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Characterization of Non Intentional Conducted Emissions Up to 500 kHz in Urban Environment

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Abstract. The current interest in Europe to extend the frequency range for Narrowband Power Line Communications up to 500 kHz requires a thorough characterization of the non-intentional emissions in this frequency range. This paper presents results of field measurements carried out in a dense urban environment, where the electrical devices are quite numerous and located at a short distance from the smart meters, and therefore, the effects of the non-intentional emissions on Smart Grids communications may be noticeable. In the study, spectral and time characterization of the recorded data was performed according to CISPR specifications, and then compared to recommended limits for non-intentional emissions in this frequency range. Results show that the levels of the emissions above 150 kHz may exceed the recommended limits for spurious emissions in the frequency band, mainly near the smart metering devices, due to the nearness of different types of electrical devices connected to the grid. This work demonstrates the need of characterizing the non-intentional emissions up to 500 kHz for the proper performance of future Smart Grid applications in this frequency range.

Key words

Electromagnetic Interference, Electromagnetic measurements, Narrowband Power Line Communications, Noise measurement, Non-intentional emissions.

1. Introduction

Many distribution system operators have opted for NarrowBand Power Line Communications (NB-PLC) worldwide for the implementation of Advanced Metering Infrastructure (AMI), which is generally considered the first step towards the Smart Grid (SG) concept. NB-PLC technologies operate in the 3-500 kHz frequency range, which is regulated by different organizations in different parts of the world [1]:

- In Europe, CENELEC bands (3-148.5 kHz) are defined by the Comité Européen de Normalisation Electrotechnique.
- In the United States, the FCC band (9-490 kHz) is set by the Federal Communications Commission.
- In Japan, the ARIB band (10-450 kHz) is specified by the Japanese Association of Radio Industries and Businesses.

In line with the regulation in United States or Japan, in Europe there is a general interest in extending the frequency range for NB-PLC up to 500 kHz.

One of the problems that NB-PLC has to face is the operation of data communication equipment in parallel with the electrical equipment connected to the grid, which becomes the source of non-intentional emissions that may generate electromagnetic interference (EMI) in the communications. The understanding of EMI requires a detailed time and frequency domain characterization of the non-intentional emissions [2].

Accordingly, the potential future use in Europe of the frequency range up to 500 kHz requires the extension of the characterization of the non-intentional emissions to this frequency range. A proper analysis should be based on measurements in different scenarios, determined by the density of smart meters and electrical devices, the relative distance between them and the connection and disconnection of devices along the time, the topology of the grid and the presence of Distributed Energy Resources (DERs).

This paper shows results of the characterization of conducted non-intentional emissions up to 500 kHz in an urban environment. In this scenario, there is a high density of smart meters and electrical devices, the distance between them is quite short and the types of emissions are diverse. Results are based on field measurements.

The paper is organized as follows. First, non-intentional emissions are described and categorized in Section 2. Then, the measurement campaign specifically carried out for this work is described in Section 3. Results are shown and analyzed in Section 4, and finally, the main conclusions of the study are outlined in Section 5.

2. Non-intentional emissions in the 10-500 kHz range

A. Types of non-intentional emissions

This paper deals with conducted high-frequency phenomena, this is, directly coupled or induced voltages or currents, in the frequency range above 2 kHz, without any connection to the fundamental 50 or 60 Hz. Sources of non-intentional emissions in this frequency range include power supplies, electronic devices with inverters, electric tools, lightning equipment and other equipment such as the rectifiers used in cell towers and fiber switches [2].

Throughout the literature, non-intentional emissions in this frequency band have been mainly classified in three different types [3],[4]:

- Impulsive noise: can be classified as aperiodic and periodic – divided in turn into synchronous or asynchronous to the mains frequency. The switching procedure of power transistors used to DC/AC conversion generates asynchronous periodic 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 approximated by several sources of white noise in non-overlapping frequency bands.

Non-intentional emissions can also be classified according to their behavior on short time scale and long time scale [2]. On long-time scale (occurrence over time periods much longer than a fundamental cycle) it has to be distinguished between:

- (Quasi-) continuous occurrence, when the emission appears over longer time intervals (multiple hours).
- Discontinuous occurrence, when the emission appears over shorter time intervals (few milliseconds).

B. Limits for non-intentional emissions

Electromagnetic Compatibility (EMC) problems in this frequency range have been and still are an item for extensive discussion in standardization committees, like IEC SC 77, as this is a matter that affects several types of electrical equipment and not only NB PLC devices. Up to now, with exception of emission limits for cooking appliances (EN 55011) and for lighting equipment (EN 55015) for the frequency range 9 kHz to 150 kHz, no standards limiting non-intentional emissions in the high frequency range have been established [5][6].

Considering the specific EMC matter related to EMC between non-communicating equipment and NB-PLC systems, some reports such as [5][6] suggest that it should be guaranteed that non-intentional emissions from electrical equipment should be lower than the emissions from NB PLC devices in order to ensure its proper functionality. Therefore, in this paper, the non-intentional emissions measured in the trials are compared to the limits for perturbations generated by communicating equipment given in EN 50065-1.

In EN 50065-1, the limits are defined by means of quasi-peak voltage limits for the whole 10-500 kHz frequency range, but average voltage limits only for the 150-500 kHz range [7].

IEEE 1902.1 standard [8] includes similar measurements conducted in the field in LV sites. Spectrograms and averaged spectral density in the frequency range of 45 kHz to 450 kHz are plotted. Nevertheless, limits defined in EN 50065-1 cannot be directly compared to these plots.

3. Field measurements

A. Scenario of the field trials

The measurements were performed in two locations within the Low Voltage distribution network of a dense urban environment of Bilbao (Spain). In this scenario, the density of smart meters is high, the electrical devices are quite numerous and located at a short distance from the smart meters, with no DERs in the area. Therefore, the potential sources of non-intentional emissions may be high in number and diverse in nature. In the measurement area, all the smart meters are managed by the data concentrator located in a secondary substation and connected in a tree topology.

The first measurement location is a PLC data concentrator sited inside the secondary substation (location A in Fig. 1). The measurements at this location were carried out between each phase and the neutral of the Low Voltage part of the secondary substation. The second measurement location is a fuse box located in a meter room inside a residential building, at a distance about 50 meters from the secondary substation (location B in Fig. 1). This residential building has more than 30 smart meters, as shown in Fig. 2. The measurements in this second location were also taken between each phase and the neutral of the Low Voltage grid.

Fig. 1. Aerial view of the scenario of the field trials.

Fig. 2. Measurement location B: meter room of a residential building.

B. Measurement equipment

The choice of an adequate measurement method depends on the purpose of the measurement. In this case, the aim is to measure emission levels in the grid, i.e., the assessment of the levels that are present in the frequency range from 10 kHz to 500 kHz. As recommended in CISPR 16-2-1 [8], both frequency and time domain analyses must be performed for EMI characterization [2].

In this work, the Anritsu MS2690A Signal Analyzer [10] was used for digitizing and recording the measurement data in IQ (In-phase, Quadrature) samples in the time domain. The spectral analysis was then carried out by applying the Fast Fourier Transform (FFT) to time domain scan in laboratory post-processing, as described in Section 4.

As a coupling device, a TABT-2 – LV capacitive coupler was used [11], which allows measuring the emission levels present in the grid in a frequency range of 10 - 600 kHz.

4. Analysis and results

A. Data processing

This section describes the data processing performed to obtain detailed spectral and time characterization. As mentioned in IEC 61000-4-30:2015 [12], following CISPR16 specifications may provide a large amount of data in an in-situ context; however, the amount of data for in-situ measurements specified by CISPR 16 may be required for coordination with levels defined by various IEC standards. Therefore, despite the involved complexity, measurement datasets were processed according to CISPR16 specifications described in [9],[13],[14].

- A Gaussian time-windowing is required, which provides a 6 dB bandwidth of 200 Hz in the 10-150 kHz range and a 6 dB bandwidth of 9 kHz in the 150-500 kHz range.
- A time overlap of more than 75% is required to ensure that measurement uncertainty of the pulse amplitude remains within ±1.5 dB. An overlap of 93% was employed in this case in order to ensure that this condition was fulfilled.
- The frequency step size should be equal or less than the half of the required values of 6 dB bandwidth. Accordingly, in this analysis the number of points of the FFT was selected to be a quarter of the required bandwidth (50 Hz and 2.25 kHz for the 10-150 kHz range and 150-500 kHz range, respectively).
- The required charge and discharge time constants and the meter time constants for quasi-peak and average detectors were digitally implemented by means of Infinite Impulse Response (IIR) filters.
- The minimum measurement time is 10 ms in the 10-150 kHz band and 0.5 ms in the 150-500 kHz band [14]. Longer measurement intervals were used in order to characterize the signal time-variability. In order to avoid that the communication signals distort the results and to ensure that only non-intentional emissions were considered, the IIR filters implemented in this analysis for quasi-peak and average detectors were applied on recordings where no PRIME v1.3.6 signal bursts were present.

In this study, the above-mentioned methodology was applied for the spectral characterization of the non-intentional emissions. Then, the quasi-peak and average voltage levels were compared to the limits defined by EN-50065-1.

Additionally, the time variability of the emissions is graphically represented by means of spectrograms that show the evolution in time of the Power Spectral Density (PSD) values. The Gaussian time-windowing employed for the 200 Hz bandwidth was used for this purpose, maintaining the 50 Hz step size.

B. Results

Representative results from the measurements campaign are shown in the figures below. For each measurement, results are summarized, first, in a spectrogram that represents, graphically and numerically, the amplitude and variability of the PSD of the recorded signal, and second, in a graph of the level of the non-intentional emissions, which are compared to the limits defined by EN-50065-1. Both graphs are for the frequency range under analysis, from 10 kHz to 500 kHz. The spectrogram allows the detailed analysis of the variation of the spurious emissions, while the spectral characterization allows the identification of the specific frequencies where the levels of spurious emissions are higher than the recommended limits. In some cases, the combination of both graphs provides useful information to identify the interfering noise sources.

Figures 3 to 6 contain the results of two measurements recorded at the data concentrator in the secondary substation (location A), in particular, in two different phases at the Low Voltage part of the secondary substation.

The spectrograms of the PSD of the spurious emissions (see Figures 3 and 5) show that the highest levels are concentrated in the lowest frequencies, and mainly below 50 kHz. The emissions remain quite stable in time and level during the measurement, with only some variation in amplitude. Therefore, according to the classification defined by CENELEC SC 205A [2], they can be considered as long-time scale quasi-continuous occurrences. In any case, the PSD levels decrease with frequency and PSD levels above 150 kHz are considerably lower than levels observed below 150 kHz.

Figures 4 and 6 contain the results of the assessment of the quasi-peak and average voltage levels for the same recordings, together with the limits stated in EN-50065-1 [7]. As it can be observed, as the emission levels remain below the limits for frequencies below 150 kHz, they are close to the limits for frequencies above 150 kHz, and they even exceed the limits in some frequencies.

It should be noted that the sharp transition at 150 kHz is not due to a sudden increase of noise level, but to the different bandwidth values used in the time-windowing for frequency ranges below and above 150 kHz, as described in the methodology. It should also be reminded that EN-50065-1 proposes quasi peak voltage limits for the whole frequency band, but average voltage limits only for the 150-500 kHz range, and this is the reason of calculating the average levels only for this range.

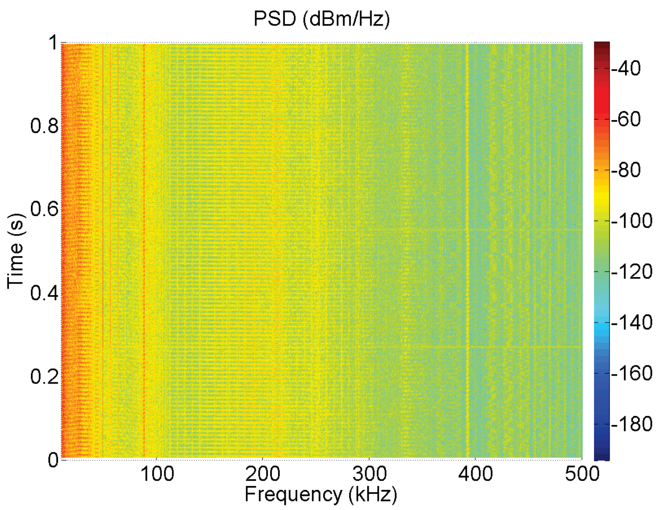

Fig. 3. Example 1 of measurement in the secondary substation: spectrogram of the Power Spectral Density up to 500 kHz

Regarding the measurements in the meter room of a residential building (location B), representative results are shown in Figures 7 to 10. They correspond to recordings in two different phases at the electric grid in the meter room.

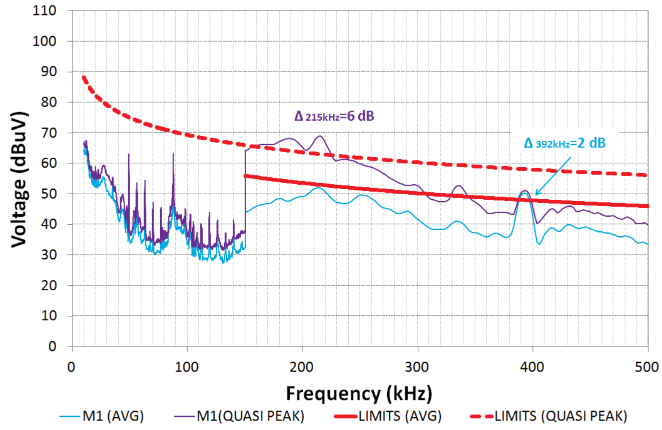

Fig. 4. Example 1 of measurement in the secondary substation: spectral characterization and comparison to the limits determined by CENELEC.

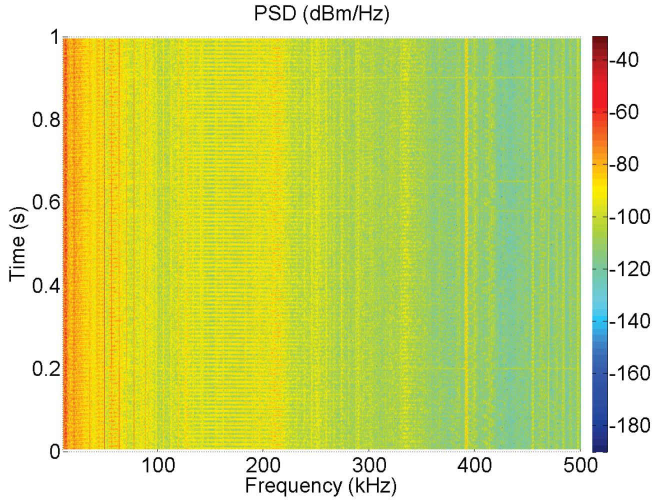

Fig. 5. Example 2 of measurement in the secondary substation: spectrogram of the Power Spectral Density up to 500 kHz.

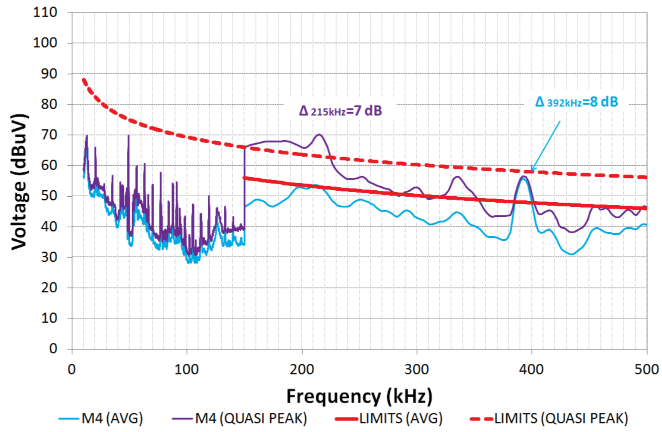

Fig. 6. Example 2 of measurement in the secondary substation: spectral characterization up to 500 kHz and comparison to the limits determined by CENELEC.

As it can be observed in Figures 7 and 9, the PSD values of the spurious emissions are much higher than in the previous case, and they are extended along the whole frequency range. As in the secondary substation, the emissions remain quite stable in time and level during the measurement, and therefore, they can be considered as long-time scale quasi-continuous occurrences;

nevertheless, occasional impulsive noise occurrences were also observed during the measurements.

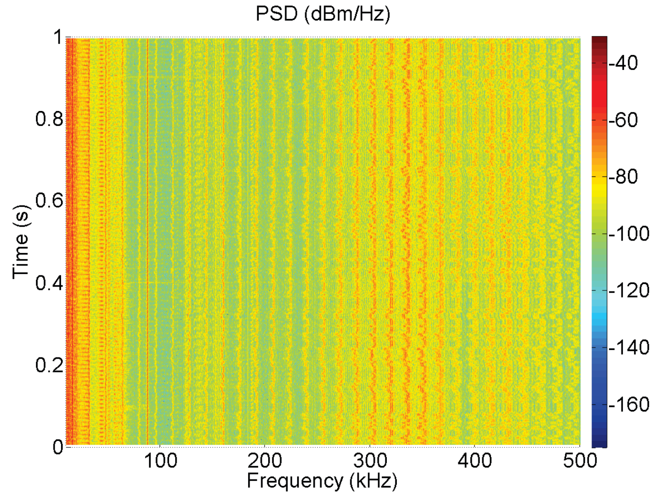

Fig. 7. Example 1 of measurement in the meter room of a residential building: spectrogram of the Power Spectral Density up to 500 kHz.

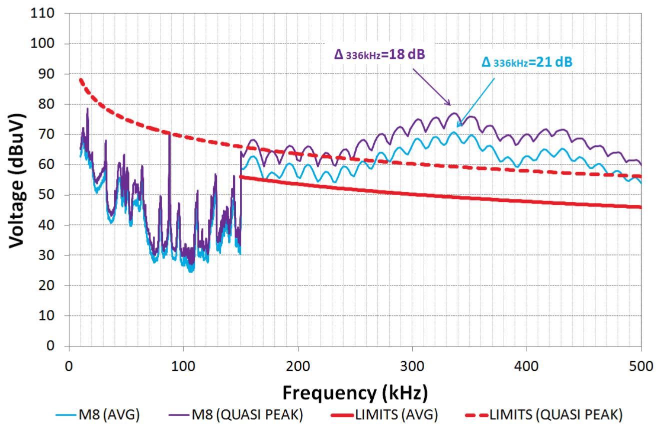

Fig. 8. Example 1 of measurement in the meter room of a residential building: spectral characterization up to 500 kHz and comparison to the limits determined by CENELEC.

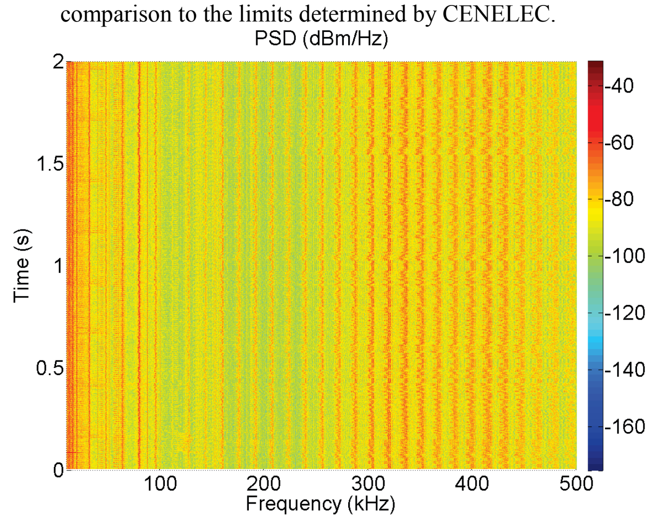

Fig. 9. Example 2 of measurement in the meter room of a residential building: spectrogram of the Power Spectral Density up to 500 kHz.

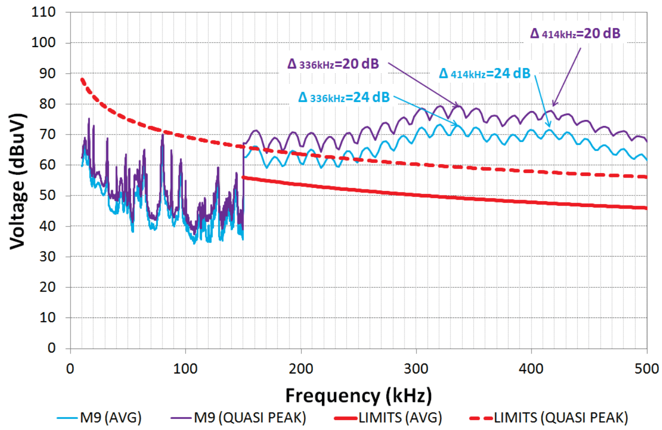

Fig. 10. Example 2 of measurement in the meter room of a residential building: spectral characterization up to 500 kHz and comparison to the limits determined by CENELEC.

As a consequence, as shown in Figures 8 and 10, the quasi-peak and average voltage levels clearly exceed the limits stated in EN-50065-1, but only for frequencies above 150 kHz. As described below, the different bandwidth values used in the time-windowing generate a sharp transition for these levels below and above 150 kHz.

5. Conclusions

The field measurements carried out in this study demonstrate that the levels of non-intentional emissions above 150 kHz in a dense urban environment can be similar to the levels observed below 150 kHz in previous studies. In fact, the voltage values of the emissions may exceed the recommended limits for spurious emissions from communication systems in the frequency band above 150 kHz. This is influenced by the data processing procedure for frequencies above 150 kHz, which leads to higher average and quasi-peak voltage levels than below 150 kHz, together with the most restrictive limits stated by CENELEC for this range.

Results show that the levels of the emissions are considerably higher near homes, where the smart metering devices are located, due to the nearness of different types of electrical devices connected to the grid. It must be also considered that the propagation losses for data transmission increase with frequency, and therefore, a specific noise level may cause a stronger degradation in the communications at higher frequencies.

Non-intentional emissions recorded in these trials can be considered as long-time scale quasi-continuous occurrences, though occasional impulsive noise occurrences were also observed during the measurements.

Last, results for different phases at the same measurement point show similar values and similar variations in time and frequency.

Consequently, this work demonstrates that a detailed characterization of the non-intentional emissions up to 500 kHz is required for the proper performance of Advanced Metering services and future Smart Grid applications based on communications in this frequency range.

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