A POWER LINE COMMUNICATION MEASURING TOOLBOX FOR THE DISTRIBUTION GRID

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ABSTRACT

In the Smart Metering pilot projects in Belgium a deeper understanding of signal attenuation and interference of PLC Communication is needed. The DNOs are confronted with "solution" suppliers that have no core competence in offering the necessary support for appropriate performance evaluation in the field which makes the choice of an efficient technical solution difficult.
The lack of tools for the analysis of PLC performance has been early observed in Belgium and that is why Laborelec has been and is developing in close cooperation with the three largest Belgian grid operators (Eandis, Ores, Sibelga) the tools and measuring devices that can enable this.
This paper describes the toolbox as it exists today and gives some examples of measurements and analyses that can be made with it..

INTRODUCTION

Power Line Communication (PLC) is a communication technology which consists of modulating and de-modulating high-frequency signals on the power lines. These frequencies are controlled by CENELEC in Europe and divided into several bands. The CENELEC A-band, ranging from 3 to 95 kHz is reserved for the utilities. PLC is considered to be one of the most adapted ways of communicating with devices in the low voltage grid. The fact that no additional cabling is needed and that the grid operator is the owner of the grid (so no extra third party costs) are of course much in favour of choosing this technology. However, problems in performance and reliability are widely discussed.

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On the market no measuring devices are available to fully and correctly measure and interpret PLC communication problems on the physical layer in the electricity grid. The ambition of Laborelec consisted in translating theoretical assumptions about the grid channel in to practical evidence through the use of self-engineered measurement equipment and advanced calculation models..

FROM THEORY TO PRACTICE

A lot of attention was given to the measurement of the fundamental parameters, i.e. impedance, noise and transfer functions of PLC-signals, in the grid. A measuring setup has been elaborated to perform analysis in the field and in a laboratory environment. Since PLC communication for Smart Metering is situated in the frequency range between 3kHz and 95kHz, the adequate measuring circuits, procedures and device were developed. This system is able to monitor and log the parameters that influence the communication quality.

IMPLEMENTATION OF THE TOOLBOX

The toolbox consists of a measuring device and a software suite of acquisition, calculation and analysis tools. The basic features are described in the following sections.

Hardware Implementation

The complete system consists of several building blocks who all have their specific purpose and can be combined in various setups.

Figure 1: On-site configuring of the measurement system

The core of the measurement device is a computer running a commonly used operating system. This allows us to take advantage of the pre-defined features. A scheduler is used to plan recurrent or specific measurements. Through remote access via networking the device can be configured and controlled to record and do post-processing, results can even be downloaded for preview. The on-board storage space allows for long-term logging and depending on the configuration, additional storage space can be connected by using external hard disks.

A high-end acquisition card is used to measure the needed signals after signal conditioning. The card can also emit self-generated signals. Since the measurements are done on the distribution grid, conditioning is needed. This includes a.o. high-pass filters to separate the high-frequency voltage signals from the 50Hz 230V wave. The signal conditioning has been developed in user-friendly boxes each providing an electric protection and galvanic isolation.

To be able to support different measuring setups while leaving the measurement device in the field, a switchbox has been developed. The setups are a combination of different signals and the switchbox automatically connects the acquisition channel inputs to the signals corresponding to the selected setup.
Concretely, the system can provide 8 different modes of measurement which represent a combination of 4 channels which can be a high-frequency voltage or current, a 50Hz voltage or current or any other signal that is limited (or converted) to ±10V.

Figure 2: Installing the measurement on-site

Specifically for the fundamental parameters 'impedance' and 'transfer function' a high-frequency 30W power amplifier for the CENELEC A-band has been designed and built to be able to inject signals in the electricity grid (even on low impedances).

Software Implementation

The first part of the software suite, the acquisition toolbox, consists of an application that writes the raw signal data to the memory. Since the possibilities and options are vast, a script is used to configure the measurement setup and keep track of the used combinations.
Afterwards the calculation and analysis is done in a mathematical environment giving access to fundamental signal processing and statistical functions. Here, the transfer functions of the different conditioning blocks are taken into account.
On top of this environment specific mathematical treatment was developed. This will be described in the next section.

ADVANCED CALCULATION METHODS

Using specialized spectral analysis, it was a.o. possible to evaluate the consequences for PLC communication of 50Hz synchronized higher frequency phenomena

The presence and behavior of the following fundamental parameters were investigated:
• **Noise behavior**: numerous loads emit noise in the PLC frequency range. This can be measured and analyzed in different ways: stationary phenomena (Stationary Noise) as well as disturbances having a clear relation with the 50Hz cycle (in the frequency and time domain) (Periodic Noise). A clear relation was shown between the quality of PLC Communication and the presence of certain noise levels.
• **Impedance behavior**: according to the nature of each grid topology together with some connected loads, impedance variations can be measured. In this analysis the periodic impedance variations related to the 50Hz cycle are studied..
• **Transfer function**: through the injection of PLC signals it is possible to analyze signal propagation in different grid topologies.

Example: energy saving light bulb

In the following the example of an energy saving light bulb is used to explain some of the fundamental parameters that were presented previously. This is one example of the numerous electric loads that were measured in the laboratory.

A first figure that gives an interesting view on the behavior of an electric load is the time-domain view. In Figure 3 the high-frequency voltage (blue) and current (red) and the 50Hz voltage (green) and current (black) are plotted.

It can be seen that a high-frequency signal is present just before the maxima of the 50Hz cycle.

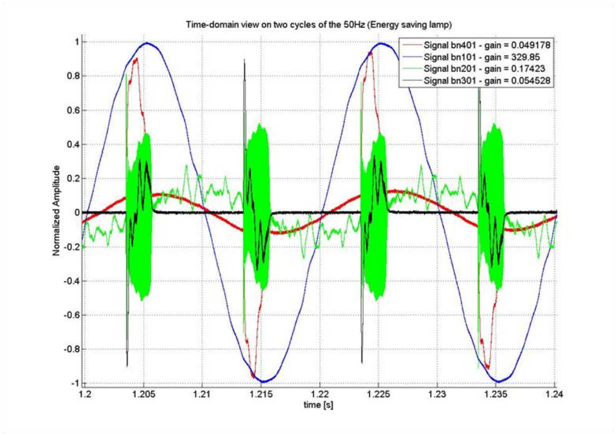

Figure 3: Time domain view on two 50Hz cycles for an energy saving light bulb

In Figure 4 the periodic impedance is shown. The horizontal axis shows the time in the cycle of the 50Hz between 0 and 20ms, the frequency is shown between 20kHz and 120kHz and the vertical axis is a measure for the impedance in Ohm. The impedance shows to be very high during the major part of the 50Hz cycle with a peak of 20kOhm around 50kHz and going down to 15Ohm around the peaks of the 50Hz cycle being at 5ms and at 15ms. This result proves the extremely variable impedance showed to the PLC signal by e.g. an energy saving light bulb during the 50Hz cycle.

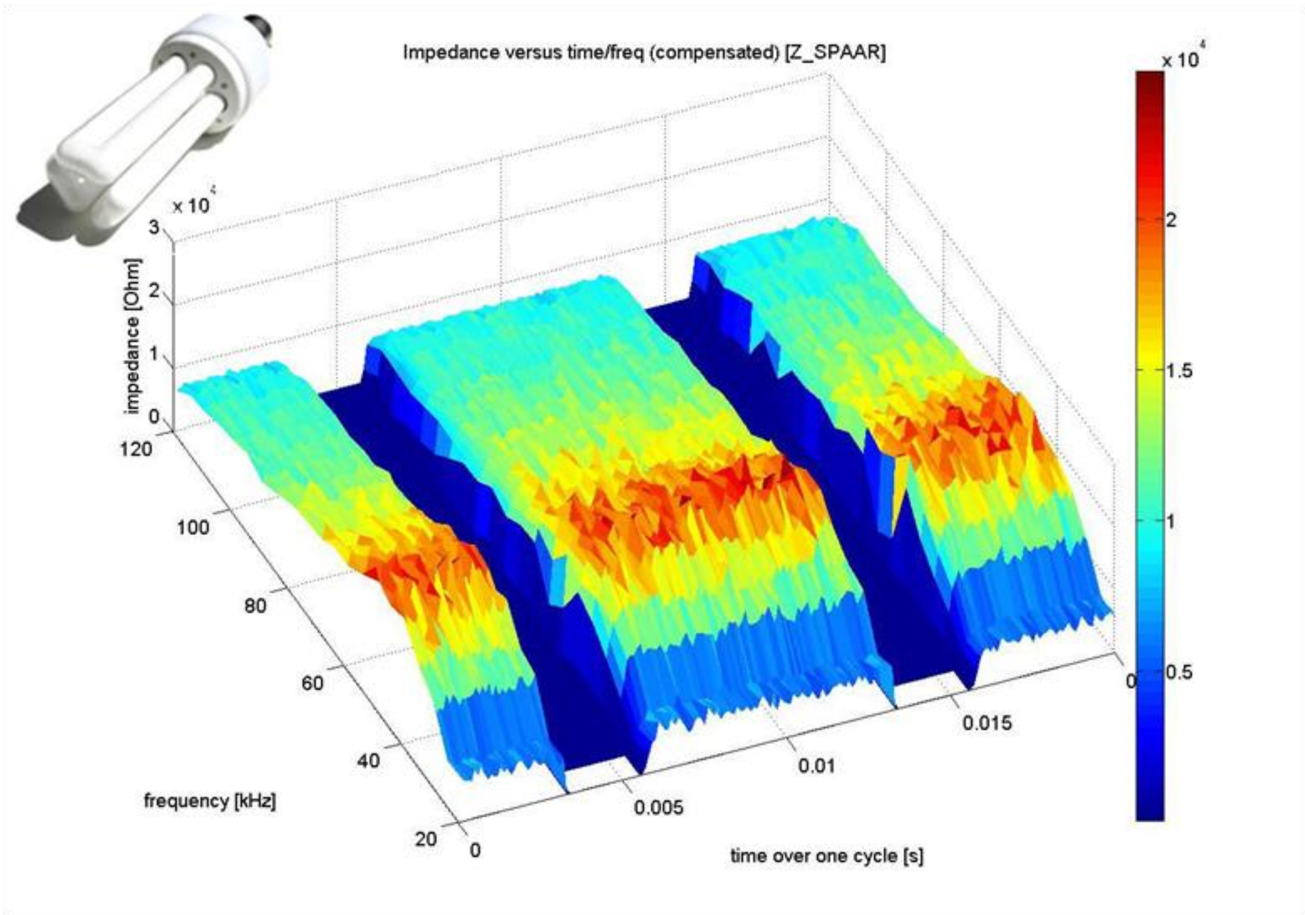

Figure 4: Periodic Impedance of an Energy saving light bulb

Figure 5 presents the periodic noise of this energy saving light bulb. The horizontal axis represents the time in the cycle of the 50Hz and the vertical axis the frequency between 20kHz and 120kHz. The color represents the amplitude of the noise emission.
It can be seen that the noise emission is not constant during the 50Hz cycle. During the maxima of the 50Hz there is a peak present at 35kHz with its harmonics at 70kHz and 105kHz.

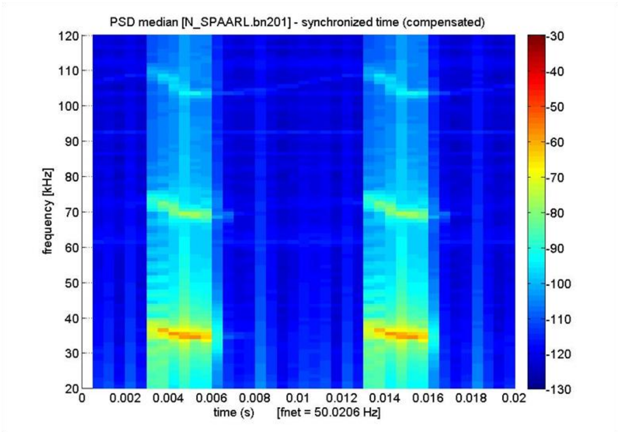

Figure 5: Periodic Noise of an Energy saving light bulb

This behavior is directly related to the type, design and filtering of the power supply circuit.

As a conclusion it was found that four power supply design categories determine the kind of influence of all grid loads on PLC communication.

REAL WORLD EXPERIENCE

The most common grid elements, like feeder cables, transformers and loads were identified and analyzed. Numerous field measurements helped to gain insight in the characterization of these grid elements.

The calculation models were intensively tested and optimized through a number of measurement campaigns done in the field. Measurement campaigns range from a few days up to several weeks.

Grasp of results obtained using the PLC measuring toolbox

Time-periods of malfunctioning of PLC based metering applications were linked to the locally measured fundamental parameters. Specific periods of low performance were brought into connection with disturbing loads.
Analysis done on loads present in the grid showed different categories of polluting charges leading to the possible disturbance of PLC communication.
Insights gained in the behavior of common grid elements through fundamental characterization allowed to give feedback to grid operators and manufacturers, assisting them in the right choice of technologies, considering PLC propagation.
Apart from statistically present disturbances, the importance of the grid topology was assessed in the basic performance of PLC based metering applications.

CONCLUSION

Potential future problems in PLC reliability were identified through fundamental research. This would not have been possible using off-the-shelve equipment.

ACKNOWLEDGEMENT

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