

Integration of PEV in Portuguese Distribution Grid

Analysis of harmonic current emissions in charging points

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Abstract—Regarding expected contribution of Plug-in Electric Vehicles (PEV) to improve the energy efficiency, to reduce CO₂ emissions and to support the integration of renewable energy sources, this paper presents the legal framework for development of electric mobility in Portugal. Followed by a brief description of methods and modes of PEV charging and by an introduction to the harmonic theory, measurement results are presented for Normal Power and High Power DC charging methods. The results include the characterization of voltage and current harmonic distortion during charging operations of the ISR's Nissan Leaf, by a normal socket outlet in office-building, and the EDP's Mitsubishi i-MiEV, by a High Power DC charging point in a Galp's gas station.

Keywords—PEV; charging methods; harmonic distortion; distribution network

I. INTRODUCTION

Regarding worldwide requirements for reduction of Greenhouse Gas (GHG) emissions and the recent oil market volatility, associated to the increasing demand, potential depletion of fossil resources and geopolitical instability, an increasing development of electrical storage technologies has been noticed with main focus on the electrochemical batteries. This technological development has been sprung up again the old dream of the electric mobility.

On the other hand, electric power systems have been developed for more than one century and designed in a top-down perspective, based on predictable centralized generation with power flowing from transmission to the distribution network. The recent advent of large-scale intermittent renewable generation, with broad installation at all voltage levels, is challenging the operation of power systems, namely in terms of generation forecasting, system stability and Quality of Service (QoS). This new paradigm, associated to requirements of efficiency, as well as needs of integration and control of Plug-in Electric Vehicles (PEV) is requiring the development of smarter distribution grids with controllable loads.

Aware about forthcoming challenges and opportunities, automotive industry, electric utilities and other potential stakeholders are investing millions of Euros developing PEV and its control systems, with organizations such as Google spending \$10 million for PEV research and testing [1]. Several governments are supporting the implementation of charging

infrastructures and stimulating the adoption of PEV, being the U.S. government committed to a goal of 1 million of PEV in the next 5 years [1], Portuguese government aiming to achieve 160.000 Full Electric Vehicles (FEV) by 2020, through the Mobi.E Program [2], as well as some predictions suggesting that by the year 2020 there can be as much as 500.000 PEV in Portugal [3] and 6,7 million in Germany [4].

In overall perspective, Electric Vehicle (EV) is any vehicle with an electric-drive motor powered by batteries, fuel cells or hybrid drivetrain. In this broad group are included FEV, also called “pure” EV, Fuel Cell Electric Vehicles (FCEV), Hybrid Electric Vehicles (HEV), Plug-in Hybrid Electric Vehicles (PHEV) and Extended Range Electric Vehicles (EREV). The subgroup of PEV is characterized by its capability to charge battery packs from the distribution network, directly by plug into a typical socket outlet or by a dedicated Electric Vehicle Supply Equipment (EVSE). Therefore, this subgroup includes FEV, PHEV and EREV.

Some studies have been done in the field of PEV integration in power systems, namely in terms of load impact and network congestion during peak and off-peak hours, for large-scale penetration of PEV. On the other hand, some works have been presented regarding the potential impact of PEV's chargers on the Power Quality (PQ). This new load is typically characterized by 1-phase (230 VAC) or 3-phase (400 VAC) rectifiers to convert AC in DC power to charge battery packs, which typically store energy at 300 – 400 VDC. As any other non-linear electronic load, based on diodes, thyristors or Isolated Gate Bipolar Transistors (IGBT), these rectifiers may generate some harmonic currents. Actually, harmonic distortion is an important issue that is drawing attention in the field of integration of PEV in power systems. The work [5] presents a simulation study of impact of PEV charging on the PQ of smart distribution systems, in Australia. The simulations, based on the expansion of the IEEE 30 bus system, conclude that low PEV penetration levels, with normal charging rates, will have acceptable low harmonic levels and voltage variations, but fast charging rates would cause significant voltage harmonics and losses.

Based on analysis of the effect of battery charging on distribution transformers, presented in [6], it exists a quadratic relationship between the transformer lifetime consumption and the current Total Harmonic Distortion (THD_I) of battery

charging, suggesting that THD_1 should be limited to 25% – 30% to have an acceptable transformer lifetime expectancy. Also simulation results for large-scale penetration of PEV are presented in [7], based on a Low Voltage (LV) residential network, with 19 buses, for assessment of voltage variations, system losses, transformer overloading and harmonic distortion, assuming several charging scenarios over the time of one day. The authors of this study conclude that the penetration of PEV, as well as the regime and the period of charging have major impacts on system losses and on voltage distortion, putting in evidence the advantages of coordinated charging.

In a complementary perspective, considering that some charging technologies tend to cancel or amplify harmonics generated by other loads, [8] presents a comparison between four typical PEV charger designs: Pulse Width Modulated (PWM); square wave; basic 1-phase bridge rectifier; 3-phase bridge rectifier. These authors suggest that PWM chargers can be an interesting option to reduce or remove undesirable harmonics from the power system, if properly configured to automatically minimize the sum of preselected components.

II. ELECTRIC MOBILITY IN PORTUGAL – LEGAL FRAMEWORK

The Portuguese government has been promoting the development of electric mobility solutions and the adoption of FEV. The Portuguese Electric Mobility Program (Mobi.E) includes a consortium of companies and a network of municipalities for implementation and operation of a pilot Electric Mobility Network (EMN), in order to stimulate electric mobility across all country. This program defines a market model to be implemented in a pilot phase and developed in two subsequent phases. With this program, Portuguese authorities aim to achieve a global reduction of 25% in CO₂ emissions by 2020.

The Decree-Law (DL) n. 39/2010, of April 26th, has the following 3 main targets:

- Incentive the purchase and utilization of FEV;
- Ensure that battery charging is done by an integrated charging network;
- Establish a regime of universality and equity on access to electric mobility services.

This DL enacts the organization, access and framework to electric mobility activities, it establishes a pilot EMN and regulates the incentives for utilization of FEV. Among other financial support to end-users, the DL includes an incentive of 5.000 €, per vehicle, for purchasing, by natural persons, of the first 5.000 new FEV, with a minimum 120 km range.

Based on this DL, a pilot EMN is being implemented in the 25 main cities across all country. According to the initial planning, this infrastructure will include 1.300 normal charging points (power lower than 40 kVA in AC or 40 kW in DC) and 50 fast charging points (power higher or equal to 40 kVA in AC or 40 kW in DC) by the end of 2011.

Regarding market organization, the main activities to support the electric mobility in Portugal include:

- Management of EMN operations – management of financial and power flows associated to charging operations;
- Operation of charging points of the EMN – installation, operation and maintenance of charging points integrated in the EMN;
- Electricity commercialization for electric mobility – buy energy in the wholesale market and sell energy to retail end-users of electric vehicles, in charging points of the EMN.

Also based on this DL, the following market agents have been established:

- Electric Mobility Operations Manager (MOM), SGORME – Sociedade Gestão de Operações de Mobilidade Eléctrica, participated by the main Portuguese Distribution System Operator (DSO) with a minimum share of 51%, being responsible by: management of the EMN for all Charging Points Operators (CPO) and Electric Mobility Energy Suppliers (MES); management of charging sessions and end-user validation; issue Mobi.E identification cards on behalf of MES; certification of charging equipment; provision of information about the EMN through a web site (www.mobie.pt) and a call center.
- CPO are companies responsible by: installation, operation and maintenance of normal and fast charging points in open market; make available the infrastructure to MES, being remunerated by each kWh supplied to end-users. These market agents are independent from MES and they have no relation with end-users. EDP Mop is the EDP's reference company to operate on this market.
- MES are typical energy service provides, in open market, responsible by energy supplying for battery charging and other services. According to their commercial strategies, energy might be supplied in pre-paid or pos-paid packages, by previous configuration of Mobi.E identification cards.

III. METHODS AND MODES OF PEV CHARGING

According to the Eurelectric position paper [9], to express the charging process in terms of power is more accurate than in time-related terms. Thus, the TABLE I. suggested classification will be used from now, in this paper.

TABLE I. CLASSIFICATION OF PEV CHARGING METHODS [9]

PEV Charging Methods				
<i>Classification</i>	<i>Mains connection</i>	<i>Power (kW)</i>	<i>Current (A)</i>	<i>Range^a (km)</i>
Normal Power	1-phase AC	≤ 3,7	10 – 16	< 20
Medium Power	1-phase or 3-phase AC	3,7 – 22	16 – 32	20 – 110
High Power AC	3-phase AC	> 22	> 32	> 110
High Power DC	DC	> 22	> 32	> 110

a. Assuming an average consumption of 20 kWh/100km

A. Normal Power Charging

This charging method shall be typically used in applications such as residential and office buildings, as well as in some public locations as curbside charging points and parking lots. Mobi.E includes the installation of 1.300 Normal Power charging points.

The Normal Power charging method is characterized by an onboard charger with 1-phase connection to the supply network. The charger draws AC power from the distribution network and converts it into DC power for battery charging. This charging method can be implemented according to charging Mode 1 or Mode 2 of the standard IEC 61851-1 [10].

1) Charging Mode 1

Non-dedicated socket outlet – The PEV is connected to the mains AC supply network through a standard socket outlet (rated current: 16 A) at the supply side, with 1-phase or 3-phase, neutral and protective earth conductors. The adoption of this mode depends on the availability of a residual current device at the supply side. This mode is not allowed where residual current devices are not required by national standards.

2) Charging Mode 2

Non-dedicated socket outlet with cable-incorporated protective device – The PEV is connected to the mains AC supply network through a standard socket outlet (rated current: 16 A) at the supply side, with 1-phase or 3-phase, neutral and protective earth conductors and a control pilot-conductor between the vehicle and an in-Cable Control Box (ICCB), at the cable supply side ending, or a control connector.

B. Medium and High Power AC Charging

These charging methods, with 1-phase or 3-phase AC connections to the supply network, shall be mainly used by end-users in shopping centers or in parking lots in city areas.

In Medium and High Power AC charging configurations, a high power onboard charger can be used for currents higher than 16 A, or the drivetrain inverter can operate as AC/DC converter to charge the battery. In this last option, the charging power will be equivalent to power of the motor.

These charging methods can be implemented according to Mode 3 of the standard IEC 61851-1 [10]. This charging mode requires a dedicated socket outlet – The PEV is connected to the mains AC supply network through a dedicated EVSE, with a control pilot-conductor between the vehicle and the EVSE.

C. High Power DC Charging

This charging method shall be mainly used to ensure longer journeys with short charging periods, namely in highways. It is probably the most suitable solution for installation in typical gas stations, as already available in some main Portuguese gas stations (e.g. Galp's A1-Aveiras, A1-Pombal and A5-Oeiras).

The High Power DC charging method is characterized by an external 3-phase AC/DC converter. The output of the charger is directly connected to the battery input and the DC power is controlled by the onboard Battery Management System (BMS).

This charging method can be implemented according to Mode 4 of the standard IEC 61851-1 [10]. This charging mode is based on a DC connection – The PEV is indirectly connected to the mains AC supply network through an external DC charger, with a control pilot-conductor between the vehicle and the DC charger.

IV. HARMONIC DISTORTION THEORY

Voltage systems generated by large synchronous machines are typically symmetrical and balanced, characterized by 3-phase sinusoidal waveforms. In ideal power system, supplying linear loads, which draw sinusoidal currents proportional to the voltage waveform, like resistance heaters and incandescent lamps, the voltage waveform would remain sinusoidal across all Transmission and Distribution (T&D) networks. However, current power systems are no longer supplying only linear loads. Non-linear loads, like switched mode power supplies, which draw non-sinusoidal currents, are proliferating in domestic and industrial appliances, generating harmonic currents and inducing voltage distortion in distribution systems.

According to the Fourier theorem, any periodic function can be expressed by a series composed by: a sinusoidal component at the fundamental frequency; plus a series of sinusoidal components, which are integral multipliers of the fundamental frequency; and a constant – the continuous component. Thus, the instantaneous value of current, drawn by a non-linear load, can be expressed by:

$$i(t) = I_0 + I_{p1} \sin(\omega t + \varphi_1) + I_{p2} \sin(2\omega t + \varphi_2) + \dots \\ \dots + I_{ph} \sin(h\omega t + \varphi_h)$$

where:

$i(t)$ – instantaneous value of current on t ;

I_0 – mean value of current (DC component);

I_{ph} – peak value of the harmonic component h ;

φ_h – lag of the harmonic component h on $t=0$;

$\omega = 2\pi f$ (f – frequency of the fundamental component).

Ignoring the DC component:

$$i(t) = \sum_{h=1}^{\infty} I_{ph} \sin(h\omega t + \varphi_h)$$

$$i(t) = \sum_{h=1}^{\infty} \sqrt{2} I_h \sin(h\omega t + \varphi_h)$$

where:

I_h – RMS value of the harmonic component h .

The RMS current can be expressed by:

$$I = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt} \\ I = \sqrt{\sum_{h=1}^{\infty} I_h^2} = \sqrt{I_1^2 + I_2^2 + I_3^2 + \dots + I_h^2}$$

The RMS current THD can be also expressed by:

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \times 100\%$$

$$THD_I = \frac{\sqrt{I_2^2 + I_3^2 + \dots + I_h^2}}{I_1} \times 100\%$$

In ideal conditions, power conversion with full wave rectifiers generates harmonic currents with the following components:

$$h = np \pm 1$$

where:

h – harmonic order;

n – integer 1, 2, 3, 4...;

p – number of current pulses per cycle.

Theoretically, a 1-phase full wave diode rectifier generates harmonic currents, based on 2 rectified current pulses per cycle (1 per half cycle) converted to DC, with the following main components: 3, 5, 7, 9, 11, 13... On the other hand, a 3-phase full wave diode rectifier generates harmonic currents, based on 6 rectified current pulses per cycle (1 per half cycle, per phase) converted to DC load, with the following main components: 5, 7, 11, 13...

As this kind of non-linear loads have symmetrical waveforms (positive half cycle is identical to the negative half cycle), only odd harmonics components are generated. Loads with asymmetrical waveforms generate odd and even harmonic components, as well as possibly DC components.

The harmonic distortion of supply voltage typically is a direct consequence of harmonic current flows by impedances of T&D lines and transformers, causing harmonic voltage drops on related components.

V. ANALYSIS OF FEV CHARGING IN NORMAL POWER AND HIGH POWER DC POINTS

A. Results in Normal Power Charging

The analysis and characterization of the impact of Normal Power charging method on the supply network were based on voltage and current monitoring of the onboard 1-phase charger, during a charging operation by Mode 2 in a standard non-dedicated socket outlet in an office-building.

Measurements were carried out with the ISR's Nissan Leaf, with a battery pack of 24 kWh, during a charging operation of 14,4 kWh, from onboard displayed 64 km range to 166 km range. Monitoring data were collected by a recording device Fluke 1760, in accordance to the class A requirements of the IEC 61000-4-30.

The Figure 1. shows the RMS values of current and voltage during the charging period of 4h:10min. Voltage has remained constant (about 225 V) during all operation time. Current has also remained constant (about 16,4 A) during the first 3h:44min. In the last 26 minutes, the current has decreased progressively from 16,4 A to about 6 A, followed by the automatic switch-off.

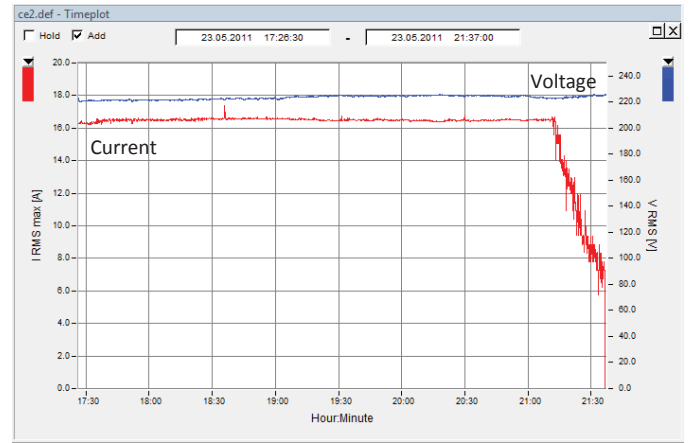


Figure 1. Maximum RMS values of current and average RMS values of voltage recorded in 10s intervals

Regarding harmonic distortion, the Figure 2. shows the maximum values of THD of current and voltage during the charging period. The values of THD_V have been among the typical values recorded in office-buildings (2% - 3%), supplied in Medium Voltage (MV). The values of THD_I have remained constant (12%) during the first 3h:44min and they have reached a maximum of 16% in the last 26 minutes, with lower charging currents.

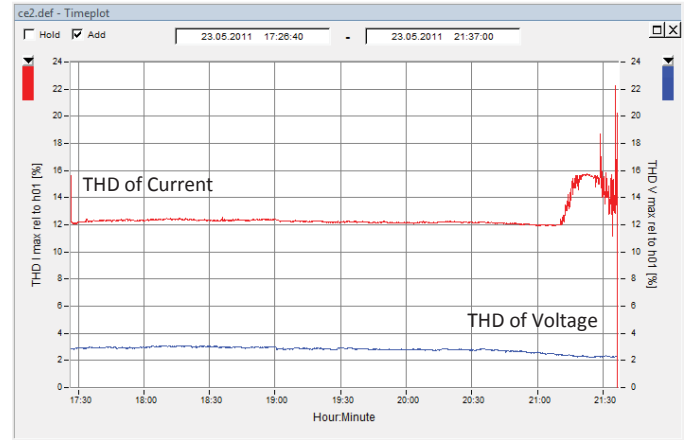


Figure 2. Maximum values of THD of current and voltage recorded in 10s intervals

The 3rd harmonic current reached maximum RMS values around 1,9 A (11,6%), during the initial period of 3h44min, being by far the most significant component contributing to the THD_I . These significant values of the 3rd harmonic component show that charging PEV can contribute to increase the harmonic distortion in LV networks, supplied typically by power transformers in delta-star connection, inducing additional losses in neutral conductors and power transformers.

Based on data collected, TABLE II. compares maximum RMS values of the most important harmonic current components with limits defined by the standard IEC 61000-3-2 [II] for class A equipment. Recording data on this field test would not be directly compared with limits of the standard IEC 61000-3-2 [II], because measurements were not carried out in

lab environment, as required by the standard. However, this approach allows an outlining of the main expected conclusions.

This comparison shows that all recorded harmonic components have maximum values significantly below to limits of the standard.

TABLE II. COMPARISON BETWEEN SOME HARMONIC CURRENT LIMITS FOR CLASS A EQUIPMENT [11] AND RECORDED VALUES

Harmonic Currents in Normal Power Charging (16 A)		
Harmonic order (n)	Maximum permissible harmonic current (A)	Maximum harmonic current recorded (A)
Odd harmonic		
3	2,30	1,91
5	1,14	0,62
7	0,77	0,35
9	0,40	0,20
11	0,33	0,17
13	0,21	0,14
15	0,15	0,12
Even harmonics		
2	1,08	0,06
4	0,43	0,05
6	0,30	0,04
8	0,23	0,03

B. Results in High Power DC Charging

The analysis and characterization of the impact of High Power DC charging method on the supply network were based on voltage and current monitoring of the 3-phase charger input, during a charging operation in a Galp's gas station.

Measurements were carried out in a Galp's High Power DC charging point, supplying the EDP's Mitsubishi i-MiEV, with a battery pack of 16 kWh, during a charging operation of 4,3 kWh, from on EVSE displayed 57% to 82% of the battery capacity. Monitoring data were collected by the same recording device – Fluke 1760.

The Figure 3. shows the RMS values of current and voltage during the charging period of 13 minutes. Voltage has remained constant in 3 phases (about 231 V) during all the time. The charging operation started with a significant inrush current of 105 A in 2 phases, followed by a stabilization period of 2 minutes around 60 A and by a progressive decreasing during the remaining charging time.

The Figure 4. shows the maximum THD values of current and voltage during the charging period. Values of THD_V have remained quite low (lower than 1%) during all charging period. The maximum values of THD_I reached a very high peak (95%) during the inrush current event, drooping suddenly to around 12%. After this initial transient, maximum values of THD_I have progressively increased in opposition to the current reduction. In 12 minutes, the maximum current values have decreased

from 60 A to 17 A and maximum THD_I values have increased from 12% to 24%. One of the most significant harmonic components contributing to the THD_I is the 5th harmonic current, showing the Figure 5. a constant increasing similar to THD_I , with its maximum values rising from 3% to 12% in 12 minutes.

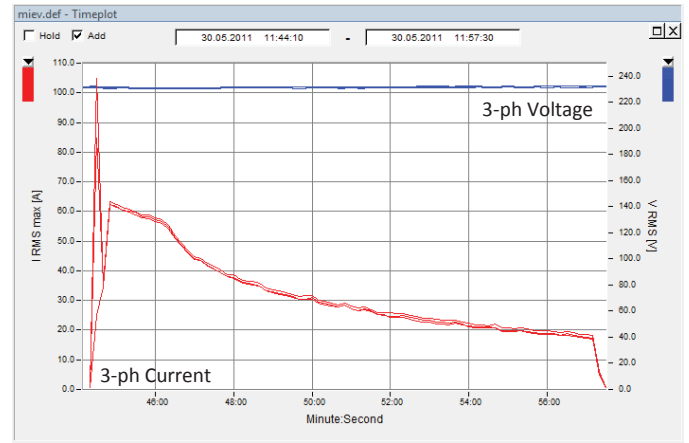


Figure 3. Maximum RMS values of current and average RMS values of voltage recorded in 10s intervals

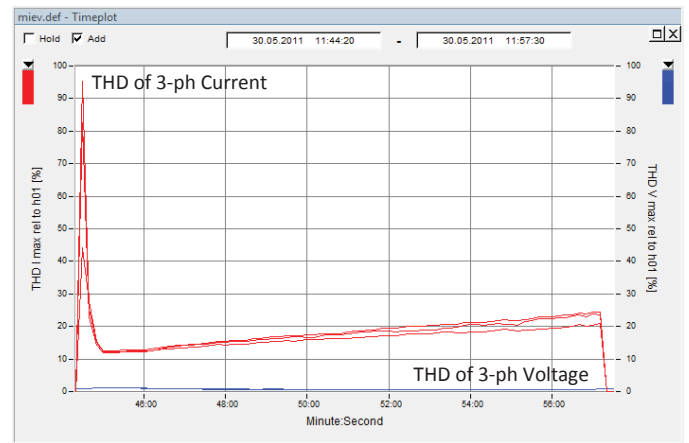


Figure 4. Maximum values of THD of current and voltage recorded in 10s intervals

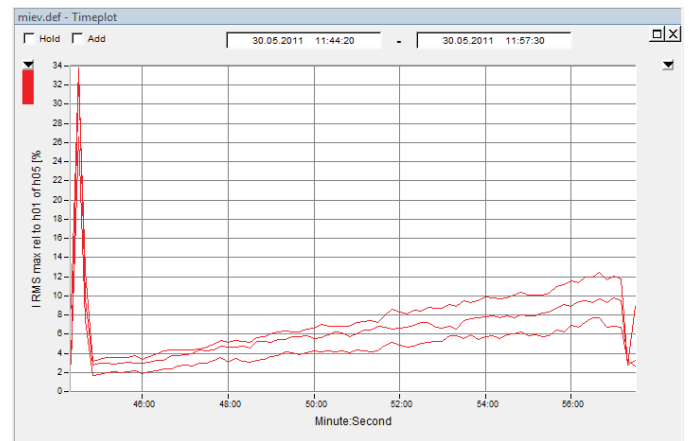


Figure 5. Maximum RMS values of 5th harmonic current in percentage of I_1 , recorded in 10s intervals

Although these measurements have been carried out in the LV network of the gas station (private installation supplied in MV), the results can be approximated to the public LV distribution network with no major error.

The TABLE III. presents the harmonic current limits established by IEC 61000-3-12 [12] for balanced 3-phase equipment with rated input current exceeding 16 A and up to 75 A per phase, intended to be connected to public LV distribution networks. Recording data on this field test are not compared with limits of the standard IEC 61000-3-12 [12], but they give an outline of the situation.

TABLE III. CURRENT EMISSION LIMITS FOR BALANCED 3-PHASE EQUIPMENT [12]

Minimum R_{SCE}	Admissible individual harmonic current I_h/I_{ref} (%)				Admissible harmonic parameters (%)	
	I_5	I_7	I_{11}	I_{13}	THC/ I_{ref}	PWHC/ I_{ref}
33	10,7	7,2	3,1	2	13	22
66	14	9	5	3	16	25
120	19	12	7	4	22	28
250	31	20	12	7	37	38
≥ 350	40	25	15	10	48	46
The relative values of even harmonics up to order 12 shall not exceed 16/h %. Even harmonics above order 12 are taken into account in THC and PWHC in the same way as odd order harmonics. Linear interpolation between successive R_{SCE} values is permitted.						
R_{SCE} – Short-circuit ratio; I_h – Harmonic current component; I_{ref} – Reference current; THC – Total Harmonic Current; PWHC – Partial Weighted Harmonic Current						

VI. CONCLUSIONS

As enacted by the DL n. 39/2010, Portugal is developing an ambitious electric mobility program and establishing all market agents in order to implement an integrated EMN. Based on this program it is expected to achieve 160.000 FEV in 2020 and a long-term change on the mobility paradigm, with benefits to energy efficiency, reduction of CO₂ emissions and national economy.

Based on field tests carried out in this work, the following main conclusions can be highlighted.

- Normal Power charging of PEV can contribute to increase the harmonic distortion in LV public distribution networks, despite expected harmonic current emissions significantly below to limits of the standard IEC 61000-3-2 [11] to class A equipment.
- The simultaneous operation of several 1-phase chargers in the same LV feeder, with maximum 3rd harmonic currents around 12% and THD₁ between 12% and 16%, can have a significant impact on distribution networks. In these situations, right technologies should be adopted in order to prevent the potential impact of the 3rd harmonic current on neutral conducts and power transformers.
- High Power DC charging shows a larger potential to impact the public distribution network, when installed directly in LV networks, especially in points with lower short-circuit power. Recorded maximum values of THD₁, between 12% and 24%, can have a significant impact on weaker networks.

- High Power DC charging points should be preferably installed in facilities supplied by dedicated MV/LV transformers.

For an efficient integration of this new load/resource in distribution networks, further studies and field measurements are suggested, in order to characterize its potential contribution to load congestion and harmonic distortion in large-scale penetration scenarios, as well as to identify the right smart grid control strategies. Based on suitable smart grid control strategies, PEV have a large potential to improve the efficiency and management of electric power systems, with expected contribution to support the integration of renewable energy sources and to provide load management and ancillary services.

ACKNOWLEDGMENT

Authors thank to Galp Energia by make available a High Power DC charging point for monitoring purposes and to ISR – University of Coimbra for providing its Nissan Leaf. Authors would also thank to Flávio Cação, Pedro Veloso, António Lebre, Teresa Couceiro and Ricardo Faria for their valuable contributions. This work has been partly supported by the FEDER/COMPETE FCT grant MIT/MCA/0066/2009.

REFERENCES

- [1] Larry Dickerman and Jessica Harrison, "The Electric Car Is Back (with Help from New Batteries, a Smarter Grid, and Uncle Sam)," *IEEE Power & Energy Magazine*, pp. 19-25, 2011.
- [2] INTELI. (2010) MOBILE Electric Mobility. [Online]. www.mobie.pt/en/homepage
- [3] Pedro S Moura, Anibal T De Almeida, Pedro G Cabral, Nuno F Martins, and Maria N Tavares, "Integration of Renewable Intermittent Resources with Electric Vehicles," in *IEEE Intelligent Transportation Systems Conference*, Funchal, 2010.
- [4] D. Salmonsson and V. Neimane, "Plug-in Hybrid Electric Vehicles: Capacity Study in European Perspective," Vattenfall R&D, Tech. Rep. 2008.
- [5] Paul S. Moses, Sara Deilami, Amir S. Masoum, and Mohammad A. S. Masoum, "Power Quality of Smart Grids with Plug-in Electric Vehicles Considering Battery Charging Profile," in *Innovative Smart Grid Technologies Conference Europe (ISGT Europe)*, Gothenburg, 2010, pp. 1-7.
- [6] J. C. Gomez and M. M. Morcos, "Impact of EV Battery Chargers on the Power Quality of Distribution Systems," *IEEE Transactions on Power Delivery*, vol. 18, no. 3, pp. 975-981, July 2003.
- [7] S. Deilami, A.S. Masoum, P.S. Moses, and M.A.S. Masoum, "Voltage profile and THD distortion of residential network with high penetration of Plug-in Electrical Vehicles," in *2010 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe)*, Gothenburg, 2010, pp. 1-6.
- [8] E.C. Bentley et al., "The interactive effects of multiple EV chargers within a distribution network," in *2010 IEEE Vehicle Power and Propulsion Conference (VPPC)*, Lille, 2010, pp. 1-6.
- [9] Task Force Electric Vehicles, "European Electricity Industry Views on Charging Electric Vehicles," Eurelectric, Brussels, Position Paper 2011.
- [10] IEC, IEC 61851-1 Electric vehicle conductive charging system – Part 1: General requirements, 2010.
- [11] IEC, IEC 61000-3-2 Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤ 16 A per phase), 2009.
- [12] IEC, IEC 61000-3-12 Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase, 2011.