THE NEED TO REDEFINE EMC STANDARDIZATION: POWER SPECTRAL DENSITY LIMITS OF NON-INTENTIONAL EMISSIONS FOR RELIABLE NB-PLC COMMUNICATIONS

Noelia URIBE-PÉREZ
TECNALIA – Spain
noelia.uribe@tecnalia.com

Ibon ARECHALDE
TECNALIA – Spain
ibon.arechalde@tecnalia.com

Alberto SENDIN
IBERDROLA - Spain
asendin@iberdrola.es

Ainara FERNANDEZ
IBERDROLA – Spain
afernandezol@iberdrola.es

Juan Sebastian GOMEZ
IBERDROLA – Spain
jgua@iberdrola.es

ABSTRACT

Existing problems from Non-Intentional Emissions (NIE) over NB-PLC devices are well known to the community as well as widely covered in related researches and in reports of technical committees. Currently, the various limits set in different EMC standards for compatibility levels below 150 kHz are neither based on total power injected, nor based in real field measurements, so their validity may be questioned. In this sense, this paper presents a set of tests aiming at addressing both the influence of different emissions over different NB-PLC metering devices and the need to fix limits in the unintentional power injected in NB-PLC bands. The results and conclusions of the study present a valuable input for a fair coexistence between NB-PLC and electrical and electronic devices that can disturb signalling over LV grids below 150 kHz.

The paper gives details of the performance evaluation of NB-PLC technologies, relevant for practicable smart meters implementation to improve resistance against NIE. Furthermore, the paper demonstrates that the power density of NIE should be limited in EMC standards to ensure a correct coexistence of NIE sources and NB-PLC technologies.

INTRODUCTION

The success of NarrowBand Power Line Communications (NB-PLC) for Automated Metering Infrastructure (AMI) is evident from the high number of mature deployments around the world. This poses the question of whether other applications beyond metering could also be considered over PLC [1]. A crucial question in this respect is how to ensure the performance of the communications channel, in which Non-Intentional Emissions (NIE) present throughout Low Voltage (LV) grids represent the main, most adverse influence.

Problems caused by interference to PLC devices are well known to the Smart Grid community. This is so to the extent that relevant standardization bodies such as IEC, CENELEC, and ETSI have created specific working groups to address the issue [2].

Back in 2015, CENELEC Subcommittee SC 205A Mains communicating systems published the Third Edition of the Study Report on "Electromagnetic Interference between Electrical Equipment in the Frequency Range from 2 to 150 kHz" [3]. This Report concluded more measurements were needed to better understand the interferences that affect existing PLC technologies in that frequency range. Furthermore, "Investigation Results on Electromagnetic Interference in the Frequency Range below 150 kHz", was also published by CENELEC SC 205A as a Technical Report in 2017, presented a comprehensive set of additional measurement results on electromagnetic interference [4]. A clear conclusion from the Report was on the need to close the then-existing gap in standardization related to EMC in the frequency range 2 kHz – 150 kHz.

In Europe, European Commission included the family of standards EN 50065 [5] as harmonized standards according to the 2014/30/EU EMC Directive [6] to regulate signalling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz. Unfortunately, this regulation that limits the NB-PLC communications is not extended to other products that may inject noise in LV grids below 150 kHz.

Two amendments -published in 2017 and 2018- to International Standard IEC 61000-2-2:2002 Electromagnetic compatibility (EMC) - Part 2-2: Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems tried to represent a first step towards a final solution, by defining compatibility levels below 150 kHz. The compatibility levels are not based in real field measurements but rather in a compromise between theoretical curves, so their validity is to be questioned. Compatibility levels in any case must be converted into generic emission and immunity limits, and then find their way into EMC product standards. The current various limits set in different EMC standards for emissions (and immunity) below 150 kHz can be seen in Figure 1.

Moreover, compatibility levels ignore the fact that from a telecommunications perspective, it is the total injected power the magnitude that determines SNR and, as a consequence, performance of telecommunication systems. If the power spectral density, and the total injected power are not limited, SNR and performance cannot be guaranteed.

Considering that PLC transmissions are set so as not to exceed peaks over 134 dBuV (according to EN 50065-1:2011 and its international equivalent IEC 61000-3-8:1997), the disturbance limits allowed to other equipment may greatly impair the communication. This happens even where there is minimal attenuation between a PLC transmitter and receiver.

In this context, this paper presents a set of tests which investigate and address the influence of different emissions on different NB-PLC metering devices manufacturers currently deployed in LV grids through Europe (for a total of tens of millions of smart meters). Tests have been performed in a controlled environment, with real PLC equipment working in the CENELEC 30 kHz to 150 kHz frequency range.

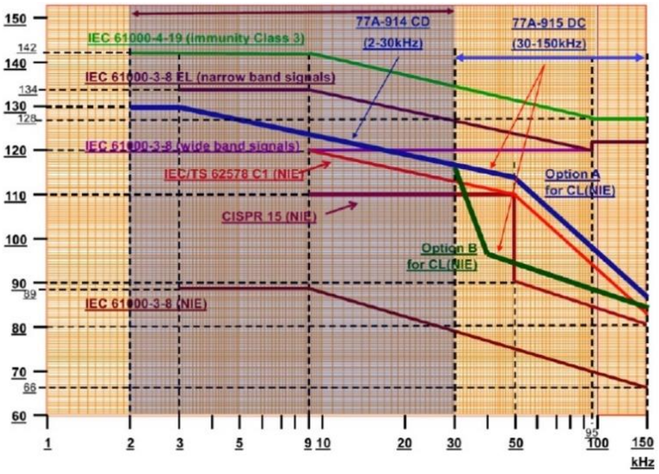

Figure 1. Different EMC standards and limits for emissions from electronic equipment [7].

MEASUREMENTS SET-UP

Laboratory testbench

The tests were performed in a controlled environment following the set-up showed in Figure 2. A picture of the testbench can be seen in Figure *3*. In order to guarantee that no external noises affect the performance of the tests, an isolating transformer was located upstream of the testbench. The following devices were used:

- Both the transmitter and receiver modems are ITU-T G.9904 compliant PLC devices using the most robust modulation supported by the specification (DBPSK with error correction). They were located close to each other, in order to test the best conditions, i.e., practically zero losses between transmitter and receiver.
- The noise generation was done with the waveform generator AGILENT 33250A, together with an amplifier AR40AD1 to obtain the needed power in each configuration.
- The injection of the noises was performed through the RF probe FCC F-120-9A, an inductive coupler to avoid affection of the impedance. The noise was injected between the PLC transmitter and the PLC receiver.
- The CISPR-16 LISN is connected to calibrate the generated noise. The calibration is done at the same point that the measurement points for conducted emissions measurements.
- The PRIME LISN is used to maintain a controlled impedance in the network of 2Ω, close to real low voltage network impedances.

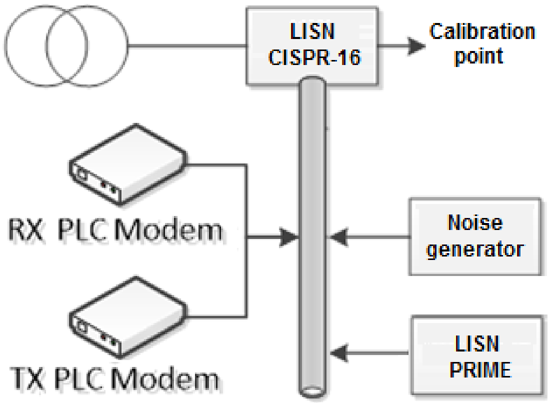

Figure 2. Set-up for the tests.

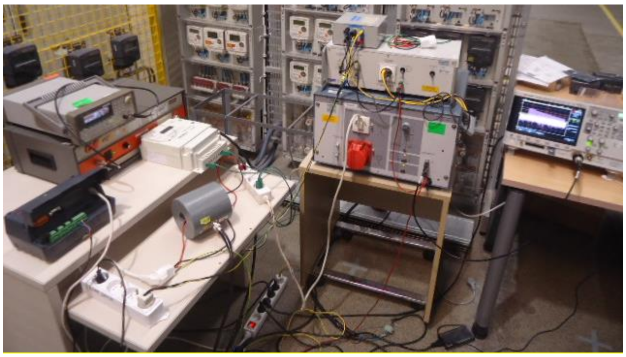

Figure 3. Picture of the laboratory testbench.

Considered noises

Three different curves have been considered for the tests, as showed in Figure 4. Their limits in frequency and amplitude can be consulted in Table 1.

- CISPR-15 is a widely considered normative curve for electronic devices and defines the emission limits for lighting equipment [8].
- Option B is a proposal of compatibility levels for non-intentional emissions by IEC TC77A-WG8 DSO and MCS experts and it is based on on a modified CISPR-15 curve. According to them, the proposed compatibility levels ensure both an acceptable compromise for the

conducted non-intentional emission levels generated by general equipment (non-mains communicating equipment, non-MCS) as well as the protection of MCSs operating in the frequency range 30-150 kHz [9].

- TF4 is a proposal recently presented by the IEC SC77A-WG8 on the compatibility level for the frequency band ranging from 30 to 150 kHz and it is a as a trade-off between the Option B (described above) and the Option A, which was supported by WG8 experts related to industry producing general equipment (excluding MCS) [9], [10].

The three different noises were created with the first carrier at 30 kHz for both Option B and TF4 and at 9 kHz for CISPR-15. The rest of the carriers were separated in frequency steps of 1 kHz. In all cases, the final carrier was at 150 kHz.

Before the execution of the tests, the calibration of the injected noises was done in the point indicated in Figure 2 with the PLC modems disconnected. During the calibration, the signals were injected with duty cycle equal to 100%. For each noise level, the total power of the injected noise was also measured.

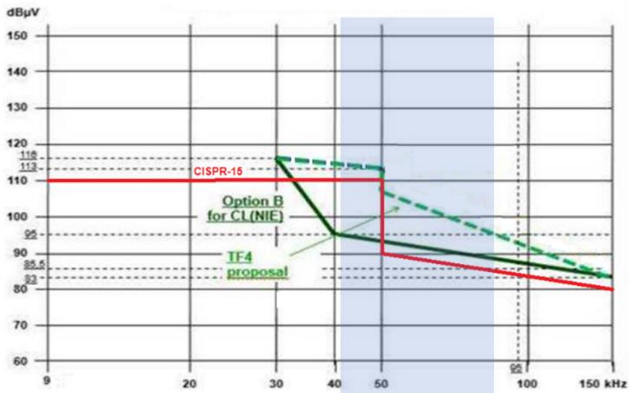

Figure 4. Considered emissions for the tests. The blue zone corresponds to the frequency band of interest (41-89 kHz).

Table 1. Frequency ranges and levels for the considered emissions.

Frequency range	Level dB (µV)
CISPR-15	
9kHz to 50kHz	110
50kHz to 150kHz	90 to 80
Option B	
9kHz to 30kHz	undefined
30kHz to 40kHz	116 to 95
40kHz to 150kHz	95 to 83
TF4	
9kHz to 30kHz	undefined
30kHz to 50kHz	116 to 113
50kHz to 150kHz	113 to 85.5

Test procedure

Before the tests, it was checked that all the meters can complete the requests successfully without the presence of noise.

The noise was calibrated according to the levels shown in Figure 4. Then, the noise was injected through the RF probe. An example of one of the injected emissions can be seen in Figure 5. The performance of the communication under NIE conditions is evaluated with the request of 1000 data frames from the receiver by the transmitter. The request is programmed at the PLC transmitter, through an ftp task. If the 1000 petitions are not completed, e.g. due to the presence of noise in the channel, the request stops, leading to an empty file. Hence, the results of the tests are evaluated as "fail". If the 1000 petitions are completed, the file with the 1000 data entries is received at the server and the test is evaluated as "pass".

Real AMI devices were considered for the tests with the intention of evaluating a realistic scenario. A concentrator and a meter were used as PLC transmitter and PLC modems, respectively. Several meters from different manufacturers, already installed and working in existing AMI deployments across Europe, have been tested. 7 meters, listed in Table 2, were evaluated.

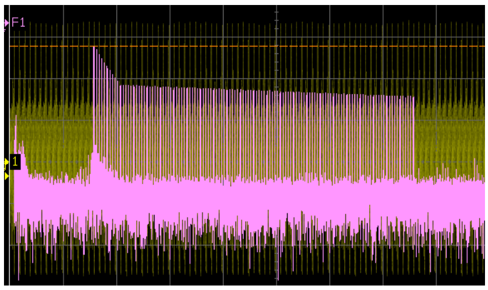

Figure 5. Example of injected noise measured at the calibration point – curve Option B.

Table 2. List of considered meters acting as PLC receivers.

Meter	Manufacturer	Type
1	Manufacturer A	Single-phased
2	Manufacturer B	Single-phased
3	Manufacturer B	Three-phased
4	Manufacturer C	Single-phased
5	Manufacturer C	Three-phased
6	Manufacturer D	Single-phased
7	Manufacturer D	Three-phased

Table 3. Channel power with noises according to the curves.

Noise curve	Channel power of the emission between 41 and 89 kHz
Option B	95.93 dBuV/48kHz
CISPR-15	102.25 dBuV/48kHz
TF4	106.72 dBuV/48kHz

RESULTS

The results from the tests can be seen in Table 3. The channel power shown in the third column was measured for the 41-89 kHz frequency range for each of the curves, hence the power level is defined in that range (dBuV/48kHz). The fourth column includes the result of the test (pass/fail), as described in the previous section. The last column shows the power levels that change the results of the tests for each of the considered meters, i.e., if the communication between the transmitter and the receiver was successful under an emission (pass), then this column will show the channel power that hamper the requests (fail), and vice versa.
In addition, Figure 6 shows the obtained channel power values for the tests graphically. The values above the reference channel power of each curve ("Ref"), represent the power level from which the meter cannot complete the requests, while the values below the reference level indicate the power level from which the meter is able to complete the requests.

Table 3. Results of PLC communications under noise emissions.

Meter	Test	Communication result applying noise according to the limits	Minimum channel power of noise to fail the communications
1	Option B	Pass	98.15
	CISPR-15	Pass	104.65
	TF4	Fail	96.8
2	Option B	Fail	94.46
	CISPR-15	Pass	105.41
	TF4	Fail	94.9
3	Option B	Fail	94.46
	CISPR-15	Pass	104.36
	TF4	Fail	96.8
4	Option B	Fail	92.56
	CISPR-15	Fail	95.45
	TF4	Fail	93.77
5	Option B	Fail	94.46
	CISPR-15	Fail	94.6
	TF4	Fail	89.05
6	Option B	Pass	98.15
	CISPR-15	Pass	104.36
	TF4	Fail	98.36
7	Option B	Pass	98.15
	CISPR-15	Pass	104.36
	TF4	Fail	98.36

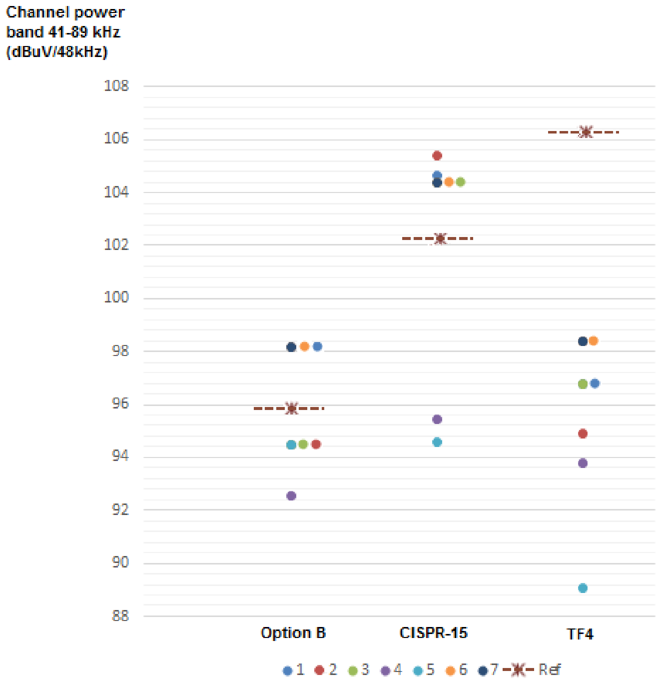

Figure 6. Minimum channel power of noise in band 41-89 kHz required to fail the communications for each of the considered meters (1-7). The channel power value of the noises adjusted to the curves (Option B, CISPR-15 and TF4) is defined as "Ref".

DISCUSSION

According to the results presented in the previous section, several findings can be observed:

- The curve TF4, which presents the highest channel power in the considered frequency band, is the most harmful emission, to the extent that any of the considered meters can complete the petitions. The channel power had to be reduced up to power levels between the curves Option B and CISPR-15 to pass the tests.
- Despite having higher power in the band of interest, the curve CISPR-15 had higher degree of success in comparison to the curve Option B for the considered meters. This can be related to the fact that the power in band in the curve CISPR-15 is accumulated only in a part of the transmission band (between 41 a 50 kHz) so the meter can manage the communication in the rest of the transmission band (between 50 and 89 kHz)
- Focusing on the differences between manufacturers, it can be observed that meters 1, 6 and 7 were the most robust devices for the considered emissions.
- Comparing the results of the communications between the three-phased meter and the single-phased meter of the same manufacturer, the results are very similar, so it can be assumed that, compared to the same implementation, the

noises affect a single-phased meter and a three-phased meter in the same way.

- Influence of the power density in band is more relevant for the performance of PLC communications than the peak levels and quasi-peak levels traditionally used to limit the emissions in the EMC standards.
- Influence of noises out of band depends on the quality of the filters implemented inside the meters

CONCLUSIONS

Existing problems from NIE over NB-PLC devices are well known and various limits for compatibility levels have been studied along the last years in EMC standards. However, these limits have not taken into account all the parameters that influence the performance of NB-PLC telecommunication devices.

Once these limits have been fixed, communications performance can be tested, to see if these compatibility levels are useful to limit the noises allowed in the EMC standards, and checking the performance of the NB-PLC communication in a controlled environment.

In this paper, the three curves that have been proposed to derive compatibility levels have been evaluated. The results show that the curve TF4 allows emissions that hamper NB-PLC communications in all of the evaluated devices. However, CISPR-15 and Option B curves, whose limits are below TF4, allow the communications of some of the tested devices. The differences in the performance depend on the particular implementation of each manufacturer.

In these latter cases, NB-PLC device manufacturers must include out of band filters and other algorithms that supervise the disturbances and manage the spectral use to improve the performance of the communications. As a consequence, these implementations increase the cost of the NB-PLC devices and limit the evolution of the uses of the NB-PLC technologies.

The reason for this awkward consequence of the existing definition of NIE limits lies on the fact that the approach of traditional EMC standards is to establish peak and quasi- peak limitations that are not enough to ensure the coexistence of NB-PLC telecommunication devices. NIE limits must define values for the total injected power in the bands of interest when telecommunication devices are involved.

Thus, this paper has demonstrated that the power density of NIE should be limited in EMC standards to ensure a correct coexistence of NIE sources and NB-PLC technologies when the later are involved.

REFERENCES

[1] A. Sendin, I. Urrutia, M. Garai, T. Arzuaga and N. Uribe, "Narrowband PLC for LV smart grid services, beyond Smart Metering," *18th IEEE International Symposium on Power Line Communications and Its Applications*, Glasgow, 2014, pp. 168-172.

[2] A. Moreno-Muñoz; A. Gil-de-Castro; S. Rönnberg; M. Bollen and E. Romero-Cadaval, “Ongoing work in CIGRE working groups on supraharmonics from power-electronic converters”. *In Proceedings of the CIRED 23rd International Conference and Exhibition on Electricity Distribution*, Lyon, France, 15–18 June 2015.

[3] CENELEC CLC/SC205A, “Study Report on Electromagnetic Interference between Electrical Equipment/Systems in the Frequency Range below 150 kHz”, Edition 3. 2015.

[4] CENELEC CLC/TR 50669, “Investigation Results on Electromagnetic Interference in the Frequency Range below 150 kHz”, 2017.

[5] CENELEC CLC/SC205A, EN 50065-1:2011, “Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148,5 kHz”, 2011.

[6] European Comission, “2014/30/EU EMC Directive on the harmonization of the laws of the Member States relating to electromagnetic compatibility”, 2014.

[7] IEC 61000-2-2: Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems.

[8] IEC. CISPR-15, “Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment”, 2018.

[9] IEC 77A/915/DC. DC Document for IEC 61000-2-2: Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low -voltage power supply systems, 2015.

[10] G. López.; J.I Moreno; E. Sánchez; C. Martínez and F. Martín. “Noise Sources, Effects and Countermeasures in Narrowband Power-Line Communications Networks: A Practical Approach”. *Energies* 2017, 10, 1238.