EMC ANALYSIS OF THE EDP DISTRIBUIÇÃO SMART GRID

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ABSTRACT

With the smart grid revolution, many questions have been raised regarding the compliance of the electromagnetic emissions of the smart meters installed on the grid.

In this paper are presented some measurements carried out on real field conditions over installed equipment using different communication technologies. The results proved that the values of the signals generated by the devices measured near EDP facilities and customers' premises are several times lower than the maximum levels defined by the current legislation.

EDP Distribuição decided to perform all these measures and study different technologies to ensure a safe and compliant to the current regulation smart grid deployment. The results gave EDP Distribuição the confidence to continue exploring these communication technologies and to continue improving the electrical grid.

INTRODUCTION

In the past, Electrical utilities faced a series of challenges because of the Extremely low frequency fields (50Hz) and it will always be a great concern. EDP Distribuição still measures and controls the 50Hz field produced by the power grid, not only for mandatory reasons, but also to ensure the safety of their clients and their employees.

Nowadays, utility companies face a new challenge that comes along with the natural evolution of the communication technologies. A smartgrid comprises the installation of a variety of devices – smart meters, data concentrators, repeaters and sensors – all with communication capabilities. All these devices produce electromagnetic signals and it is mandatory to ensure the safety of general population and the Power Grid's compliance with the existing regulation. For that purpose and bearing in mind that this subject is very sensitive and often controversial, it's important to measure and assess the EMF in real installations.

It has been reported some anti-smart grid reactions on some countries, for instance US, Australia but also in UK, Sweden etc.

EDP Distribuição is installing smartgrid devices with several technologies. These devices can be divided in two main functional groups according to their location and role. The largest share of installed devices are Smart Meters, which are located at or near customers' premises. There is also a smaller subset of devices, installed at the secondary substation, such as Distribution Transformer Controllers (DTC), routers and some sensors.

EDP Distribuição is using several communication technologies, such as PLC, GPRS and RF-Mesh. The goal of the work to be presented in this article is to carefully investigate if, in any case, the EMF exceeds the limits defined on the ICNIRP normative and on the Portuguese legislation (Portaria 1421/2004), with regard to the exposition of general population and the values defined in the European Directive 2009/EC/72.

Before the field installation, the devices were tested on a controlled scenario in order to check the signal levels of the communications. After the laboratory test, several measures were performed on real field situations. During the field campaign, the EMFs were measured before and after the smart meters installation, in order to compare the results and measure the signal emissions of all the different equipment in several scenarios. The field measurements were conducted in several customers' premises, secondary substations, substations and other locations where the signal repeaters were installed.

The great majority of measurements were focused on the radiated Electromagnetic emissions from the devices.

Because the vast majority of smart meters installed in Portugal use Power Line Communication technology, some conducted radiation measurements were also performed, to check if the signal levels were within the standard limits. The signal transmission levels, and the measurement conditions, can be found on the EN 50065-1 standard. It is important to control the conducted emissions because this low frequency signals injected on the grid can act as a giant antenna. That is why the standard defines a power line emission level to reduce this effect.

The smart grid devices, as all the other electrical devices, emit some radiofrequency (RF) electromagnetic radiation. They emit conducted and radiated radiation in the same way a TV, Laptop, cell phone or a modem. Because there are some similar aspects between the smart grid devices and cell phones, the same public concerns are applied. Some Smart grid devices use the same technologies found on the cell phones, but are significantly fewer than all the cell phones, smartphones and similar equipment, besides smart grid devices have lower emission levels.

Considering these facts, this subject should be carefully handled and that is why EDP Distribuição decided to study the emission of these devices.

COMMUNICATION TECHNOLOGIES

In this section it is presented some of the communication technologies considered in the measurement tests. The knowledge of these communication standards is very important in order to be able to compare the results between them (when related to their standard emission levels) and to guarantee a proper measure of the RF signals emitted of each technology.

To perform the measurements of RF signals it is necessary to know the characteristics of the communication protocols, the bandwidth reserved for each technology, the carriers' frequency and channel spacing, in order to configure the measurement equipment. The communication technologies' main characteristics, used to configure the equipment, are addressed in the following sub sections. Some of the technologies presented below are not being used on smart grid devices, but it was decided to measure all these RF signal to understand the spectrum contribution of this new elements installed on the power grid.

In the following figure, it is possible to see that each technology has its own spectrum band and it is crucial to adjust the measurement device to each technology in order to perform a reliable measure.

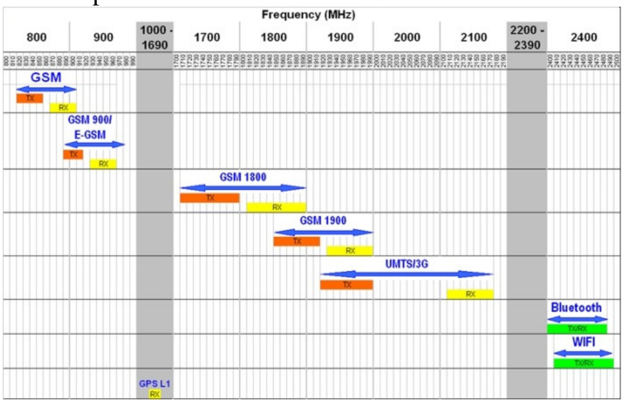

Figure 1 Spectrum of the radio technologies

GSM/GPRS, LTE, UMTS

The GSM/GPRS technology used for mobile communications transmits in 900 and 1800 MHz band. To measure the signal in these frequency bands it was used the Software predefined configurations of the measurement device, the GSM/GPRS900 and GSM/GPRS1800 with "Resolution BW" set to 200 kHz.

These configurations feature 200 kHz channel spacing, carriers with frequency centered at 925.2, 925.4 to 959.8 MHz, for the 900 MHz band, carriers with frequency centered at 1820.2, 1820.4 to 1875.4 MHz, for the 1800 MHz band. These configurations were modified in order to detect signals transmitted at frequencies between 880 and 915 MHz for the 900 MHz band, and signals transmitted at frequencies between 1710 and 1784 MHz, for the 1800MHz band, since in Portugal these bands are used by GSM/GPRS signal. To measure the signal in these frequency bands it was used the GSM/GPRS900_E with "Resolution BW" set to 200 kHz (slow measurement) and the GSM/GPRS900_E_fast with "Resolution BW" set to 100 kHz (fast measurement).

In addition to the GSM/GPRS signal it was also measured other mobile communication technologies, such as the UMTS and LTE technology.

RF-MESH

Since the smart meter with RF-mesh technology is yet a device under test, it was assigned by the regulatory authority for telecommunications communications in Portugal (ANACOM) a temporary license for transmission on bandwidth between 870.2 and 873.8 MHz, with 200 kHz channel spacing, enabling 14 channels with maximum transmission rate of 100kbps. It were used 2 RF-mesh measurement configurations, the RF-MESH with "Resolution BW" set to 100 kHz (fast measurement) and RF-MESH_2 with "Resolution BW" set to 300 kHz (slow measurement);

PLC PRIME

Power Line Communications (PLC) is the communication technology that allows the transmission/reception of data through the AC electrical power grid. There are several PLC protocols and technologies for different application, but for regulation reasons, according to the EN 50065-1, the PLC used for smart grid purposes is a narrow band PLC and the frequency band is the CENELEC A (3 kHz to 95 kHz). EDP Distribuição uses an open standard technology known as PLC PRIME which operates within the CENELEC A band.

It is important to state that the main concerns with this technology are related to the conducted emissions, because the radiated emissions are very low and it is important to control the signal transmitted by the PLC devices into the Power Grid.

LEGISLATION AND STANDARDS

According to the article 152 of the Amsterdam Treaty, the EU has approved, on the health board, the 1999/519/CE recommendations to the limits of electric and magnetic exposure. These recommendations are the same as the ones defined by the ICNIRP [2].

The limits set by the ICNIRP recommendations [2], for public exposure to electromagnetic fields from 0 Hz to 300 GHz and adopted in the Portuguese Law through 1421/2004 decree on 23 November [4], are presented in the following table:

Table I – Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values);

Frequency range	***E* - field strength (V/m)**	***H* - field strength (A/m)**	***B* - field (μT)**	**Equivalent plane wave power density $S_{eq}(W/m^2)$**
< 1Hz	-	$3{,}2\times 10^4$	4×10^4	-
1-8 Hz	10 000	$3{,}2\times 10^4/f^2$	$4\times 10^4/f^2$	-
8-25 Hz	10 000	$4000/f$	$5000/f$	-
0,025-0,8 kHz	$250/f$	$4/f$	$5/f$	-
0,8-3 kHz	$250/f$	5	6,25	-
3-150 kHz	87	5	6,25	-
0,15-1 MHz	87	$0{,}73/f$	$0{,}92/f$	-
1-10 MHz	$87/f^{1/2}$	$0{,}73/f$	$0{,}92/f$	-
10-400 MHz	28	0,073	0,092	2

400-2000 MHz	$1,375f^{1/2}$	$0,0037f^{1/2}$	$0,0046f^{1/2}$	$f/200$
2-300 GHz	61	0,16	0,20	10

The limits presented on **Error! Reference source not found.** are for the general population exposure levels. The conclusions of this paper are based on these limit values.

It is also important to state that, for the PLC measurements, it was taken in consideration the EN50065-1 standard [5], in which the frequency band, emission levels and measurement methodology are defined. The maximum signal transmission allowed for the Smart Grid PLC devices decreases linearly with the logarithm of frequency from 134dBµV to 120dBµV.

MEASUREMENT DEVICES

An isotropic antenna was used to measure the electric field created by RF signals, which allows field measurements for frequencies between 30 MHz and 3.6 GHz, a spectrum analyzer FSH4 that allows frequency range selection and a tripod. The isotropic antenna is composed of three independent elements which are positioned orthogonal to each other and which allows three measurements along the X, Y and Z axis without requiring adjustment of the antenna. The total field value results from these three measurements.

$$|E| = \sqrt{E_x^2 + E_y^2 + E_z^2} \quad (1)$$

The equipment allows measurement of the electric field $\mathrm{E\,(V/m)}$, power density $\mathrm{S(\mu W/cm^2)}$ and electric field exposure in relation to the ICNIRP limits (parts per thousand). The electric field E exposure in relation to the ICNIRP limits L, is given by the following expression:

$$Exposure[‰] = \frac{E^2}{L^2} \times 1000 \quad (2)$$

The equipment doesn't measure the magnetic field intensity H or magnetic flux density B, but all the measurements were done in far field conditions. The magnetic field intensity and flux density values can be calculated using the free space characteristic impedance ($\mathrm{Z_0} = 377\Omega$) [3],

$$H = \frac{E}{377} \quad (3)$$

And,

$$B = \mu . H \quad (4)$$

Since all measures were performed in far field, the magnetic flux intensity and the magnetic flux density can be calculated from the electric field value, using the expressions 3 and 4.

To check if the transmission levels of the PLC devices are according to the EN50065-1, a Line Impedance Stabilization Network (LISN) was used. This device is an artificial network that has two main features. The first one is that it filters the noise from the electrical grid and the second one is that it has a well-known impedance.

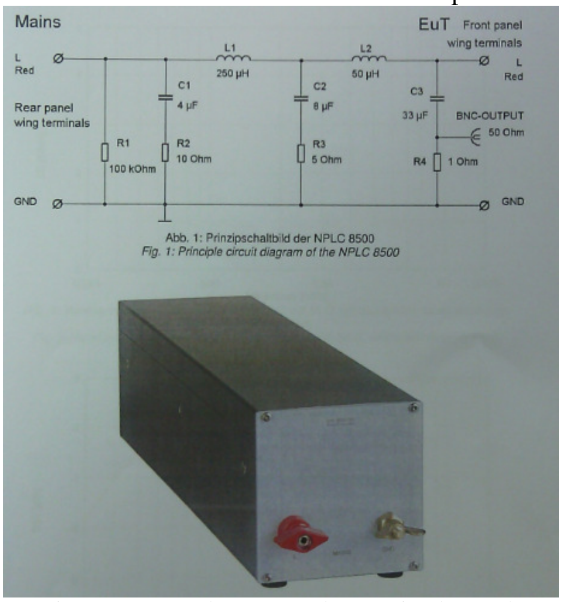

Figure 2 LISN used to measure the PLC signal strength

The LISN presented in Figure 2, is the recommended LISN on the ITU-T G.9901 standard [6], and because the impedance of this LISN is 2Ω (not 1 Ω, as defined on the EN50065-1), the measurement results should be increased by 6dB.

MEASUREMENT PROCEDURES

The electric field caused by RF signals was measured in several stages and the RF technologies used by the smart grid devices were the GSM/GPRS and RF-Mesh.

The first stage corresponds to the preliminary measurements, performed under controlled conditions on EDP LABELEC facilities.

The second stage refers to the tests performed inside some EDP Distribuição facilities (primary and secondary substations), where some devices were installed.

The last stage regards the measures performed near some RF-Mesh smart meters already installed.

All the measures were performed on far field conditions according to the standards recommendations in several locations around the devices, different heights (0-1.8m) and repeated several times for each situation.

The PLC maximum signal transmission levels were measured on laboratory in EDP LABELEC, according to the recommendations of the standards.

MEASUREMENT RESULTS

In this section are presented some of the most relevant results. Considering the large amount of data generated during the tests, the results are focused on the maximum levels recorded for all scenarios.

Laboratory RF measurements

The following results correspond to a scenario in which 2 data concentrators (with GPRS and RF-MESH) capabilities, 2 GPRS smart meters and 3 RF-MESH meters where in the same division. Measurements were performed inside this laboratory division (5x10meters) and these were the highest results recorded:

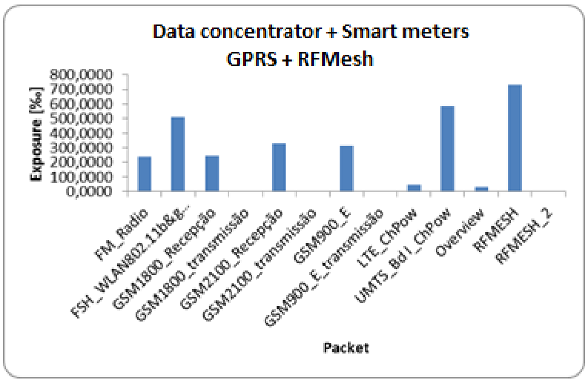

Figure 3 Results of the Laboratory tests

All the Electric emissions from the different technologies were several times below the limits. On the previous graphic, it is possible to compare the exposure of the different technologies. In this particular case, the highest values were recorded for the RF-Mesh technology. The electric field was 34V/m, but the limit for this frequency is 41V/m. Note that the exposure was very similar to the UMTS and WIFI technologies. It is also important to refer that the communication between the devices was forced and that in real field scenarios, there are not such a concentration of devices installed in the same room.

Another test was performed when all devices were shut down. It was noticed that the GSM/GPRS levels were basically the same and some times higher. This shows that the contribution of the smart grid devices to the total radiation exposure of the GSM/GPRS technology is not significant.

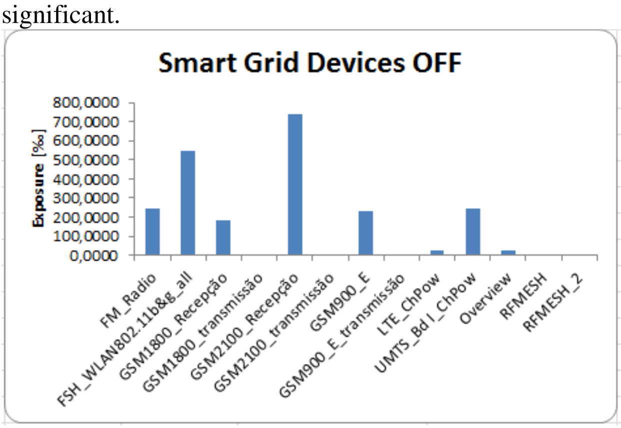

Figure 4 Results of the Laboratory tests with devices off

Laboratory PLC measurements

The Power line output transmission from the PLC devices was measured with a spectrum analyzer and using a LISN.

It were measured the signals from several devices from different manufacturers. The highest values measured from all devices are presented in the following table.

Table III – Results from the PLC measurements;

	Devices	Maximum value (dBµV)	Frequency (KHz)
Smart Meters	A	116,6	66,7
	B	115,7	60,7
	C	109,9	59
	D	110,4	49,7
	E	115,9	75,85
	F	111,9	52,8
	G	112,7	56,3
Data concentrators	H	113,5	61,4
	I	116,2	52,12

On the previous table, it is possible to see the maximum results from the PLC emissions measurements, from several devices. This test was performed on 7 meters and 2 data concentrators. Note that for the CENELEC A, the transmission level limit is between 134-120dBµV. The values presented and measured were always below 120dBµV.

In Figure 5, it is possible to see the spectrum emission of the PLC Device I on the CENELEC A Band. It is important to say that it is needed to add 6dB to the result.

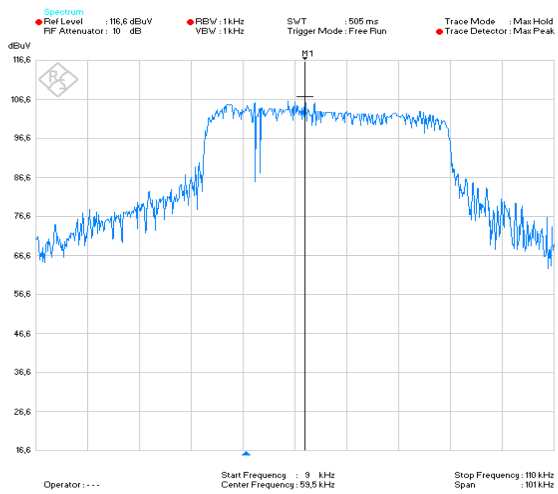

Figure 5 Results of the Laboratory measures to Device I

Field RF measurements without RF-MESH devices

In this scenario, the goal was to measure the GPRS band signal in several locations, with some smart grid devices with GPRS capabilities installed. On some of this locations (primary and secondary substations) will be also installed some RF-MESH devices and it is important to understand the spectrum emission and the exposure ratios of each technology.

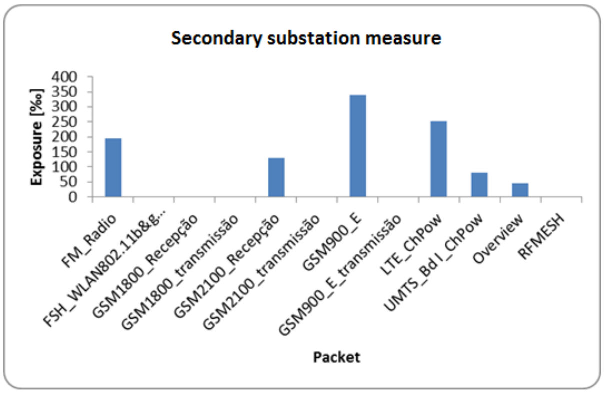

Figure 6 Results from field tests with only GPRS devices

The GSM/GPRS exposure, in this situation, was the highest one but all the values measured were several times below the standard limits.

Field RF measurements with RF-MESH devices

On the last stage, some measurements were performed near RF-MESH devices, and in all situations the fields measured were several times below the limits. In Figure 7 it is presented the highest RF-MESH field values recorded. This occurred on an electrical secondary substation with 2 data concentrators installed.

The results show that, once again, the values measured were several times below the limits (the limit is 40V/m, and the maximum value measured was 1.8V/m).

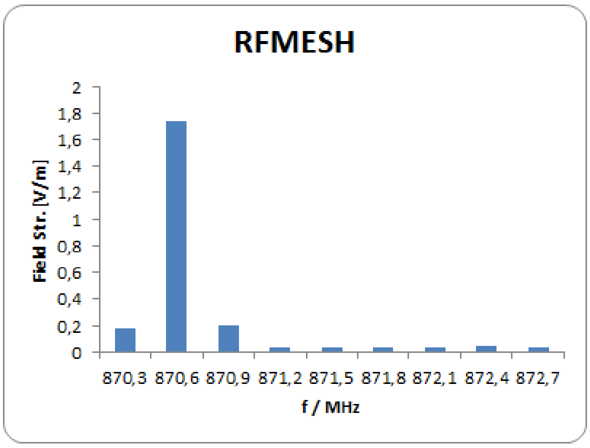

Figure 7 Results from field tests with RF-MESH devices

CONCLUSIONS

Several communication technologies used on Smart Grid devices were presented in the present paper. EDP Distribuição has decided to study these technologies and measure the EMF produced by the devices to verify the compliance of the equipments installed on the Grid according to the existent standards.

Measurements were performed in several scenarios and the results showed that the field emissions from these Smart Grid devices are within the limits and that the field levels are very low.

Other radio technologies were measured in addition to the ones used on the EDP Distribuição's smart grid devices, such as GSM / 3G / 4G / Wifi and **in none of the scenarios were identified levels above the limits**.

It was also noticeable that the technology with the highest exposure ratio in almost all scenarios was the FM Radio, but also several times below the limits.

The Power line emissions measurements showed that the devices used by EDP Distruibuição transmit according to the CENELEC standard, i.e. on the A band and with a maximum transmission output below the limits defined.

On the GPRS measurements performed on the field, it was not possible to highlight the contribution of EDP devices, because, as it is known, this kind of electromagnetic radiation covers almost all the urban areas for telecommunication purposes and therefore the contribution of the smart grid devices is not significant for the total emission.

EDP Distribuição will continue to monitor the electromagnetic field produced by the smart grid devices and will continue the study of these new communication technologies. Measurement plans have been defined in order to continue the field measurements according to the installation of new smart grid devices. The goal is and will always be insuring the safety of the grid and the public.

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