IEEE 1901.1 Power Line Communication electromagnetic emission study

Nuno Amaro1,3, João Saragoça1, Ricardo Cartaxo1, Wei Yang1 and Ren Yi2

1 R & D NESTER, Lisbon, Portugal
2 China Electric Power Research Institute, Beijing, China
3 E-mail: nuno.amaro@rdnester.com

Abstract. IEEE 1901.1 Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications was officially released in 2018. This standard expands the possible applications of Power Line Carriers communications by using a medium frequency technology, allowing for a higher bandwidth and bit rates compared to the current industrially used solutions. As the standard operates below a frequency of 12 MHz, and constituting a new solution in this area, it is fundamental to evaluate electromagnetic emissions and evaluate possible electromagnetic disturbances. In this paper, we present a methodology to measure electromagnetic emissions of IEEE1901.1 compatible devices. This methodology is then used to measure real emissions from two different IEEE compliant modules from two different manufacturers, including central coordinator and station devices.

1. Introduction

The deployment of smart grids and innovative power systems related services depend on the existence of smart meters allowing, among other, real time measurement and pricing and control of loads. In order to allow the implementation of these innovative services, a bidirectional communication link is required between the smart meter and the concentrator, connecting the smart meters to the core of the network.

Different communication technologies are available to implement this bidirectional communication channel, including wired and wireless solutions [1]. From these different technologies, Power Line Carrier (PLC) communications assume a very significant role, as they do not require any additional infrastructure to the existing power cables. PLCs use the power cable as communication transmission medium and a multitude of solutions are already developed, using different modulation techniques and frequencies.

It is common to separate PLC standards into two main types [2]: Narrow Band PLC (NB-PLC) – operating at frequencies lower than 500 KHz and Broad Band PLC (BB-PLC) – operating at frequencies higher than 1.8 MHz. Several PLC standards are already deployed and being used at large scale in different utilities. As one example, PRIME, an NB-PLC standard, is currently used by 32 utilities and associations with over 20 million smart meters deployed in 15 different countries [3]. BB-PLC solutions have several advantages when compared to NB-PLC, due to larger bandwidths and bit rates. These will allow the creation/implementation of additional services requiring higher communication rates and are therefore of great importance for the deployment of smart grid solutions.

In 2018, IEEE released officially the IEEE 1901.1 standard for Medium Frequency (less than 12 MHz) Power Line Communication for Smart Grid Applications standard [4]. The standard uses...
OFDM modulation and other innovative solutions as dual turbo coding, time-frequency inter-leaving and multi-area network coordination. The standards define a frequency band of 2 MHz to 12 MHz for compliant devices to operate. In order to ensure a safe deployment of IEEE1901.1 device, it is necessary to ensure that electromagnetic (EM) emissions from the devices implementing this standard are compatible with existing short-wave services. Maximum EM emissions are regulated by different standards. In Europe, CENELEC EN 50561-1 establishes methods of measurement for devices operating at frequencies up to 30 MHz [5], while EN 55032 and CISPR 32, replacing CISPR 22 / EN 55022, define the maximum limits for conducted and radiated emissions [6]. In the United States, this definition is performed through FCC 15 subpart G Standard [7]. In this paper, we adapt the methodology previously presented in [8], to measure EM emissions of two different IEEE1901.1 compatible modules, from Leaguer and Eastsoft manufacturers. Each module includes a central coordinator (CCO) and a single-phase station (STA) device. Performed measurements are explained and obtained results are herein included.

2. EM emission testing methodology

The methodology presented is applicable to test EM emissions of buried or shielded cable emissions. The main goal of applying this methodology is to verify what the IEEE 1901.1 emission levels are. As the standard is not currently deployed in low voltage networks, and since the emitters of EM radiation are the IEEE 1901.1 communication devices, a setup was created to measure emissions of these devices. This setup follows CISPR 32 and FCC 15 Subpart G standard procedures and includes the following requirements:

- The receiving/measuring antenna and the receiver should be placed in a distance of 3 to 10 meters from the device under test (DUT) or system under test (SUT) if more than one device are being tested simultaneously.
- The receiving/measuring antenna should be compliant with CISPR 16-1 and GB/T6113 standards and suitable for performing the tests specified in CISPR11 and GB4824 standards
- There is no obvious source of EM emissions neither an EM wave reflector nearby;
- Tests should be performed for both: horizontal and vertical polarization of the receiving antenna;

FCC 15 Subpart G requirements states that measurements should be carried out in a circle around the emission point, using at least 16 measurements. However, it also states that if there are environmental constraints, the number of measurement points can be reduced as long as the results obtained are enough to indicate the EM emissions profile of the DUT. For this purpose, the setup depicted in Figure 1 was created. The DUT is placed in the center of the circle while the measurements are carried out by the antenna in the different positions around the circle edge. The considered distance between the DUT and the antenna is 3 meters and the measuring points are separated by an angle of 22.5°, resulting in 16 possible measurements. In this particular case, the DUT is replaced by an SUT as there the full communication system (CCO, STA and cable) are placed in the middle of the circle.

The following test procedure was followed in order to detect and identify EM emissions originated by the communication unit and meter:

1. With the SUT at the center of the circle, draw a circle with a radius of 3 meters (which can be appropriate-ly changed according to the geographical environment, but not shorter than 3 meters), and draw 16 points at intervals of 22.5°. The number of points can be lower if there are environmental constraints that justify it. The SUT is composed of a CCO, a STA and a shielded cable connecting them. Place the receiving antenna at one of the points and adjust it to horizontal polarization (i.e., parallel direction), directly facing the SUT.
2. Connect the antenna to the receiver with the radio frequency cable. To avoid interference with the signal received by the antenna, the receiver should not be placed inside the circle.
3. Turn off the CCO and the STA so that there is no PLC communication signal transmission;
4. Perform a first frequency sweep to detect back-ground noise. At 9 kHz-150 kHz, use the peak detection method and a resolution bandwidth of 200 Hz for sweep, with a sweep time of 50 ms.
At 150 kHz-30 MHz, use the peak detection method and a resolution bandwidth of 9 kHz for sweep, with a time of 50 ms. The resolution bandwidth and scanning time can be fine-tuned according to the receiver or field test conditions. Use the maximum hold mode during the frequency sweep to obtain the measurement curve of EM background noise – curve A.

5. Turn on the CCO and the STA and start the PLC communication.

6. Repeat step 4 to obtain the measurement of EM emissions related to PLC devices - curve B.

7. Compare the two curves A and B. For the frequency points where curve B is higher than curve A by more than 6 dB, select a relatively higher number of points for final sweep. The reading time should not be less than 15 s. Record the location of the measuring point, the frequency of the reading point, the antenna polarization direction, and the reading value in detail;

8. After the reading point is completed, set the receiver SPAN to 0 and the resolution bandwidth to 100 kHz, and observe whether there is a 1ms or 4ms pulse signal.

9. Adjust the antenna to be vertically polarized (i.e., axial), and repeat steps 3 to 8.

10. Change to another measurement position and repeat steps 1 to 9 until all measurements are performed.

Figure 1. Setup for measuring EM emissions.

3. Testing setup and equipment

The testing setup followed the requirements defined in the last section. However, due to environmental constrains, only eight measuring points were considered, at angles: 0°, 22.5°, 45°, 90°, 112.5°, 135°, 157.5° and 180°. Measuring equipment included a loop antenna and the receiver and complementary connection equipment (RF cable). The loop antenna is compliant with CISPR16-1 and GB/T6113 standards consists of a loop antenna with constant conversion factor (20 dB/m) operating in the range of 9 kHz to 30 MHz. The main characteristics of the RF receiver are given in Table 1.

| Table 1. Receiver characteristics.                          |
|-------------------------------------------------------------|
| **Operating frequency range**                               |
| 9 KHz – 30 MHz                                             |
| **Maximum RF level**                                        |
| 30 dBm (1 W), with RF attenuation ≥ 10 dB                   |
| **Maximum pulse level**                                     |
| 150 V with RF attenuation ≥ 30 dB                           |
| **Resolution bandwidth – analyzer mode**                    |
| 10 Hz – 1 MHz (-3dB) with 1/2/3/5/10 steps                  |
| **Resolution bandwidth – receiver mode**                    |
| 200 Hz, 9 kHz, 120 kHz (-6dB), 1 MHz (pulse width);         |
| **Pre-selector**                                            |
| 16 fixed filters                                            |
| **Preamplifier**                                            |
| 9kHz - 3GHz, 20dB gain, normalized                          |
| **Measuring Time**                                          |
| 1 ms – 10 s                                                 |
| **Detector mode**                                           |
| Peak, quasi-peak, effective value, average value            |
This setup and measuring equipment was used to measure EM emissions of two different IEEE 1901.1 compliant modules from two manufacturers: Leaguer and Eastsoft. Each module is composed of a CCO and a STA. According to the manufacturers’ information, both modules operate in the frequency range of 2.4 MHz – 5.6 MHz.

4. Results
Using the methodology presented in Section 2 and the equipment presented in Section 3, a set of tests were performed to obtain the maximum EM emissions of the two SUT. As described in the testing procedure, the first testing step corresponds to the measurement of environmental EM emissions, to determine the noise level for measurements. Figure 2 includes an example of the background noise measurement, performed at the first measuring position (0°). Other measurements provided similar profile for the analyzed frequency spectrum.

As can be seen, there are a set of narrow band signals in the 2.4 MHz - 5.6 MHz frequency band (the band in which the SUT operates), together with higher intensity signals detected for frequencies higher than 10 MHz (not considered as relevant for this study). The Peak detection amplitude of the electromagnetic environment noise is 35-40 dBuV/m.

After the background noise was measured (corresponding to steps 3-4 of the testing procedure), the IEEE1901.1 modules were turned on and new frequency sweeps were performed to measure EM emissions originated from the PLC devices. Steps 5 to 10 of the aforementioned procedure were followed, measuring the EM emissions from the PLC modules and comparing those to the previously measured environmental EM noise. Due to physical constraints, eight different angular positions were selected to perform measurements.

Both modules were tested in the exact same conditions and using the same test procedure, minimizing possible external factors for the testing results. Table 2 contains a summary of results obtained for the tests performed using the module from Eastsoft while Table 3 contains results for tests performed to the Leaguer device. Each module is composed of a CCO and a single-phase STA.

Results obtained for the EM emissions tests performed to the Eastsoft IEEE1901.1 module indicate that EM radiation emitted by the devices (CCO and STA) are within limits established by current standards and best practices. Maximum EM radiation measured at 3 meters distance is 53 dBuV/m while quasi-peak radiation is 58 dBuV/m, being generally below 45 dBuV/m, meeting the requirements of FCC 15 Subpart G. These results also indicate that there is not a relevant variation of measured emissions in the different measured angles, indicating that there is a homogeneous emission of EM radiation, as could be expected from the measured PLC devices, since the radiation emitted corresponds to EM “leakage” and not signal emissions. Thus, the fact that only eight different
measuring angles were considered due to physical restrictions, which is lower than the recommended number of measuring points (16), should not present any source of incompleteness in the performed tests. Additionally, it can also be seen that there is no clear dependence on the polarization method, since values measured for the same frequencies are similar disregarding the polarization method defined in the measuring antenna.

Table 2. Test results to Eastsoft module.

| Position (refer to Figure 1) | Antenna Polarization | Frequency (MHz) | Peak (dBuV/m) | Quasi-peak (dBuV/m) |
|-----------------------------|----------------------|----------------|--------------|---------------------|
| 0                           | Horizontal           | 2.514          | 41.59        | 36.92               |
| 0                           | Horizontal           | 4.234          | 46.3         | 51.24               |
| 0                           | Vertical             | 3.258          | 46.38        | 30.78               |
| 0                           | Vertical             | 3.426          | 42.39        | 40.08               |
| 22.5                        | Horizontal           | 2.606          | 45.38        | 37.43               |
| 22.5                        | Horizontal           | 3.238          | 44.75        | 30.69               |
| 22.5                        | Horizontal           | 3.634          | 44.92        | 40.49               |
| 22.5                        | Vertical             | 2.834          | 42.62        | 36.37               |
| 22.5                        | Vertical             | 3.446          | 41.39        | 30.73               |
| 22.5                        | Vertical             | 3.986          | 40.14        | 40.41               |
| 45                          | Horizontal           | 2.642          | 46.11        | 41.16               |
| 45                          | Horizontal           | 3.138          | 50.06        | 30.65               |
| 45                          | Horizontal           | 3.618          | 46.8         | 31.05               |
| 45                          | Vertical             | 2.758          | 46.6         | 37.83               |
| 45                          | Vertical             | 3.866          | 45.32        | 39.98               |
| 90                          | Horizontal           | 2.61           | 40.39        | 33.6                |
| 90                          | Horizontal           | 3.218          | 48.22        | 40                  |
| 90                          | Horizontal           | 3.482          | 52.3         | 45.22               |
| 90                          | Vertical             | 2.85           | 48.03        | 58.18               |
| 90                          | Vertical             | 3.318          | 45.11        | 52.85               |
| 112.5                       | Horizontal           | 3.554          | 43.19        | 30.51               |
| 112.5                       | Horizontal           | 3.822          | 53.26        | 30.84               |
| 112.5                       | Vertical             | 2.806          | 42.72        | 35.83               |
| 112.5                       | Vertical             | 3.898          | 47.13        | 31.32               |
| 135                         | Horizontal           | 2.586          | 38.29        | 31.7                |
| 135                         | Horizontal           | 4.986          | 44.06        | 44.16               |
| 135                         | Vertical             | 2.726          | 39.94        | 32.34               |
| 135                         | Vertical             | 3.554          | 39.57        | 30.23               |
| 157.5                       | Horizontal           | 2.586          | 39.09        | 33.14               |
| 157.5                       | Horizontal           | 4.71           | 44.9         | 38.94               |
| 157.5                       | Vertical             | 2.566          | 39.78        | 34.08               |
| 157.5                       | Vertical             | 2.674          | 41.2         | 31.39               |
| 180                         | Horizontal           | 4.702          | 44.92        | 31.32               |
| 180                         | Horizontal           | 5.134          | 51.45        | 34.37               |
| 180                         | Vertical             | 2.59           | 39.12        | 31.81               |
| 180                         | Vertical             | 4.746          | 43.76        | 32.48               |

For the completeness of the performed tests, it is relevant to mention that the device broadcasts were identified at a frequency of 3.554 MHz and suspected broadcasts were identified at frequencies: 2.85 MHz, 3.318 MHz, 3.986 MHz and 4.986 MHz.

Measurements performed to the Leaguer module indicate that this device also generally respects the FCC 15 Subpart G established EM emissions limits. Measured peak emission at three meters
distance was 59 dBuV/m, while the highest quasi-peak emission is 50 dBuV/m for frequencies of 4.49
MHz (135°) and 3.318 MHz (90°) respectively.

Table 3. Test results to Leaguer module.

| Position (refer to Figure 1) | Antenna Polarization | Frequency (MHz) | Peak (dBuV/m) | Quasi-peak (dBuV/m) |
|-----------------------------|----------------------|-----------------|---------------|---------------------|
| 0                           | Horizontal           | 2.666           | 43.35         | 36.43               |
| 0                           | Horizontal           | 3.898           | 53.96         | 31.25               |
| 0                           | Horizontal           | 4.614           | 59.19         | 32.19               |
| 0                           | Vertical             | 3.246           | 38.54         | 31.87               |
| 0                           | Vertical             | 4.234           | 44.31         | 38.81               |
| 0                           | Vertical             | 4.996           | 48.66         | 31.9                |
| 22.5                        | Horizontal           | 2.658           | 45.01         | 37.55               |
| 22.5                        | Horizontal           | 3.482           | 38.9          | 35.43               |
| 22.5                        | Vertical             | 2.434           | 42.32         | 30.27               |
| 22.5                        | Vertical             | 3.27            | 38.41         | 32.77               |
| 22.5                        | Vertical             | 3.438           | 38.46         | 32.08               |
| 45                          | Horizontal           | 2.506           | 43.36         | 34.13               |
| 45                          | Horizontal           | 2.63            | 45.54         | 37.87               |
| 45                          | Horizontal           | 2.682           | 44.32         | 38.16               |
| 45                          | Vertical             | 2.662           | 41.52         | 35.2                |
| 45                          | Vertical             | 2.85            | 42.2          | 38.9                |
| 45                          | Vertical             | 3.478           | 42.29         | 38.46               |
| 90                          | Horizontal           | 3.05            | 38.89         | 32.94               |
| 90                          | Horizontal           | 3.318           | 49.67         | 49.96               |
| 90                          | Vertical             | 2.422           | 43.3          | 32.07               |
| 90                          | Vertical             | 3.322           | 50.26         | 50.24               |
| 112.5                       | Horizontal           | 3.046           | 39.44         | 32.74               |
| 112.5                       | Horizontal           | 3.154           | 41.85         | 42.42               |
| 112.5                       | Vertical             | 3.27            | 41.54         | 32.26               |
| 112.5                       | Vertical             | 4.174           | 41.14         | 34.33               |
| 135                         | Horizontal           | 3.874           | 59.09         | 30.55               |
| 135                         | Horizontal           | 4.49            | 59.34         | 31.08               |
| 135                         | Vertical             | 3.442           | 40.28         | 33.29               |
| 135                         | Vertical             | 4.75            | 45.46         | 35.94               |
| 157.5                       | Horizontal           | 2.662           | 38.44         | 32.6                |
| 157.5                       | Horizontal           | 3.398           | 41.65         | 30.71               |
| 157.5                       | Vertical             | 4.518           | 41.74         | 32.87               |
| 157.5                       | Vertical             | 4.966           | 49.25         | 31.9                |
| 157.5                       | Vertical             | 5.194           | 50.74         | 31.86               |
| 180                         | Horizontal           | 4.454           | 45.36         | 31.44               |
| 180                         | Horizontal           | 4.898           | 49.12         | 38.77               |
| 180                         | Horizontal           | 5.122           | 48.35         | 32.15               |
| 180                         | Vertical             | 3.71            | 38.19         | 32.47               |
| 180                         | Vertical             | 5.098           | 42.42         | 31.78               |

Similar to the previous device, measurements performed indicate that there are no relevant
correlations between the measuring angle and the antenna polarization, also indicating that the device
emits EM radiation in a homogeneous way. These results also indicate that there is no relevant issue in
decreasing the number of measurements from six-teen to eight, which was done for both devices.
Leaguer device had a confirmed broadcast for frequencies of 3.154 MHz and 3.312 MHz and there are
suspected broadcasts at 2.85 MHz, 3.478 MHz and 4.75 MHz.
Generally, EM emissions of Leaguer module are higher of those emitted by Eastsoft module, whereas both devices respect maximum emission limits established by the current standards.

5. Conclusions

Broadband power line carrier technologies can contribute greatly to the further development of smart grid applications and services, due to their increased bandwidth and bit rates when compared to most used solutions which as narrow band. IEEE 1901.1 is a standard for broadband power line carrier communications with these capabilities. As the standard operates in a frequency range up to 12 MHz, it is important to measure the impact that EM emissions from compliant devices can have on their vicinity as these emissions can interfere with other EM systems.

In this work, we adapted a previously developed methodology to measure EM emissions from devices compliant with IEEE 1901.1 and used this methodology to measure EM radiation from devices from two different manufacturers. Measurements performed allow concluding that both devices comply with the maximum limits established for EM emissions in different standards (FCC 15 Subpart G and CISPR 32) and are less likely to interfere with other EM systems. Furthermore, obtained results indicate that emissions generated by these devices are not dependent of angle of measurement and/or receiving antenna polarization. The developed methodology can be applied to other devices, providing a feasible technical solution for measurement of EM emissions of IEEE1901.1 compliant devices.

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References

[1] Z Liposcek and M Boskovic 2013 Survey of smart metering communication technologies In Eurocon 2013, pp. 1391-1400
[2] S Galli, A Scaglione and Z Wang 2011 For the Grid and Through the Grid: The Role of Power Line Communications in the Smart Grid Proc. IEEE vol. 99, no. 6, pp. 998-1027
[3] Prime Alliance 2021 Interoperable Standard for Advanced Meter Management & Smart Grid
[4] IEEE 1901.1 2018 Standard for Medium Frequency (less than 12 MHz) Power Line Communications for Smart Grid Applications
[5] CENELEC EN 50561-1 Power line communication apparatus used in low-voltage installations - Radio disturbance characteristics - Limits and methods of measurement - Part 1: Apparatus for in-home use 2013. [Online]. Available: https://standards.globalspec.com/std/13385512/en-iec-55016-1-1
[6] CISPR CISPR 32:2015 Electromagnetic compatibility of multimedia equipment - Emissions requirements,” 2015. [Online]. Available: https://webstore.iec.ch/publication/22046
[7] FCC FCC 15 Subpart G Broadband Over Power Line (BPL) Measurement Guidelines [Online]. Available: https://www.govinfo.gov/content/pkg/CFR-2014-title47-vol1/pdf/CFR-2014-title47-vol1-part15.pdf
[8] H Zhang, X Liu, R Li and K Zheng 2019 Test Methods for EM Emission for Broadband Carrier Communication Systems over Low-voltage Power Lines In 2019 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm) vol. 01, no. 01, pp. 1-7