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Characterization of non-intentional emissions from distributed energy resources up to 500 kHz: A case study in Spain

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ABSTRACT

Narrow Band Power Line Communications (NB-PLC) systems are currently used for smart metering and power quality monitoring as a part of the Smart Grid (SG) concept. However, non-intentional emissions generated by the devices connected to the grid may sometimes disturb the communications and isolate metering equipment. Though some research works have been recently developed to characterize these emissions, most of them have been limited to frequencies below 150 kHz and they are mainly focused on in-house electronic appliances and lightning devices. As NB-PLC can also be allocated in higher frequencies up to 500 kHz, there is still a lack of analysis in this frequency range, especially for emissions from Distributed Energy Resources (DERs). The identification and characterization of the emissions is essential to develop solutions that avoid a negative impact on the proper performance of NB-PLC.

In this work, the non-intentional emissions of different types of DERs composing a representative microgrid have been measured in the 35–500 kHz frequency range and analyzed both in time and frequency domains. Different working conditions and coupling and commutation procedures to mains are considered in the analysis. Results are then compared to the limits recommended by regulatory bodies for spurious emissions from communication systems in this frequency band, as no specific limits for DERs have been established. Field measurements show clear differences in the characteristics of non-intentional emissions for different devices, working conditions and coupling procedures and for frequencies below and above 150 kHz. Results of this study demonstrate that a further characterization of the potential emissions from the different types of DERs connected to the grid is required in order to guarantee current and future applications based on NB-PLC.

1. Introduction

Distributed Energy Resources (DERs), including Distributed Generation (DG) and Distributed Storage (DS), are being progressively integrated in the Low Voltage (LV) section of the electrical network and their management needs to be accomplished for the proper functioning of the Smart Grids (SGs).

For this purpose, several technologies of NarrowBand Power Line Communications (NB-PLC) to provide data transmission in smart metering systems have been developed [1,2]:

- PRIME (PoweRline Intelligent Metering Evolution) specification [3], published by International Telecommunication Union in Recommendation ITU-T G.9904 [4], includes 2 versions: PRIME v1.3.6 [5] and PRIME v1.4 [6,7].
- G3-PLC specification [8], published in Recommendation ITU-T G.9903 [9].
- IEEE 1091.2 standard [10].

These NB-PLC technologies operate in the 3–500 kHz frequency range, which includes CENELEC bands (3–148.5 kHz) defined by the Comité Européen de Normalisation Electrotechnique, the FCC band (9–490 kHz) set by the United States Federal Communications Commission, and the ARIB band (10–450 kHz) specified by the Japanese Association of Radio Industries and Businesses [11]. Most of the recently developed communication technologies avoid the lowest frequency range (3–30 kHz) due to the high level of noise and interfering emissions existing in the electrical grid.

Although NB-PLC technologies allow the use of robust modulation and coding techniques, strong disturbances present in the transmission

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channel may degrade the communications in some cases. These channel disturbances are mainly non-intentional emissions in the NB-PLC frequency bands generated by devices connected to the electrical grid, such as electronic appliances and lightning devices, but also DERs such as photovoltaic (PV) inverters, battery chargers, hydropower systems or wind turbines. As more renewable power generators, electric vehicle (EV) chargers and energy-efficient devices are added to the grid, the number and amplitude of the emissions increases. The proper characterization of the different types of non-intentional emissions is required to know in advance the potential interferences that NB-PLC will have to face. As a reference, in December 2017, the IEC established a joint working group of TC77A and CISPR SC/H to define requirements for the regulation of emissions from 2 kHz to 150 kHz, in order to ensure the compatibility of electrical products. CENELEC has recently recommended the analysis of the non-intentional emission levels both in time and frequency domains also [12].

Moreover, the characterization of non-intentional emissions in the electrical grid has been mainly limited to the frequency range up to 150 kHz; however, there is an increasing interest in Europe to extend the frequency range for NB-PLC up to 500 kHz. As few field measurements have been carried out for these higher frequencies, particularly for DERs, a detailed characterization of the different types of non-intentional emissions in the frequency range up to 500 kHz is needed, in order to estimate if these emissions might cause problems in the communications, and therefore, if they should be limited through regulation. A potential solution is that the future coding techniques used by NB-PLC in these higher frequencies must be adapted to face the different types of disturbances of the propagation channel, in order to ensure the data transmission.

In this paper, non-intentional emissions generated by different types of DERs that compose a representative microgrid have been measured and characterized in the frequency range from 35 kHz to 500 kHz. This frequency range includes current and expected frequencies used by the above-mentioned NB-PLC transmission technologies. Field measurements were carried out according to the measuring methods recommended by CISPR (Comité International Spécial des Perturbations Radioélectriques) for compliant receivers, including two types of detectors: CISPR quasi-peak and CISPR average [13–15]. The emissions recorded in the field measurements have been compared to the limits defined by the European Standard EN-50065-1 for conducted perturbations from mains communicating equipment [16], as no specific limits for DERs have been established. The results of the paper will help to enable the proper performance of NB-PLC in an electrical grid with a high number of DERs.

The paper is organized as follows. First, non-intentional emissions analyzed in different previous measurement campaigns are summarized in Section 2. Then, in Sections 3 and 4 the measurement campaign that has been specifically carried out in this work and the analysis of the results obtained from measurements are thoroughly described, respectively. Finally, the main conclusions, including the potential effect of non-intentional emissions on NB-PLC, are described in Section 5.

2. Non intentional emissions generated by devices connected to the grid

Throughout the literature, non-intentional emissions have been mainly classified in three different types [17,18]:

- Impulsive noise: the switching procedure of power transistors used to DC/AC conversion generates impulsive signals of high amplitude around 100 kHz and above.
- Harmonics of the switching frequency: switching devices generate spurious signals in multiples of the switching frequency, which is usually above 10 kHz, or in other cases even above 20 kHz to be inaudible.
- Colored background noise: this kind of noise is usually higher in lower frequencies and it can be characterized by several sources of white noise in non-overlapping frequency bands.

CENELEC, the European committee for electro-technical standardization, launched the SC 205 Working Group 11 to promote, gather and analyze non-intentional emissions in electrical grids, and to determine adequate immunity levels for communications. The problematic of non-intentional emissions is summarized in the study report SC 205 A of CENELEC [12]. Additionally, the IEC has launched a joint working group of TC77A and CISPR SC/H to define requirements for the regulation of emissions, in order to ensure the compatibility of electrical products in the frequency band assigned to NB-PLC.

According to the requests of these regulatory bodies and standardization committees, in this report, some examples of non-intentional emissions generated by a wide range of devices for the 2–150 kHz range are analyzed, and at a lower extent, for frequencies up to 500 kHz:

- Power supplies: These devices usually include a small inverter that employs switching techniques and, as observed in some measurement campaigns, the levels of the generated non-intentional emissions could be high [19–21]. It was also demonstrated in other studies based on measurements that the power supplies of different electronic devices generated emissions that affected the NB-PLC [22–29].
- Electronic devices including inverters: The power devices that include inverters (such as elevators or uninterrupted power supplies) are being more frequently used both in commercial and residential environments [30]. Some research carried out in different environments with different types of inverters (including PV systems) proved that the harmonics of the switching frequencies reached considerable levels [19,31,32]. The non-intentional emissions generated by devices such as PV inverters, inverters for the control of engines or the ones included in some washing machines sometimes disturbed the communications [23,33–37].
- Electric tools: Tools such as drills and saws also generated emissions, in this case, up to 500 kHz, as demonstrated in [19].
- Lightning equipment: The non-intentional emissions generated by compact lamps, fluorescent lamps and LED lamps were also analyzed in some measurement campaigns up to 500 kHz [38–40]. In other studies, it was observed that the communications between different devices were sometimes lost [41,42].
- Other equipment such as the rectifiers included in cell towers and fiber switches sometimes affected the communications [43,44].

This Working Group is now demanding recent results in this area that provide the basis for updated criteria and reference levels [12].

Apart from the study report SC 205 A of CENELEC, other measurements campaigns have been carried out in the last years, although the analyzed frequency range has been mainly limited to 2–150 kHz [18,45–59]. All these studies demonstrate the need to carry out additional field measurements, mainly for DER devices, due to the wide variety of devices that generate emissions of different nature, level and variation in time and frequency.

In many of the described studies, the voltage levels were usually compared to limits defined by CISPR specifications:

- Non-intentional emissions generated by lightning equipment (CISPR15, EN 55015) [60].
- Non-intentional emissions generated by induction cooking equipment (CISPR11, EN 55011) [61].
- Intentional emissions generated by mains communicating equipment (EN 50065-1).
- Non-intentional emissions generated by mains communicating equipment (EN 50065-1).

These limits, together with the voltage limits for intentional