Implementation of an Application for the 
Time-Spectral Analysis of Supra-harmonic 
Interferences in Smart Grids

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Abstract- Distributed energy resources generate interfering 
signals and electrical noise that may have severe influence on 
the Smart Grids communications over Power Line 
Communications, as they can generate interfering signals and 
high level electric noise that can cause loss of metering and 
control data. The main object of this project was to create an 
application that characterizes those noise levels, in order to 
describe and analyze the influence of the power generated by 
distributed energy resources on Narrowband Power Line 
Communications through several test measurements. Results 
achieved in the application show the origin of these 
perturbations and may help to address a future solution to these 
communication disturbances.

I. INTRODUCTION

The need to find new sources of energy has become a 
challenge for all scientific and technological areas. The use 
of renewable resources in distributed generation is one of the 
considerable options for the increasing energy demand. Also 
Smart Grids have made a huge impact in the electric market. 
Smart Grids are energy networks that can automatically 
monitor energy flows and adjust to changes in energy supply 
and demand accordingly. When coupled with smart metering 
systems, smart grids reach consumers and suppliers by 
providing information on real-time consumption.

This next-generation transmission and distribution 
infrastructure is able to handle possible bidirectional energy 
flows, allowing for distributed generation such as from 
photovoltaic panels on building roofs. It also allows the use 
of fuel cells, charging to/from the batteries of electric cars, 
wind turbines, pumped hydroelectric power, and other 
sources.

The disturbances generated by distributed generation 
have been addressed in literature [1], [2] as well as simulated 
[3], [4]. However, their influence in Power Line 
Communication (PLC) has been barely addressed and there 
exists a lack of empirical tests. In this project real 
measurements have been carried out in a real microgrid in 
order to complete the analysis to be done. Measurements 
were carried out using a spectrum analyzer and then a digital 
signal-processing program has been specifically designed in 
order to analyze all the recorded data.

II. POWER LINE COMMUNICATIONS

A. Introduction and main features

Smart meters (SM), as being one of the technologies of 
Smart Grids, have become popular since Distribution 
Network Operators prefer to apply Time-of-Use rates. These 
devices need economical and reliable communication system. 
Power Line Communication (PLC) has several advantages for 
avoaching it. PLC is a communication protocol that uses 
electrical wiring to simultaneously carry both data, and 
Alternating Current.

Power Line Intelligent Metering Evolution (PRIME) is a 
worldwide PLC standard for Advanced Metering, Grid 
Control and Asset Monitoring applications and the objective 
to establish a set of open international PLC standards has 
been met. It is also one of the key technologies for data 
transmission in Smart Grids (SG) [5].

PRIME uses carrier frequencies (42 – 89 kHz) within the 
CENELEC A band, sampled at 250 kHz, with 512 differential 
phase shift-keying channels. Offers raw data rates between 
5.4 kbit/s (Robust mode: DBPSK with convolutional 
encoding and repetition code) and 128.6 kbit/s (D8PSK). 
Since specification version 1.4, more frequency bands were 
introduced the possibility to utilize the higher frequencies (up 
to 471 kHz). Using the full FCC band, raw data rates are eight 
times as high as in CENELEC A band.

In a PRIME subnetwork two device types exist: Base 
node (BN) and Service node (SN). BN manages subnetwork 
resources and connections. SN keeps connectivity to the 
subnetwork and switches the data of other nodes to propagate 
connectivity [6].

B. Techniques in PRIME to overcome channel disturbances

PRIME employs several techniques to overcome channel 
disturbances. PLC represents a challenge because the power 
wiring is unshielded and untwisted, the wiring acts as an 
antenna.

The primary advantage of Orthogonal Frequency Division 
Multiplexing (OFDM) over single-carrier schemes is its 
ability to cope with narrowband interference and frequency-
selective fading due to multipath. Therefore PRIME’s 
physical layer is based OFDM and Differential Phase Shift 
Keying (BPSK, DQPSK and D8PSK) as carrier modulation.
To address adverse power line channel properties, uses a convolutional code for error detection and correction, which consists of a Viterbi convolutional encoding together with time interleaving. PRIME Specification v1.4 also introduces repetition coding [7] as additional robustness mechanism.

In addition, PRIME can also tackle noise by promoting nodes to switch states. If the communication capabilities of a SN are affected by noise disturbances, the BN can decide to promote a neighbor SN from terminal to switch state in order to guarantee the communication between the affected SN and the BN.

However, disturbances from distributed grids haven’t been addressed yet.

III. TYPES OF DISTURBANCES GENERATED BY DISTRIBUTED ENERGY RESOURCES

With the increasing development of the Distributed Generation (DG) new technical and economic issues occur in the integration of these resources into a grid. Technical problems arise in the areas of power quality, voltage stability, harmonics, reliability, protection and control [8]. Due to their electronic nature, grid-connected devices referred to as distributed energy resources (DER) generate electric noise. Can be further classified into [9]:

1) Impulsive Noise. Switching of the power transistors generates impulsive signals of high amplitude around 100 kHz and above.

2) Harmonics of Main Frequency. Signals whose frequency is a multiple of the mains hum (50 or 60 Hz).

3) Harmonics of Commutation Frequency. Commutation techniques generate spurious signals in multiples of the commutation frequency above 1 kHz.

The introduced components between 2 and 150 kHz are usually referred as supra-harmonics.

Each distributed generation resource has its own integration issues. So despite the very promising features of PLC for the SG [8], they can be highly affected if strong disturbances are present in the transmission channel. These disturbances must be characterized in order to both identify potential impact situations and to develop strategies that overcome the communications impairments.

IV. MEASUREMENTS SETUP AND METHODOLOGY

The tests were carried out at CEDER-CIEMAT facilities (Soria, Spain), a national institution for the research, growth and promotion of renewable energies, where a microgrid was installed to be monitored. A microgrid is a discrete energy system consisting of distributed energy sources (including demand management, storage, and generation) and loads capable of operating in parallel with, or independently from, the main power grid.

A simplified scheme of the microgrid with the location of the different distributed generation (DG) and storage (DS) elements can be seen in Fig. 1.

As it can be seen, there are several sources of noise that can be analyzed in the microgrid such as:

- Photovoltaic inverters
- Wind turbines
- Battery chargers

Measurement set was composed of the following equipment:

- TABT-2 – LV Insulated Coupler inductive coupler, which allows measuring the PLC signal and/or noise or interferences present in LV networks. Frequency range: 10 - 600 kHz.
- Anritsu MS2781A Signal Analyzer. Used to make measurements in several equipments, which were parts of the microgrid.

The Anritsu Signature High Performance Signal Analyzer is a combined high performance Spectrum Analyzer for characterizing RF signals and a high performance Vector Signal Analyzer for characterizing digitally modulated signals. Signature expands the ability to analyze RF signals by offering seamless connectivity with MATLAB® and Simulink® from The MathWorks.

This signal analyzer saves the data from the measurements in IQ samples, which is really useful, because working with IQ samples allows all kinds of signal processing. Also a signal analyzer allows a spectral and also temporal analysis. Unlike an oscilloscope it allows to capture more than just an instant of time. Measurements realized were of 5 seconds duration.

V. DESIGNED APPLICATION

The main aim of this project was to create a tool or application to analyze the empirical data recollected in the several tests that were carried out in the CEDER-CIEMAT facilities.

The programming language used was MATLAB® due to its easy connectivity with the chosen signal analyzer. The implemented application reads the data obtained by the signal analyzer and then offers different possibilities of processing.

Fig. 1. CEDER-CIEMAT microgrid

Fig. 2. Application interface
It allows the user to select different types of windows (Hamming, Rectangular, Blackman), number of points of the FFT and other configurations to plot a spectrogram. It also gives the option to carry out a power analysis in which the application calculates the power of a given frequency in a given bandwidth.

In the following page different examples obtained with the application will be shown. Same configuration was used in all the examples: Hamming window of 20480 samples and a FFT of the same size. Fig. 3 is a measurement in an inverter put into operation but not coupled. Emissions from the inverter are composed, mainly, by a set of supra-harmonics of decreasing amplitude (see Table 1). The main injection of this set of supra-harmonics is at 12.8 kHz.

<table>
<thead>
<tr>
<th>Freq (kHz)</th>
<th>10.2</th>
<th>20.4</th>
<th>40.8</th>
<th>61.2</th>
<th>81.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power in 2kHz RBW (dBm)</td>
<td>-21.0</td>
<td>-38.7</td>
<td>-38.5</td>
<td>-49.1</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5 corresponds to a battery charger charging. A set of supra-harmonics can be seen, which have 5 kHz as their fundamental frequency. The amplitude of these supra-harmonics within PRIME band (42 kHz – 89 kHz) is similar to the PRIME signals (see Table 3). This figure clearly demonstrates that distributed generation has a relevant influence on the quality of the PLC.

### TABLE I

<table>
<thead>
<tr>
<th>Freq (kHz)</th>
<th>12.8</th>
<th>25.6</th>
<th>38.4</th>
<th>51.2</th>
<th>64.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power in 2kHz RBW (dBm)</td>
<td>-17.7</td>
<td>-18.9</td>
<td>-23.7</td>
<td>-39.1</td>
<td>-43.1</td>
</tr>
</tbody>
</table>

Results of the electric noise generated by a coupled and working inverter can be seen in Fig. 4. Tests show that the inverter injects a primary emission at 12.8 kHz, similar to the previous case. Additionally it is noticeable another set of supra-harmonics at 10.2 kHz (see Table .2).

<table>
<thead>
<tr>
<th>Freq (kHz)</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>75</th>
<th>85</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power in 4kHz RBW (dBm)</td>
<td>-3.3</td>
<td>-0.5</td>
<td>-4.3</td>
<td>-8.8</td>
<td>-10.4</td>
</tr>
</tbody>
</table>

### VI. CONCLUSIONS

As it could be seen in CEDER-CIEMATIC measurements, there are important disturbances, which have a severe influence in PRIME, to be analysed. This paper presents an application that has demonstrated to be really useful to characterize these disturbances.

### ACKNOWLEDGEMENTS

This work has been financially supported in part by the University of the Basque Country (UFI 11/30) and by the Basque Government (IT-683-13).

### REFERENCES


