The Effects of LED Lamps Emissions on PLC: a Preliminary Study in a Realistic Scenario

Giovanni Bucci
Dept. of Industrial and Information Engineering and Economics
University of L'Aquila
L'Aquila, Italy
giovanni.bucci@univaq.it

Fabrizio Ciancetta
Dept. of Industrial and Information Engineering and Economics
University of L'Aquila
L'Aquila, Italy
fabrizio.ciancetta@univaq.it

Andrea Fioravanti
Dept. of Industrial and Information Engineering and Economics
University of L'Aquila
L'Aquila, Italy
andrea.fioravanti@graduate.univaq.it

Edoardo Fiorucci
Dept. of Industrial and Information Engineering and Economics
University of L'Aquila
L'Aquila, Italy
edoardo.fiorucci@univaq.it

Carmine Landi
Department of Engineering
University of Campania
"Luigi Vanvitelli"
Aversa (CE), Italy
carmine.landi@unicampania.it

Mario Luiso
Department of Engineering
University of Campania
"Luigi Vanvitelli"
Aversa (CE), Italy
mario.luiso@unicampania.it

Simone Mari
Dept. of Industrial and Information Engineering and Economics
University of L'Aquila
L'Aquila, Italy
simone.mari@graduate.univaq.it

Andrea Silvestri
Dept. of Industrial and Information Engineering and Economics
University of L'Aquila
L'Aquila, Italy
andrea.silvestri1@univaq.it

2022 IEEE International Workshop on Metrology for Industry 4.0 & IoT (MetroInd4.0&IoT) | 978-1-6654-1093-9/22/$31.00 ©2022 IEEE | DOI: 10.1109/METROIND4.0IOT54413.2022.9831488

***Abstract*—The measurement of conducted emissions in the 2 kHz to 150 kHz frequency range, also referred to as High Frequency (HF) Emissions (HFEs) or Supraharmonics, is gaining more and more importance. This is due to highly increasing switching frequency of power converters. In low voltage power systems, Light Emitting Diode (LED) lamps are a widespread diffused loads with switching frequency up to some tens of kilohertz. HFEs from LED lamps are in the same frequency range of Power Line Communications (PLCs), widely used for vital grid operations as protection or meter reading. This paper presents the results of a preliminary experimental study focused on the evaluation of the effects of HFEs from LED lamps on the reliability of PLCs.**

Keywords— High Frequency Emissions, LED lamp, Power Line Communication, Power System measurements, Voltage Measurement, Current Measurement

I. Introduction

The measurement of conducted emissions in the 2 kHz to 150 kHz frequency range [1], also referred to as High Frequency (HF) Emissions (HFEs) [2] or Supraharmonics [3], is gaining more and more importance. In fact, in the last years, thanks to the advance in power electronics, the switching frequency of power converters (used both for loads as well as for generators from renewable sources) is highly increasing. One of the most used loads in civil and industrial low voltage power systems are the lighting devices. Among them, nowadays, Light Emitting Diodes (LED) lamps are more and more used and they can have powers ranging from a few watt up to some tens of watt and switching frequencies, respectively, from some tens of kilohertz down to some kilohertz [4].

This fact causes the inject of spectral components having frequencies equal to the switching frequency of the devices and its harmonics, that can reach several hundreds of kilohertz [5].

HFEs in the frequency range from 2 kHz up to 150 kHz are particularly critical since it includes the frequency ranges (also known as CENELEC A, B and C bands, ranging from 3 kHz up to 148.5 kHz) used for Power Line Communication (PLC) [6], widely used for vital grid operations as protection, automation and meter reading.

Some papers in literature are focused on the evaluation of the influence of HEFs from LED lamps on PLC. Most of them report just partial results.

Birra et al. in [7] evaluate the interference level of various LED lamps classified according to the type of driver; they also show how the interference level of the individual LED lamps is significantly lower than the maximum allowed PLC signal levels. In [4] the impact of LED lamps on the power line transmission is evaluated only through the Frame Error Rate (FER). In [8] the interference of the LEDs on narrowband PLCs is measured and the EMI from LEDs current pulse widening is analyzed separately in the time and frequency domain and simultaneously using a spectrogram. The paper [9] shows that the presence of LED tubes in an electrical grid involves a decrease up to 50% of the PLC data rate. The authors of the paper [10] show, on the other hand, that the PLC transmission with X-10 technology, used in some home automation applications, is immune to the interference generated by LED and compact fluorescent lamps.

Users produce harmonic currents that flow through the common coupling point (PCC) to system operators leading to voltage harmonics that are reflected on other users. Recommended Practice 519-2014 [11] should be used as a guide in the design of power systems with non-linear loads to minimize interference between electrical equipment. The amount of harmonic voltage distortion is a function of the aggregate effects of the harmonic current and therefore there must be a shared responsibility for harmonic control between plant owners or operators and users.

This paper wants to analyze, from an experimental point of view and in a realistic scenario, the effects of HEFs from LED lamps on the reliability of the PLC.

The paper is organized as follows. Section II deals with the description of the testing system. Section III describes the PLC devices adopted, Section IV presents some results and, finally, Section V draws the conclusions.

II. The Testing System

The evaluation of HFEs from LED lamps has required the development of a dedicated measurement system (Fig. 1), whose main components are described in the following. A

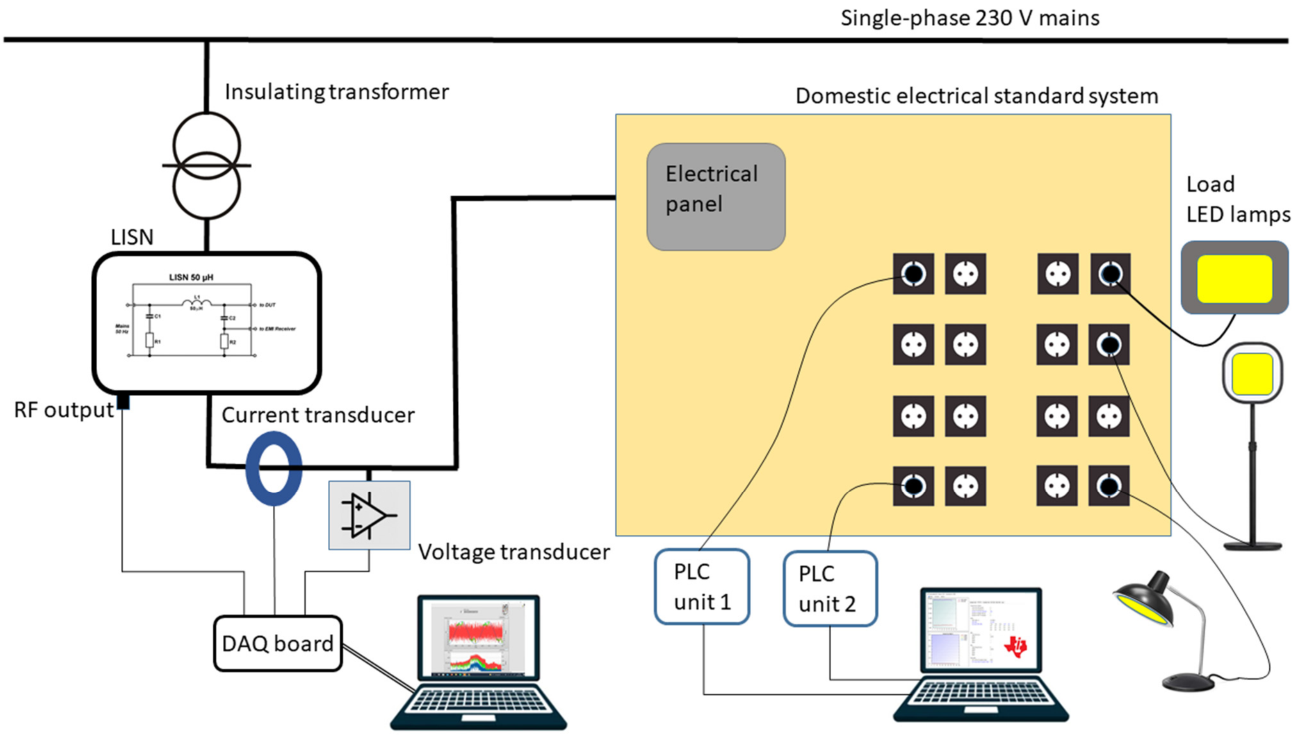

Fig. 1 Block diagram of the experimental setup.

Line Impedance Stabilization Network (LISN, model AFJ LS 16), compliant with the requirements of CISPR 16-1-2 [12] in the frequency range from 9 kHz to 30 MHz, has been adopted to prevent the high-frequency noise of the power source from coupling in the system, acting as a low-pass filter.

It is cascaded to a single-phase insulating transformer (apparent power of 4 kVA), compliant with EN IEC 61558-1 [13]. The Radio Frequency (RF) output of the LISN is used to monitor the HFEs from LED lamps and the PLC spectra during the different tests.

A LEM IT 150 S Ultrastab current sensor (DC to more than 100 kHz), with ten supplementary primary turns to adapt the input amplitude to the input range, has been adopted to measure the output current from the LISN to the load.

LISN output voltage has been measured through a Sony Tektronix High Voltage Insulator (DC to 50 MHz). These three signals have been acquired with the Data AcQuisition (DAQ) board National Instruments (NI) Universal Serial Bus (USB) 6255 (16 bit, 80 analog inputs, 1.25 MHz aggregated sampling frequency).

The DAQ board is managed by an application developed in the NI LabVIEW environment, also performing data processing and logging, running on a Windows 10 laptop PC; it performs the acquisition, the spectral analysis and the logging of the voltage and current waveforms (Fig.2).

A prototype of a Domestic Power System (DPS) [14], previously developed in the Laboratory of Electrical Engineering of the University of L'Aquila, has been adopted for the PLC testing.

It reproduces a medium-sized apartment with an area of 74 m^2 and complies with the IEC 60364-1 [15], which prescribes the realization of at least three circuits for apartments having an area between 50 m^2 and 75 m^2. The circuits are the following: i) Kitchen line, ii) Socket line and iii) Lights line.

In the present application, the system is fed by the LISN. The system is equipped with an electrical panel, with the main switch for the protection against overloads and short circuits, operable under loads, and a differential switch with a rated residual current of 30 mA.

The socket line and kitchen line are protected by a circuit breaker with a rated current of 16 A, while the light line is protected by a circuit breaker with a rated current of 10 A. Lumped elements have been used to implement the equivalent electrical length of the different lines of the real model.

Each section of the line and derivation socket has been modelized with a circuital element that follows the structure of the two-port at π configuration but thought for three conductors, phase (P), neutral (N), and earth (E). The values of the transverse capacitor are to be considered mutually between all three conductors.

Three types of LED lamps have been used, to reproduce various emissions conditions. They are: 1) LEDVANCE flood

Fig.2 Acquisition, processing and logging software.

led (20 W, 3000 K, 220-240 V, 50-60 Hz), 2) DISANO 842 LED PANEL (CRI80, 33 W, 220-240 V, 50-60 Hz), 3) CENTURY E27 (4W lamp, 2700 K, 220-240 V, 50-60 Hz). Fig.3 shows a picture of the system during the experimental tests.

III. The Power Line Communication System

The Texas Instruments (TI) PLC Development Kit has been used. It contains the following main components and supported features: i) DSP control card with Texas Instruments F28069 microcontroller; ii) Analog Front End (AFE) daughter card with Texas Instruments integrated powerline communications analog front-end AFE031; iii) Data rates from 5.592 kbps to 34.16 kbps (@36 tones per symbol) for Cenelec A band and up to 289 kbps for Federal Communciations Commission (FCC) band; iv) Transmission with Orthogonal Frequency Division Multiplexing (OFDM) and Forward Error Correction (FEC); v) Number of used data carriers up to 36 for Cenelec and 72 for FCC; v) Differential Phase modulation (ROBO/DBPSK/DQPSK/D8PSK); vi) Reed Solomon encode/decode and Repetition code; vii) Convolutional encoder/Viterbi decoder; viii) Bit interleaving for noise effect reduction.

Two PLC modules installed on the sockets of the DPS are used to perform data transfer using Zero Configuration Graphical User Interface (ZCGUI): a Windows application that allows to transfer text and files, examine the powerline modules information and display powerline parameters.

The parameters used to measure powerline performance are: i) RSSI (Received Signal Strength Indicator) in dBμV; ii)

Fig. 3 Photo of the experimental setup.

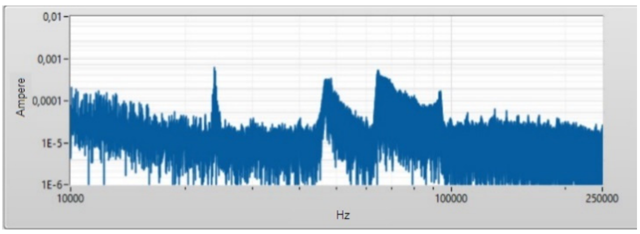

Fig. 4 Current specta of the LED lamps under test.

TABLE I. Statistics of PLC testing without loads connected to the DPS

Channel Sync Status:						
Number of packets detected:	141					
Number of Header failures:	129					
Number of PHY TX packets:	0					
RSSI						
RSSI (dBuV):	91					
SNR (dB)	11.0					
Sub-band SNR (dB)	13.0	7.0	12.0	-10.0	11.0	11.0
BER						
Total Bit Error	0					
ROBO	0%					
BPSK	-					
QPSK	-					
8PBS	-					
PER						
Total Packet Errors	0					
ROBO	0%					
BPSK	-					
QPSK	-					
8PBS	-					
Data Rate						
PHY ontime throughput (bps)	6475					
PHY actual data throughput (bps)	3417					

SNR (Signal-to-noise rate) in dB; iii) BER (Bit Error Rate) of received packets; iv) PER (Packet Error Rate) of received packets [16].

IV. Experimental Results

Some preliminary measurements of the currents of the LED devices have been performed, focusing the attention to the range 10-250 kHz.

In Fig.4, the superimposed effect of the two higher power units under test is evident. The current components are in the range 45÷60 kHz for the DISANO Panel and in the range 65÷95 kHz for the CENTURY lamp, which is potentially a cause of interference for PLC in the considered CENELEC A band (3÷95 kHz).

This band is used for monitoring and control applications for low voltage distribution networks, including the use of energy equipments and premises connected.

Other tests has been performed to investigate the PLC performance when the lamps are powered thorugh the DPS. ZCGUI and Intermediate GUI (IGUI) are adopted to test the powerline link.

The ZC GUI allows to define the CELENEC band, the modulation configuration, the adopted communication port, to ping and send data to other modules, and to set other parameters for the powerline communication.

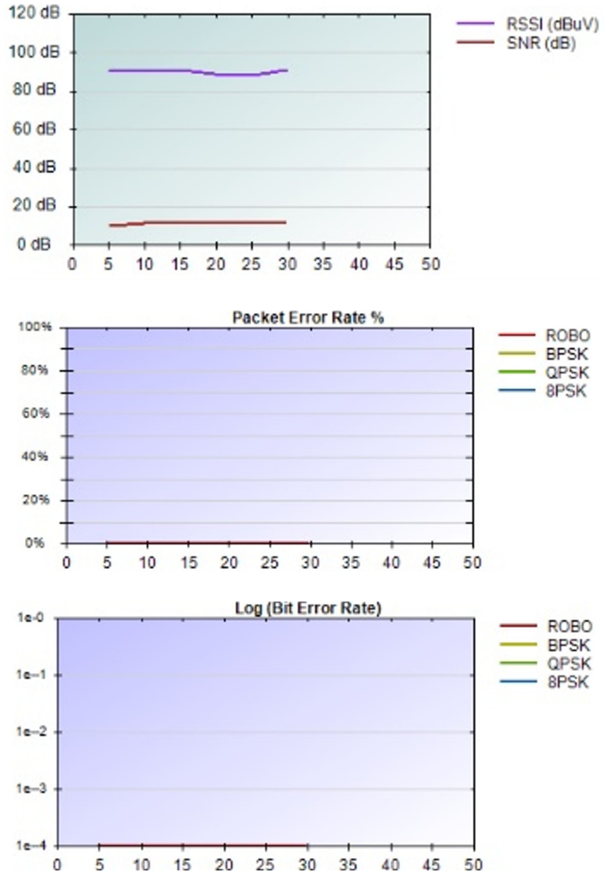

Fig.5 PLC testing results without loads connected to electrical system

TABLE II. STATISTICS OF PLC TESTING WITH POWERLINE MODULES PLACED IN DIFFERENT SOCKETS FROM THE LED LAMPS

Channel Sync Status:						
Number of packets detected:	2570					
Number of Header failures:	196					
Number of PHY TX packets:	0					
RSSI						
RSSI (dBuV):	88					
SNR (dB)	10.0					
Sub-band SNR (dB)	13.0	6.0	12.0	-10.0	10.0	10.0
BER						
Total Bit Error	128					
ROBO	0%					
BPSK	0%					
QPSK	0%					
8PBS	0.17%					
PER						
Total Packet Errors	5					
ROBO	0%					
BPSK	0%					
QPSK	0%					
8PBS	10.00%					
Data Rate						
PHY ontime throughput (bps)	77697					
PHY actual data throughput (bps)	12769					

The IGUI allows to test the powerline link, by setting the output power, analyzing statistical results, transferring data related to PHYsical Layer (PHY) and Medium Access Control Layer (MAC).

The tests are performed by configuring a module to transmit a continuous ramp, while the other module to receive the data. In Table I, the statistics of GUI, RSSI, SNR, BER and PER are reported.

In the first set of tests, the powerline modules are installed in different points of the DPS, without loads connected to it. The same results have been found and reported in Fig. 5: RSSI is 91 dBµV, SNR is 11 dB, BER and PER are 0%. The link does not present errors.

In the second set of tests, the powerline modules are installed in different points of the DPS, with loads connected to it. The same results have been found and reported in Fig. 6: RSSI is 88 dBµV, SNR is 19 dB, BER is 0.17 % and PER is 10 % for 8PSK. are 0%.

The link presents some error but using a high level communication protocol, with retransmission of data, the link can be used for data transmission.

In the third test, the powerline modules and the loads are both connected to the same socket of the DPS, in such a way that the disturbances are located nearthe transmitter and the receiver.

The results are reported in Fig. 7: RSSI is 78 dBµV, SNR is 3 dB, BER is 6.08 % for BPSK, 43.02% for QPSK and 49.22% for 8PSK, PER is 100% for BPSK, QPSK and 8PSK. The link is completely compromised.

V. CONCLUSION

This paper has presented the results of a measurement campaign, aimed at assessing the influence of the presence of LED lamps on the performance of PLCs. Experimental tests in a realistic scenario clearly indicate that, even in situations where PLCs have excellent performance, that is with PER of 0%, if a LED lamp is present the link can be completely compromised, with a PER of 100%.

The future objective may be that of a collaboration with the major Italian distribution companies to establish emission limits in these ranges in order to limit disturbances on the PLC between Smart meters and concentrators [17].

These limits could lead to the use of input filters for the users, after the Point Of Delivery (POD), in order to limit the emissions in the range 2÷150 kHz, especially when there is a high concentration of LED lamps.

REFERENCES

[1] IEC 61000-4-30:2015, Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods

[2] A. J. Collin, A. Delle Femine, C. Landi, R. Langella, M. Luiso and A. Testa, "The Role of Supply Conditions on the Measurement of High-

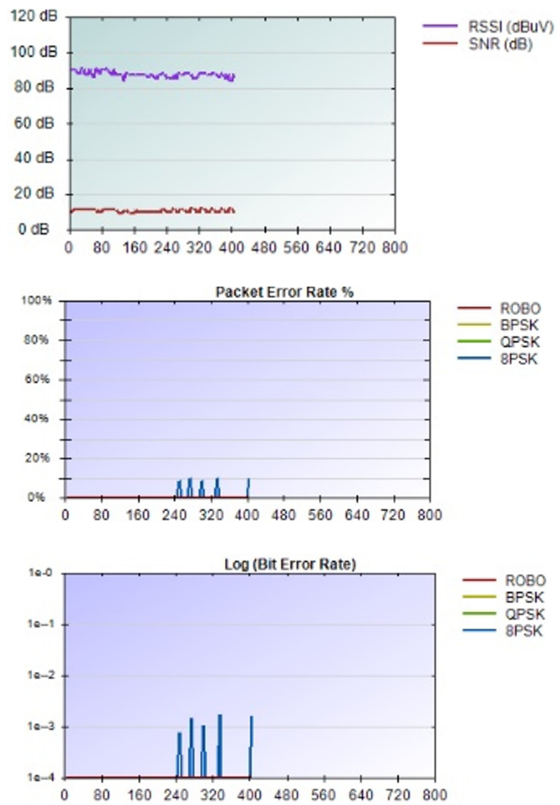

Fig.6 PLC testing results with powerline modules placed in different sockets from the LED lamps.

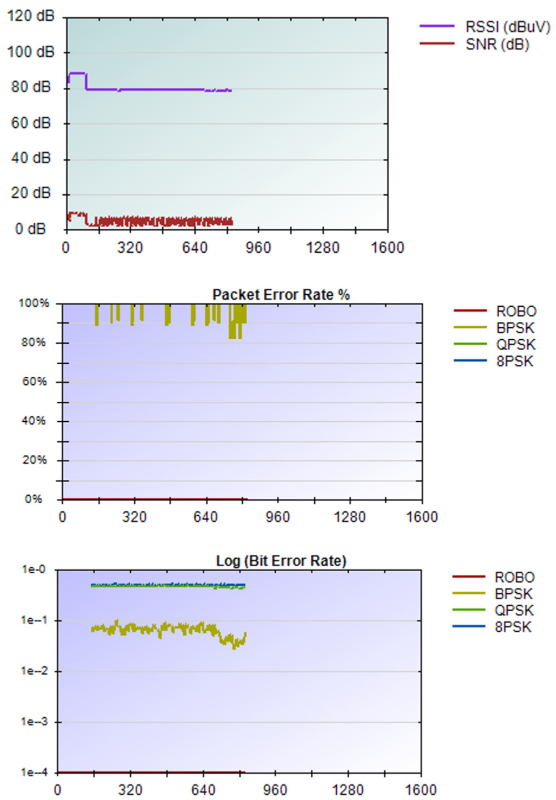

Fig.7 PLC testing results with powerline modules placed in the same sockets of the LED lamps.

TABLE III. STATISTICS OF PLC TESTING WITH POWERLINE MODULES PLACED IN THE SAME SOCKETS OF THE LED LAMPS

Channel Sync Status:	
Number of packets detected:	6047
Number of Header failures:	623
Number of PHY TX packets:	25
RSSI	
RSSI (dBuV):	78
SNR (dB)	3.0
Sub-band SNR (dB)	7.0 2.0 5.0 -10.0 2.0 1.0
BER	
Total Bit Error	2517523
ROBO	0%
BPSK	6.08%
QPSK	43.02%
8PBS	49.22%
PER	
Total Packet Errors	3992
ROBO	0%
BPSK	100.0%
QPSK	100.0%
8PBS	100.0%
Data Rate	
PHY ontime throughput (bps)	77697
PHY actual data throughput (bps)	1566

Frequency Emissions," in IEEE Transactions on Instrumentation and Measurement, vol. 69, no. 9, pp. 6667-6676, Sept. 2020.

[3] M. Klatt, J. Meyer and P. Schegner, "Comparison of measurement methods for the frequency range of 2 kHz to 150 kHz," 2014 16th International Conference on Harmonics and Quality of Power (ICHQP), Bucharest, Romania, 2014, pp. 818-822.

[4] M. A. Wibisono, N. Moonen and F. Leferink, "Interference of LED Lamps on Narrowband Power Line Communication," 2020 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI), 2020, pp. 219-221

[5] S. K. Ronnberg et al., "On waveform distortion in the frequency range of 2 kHz–150 kHz—Review and research challenges", Electr. Power Syst. Res., vol. 150, pp. 1-10, Sep. 2017.

[6] IEC 62488 Standard family, "Power line communication systems for power utility applications"

[7] De Beer, A.S., Emleh, A., Ferreira, H.C., Vinck, A.J.H., "Effects of LED lamps on the power-line communication channel", (2013) ISPLC 2013 - 2013 IEEE 17th International Symposium on Power Line Communications and Its Applications, Proceedings, art. no. 6525851, pp. 209-213.

[8] M. A. Wibisono, T. Hartman, N. Moonen, D. Hamdani and F. Leferink, "The Effect of the Current Pulse Width from LEDs on Narrowband Power Line Communication and its Analysis in Time and Frequency Domain," 2020 International Symposium on Electromagnetic Compatibility - EMC EUROPE, 2020, pp. 1-6

[9] A. S. de Beer, A. Emleh, H. C. Ferreira and A. J. H. Vinck, "Influence of LED tubes on the throughput of an indoor broadband PLC channel," 2017 40th International Conference on Telecommunications and Signal Processing (TSP), 2017, pp. 251-254

[10] A. S. Delfino, R. P. Brandão, T. S. Bumpus, M. Z. Fortes, H. O. Henriques and V. H. Ferreira, "Evaluation of the Impact of LED and Compact Fluorescent Lamps on the PLC Transmission with X-10 Technology," 2019 IEEE Milan PowerTech, 2019, pp. 1-6

[11] "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems", in IEEE Std 519-2014 (Revision of IEEE Std 519-1992) , vol., no., pp.1-29, 11 June 2014, doi: 10.1109 /IEEESTD.2014.6826459.

[12] CISPR 16-1-2:2014 Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-2: Radio disturbance and

immunity measuring apparatus - Coupling devices for conducted disturbance measurements

[13] EN IEC 61558-1 “Safety of transformers, reactors, power supply units and combinations thereof Part 1: General requirements and tests”

[14] D'Innocenzo, F., Bucci, G., Fiorucci, E., Ciancetta, F.Domestic electrical standard system for power line communication tests(2017) I2MTC 2017 - 2017 IEEE International Instrumentation and Measurement Technology Conference, Proceedings, art. no. 7969930.

[15] IEC 60364-1:2005 Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions

[16] Ciancetta, F., Bucci, G., Fiorucci, E., Mari, S., Fioravanti, A., Prudenzi, A.Measurement of powerline performance in residential context (2020) 24th IMEKO TC4 International Symposium and 22nd International Workshop on ADC and DAC Modelling and Testing, pp. 303-308

[17] F. Ciancetta, A. Fioravanti, E. Fiorucci, S. Mari, A. Prudenzi and A. Silvestri, "Some practical solutions to improving power quality at LV distribution customers’: a case study," 2021 AEIT International Annual Conference (AEIT), 2021, pp. 1-6, doi: 10.23919/AEIT53387.2021.9626891.