ERDF ENDORSES POWER QUALITY FOR E-MOBILITY

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ABSTRACT

ERDF endorses every electrical connection request for charging infrastructures on the distribution network. Within that context, this paper investigates current harmonics (0 – 2 kHz) and high-frequency disturbances (2 - 150 kHz) induced by electric vehicles in the low-voltage network. Regarding harmonics, the vehicles tested individually do not emit high current harmonics. However, when few vehicles of the same model charge nearby, current harmonics add up and can cause high voltage harmonics in some situations. As far as power line communications are concerned, despite the lack of a global EMC standard defining compatibility levels in the range 2 – 150 kHz, the vehicles tested did not lead to unacceptable performance losses in the conditions of the tests. Nevertheless, significant progress could still be achieved for E-mobility equipment.

INTRODUCTION

For charging purposes, most electric vehicles (EVs) are connected to the low voltage (LV) network. Since they are made up of power electronics, these chargers induce current harmonics (0 – 2 kHz) and high frequency disturbances (2 - 150 kHz) on the network. Emission limits for individual loads apply in the 0 – 2 kHz range [2], but it is not the case in the 2 – 150 kHz range.

This is why ERDF and its E-Mobility project, with EDF R&D support, aims at verifying that the emitted disturbances do not affect other devices connected to the network, especially those using power line communications (PLC) in the frequency range 2 – 150 kHz, for which no global EMC standard is yet available.

POWER QUALITY IN THE RANGE 0 – 2 KHZ

EDF R&D has carried out a laboratory test campaign to assess firstly the individual behaviour of six different models of EV, and secondly, how multiple charging affects power quality.

Individual tests

Test setup and measurement methodology

The EVs have been tested one at a time in controlled conditions. They were supplied by a pure single-phase sine wave voltage produced by a power amplifier. The measurements have been done at the power amplifier output using measurement equipment with a 100 kHz sample frequency.

In order to evaluate the harmonic levels for the current, the method specified in the IEC 61000-3-2 international standard has been used, except for the grouping of intermediate components. Indeed, the purpose of these tests is investigation and not certification. As a consequence, the results presented hereafter cannot be used for certification purposes.

Results

The average charging pattern of the vehicles tested is described in Figure 1 below. The charging mode [1], the intensity and power supplied to the vehicles are given in the table hereafter.

The harmonic spectra of the vehicles depend upon the charging phase (start, stabilised or end). The spectrum measured during the stabilised phase is the most relevant as it represents the main charging phase over time.

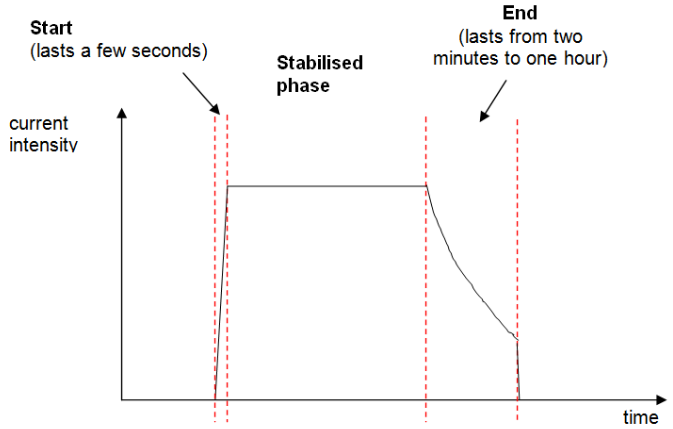

Figure 1: Average charging pattern of the vehicles tested

EV model#	#1	#2	#3	#4	#5	#6
Charging mode [1]	3	3	1	3	2	2
Max. intensity during stabilised phase (A)	15.7	15.9	12	15.7	9.6	9.4
Max. active power during stabilised phase (kW)	3.6	3.5	2.8	3.6	2.2	2.2

Table 1 : Charging information of the vehicles tested

For EV#2 and EV#3, it should be highlighted that the 3rd harmonic amplitude respectively increases and decreases by 400 mA during the stabilised phase. For all other harmonic orders and vehicles, the variations can be neglected during the stabilised phase. Thus, it can be stated that, except for the 3rd harmonic order of two vehicles, the spectra given are representative of the charging of the vehicles in the test conditions applied.

The spectra of the six vehicles are depicted on Figure 2 below. For each harmonic order, the amplitude is an average value calculated over a 2.5 min observation period. This period has been chosen during the stabilised phase such that it corresponds to the highest Total Harmonic Current (see [2] for more details). These spectra show that, except for EV#2, the harmonic amplitudes are quite low. The amplitudes of the 23rd, 25th and 27th orders produced by EV#2 reach more than twice the highest amplitude of the other vehicles. However the spectrum of an electric vehicle may vary depending on other factors than its charging state. Indeed, other studies performed by EDF R&D have shown that the current harmonics produced by equipment can vary with:

- The output power
- The amplitude and phase angle of the voltage harmonics at the equipment input

This behaviour has not been tested yet on electric vehicles in EDF R&D's laboratory. But EDF R&D has tested several EVs in charge at the same time. This test is described in the following paragraph.

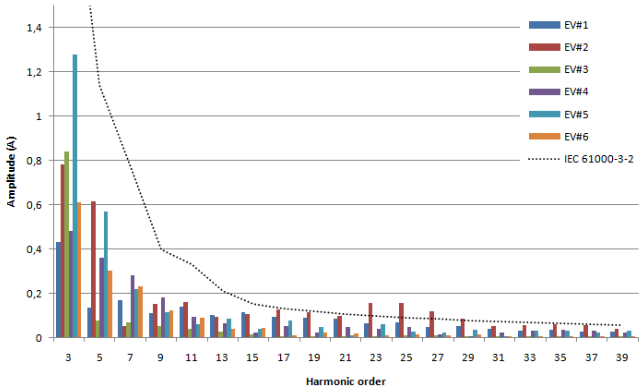

Figure 2: Current spectra during the stabilised charging phase of the vehicles tested

Several EVs charging in parallel

Test setup

Four EV#1 model vehicles were connected to the same phase at the same point of a powerful network: the network impedance at this point is in the range of 10 to 20 mΩ. In order to evaluate their influence on the voltage harmonics, two impedances have been used in order to increase the short-circuit impedance of the network. The first one has been connected in series on the phase wire and the other one in series on the neutral wire. These two impedances are used together and named in this paragraph "the test impedance". The global value of this test impedance is: $Z = 38 + j112$ mΩ. This value can be found on some public LV networks. Charging mode 3 [1] at maximum power (3.6 kW) has been used for this test for all four EVs. The measurement point was located between the test impedance and the connection point of the four EVs. The measurement equipment used was the same as the one used for the individual tests. The "total current" refers to the current measured upstream from the point of connection of the four EVs.

Results

Figure 3 below shows the evolution of the total current harmonic spectrum with the number of EVs in charge, with test impedance. It can be stressed that, up to the 29th order the current harmonics amplitudes sum up at the point of connection. Indeed, since the four EVs are of the same model, the individual current harmonics of lower orders are in phase.

Figure 4 below depicts the evolution of the voltage spectrum with the number of EVs in charge with the test impedance. The harmonic voltage limits of the European standard EN 50160 [3] have been added for information. For better readability, the scale has been adjusted and the EN 50160 limits have been cut at certain orders. Firstly, it should be noted that some voltage harmonics exist without any EV in charge. These harmonics come from the network supplying the laboratory. As these voltage harmonics vary with time apart from the EVs tested, one should be cautious when interpreting these results. Without the test impedance, adding charging EVs has no significant impact on the voltage harmonics. With the test impedance, adding EVs has a clearer impact: it increases voltage harmonics of orders 3 and 11 to 35. This confirms the well-known fact that, the higher the short-circuit impedance (i.e. the lower the short-circuit power), the higher the impact of a disturbing load on the voltage. Besides, with the test impedance, the 21st order is close to the EN 50160 limit. In these conditions, two additional EVs of the same model would have caused it to exceed the limit. Moreover, the voltage harmonics on any LV network are the addition of those coming from the MV network and those caused by LV loads on this same network. This explains why the maximum emission level of an individual LV installation should be only a fraction of the EN 50160 limits. In order not to exceed the EN 50160 harmonic voltage levels, the global harmonic voltage level induced by all the loads connected to a given LV network should generally be limited in Europe to about 25 % of the EN 50160 limit for lower non-triplen harmonic orders (see [4] for more details).

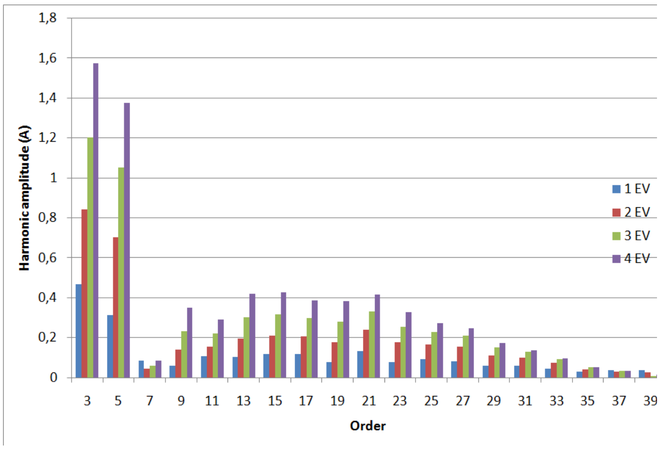

Figure 3: Evolution of the total current spectrum with the number of EVs in charge – with test impedance

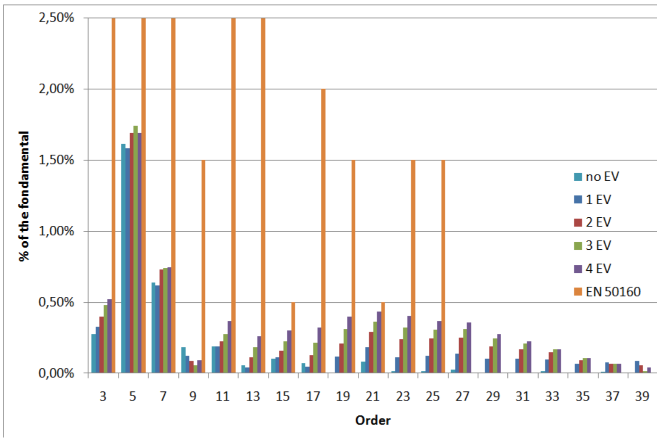

Figure 4: Evolution of the voltage spectrum with the number of EVs in charge – with test impedance

Conclusion

Current harmonics limits have been defined by IEC based on the assumption of some diversity among the loads. In the present case, since the EVs are of the same model, there is no diversity and there is therefore a risk of high emissions depending on the short-circuit power of the network. As a consequence, specific attention should be given when designing EV charging installations for fleets of vehicles made of few different models.

COEXISTENCE WITH PLC IN THE RANGE 2 – 150 KHZ

A laboratory test campaign was carried out by EDF R&D to evaluate the possible disturbing effect on power line communications (PLC) of parasitic emissions of electrical vehicles in the frequency range 2 – 150 kHz.

As a simple analysis of the spectrum of the generated noise is not sufficient to draw sound conclusions, a specific methodology has been developed.

Methodology

The test methodology used in this test campaign is based on the evaluation of the available "dynamic range" of a PLC link between a transmitter and a receiver in presence of spurious emissions generated by an electrical vehicle.

The dynamic range is defined as the maximum attenuation a PLC link may undergo without reaching a 5% frame error rate (FER) threshold, when the transmitter is transmitting at its maximum level.

Unlike the computation of other indicators such as the signal to noise ratio, the dynamic range has the main advantage of being simple to establish, independently from the type of PLC modulation, ranging from narrowband FSK (Frequency Shift Keying) or PSK (Phase Shift Keying) to wide band OFDM (Orthogonal Frequency Division Multiplexing).

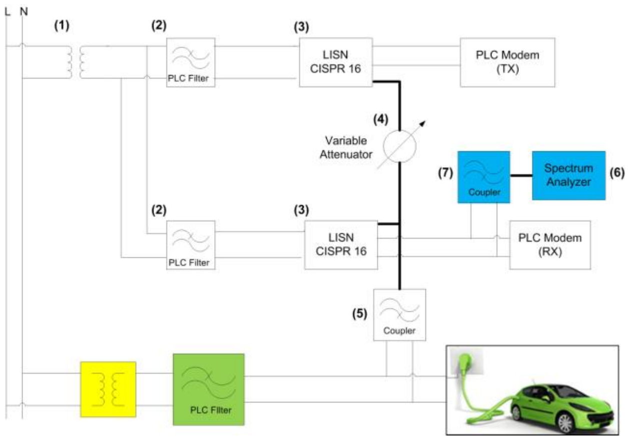

Figure 5: Laboratory test setup in the range 2 – 150 kHz

The dynamic range is evaluated using a test setup (see Figure 5) consisting of:

- A controlled environment for each PLC device (composed of an isolation transformer (1), a PLC filter (2) and a Line Impedance Stabilization Network – LISN – (3) providing a standardized CISPR-16 impedance to the PLC device connected at its mains output),

- A variable attenuator (4) installed on the PLC signal track between the transmitter (TX) and the receiver (RX) using the LISN's BNC 50 Ω output traditionally used for the connection of a measurement device,

- A coupler (5) injecting the spurious emissions on the PLC signal track on receiver's side, obtained by connecting the electrical vehicle on another independent network (using an isolation transformer and a PLC filter if needed).

In addition, a spectrum analyzer (6) and a coupler (7) are connected on receiver's side to monitor the spurious emission level the PLC device is undergoing.

Finally, the disturbing effect of parasitic emissions of electrical vehicles corresponds to the amount of performance loss (in dB) between the dynamic range measured without noise and the dynamic range obtained in presence of the electrical vehicle.

Results

In the range 2 – 150 kHz, spurious emissions generated by the electrical vehicles tested by EDF R&D are characterized by relatively low levels (most of the time below 80 dBµV) in the band typically used by utilities for PLC operation (30 kHz – 95 kHz).

Higher levels (up to 97 dBµV) can be observed at the electrical vehicle charger's switching frequency and its lower order harmonics. These very narrow spectral lines are typically located below 40 kHz (see Figure 6) or around 100 kHz (see Figure 7).

Furthermore, the electrical vehicles' spectral signatures do not significantly vary with time.

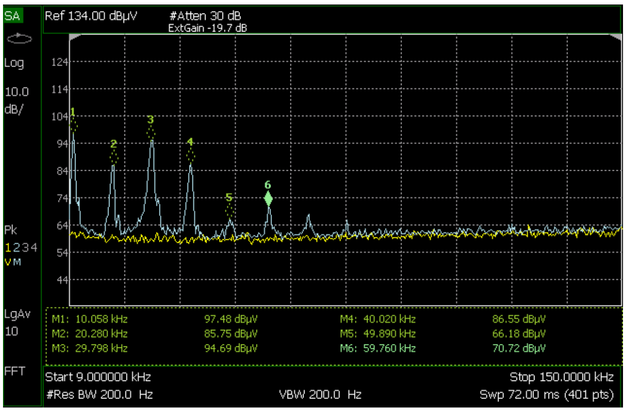

Figure 6: Spurious emissions for electrical vehicle #1

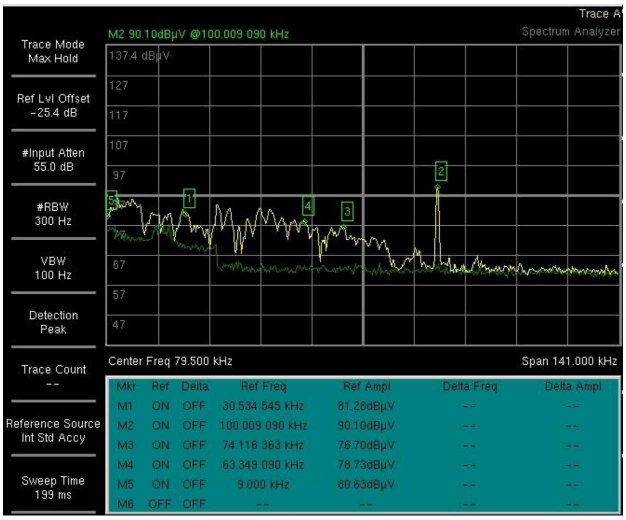

Figure 7: Spurious emissions for electrical vehicle #2

In the noise conditions depicted in Figure 6 and Figure 7, dynamic range degradation is limited to approximately 25 dB (state-of-the-art PLC technologies can typically achieve a dynamic range of 80 dB).

In addition, it should be noted that the bandwidth of spurious spectral lines is a crucial parameter when located within the frequency band used for PLC operation. Indeed, electrical vehicle #1 produces a very sharp spectral line reaching a level of 87 dBµV at 40 kHz without drastically impairing power line communications. It is very likely that a larger bandwidth of this spectral line would have led to a higher level of disturbance.

Conclusions

Despite the absence of a global EMC standard defining compatibility levels in the range 2 – 150 kHz, the electrical vehicles tested did not lead to unacceptable performance losses when the receiving PLC device was connected in close proximity of the disturbing source.

Nevertheless, significant progress could still be achieved for E-mobility equipment to reduce its emission levels in the CENELEC A band (3 – 95 kHz).

Finally, progress is also to be made on the experimental setup, allowing the disturbing effect of the electrical vehicle tested to be characterised more precisely.

REFERENCES

[1] International standard IEC 61851-1, Ed. 2.0, 2010, Electric vehicle conductive charging system – Part 1: General requirements

[2] International standard IEC 61000-3-2, Ed. 4.0, 2014, Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)

[3] European standard EN 50160, 2010, Voltage characteristics of electricity supplied by public electricity networks

[4] International standard IEC 61000-1-4, Ed. 1, 2005, Electromagnetic compatibility (EMC) – Part 1-4: General – Historical rationale for the limitation of power-frequency conducted harmonic current emissions from equipment, in the frequency range up to 2 kHz