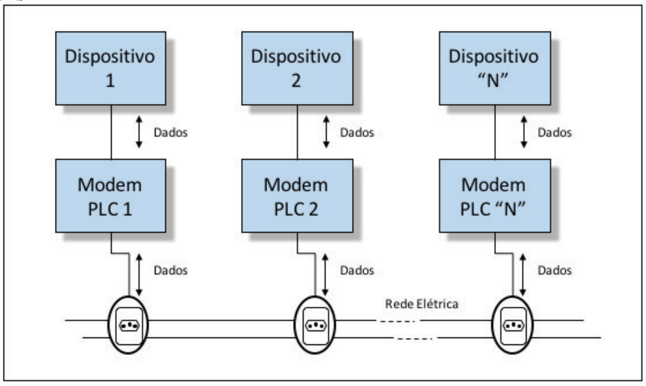


Figure 2. Diagram of communication through the electric network.

There are records of command transmission using Power Line Communication (PLC) technology since 1838, with the first patent being registered in 1897. Initially, it was called the Power Line Carrier and was widely used in high voltage networks from 69 kV to 500 kV by electric utilities for voice and data communication between substations [1].

Communications in the low voltage power line (LV) (PLC) is a key technology for the automation of electrical distribution, also known as smart grids. The advantage of this technology is not requiring a specific media deployment, providing their own network infrastructure with simple installation.

The electrical line, as a communication channel, has a very variable impedance and transfer function. The noise of the channel is also very peculiar due to its nature. The channel is varied in time, due to consumption habits, generation cycles, and technology changes, among other factors. It is also variable in space, between rural and urban areas, and between different countries/regions, due to differences in energy consumption habits, line distribution, and consumer/generator technologies [10].

Despite being very promising, the system has faced numerous problems concerning interference and noise. The first implementations were difficult because the electrical network suffers from interference such as the multiplication of harmonics (signals) of various equipment. In residences, this happens when a dryer or a blender are connected and end up interfering with the TV or the radio, for example. The Internet via the electrical network only evolved from the development of techniques of modulation of the signal, directed to protect it from these interferences [11].

PLC systems can be divided into groups according to the frequency bands allocated for operation. PLC systems can be generally classified into two groups: NBPLC, also known as narrowband PLC, and BPLC, known as broadband PLC [12].

Broadband PLC is recommended for Smart Home applications and solutions [13], while the use of narrowband PLC systems seems to be more appropriate for remote data acquisition and automatic measuring systems [14].

The architecture of PLC technology is basically divided into three blocks. The first is the PLC modem, the second is Outdoor, also known as Power Line Outdoor Communications (PLOC) and the third is Indoor, also known as Power Line Indoor Communications (PLIC) [14].

This article discusses only the PLIC (Power Line Indoor Communication) standard, using the X-10 protocol, which covers the stretch from the user's energy meter to the outlets located inside the residence. All outlets are capable of transmitting data beyond electricity, that is, they are also points of connection for the data network [15].

A. X-10 Protocol

Between 1976 and 1978, Glenrothes-based Pico Electronics (Scotland), known for the creation of the world's first calculator chip, whose projects had codes from X-1 through X-9, tried to develop a domestic automation system that uses the electrical network as a means of communication and allowed remote control of the electronic devices and lights of a residence. In 1978 the Pico Electronics joined an audio company known as BSR, which resulted in the creation of X-10 Ltda that developed the X-10 system known today [1].

Power Line Communication devices do not have a specific wiring interconnecting them directly, but for the solution's viability, the equipment needs to transmit and receive data on the existing link. The X-10 protocol is a layer 1 and 2 model of the OSI (Open Systems Interconnection) [1]. The X-10 communication protocol is based on a simple data structure, with eight bits preceded by a predetermined start code. The protocol uses a zero-crossing detector that will allow synchronization between the transmitters and receivers [16].

The receiver activates its data reception window twice for each cycle, performing 120 samples per second. Data is transmitted through 120 kHz pulses for a short time [17] shortly after the zero crossing of the sine wave since the zero crossing point has less noise and is less exposed to the interference of other devices connected to the electric grid [1].

In the transmission of an X-10 command block, 11 sinusoidal cycles are required. A PLC signal is transmitted through a header. The first two cycles for transmitting the start code (4 bits). The next 4 cycles represent letter code and the last 5 cycles represent the number code or command code (1 to 16). The function codes (command codes) are commands for executing a specific activity such as: turning on and off etc. For redundancy and reliability purposes, all X-10 protocol calls are transmitted in four frames of data for each triggered command [1]. The Figure 3 shows this sequence.

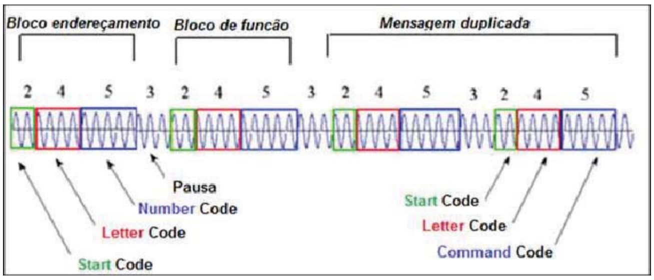


Figure 3. Standard transmission routine X-10. [1]

III. METHODOLOGY

The methodology used for the analysis of the system presented in this article is based on the evaluation of the impact of current lamp disturbances (CFL and LED) on the characteristics of the X-10 communication protocol.

In order to analyze these characteristics, basically nine tests were elaborated, all performed in the Laboratory of Luminotechnical of UFF (LABLUX) with different scenarios and configurations. The PLC kit used consisted of a lamp activation module, a gateway and a remote control for the drive (Figure 4). A Yokogawa meter, model WT210, was also used.

Figure 4. PLC Kit used in tests.

The tests performed were:

Test 0 – Only the electrical grid measurement of the laboratory was performed, before the test devices were connected;

Test 1 – Measurements were made of the PLC command and control unit turned on and connected to the grid, in order to evaluate its isolated effect.

Test 2 – Measurements were took with the PLC module turned off, but including the incandescent lamp to be controlled by module in tests 4 to 8;

Test 3 – Measurements were made considering only the turned on PLC module, and sending successive commands for the activation of the incandescent lamp;

Test 4 – Measurements were made with the PLC module acting on the incandescent lamp, however, inserting in the circuit a bench with twenty compact fluorescent lamps (CFL) of 25W each. Figure 5 shows a photo of one of the CFL used in this test;

Figure 5. 25W CFL used in tests.

Test 5 – Measurements were made with the PLC module acting on the incandescent lamp, but inserting in the circuit a pack of twenty compact fluorescent lamps (CFL) of 46W each. Figure 6 shows a photo of one of the CFL used in this test;

Figure 6. 46W CFL used in tests.

Test 6 – Measurements were made with the PLC module acting on the incandescent lamp, but inserting in the circuit a pack of ten compact fluorescent lamps (CFL) of 25W each, and ten compact fluorescent lamps (CFL) of 46W each;

Test 7 – Measurements were made with the PLC module acting on the incandescent lamp, but inserting in the circuit a pack of twenty LED bulbs of 9W each. Figure 7 shows a picture of the configuration used with the LED bulbs;

Test 8 – Measurements were made with the PLC module acting on the incandescent lamp, but inserting in the circuit a pack of five 25W compact fluorescent lamps (CFL), five 46W compact fluorescent lamps (CFL) and ten 9W LED bulbs. Figure 8 shows a picture of the configuration used for this combined test;

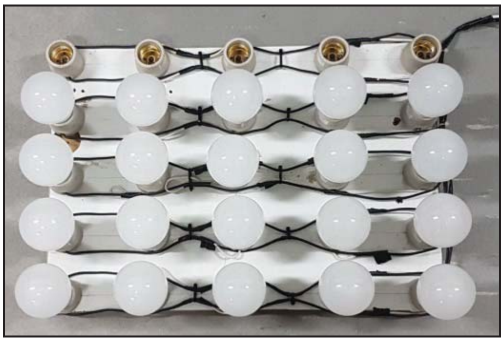


Figure 7. LED bulb bank used in testing.

Figure 8. Lamp bank used in a combined test.

For a better visualization, a summary of the tests can be visualized in Table I. On the following tests voltage, current and harmonic current were measured, and verified for possible failures on the lighting up of the incandescent lamp controlled by the PLC, in order to verify the effects caused by the different types of lamps in the circuit. Each test also included the sending of 40 commands on the X-10 PLC, 20 of these to turn on the lamp, and the 20 others to turn it off.

TABLE I. TEST ITEMS PERFORMANCE

Test	PLC	CFL 25W	CFL 46W	LED 9W
0	-	-	-	-
1	X	-	-	-
2	X	-	-	-
3	X	-	-	-
4	X	X	-	-
5	X	-	X	-
6	X	X	X	-
7	X	-	-	X
8	X	X	X	X

X = Presence of the item in the test.

IV. RESULTS

In the initial tests, only with the X-10 communication module acting, it was possible to visualize the communication signal (Figure 9) at 120 kHz in the software of the measuring equipment used.

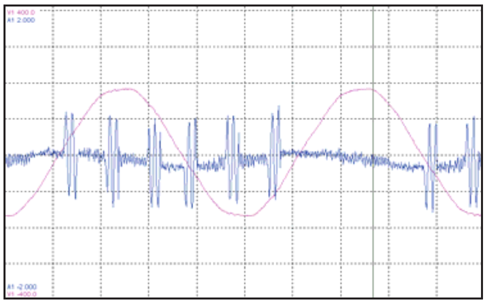


Figure 9. PLC signal in Test 3.

The current waveform for Test 4, analyzing only the influence of the 25W CFL lamps, can be seen in Figure 10. For this evaluation all 40 PLC commands were successful. In Figure 11 we have the detail containing the PLC waveform along with the consumption of the lamps.

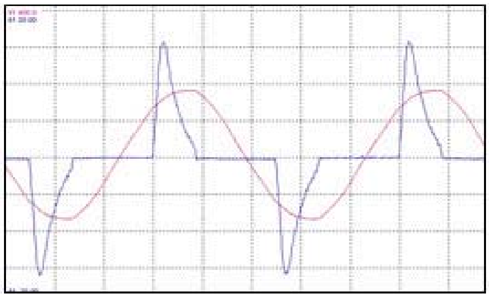


Figure 10. Test 4 lamp current.

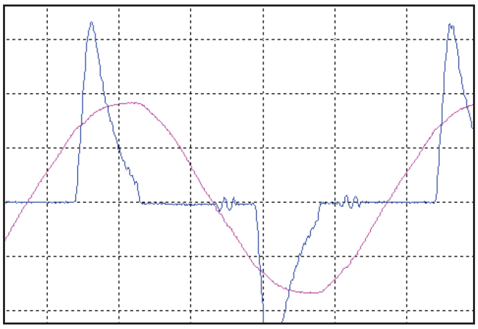


Figure 11. Detail containing the PLC signal for Test 6.

Test 5 containing the 46W CFL lamps was performed identically, and only the lamp's current signal was shown in Figure 12 and the detail with the PLC signal at the time of emission, in Figure 13. For this test, all the PLC commands were also successfully executed.

The same methodology was applied to Figures 5 and 6, and the respective results carrying the shape of the current wave with the PLC signal can be visualized in Figures 14 and 15. Again, the PLC X-10 had 100% effectiveness.

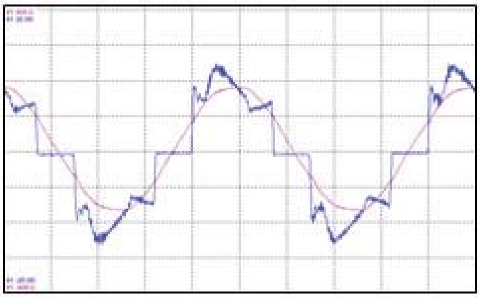


Figure 12. Detail containing the PLC signal for Test 7.

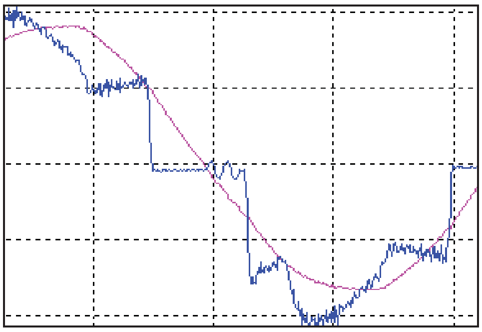


Figure 13. Detail containing the PLC signal for Test 5.

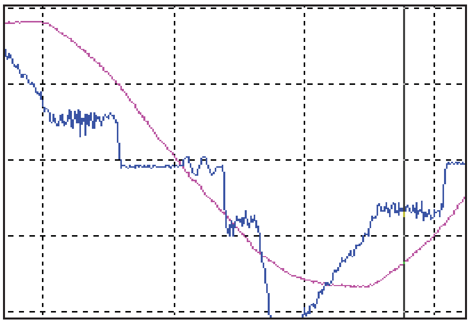


Figure 14. Detail containing the PLC signal for Test 6.

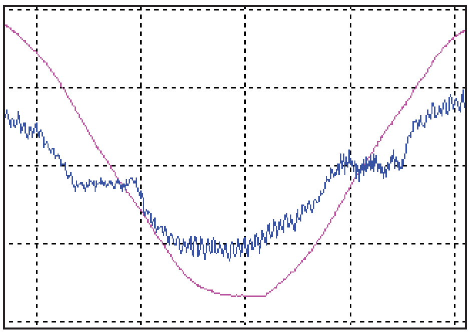
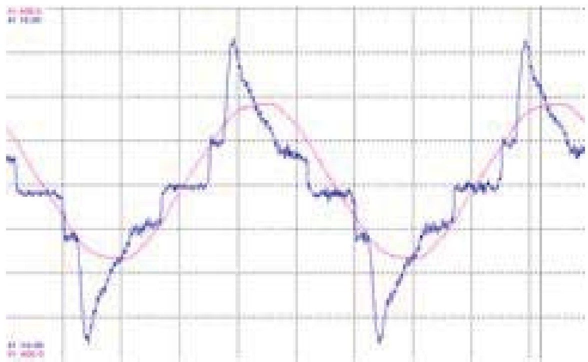
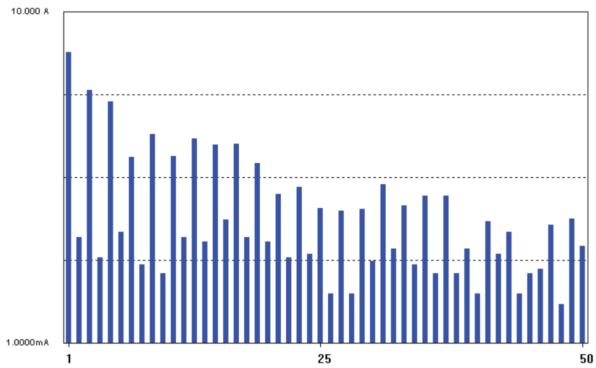


Figure 15. Detail containing the PLC signal for Test 7.

Test 8, this being a mixed check, containing all other types of lamps previously analyzed, also behaved very well, with all X-10 PLC commands running successfully. In Figure 16b we have the graph with the harmonics of this test, the vertical axis having a logarithmic scale with limits between 1mA and 10A.



(a)



(b)

Figure 16. (a) Test 8 lamp current with the X-10 signal (b) Current Harmonics for Test 8.

Test 7, containing only the 9W LED lamps, was the one that presented highest levels of current at the zero crossing point of the voltage curve. Thus, the level of electromagnetic emissions in the frequency domain for a lamp was verified. Figure 17 contains the result obtained.

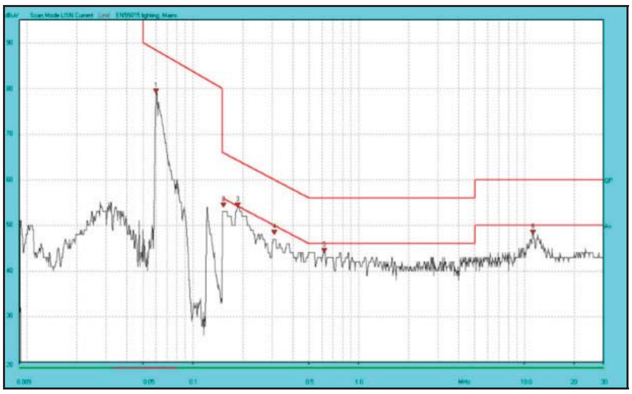


Figure 17. EMC test for LED lamp.

V. CONCLUSIONS

In all laboratory tests, the X-10 PLC had its commands executed successfully, not suffering any interference from the lamps used.

It is interesting to note that none of the lamps analyzed showed a current signal lag in relation to the voltage signal, consuming practically negligible current values at zero crossing. These current consumed values were well below the X-10 PLC signal, guaranteeing, 100 % of the communication.

For Test 7 containing the 9W LED lamps, an electromagnetic compatibility test was performed and it was found that the emission levels at 120 kHz were well below those required by IEC 62493. For comparison purposes, the threshold levels correspond to the upper curve in Figure 17. This also justifies the immunity of the X-10 PLC signal.

It should be noted that the high quality of the current CFL and LED lamps are due to the increasing requirements of INMETRO (Brazilian National Metrology Organization) in the last year´s approval tests. The analysis of the influence of equipment in the residential power grid and, therefore, in other equipment and technologies, is important to analyze its behavior and to establish mitigating and compensatory measures, if necessary. The impact on the PLC-X10 of the most common lamps to be found in homes was analyzed. However, there are other loads present in homes, with electrical characteristics diversified with each other. For these, in future works, it is also important to carry out an analysis of its influence on the residential electricity network and the impact on the same protocol of communication studied.

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