Development of a Novel Management System for Electric Vehicle Charging

J. P. Iria, F. J. Soares and I. G. Franchin
Instituto de Engenharia de Sistemas e Computadores, INESC TEC
Porto, Portugal
jpiria@inescporto.pt, fsoares@inescporto.pt and igf@inescporto.pt

N. Silva
EFACEC
Porto, Portugal
nuno.silva@efacec.com

***Abstract*—This paper describes a novel Electric Vehicle (EV) charging management system which was designed to control the EV load considering simultaneously the EV owners requirements and the electrical network technical limitations. The system was developed to be integrated with existing commercial equipment for smart grids, such as distribution transformer controllers, SCADA systems and Electrical Vehicles Charging Stations. The performance of the smart charging system was evaluated using a typical Portuguese low voltage network as test case, where several EV were assumed to exist. The results obtained prove the effectiveness of the system, as it allowed charging all the EV according to their owners' preferences without increasing the network peak load or creating voltages or overload problems.**

Keywords*—*Charging Stations, Distribution Grids, Electric Vehicles, Load Management

I. Introduction

With the expected near future integration of plug-in hybrid and pure electric vehicles in the light-duty vehicle fleet, herein referred to as Electric Vehicles (EV), the transportation sector will undergo deep changes. The main consequence of this change is a paradigm shifter. EV will promote the diversification of final energy consumption sources in a sector where most of the fleet would run on petrol derivatives, diesel and gasoline. This diversification of fuel sources is very welcomed by the society but carries great challenges to the energy sector. EV will need to be refueled and, currently, there is no extensive infrastructure deployed to meet their needs. Thus, in order to successfully deploy this new technology, an adequate recharging infrastructure must exist. It is well known nowadays that to support the large scale integration of EV in electricity networks, this infrastructure should be capable of controlling the EV charging. Several works addressing the impacts of EV in electricity networks reported that various problems might arise in the power systems if no control actions are taken over EV charging.

In [1], Heydt analysed the changes in the load diagram of a community of about 150 to 300 thousand people, in the USA, for increasing penetration levels of EV in the vehicle fleet. The author concluded that a salient factor to be considered in EV deployment is their charging during peak hours and referred that a possible method to alleviate peak loading and temperature rise in distribution transformers is through the use of load management techniques. Lopes et al., in [2, 3], studied the impacts of EV in distribution grids. These authors evaluated the EV charging impact on the grid technical constraints and concluded that EV can lead to the violation of statutory voltage and ratings limits, as well as to a significant increase in the energy losses. The authors stressed the need to develop and implement efficient management procedures for coordinating EV charging, in order to minimize the need to reinforce the grid infrastructures. Papadopoulos et al., in [4], also addressed the technical challenges related with the EV integration. Steady state voltage profiles of a typical Low Voltage (LV) network from the UK, under different EV penetration scenarios, were investigated and the results obtained showed that the grid voltage profiles are highly dependent on the number of EV integrated in the grid. Clement et al., in [5, 6], analysed the EV impacts in distribution grids power losses and voltage deviations. The authors concluded that EV uncoordinated charging is very likely to lead to voltage problems, even for low EV integration levels. Other works, such as [7-10], presented similar studies with analogous conclusions.

One common point from the studies presented in [1-10] was that the technical problems identified could be easily avoided if adequate EV load management techniques were implemented. This was proved to be true, as described by several authors in [11-19]. These works were focused on the determination of optimal (or near optimal) EV charging schedules. In [11], for instance, Lopes et al. suggested a smart charging scheme based on a hierarchical structure that monitors the grid operating conditions and manages EV charging to avoid violations of the grid technical restrictions. In [14], Geth et al. developed an algorithm to determine the optimal charging profiles for fleets of EV in Belgium. Sortomme et al., in [15], suggested three distinct smart charging schemes that exploited the relationship between

This work was made in the framework of the BEST CASE project ("NORTE-07-0124-FEDER-000056") financed by the North Portugal Regional Operational Programme (ON.2 – O Novo Norte), under the National Strategic Reference Framework (NSRF), through the European Regional Development Fund (ERDF), and by national funds, through the Foundation for Science and Technology (FCT). It was also partially supported by national funding from QREN through the " EFA iCHARGE – Gestão Inteligente de Veículos Elétricos Através de Sistemas de Gestão de Carregamento Avançados " project, grant 2012/24663 conceded by IAPMEI.

feeder losses, load factor and load variance.

Although very interesting methodologies have been proposed in these works, there is still a large gap between research and the real implementation of the concepts. Even so, there are some initiatives where EV charging systems were tested in real world situations. The Mobi.E project, in Portugal, was focused on the implementation of a nationwide network of EV charging points [20]. Nevertheless, it did not include charging management functionalities.

This paper presents an innovative EV charging management system which was designed to control EV load taking simultaneously into account the EV owners requirements and the electricity network technical limitations. This system was developed under the framework of the EFA iCHARGE project, which was an initiative of EFACEC, a global supplier of solutions in the fields of energy, environment and transportation, in partnership with INESC TEC, a leading R&D institution in the smart grid area. The system was developed to be integrated with existing commercial equipment for smart grids, such as Distribution Transformer Controllers (DTC) and Supervisory Control and Data Acquisition (SCADA) systems which are currently available products of the smart grids reference architecture used by EFACEC. The architecture of the system and the technical description of its components are presented in section II. The software module developed to compute optimal charging profiles is described in section III. The performance of the system was evaluated using the case study presented in section IV and the results obtained are presented in section V. The paper is finalized with section VI, where the main conclusions are presented.

II. Charging Management System

The Charging Management System (CMS) was developed with the aim of managing EV charging in real time, in order to avoid the increase of the peak load in distribution networks. This strategy allows flattening the load diagram by shifting EV load from the peak to valley periods.

The management of the EV charging is made in accordance with the preferences predefined by the EV owners and the technical limitations of the Charging Stations.

A detailed characterization of the architecture of the system and of the CMS is provided in the following sections.

A. Architecture of the System

As depicted in Fig. 1, the architecture of the system encompasses five active elements: EV owner, Charging Station, CMS, SCADA system and DTC.

When an EV is plugged-in in a Charging Station, its owner has to define the time of disconnection and the required battery state-of-charge. These parameters, together with the moment of connection, capacity and current state-of-charge of the battery (EV data set) are communicated to the Charging Station. The Charging Station is the infrastructure that supplies electric energy to the EV battery. It can be a public station [21] or a home charger [22], which can support single-phase and three-phase connections. A public station can have various charging points. The Charging Station is responsible for communicating the charging requests (constituted by the EV data set and the maximum and minimum power of the charging point) to the CMS. The CMS is the central entity responsible for defining the EV charging profiles according to their charging requests and with the objective of minimizing the peak load and avoiding technical problems in the network. To this end, the CMS accesses real-time alarms and historical data stored by the SCADA system in order to forecast the power demand for the following 24h.

The SCADA [23] is a central system located at the control center of an utility or at the primary substation level that provides solutions for protection, automation, monitoring, control and management of the substation and the downstream network. In this architecture the SCADA system has the function of monitoring and storing secondary substation related data, such as the power flow and the voltage in the secondary substation transformers. The SCADA system gathers this data by communicating directly with the downstream DTC.

The DTC [24] is a controller installed at the secondary substation level that has the capability of monitoring and controlling micro-generation units, storage devices, charging stations and other distributed energy resources present in the low voltage network as well as serving as a smart meter data concentrator, among other automation functionalities.

B. Technical Description of the CMS

The CMS is composed by four elements: Input/Output (I/O) Module, SCADA Module, Smart Charging Module and Database (Fig. 1).

The I/O Module is the element responsible for processing charging requests and returning EV charging profiles. When the CMS receives a charging request from a Charging Station, the I/O Module communicates the data to the Smart Charging Module. After the calculation of the EV charging profile, the I/O Module communicates the charging profile to the Charging Station. The SCADA Module is the element responsible for the interconnection of the SCADA with the Smart Charging Module. The SCADA Module is run every time the Smart Charging Module needs new data from the SCADA system. The Optimal Charging Module is responsible for computing optimum EV charging profiles. This calculation is made taking into account the charging request. The Database is used to store all the information relevant to the calculation of the EV charging profiles, such as historical data about network load and EV charging profiles previously attributed to EV. Every EV charging profile computed by the Smart Charging Module is stored in the Database.

III. Smart Charging Module

The Smart Charging Module consists on computing an optimal profile for the EV charging. In order to do that the Module runs the algorithm described in Fig. 2

The first phase of the algorithm is dedicated to the analysis of the charging request communicated by the Charging Station. It defines if the EV is authorized to start charging or not. In this phase, it is verified if there are any active alarms.

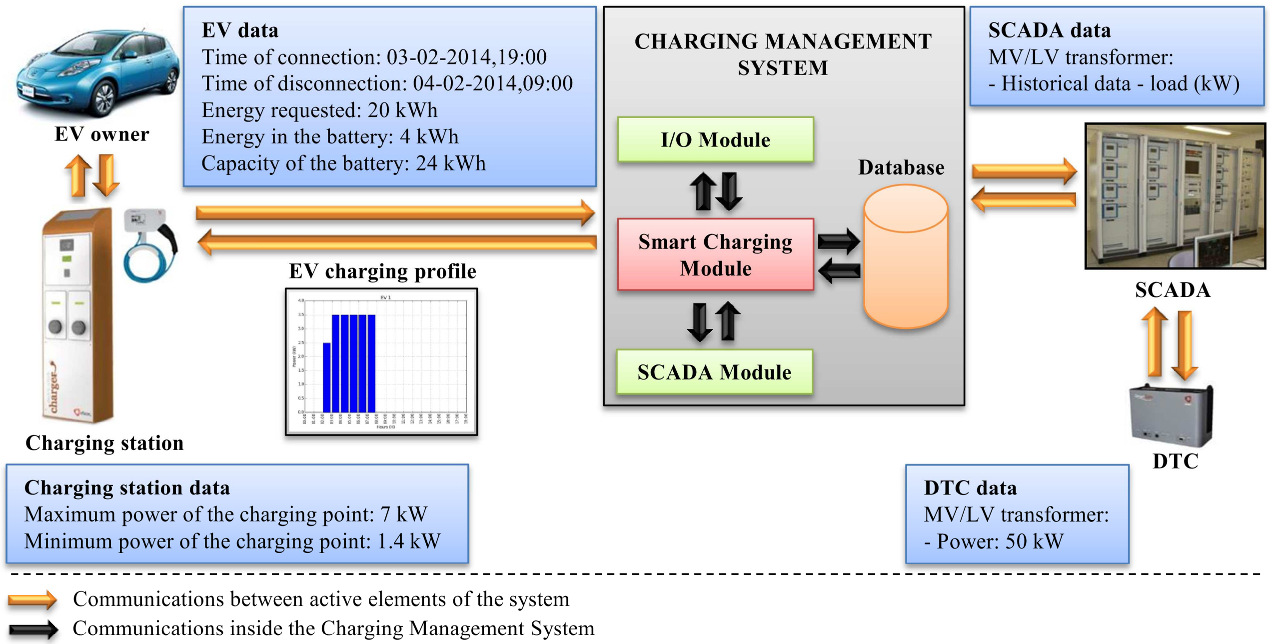

Fig. 1. Charging Management System architecture

If this condition is verified, the algorithm stops and the Charging Station receives a negative reply from the I/O Module. Otherwise, the algorithm keeps running.

The alarms can be activated by the Charging Station or the SCADA system. The Charging Station activates the alarm when the local voltage drops below the technical limit. In turn, the SCADA system activates a real-time alarm when a technical problem in the MV/LV distribution transformer is detected.

The second phase of the algorithm consists in forecasting the network load for the next 24 hours. This forecast is performed twice a day at 12h and 24h. The forecasting of the network load is performed in 2 steps.

The first one consists in forecasting the network load and the EV load using 3 months of historical data obtained from the SCADA system (overall load) and local Database (only EV load). Then, the forecasted network load is obtained by subtracting the EV load to the overall load.

The second step consists in adding the load profiles of the EV that are currently charging to the forecasted network load.

In the third phase of the algorithm, the EV charging requirements and restrictions needed to define the optimal charging profile are characterized.

Finally, the fourth phase of the algorithm consists in computing an optimal charging profile through an restrictions optimization algorithm that takes into account the forecasted network load and the EV charging requirements and restrictions (described in section A).

A. Electric Vehicle Charging Requeriments and Restrictions

Before the definition of the EV charging profile by the optimization algorithm (Section B), it is necessary to characterize the EV charging requirements and restrictions.

This characterization is based on the definition of the maximum and minimum charging power limits and the energy requirements.

The definition of the EV charging requirements and restrictions can be divided in two steps:

- Step I: Calculate the maximum and minimum charging power limits and the energy requirements of the EV, taking into account the technical limits of the secondary substation transformer;
- Step II: Calculate the new maximum charging power limit considering the connection time of the EV.

1) Step I

The first step consists in calculating the maximum and minimum charging power limits (L_t^{Max} and L_t^{Min} $- kW$) for each time step t. The maximum and minimum charging power limits are calculated using the following equations:

$$\alpha_t = T^{Max} - FNL_t \qquad t = tc, \dots td \quad (1)$$

$$L_t^{Max} = \begin{cases} P^{Max}, & if\ \alpha_t > P^{Max} \\ \alpha_t, & if\, P^{Min} \leq \alpha_t \leq P^{Max} \\ 0, & if\ \alpha_t < P^{Min} \end{cases} \qquad t = tc, \dots td \quad (2)$$

$$L_t^{Min} = \begin{cases} 0, & if\ L_t^{Max} < P^{Min} \\ P^{Min}, & otherwise \end{cases} \qquad t = tc, \dots td \quad (3)$$

The index t defines the time step (hour) and α_t is the ancillary variable used to represent equation (1). tc and td represent the time of connection and disconnection, respectively. The parameter T^{Max} (kW) is the maximum capacity of the transformer. FNL_t (kW) is the forecasted network load. The parameters P^{Max} and P^{Min} (kW) are the maximum and minimum power of the charging point, respectively.

Equations (1), (2) and (3) allow defining the charging limits of the EV, in order to avoid the violation of the maximum capacity of the MV/LV distribution transformer.

The maximum charging power limit should also be analyzed to verify if it is possible to supply the energy requested by the client ($E^{req} - kWh$). The E^{req} can be supplied if the sum of the maximum charging power limits is greater than the energy requested. Thus, the energy available for EV charging (E^{Av}) is defined by the following equation:

$$E^{Av} = \begin{cases} E^{req}, & if\ \sum_{t=tc}^{td}\left(L_t^{Max}\left(\frac{time_t}{st}\right)\right) > E^{req} \\ \sum_{t=tc}^{td}\left(L_t^{Max}\left(\frac{time_t}{st}\right)\right), & otherwise \end{cases} \quad (4)$$

The parameter st is the standard time of the step (60 minutes). $time_t$ is the time of step t in minutes.

2) Step II

The second step calculates the new maximum charging power limit to be used in the optimization algorithm, in order to distribute the load by the time intervals available. This is made considering that only three charging levels (CL_t) are allowed, as this will force the EV charging profile to be more uniform, preventing the intermittency of the power absorbed by EV and consequently reducing the battery degradation. The charging levels considered were 50%, 75% and 100% of the maximum possible power. The charging level for each time step can be defined by the following equations:

$$level \in \{0.5, 0.75, 1\} \quad (5)$$

$$ct = \sum_{t=tc}^{td}\left(\frac{time_t}{st}\right) \quad (6)$$

$$\beta_t = \begin{cases} \frac{P^{Min}}{L_t^{Max}}, & if\ \frac{E^{Av}}{ct} < P^{Min} \\ \frac{E^{Av}/ct}{L_t^{Max}}, & if\ \frac{E^{Av}}{ct} \geq P^{Min} \end{cases} \quad t = tc, \dots\ td \quad (7)$$

$$CL_t = \begin{cases} level_1, & if\ 0 \leq \beta_t < 0.5 \\ level_2, & if\ 0.5 \leq \beta_t < 0.75 \\ level_3, & if\ \beta_t \geq 0.75 \end{cases} \quad t = tc, \dots\ td \quad (8)$$

β_t is the ancillary variable used to represent equation (7) and ct is the number of hours during which the EV is connected (connection time).

In certain scenarios, the use of charging levels can lead to the allocation of the EV load in non-optimal time intervals. To avoid this type of scenarios, it is important to check if there is margin to reduce the charging levels. This analysis is made by using equation (9). In case of being possible, equation (10) is used do redefine the new charging levels:

$$\gamma_t = \frac{\left(\frac{E^{Av}}{L_t^{Max} CL_t}\right)}{ct} \quad t = tc, \dots td \quad (9)$$

Then, the redefinition of the charging levels is defined by the following equation:

$$CL_t = \begin{cases} CL_t + 0.25, & if\ \gamma_t > 0.7\ and\ CL_t < 1 \\ CL_t, & otherwise \end{cases}$$

$$t = tc, \dots td \quad (10)$$

Finally, the maximum charging power limit to be used in the optimization algorithm is calculated using equation (11), considering the charging levels previously computed.

$$L_t^{Max} = CL_t L_t^{Max} \quad t = tc, \dots td \quad (11)$$

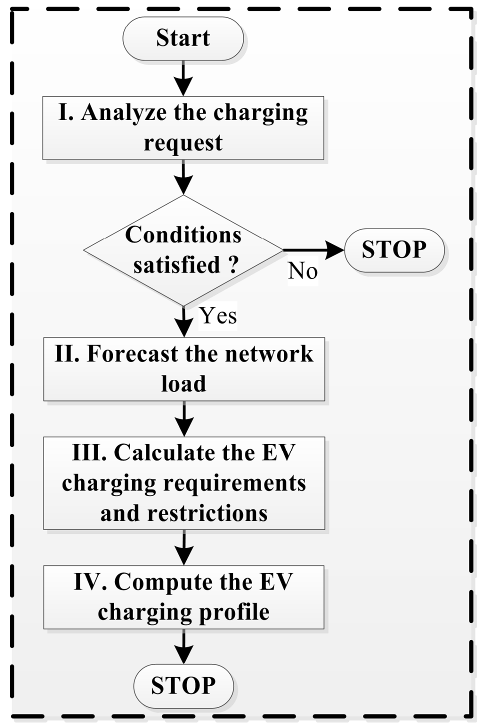

Fig. 2. Algorithm flowchart of the Smart Charging Module

B. Optimization Algorithm

The optimization algorithm consists in computing optimal load profiles for EV charging, taking into account the forecasted network load and the EV requirements and restrictions. The objective of the optimization algorithm is avoiding the concentration of EV load in the peak periods and technical problems at the MV/LV distribution transformer. For this purpose, the following mathematical model was developed:

$$Min\ \sum_{t=tc}^{td} FNL_t P_t \quad (12)$$

Subject to:

$$\delta_t L_t^{Min} \leq P_t \leq \delta_t L_t^{Max} \quad t = tc, \dots\ td \quad (13)$$

$$\delta_t \in \{0,1\} \quad t = tc, \dots\ td \quad (14)$$

$$\sum_{t=tc}^{td}\left(P_t\left(\frac{time_t}{st}\right)\right) = E^{Av} \quad (15)$$

As mentioned before, the optimization algorithm defines EV charging profiles, in order to avoid increasing the peak load of the network. To this end, the optimization algorithm minimizes the sum of the coefficients between the forecasted network load (FNL_t) and the EV load (P_t). This minimization has the objective of allocating the EV load in periods of lower forecasted load. The charging point can assume two states (1-ON/0-OFF) defined by the variable δ_t. When the state is ON, the charging point can assume continuous rates of power (P_t) limited by L_t^{Max} and L_t^{Min}. The constraint (15) is used to assure that the amount of energy requested by the EV owner is satisfied. Mixed Integer Programming techniques were used to solve the problem.

IV. TEST CASE

A typical Portuguese LV distribution network was selected to test the CMS (Fig. 3). The LV distribution network has twenty nodes, six charging stations, eighteen loads and a transformer in the secondary substation of 100 kVA.

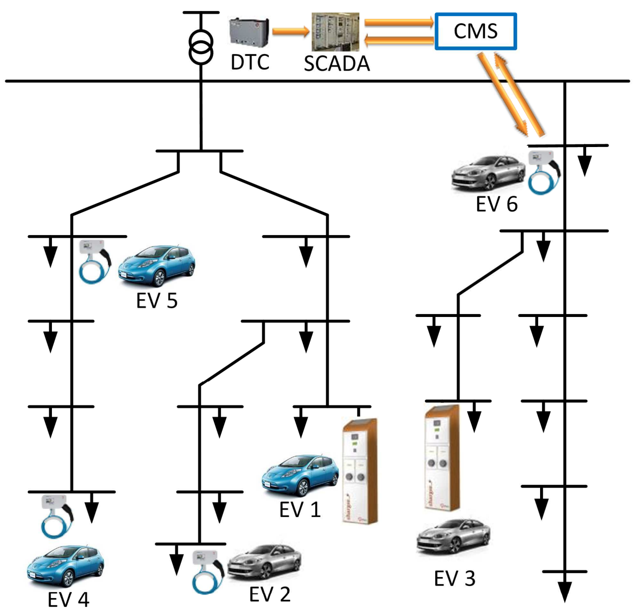

Fig. 3. LV distribution network used as test case

The EV fleet considered is constituted by six EV, whose characteristics are described in Table I, II and III. Table I shows the EV owners' preferences. Table II presents the EV data defined by the EV owner in the beginning of the charging request. This data, together with the EV owners' preferences are communicated to the Charging Station.

TABLE I. EV OWNERS' PREFERENCES (EV DATA)

	Time of disconnection	Energy requested (kWh)
EV 1	18-06-2014, 22:00	12
EV 2	18-06-2014, 23:30	18
EV 3	19-06-2014, 09:30	14
EV 4	19-06-2014, 08:00	20
EV 5	19-06-2014, 07:00	20
EV 6	19-06-2014, 09:00	18

The EV can charge in single-phase or three-phase depending on the characteristics of the EV and of the Charging Station. In single-phase, the power of the charging point varies between 1.4 and 7.0 kW, whereas in three-phase varies between 5.3 and 22 kW.

TABLE II. EV DATA

	Time of connection	Battery capacity (kWh)	Energy in the battery (kWh)
EV 1	18-06-2014, 12:00	16	4
EV 2	18-06-2014, 14:05	20	2
EV 3	18-06-2014, 18:00	22	2
EV 4	18-06-2014, 19:04	24	4
EV 5	18-06-2014, 20:02	22	2
EV 6	18-06-2014, 21:03	18.8	0.8

Table III presents the maximum and minimum power of the charging point for each case.

TABLE III. CHARGING STATION DATA

	Maximum power of the charging point (kW)	Minimum power of the charging point (kW)
EV 1 and 3	5.3	22.0
EV 2, 4, 5 and 6	1.4	7.0

V. RESULTS

This section presents the results obtained from the simulations performed. Two different charging strategies were considered: non-controlled charging and controlled (smart) charging.

In the non-controlled charging mode, the EV charge freely without being subjected to any control action. The charging starts automatically when EV plug-in and lasts until their battery is fully charged or the charge is interrupted by the EV owner. Thus, EV are regarded as normal loads, like any other home appliance.

In the smart charging mode, the EV charging is managed by the CMS, which has the objective of avoiding the increase of the peak load.

The analysis of the results is divided in two parts: aggregated and individual behavior of the EV. An overall comparison between the two charging strategies is also made.

A. Aggretated Behavior of the Six Electric Vehicles

In the smart charging mode, the CMS is responsible for computing optimal load profiles for the EV. This can be observed in Fig. 4 (lower graph), where the EV load is allocated in the periods of lower grid load (valley hours).

In the non-controlled charging mode, it is assumed that the EV start charging as soon as they connect to the electricity network. This behavior is shown in Fig. 4 (upper chart), where all EV charge at maximum rate until they reach the state-of-charge requested by their owners. As it is obvious, this strategy can increase the peak load of the distribution network, what can provoke grid technical problems.

It is important to stress that both charging modes take into account the EV owners preferences. For the same conditions, the smart charging strategy allows flattening the load diagram, bringing benefits for the system such as avoiding voltage drops, branches and transformers overloading which, in turn, allow improving the reliability indices and the energy efficiency of the system.

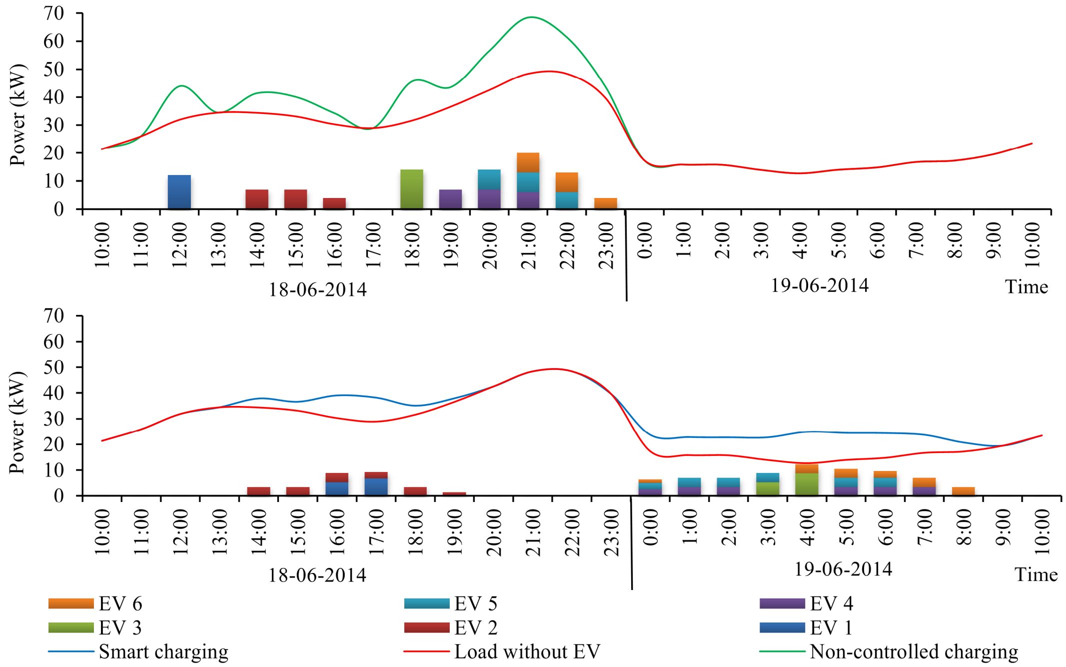

Fig. 4. Load diagram with non-controlled charging (upper chart) vs. with smart charging (lower chart)

B. Individual Behavior of the Electric Vehicle

The test case considered is characterized by four EV (2, 4, 5 and 6) charging in single-phase and two (1 and 3) charging in three-phase. The number of phases influences the charging limits and the charging time of the EV. This effect is visible in Fig. 5 and Fig. 6.

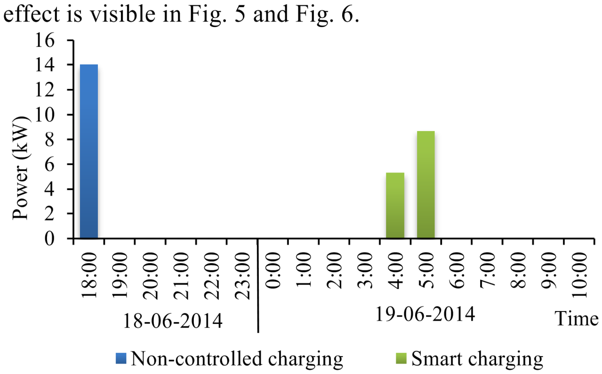

Fig. 5. Load profile of the EV 3 with non-controlled and smart charging

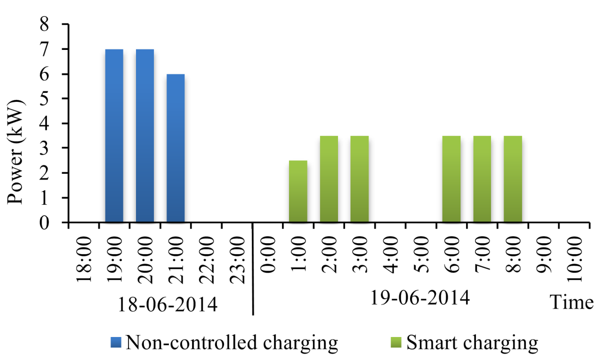

Fig. 6. Load profile of the EV 4 with non-controlled and smart charging

Independently of the number of phases, the charging strategy also influences the charging time of the EV. Non-controlled charging leads to faster charging times since EV always charge with the maximum possible power. Yet, the charging time is not considered to be relevant, since the drivers only require having the EV charged at the end of connection period.

It should also be referred that the amount of energy requested by the EV owners was satisfied in all the cases.

VI. Conclusion

Although distribution systems can handle the integration of EV up to a certain level without any load management functionalities, their integration in a large scale will surely oblige DSO to invest in network reinforcements. An alternative path is the implementation of EV charging management systems that can adapt the EV load profiles to the network needs, optimizing both the interests of the utility and the interest of the EV operator and EV owners.

This work presented a novel EV charging management system which was designed to control the EV load considering simultaneously the EV owners requirements and the electricity network technical limitations. Envisaging the future implementation in a real world scenario, the system was developed from the beginning with the objective of being integrated with existing commercial equipment for smart grids, such as the DTC and SCADA systems. This objective was already fulfilled.

The results obtained from the simulations performed proved the effectiveness of the system, as it allowed charging all the EV according to their owners' preferences and without increasing the network peak load.

Future work will be essentially focused on demonstrations, where the EV charging management system developed will be integrated in a LV network with several EV charging stations, a DTC and a SCADA system. In addition, the charging management system will also be enhanced to support the Vehicle-to-Grid (V2G) functionality [25].

REFERENCES

[1] G. T. Heydt, "The Impact of Electric Vehicle Deployment on Load Management Straregies," Power Apparatus and Systems, IEEE Transactions on, vol. PAS-102, pp. 1253-1259, 1983.

[2] J. A. P. Lopes, F. J. Soares, and P. M. R. Almeida, "Identifying management procedures to deal with connection of Electric Vehicles in the grid," in PowerTech, 2009 IEEE Bucharest, 2009, pp. 1-8.

[3] J. A. P. Lopes, F. J. Soares, and P. M. R. Almeida, "Smart Charging Strategies for Electric Vehicles: Enhancing Grid Performance and Maximizing the Use of Variable Renewable Energy Resources," in EVS24: Electric Vehicle Symposium, Stavanger, Norway, 2009.

[4] P. Papadopoulos, L. M. Cipcigan, N. Jenkins, and I. Grau, "Distribution networks with Electric Vehicles," in Universities Power Engineering Conference (UPEC), 2009 Proceedings of the 44th International, 2009, pp. 1-5.

[5] K. Clement, E. Haesen, and J. Driesen, "Coordinated charging of multiple plug-in hybrid electric vehicles in residential distribution grids," in Power Systems Conference and Exposition, 2009. PSCE '09. IEEE/PES, 2009, pp. 1-7.

[6] K. Clement-Nyns, E. Haesen, and J. Driesen, "The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid," Power Systems, IEEE Transactions on, vol. 25, pp. 371-380, 2010.

[7] S. S. Raghavan and A. Khaligh, "Impact of plug-in hybrid electric vehicle charging on a distribution network in a Smart Grid environment," in Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES, 2012, pp. 1-7.

[8] T. Helmschrott, M. Godde, E. Szczechowicz, C. Matrose, and A. Schnettler, "Methodical approach for analyzing the impact of a mass introduction of electric vehicles on the electricity networks in Europe," in Power and Energy Conference at Illinois (PECI), 2012 IEEE, 2012, pp. 1-6.

[9] P. Richardson, D. Flynn, and A. Keane, "Impact assessment of varying penetrations of electric vehicles on low voltage distribution systems," in Power and Energy Society General Meeting, 2010 IEEE, 2010, pp. 1-6.

[10] L. P. Fernandez, T. S. R. Gomez, R. Cossent, C. M. Domingo, and P. Frias, "Assessment of the Impact of Plug-in Electric Vehicles on Distribution Networks," Power Systems, IEEE Transactions on, vol. 26, pp. 206-213, 2011.

[11] J. A. P. Lopes, F. J. Soares, and P. M. R. Almeida, "Integration of Electric Vehicles in the Electric Power System," Proceedings of the IEEE, vol. 99, pp. 168-183, 2011.

[12] M. D. Galus and G. Andersson, "Demand Management of Grid Connected Plug-In Hybrid Electric Vehicles (PHEV)," in Energy 2030 Conference, 2008. ENERGY 2008. IEEE, 2008, pp. 1-8.

[13] M. D. Galus and G. Andersson, "Integration of Plug-In Hybrid Electric Vehicles into energy networks," in PowerTech, 2009 IEEE Bucharest, 2009, pp. 1-8.

[14] F. Geth, K. Willekens, K. Clement, J. Driesen, and S. De Breucker, "Impact-analysis of the charging of plug-in hybrid vehicles on the production park in Belgium," in MELECON 2010 - 2010 15th IEEE Mediterranean Electrotechnical Conference, 2010, pp. 425-430.

[15] E. Sortomme, M. M. Hindi, S. D. J. MacPherson, and S. S. Venkata, "Coordinated Charging of Plug-In Hybrid Electric Vehicles to Minimize Distribution System Losses," Smart Grid, IEEE Transactions on, vol. 2, pp. 198-205, 2011.

[16] J. Wang, et al., "Impact of plug-in hybrid electric vehicles on power systems with demand response and wind power," Energy Policy, vol. 39, pp. 4016-4021, 2011.

[17] P. Zhang, K. Qian, C. Zhou, B. G. Stewart, and D. M. Hepburn, "A Methodology for Optimization of Power Systems Demand Due to Electric Vehicle Charging Load," Power Systems, IEEE Transactions on, vol. PP, pp. 1-1, 2012.

[18] O. Sundstrom and C. Binding, "Flexible Charging Optimization for Electric Vehicles Considering Distribution Grid Constraints," Smart Grid, IEEE Transactions on, vol. 3, pp. 26-37, 2012.

[19] N. O'Connell, et al., "Electric Vehicle (EV) charging management with dynamic distribution system tariff," in Innovative Smart Grid Technologies (ISGT Europe), 2011 2nd IEEE PES International Conference and Exhibition on, 2011, pp. 1-7.

[20] Mobi.E - Electric Mobility. Available: https://www.mobie.pt/

[21] EFACEC. Public EV charger solution. Available: http://www.efacec.pt/PresentationLayer/ResourcesUser/Catalogos%202012/Mobilidade%20Electrica/SA77I1111B1_Publiccharger_EN.pdf

[22] EFACEC. Home EV charger solution. Available: http://www.efacec.pt/PresentationLayer/ResourcesUser/Catalogos%202012/Mobilidade%20Electrica/SA76I1111A1_Homecharger_EN.pdf

[23] EFACEC. SCADA system solution for HV/MV substations. Available: http://www.efacec.pt/PresentationLayer/ResourcesUser/Catalogos%202012/Automação/as132i1207a1_CLP500SAS_EN.pdf

[24] EFACEC. DTC solution for MV/LV distribution transformers. Available: http://www.efacec.pt/PresentationLayer/ResourcesUser/Cat%C3%A1logos%202013/Automa%C3%A7%C3%A3o/EN/gsmart.pdf

[25] W. Kempton and J. Tomic, "Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy," Journal of Power Sources, vol. 144, pp. 280-294, 2005.

BIOGRAPHIES

José Pedro Iria received the Master's degree in Electrical and Computers Engineering from the Faculty of Engineering of the University of Porto, Portugal, in 2011.He is currently a Researcher in the Centre for Power and Energy Systems of INESC Technology and Science (INESC TEC). His research interests include optimization, electric vehicles and demand response.

Ivan Gustavo Franchin graduated in Computer Science in the Federal University of São Carlos (UFSCar) in 2003. He also completed his Master Degree in Software Engineering in 2007 in the São Paulo University (ICMC/USP). He worked for Claro (São Paulo, Brazil) as Trainee in 2003 and for Biosalc Sistemas de AgroTI (Ribeirão Preto, Brazil) in 2004 as Software Developer. He is currently a Researcher / Software Developer in the Centre for Power and Energy Systems of INESC Technology and Science (INESC TEC).

Filipe Joel Soares received the Physics degree from the Faculty of Sciences of the University of Porto in 2004. He also received the Ph.D. degree in Sustainable Energy Systems, in the MIT|Portugal Program, from the University of Porto in 2012. He is currently a Senior Researcher in the Centre for Power and Energy Systems of INESC Technology and Science (INESC TEC) and Assistant Professor at the Universidade Lusófona do Porto (ULP) in Oporto, Portugal. His research activity is directed towards the integration of renewable energies and electric vehicles in distribution grids, as well as implementation of demand response functionalities.

Nuno Silva graduated from University of Porto in 2003 and finished his PhD in Electrical Engineering at Control and Power Group, Imperial College London in 2009. He now works at EFACEC, where he is currently Deputy Director of Strategic Projects of the Switchgear & Automation Business Unit. He is project manager on several smart grids initiatives and electrical mobility projects. Distributed Generation, Smart Grids, automation and optimization of power systems are his areas of activity.