MERGE (MOBILE ENERGY RESOURCES IN GRIDS OF ELECTRICITY)

A EUROPEAN COMMISSION FUNDED PROJECT ADDRESSING THE IMPACT OF THE ROLL-OUT OF ELECTRIC AND PLUG-IN HYBRID VEHICLES ON GRID INFRASTRUCTURE

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Received on March 31 2011

Presented at the JSAE Annual Congress on May 17 2011

ABSTRACT: This paper highlights the initial findings of the European Commission funded project called MERGE (Mobile Energy Resources in Grids of Electricity). MERGE is a €4.5m, 16-partner collaborative research project supported by the European Commission's Seventh Framework Programme (FP7). The consortium includes utilities, regulators, commercial organisations and universities with interests in the power generation, automotive, electronic commerce and hybrid and electric vehicle sectors across the entire European Union (EU). This major two-year research initiative began in January 2010. The MERGE project mission is to evaluate the impacts that electric vehicles (EV) will have on EU electric power systems with regards to planning, operation and market functioning. The focus is placed on EV and SmartGrid/MicroGrid simultaneous deployment, together with renewable energy increase, leading to CO_2 emission reduction through the identification of enabling technologies and advanced control approaches.

KEY WORDS: D-1 Smart Grid for Mobility, D-2 Energy Supply and Infrastructure, A-1 Electric Vehicles

1. Introduction

Distribution and transmission grids and power system architectures still follow traditional planning rules and procedures. Therefore, it is necessary to identify and prepare solutions for the operational problems that will be caused on the electric grid, to the generation sub-system and to its commercial operation as a result of progressively increasing deployment of EV. The MERGE project aims to do this in two key ways:

1) The development of a management and control concept that will facilitate the actual transition – the MERGE concept;

2) The development of an evaluation suite that consists of methods and programs of modelling, analysis, and optimisation of electric networks into which electric vehicles and their charging infrastructure is integrated.

The MERGE concept is inspired from consideration of dispersed energy resources (DER) deployment but differs in that resources are considered to be mobile in terms of their connection to the grid. Analogies will be derived and adapted to the case of mobile resources, which can be either consumers (e.g. when EV are in charging mode) or injectors of power (e.g. EV batteries delivering power back to the grid). By exploiting a specific computational evaluation suite that is capable of simulating real-world power systems (generation, transmission and distribution) for either steady state or dynamic behaviour it will be possible to test the adequacy of EV preliminary smart control interfaces that will be developed in the project. It will address comprehensively the impact of EV presence regarding steady state operation, intermittent renewable energy sources (RES) integration, system stability and dynamic behaviour, system restoration, regulatory aspects and market arrangements.

This paper will cover the initial findings of four topics investigated in the MERGE project:

- Defining requirements for plug-and-play charging;
- The role of smart metering technology;
- Smart grid opportunities;
- Consumer attitudes and behaviours.

2. Defining requirements for plug-and-play charging

The requirements for plug-and-play charging of electric vehicles can be divided into two main categories, namely power stage requirements and Information and Communication Technology (ICT) stage requirements. The power stage interface, which includes the parts of EV interface responsible for transferring electrical power between EV and the grid, needs to be standardised in several aspects. Firstly, the charging power levels of the power interface need to be determined. Another consideration involves determining the power transfer form, which can be either AC or DC for high power transfer rates. In addition, the power transfer technology which may be conductive or inductive should be decided. Furthermore, safety functions to be implemented such as ground fault interruption, proper connection interlock and immobilisation of the vehicle while charging need to be specified.

Apart from the connector specification, the entities involved in a charging process and the information that they need to communicate need to be determined. There is also a need for standardising the means of communication between the involved entities in the charging process. The payment methods for charging electric vehicles should also follow standard ways to enable a plug-and-play concept.

There are five main entities which, depending on the charging scenario, may need to communicate with each other. These entities are: the user, the EV, the charging point (CP), the Distribution System Operator (DSO) and the supplier/aggregator (S/A), which is responsible for providing electricity and aggregating and managing the EV charging demand. The information to be exchanged with the EV depends on a number of factors. These factors include CP location, the level of sophistication desired for charging and the business model into which the EV is to be integrated.

2.1. Steps of Charging Process

For a plug-and-play concept, proper planning for each of the steps of the charging process is necessary. It is expected that the charging process will entail four high level stages. Fig. 1 shows each of these four stages with the steps of an example charging procedure listed for each stage. It should be noted that stage 3 (payment) and stage 4 (disconnection) may be done in the opposite order depending on whether payment is done in advance or in arrears. Step 11 does not have to be performed if payment in advance is used.

2.2. Possible ICT Stages

Many different types of both wired and wireless communication methods are available for use between the different elements involved in the charging process. Some of the advantages and disadvantages of the use of each within different areas of the ICT stage are summarised in Table 1.

2.3. Evaluation of Possible ICT Stages

The communication technology selected for the ICT stage realisation needs to satisfy a number of requirements. Firstly, it needs to be a suitable solution in terms of range, bandwidth, security, rate of obsolescence, scalability and availability. The second set of requirements relates to compatibility with the already existing infrastructure, ease of implementation and ease of use for both the user and the provider. Last but not least, the cost of the solution, both to the user and the CP owner, needs to be carefully considered.

Fig. 2 shows an evaluation of methods of communication between EV and CP in terms of cost and suitability.

Authentication may not be necessary at charging locations at private areas with private access. For the situations where authentication is required, the two most important factors for considering which method should be used are the suitability of the communication method and the ease of implementing it in the CP. Fig. 3 shows the evaluation of the different methods identified against these two main drivers.

The two factors driving the decision of which payment method to use are the ease of implementation for the supplier/aggregator and the ease of use for the user. Fig. 4 shows the evaluation of the different payment methods for a domestic location. For most of the non-domestic locations, the Pay-As-You-Go (PAYG) is the simplest system to both install and use, as shown in Fig. 5.

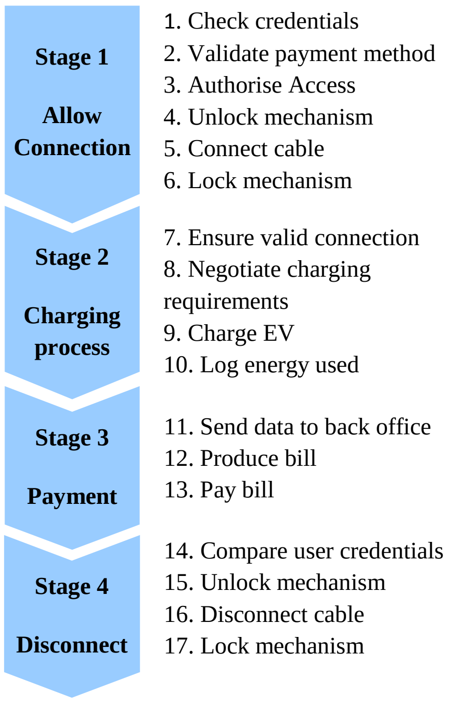

Fig. 1 Example charging procedure stages.

Table 1 Advantages and disadvantages of wired and wireless communication for different areas of the ICT stage.

✓ Advantages × Disadvantages

	Wired		Wireless	
Authen-tication	• Little risk exists about unauthorised interference	✓	• Short range needed to prevent unauthorised interference	×
	• User needs to input details to EV for communication to CP	×	• No need for direct connection to EV, so can also control access to power socket for safety	✓

EV to CP	• Can be used for proximity detection (detecting the presence of the charging connector in order to prevent movement of the EV whilst connected to the CP) • Involves no worry of connection loss	✓ ✓	• Loss of connection during charging results in no control signal • Open to snooping or interference • Difficulty in determining who is talking to who	× × ×
CP to DSO or S/A	• May require installation of cables, implying high cost for civil works	×	• Less installation required • Can use a mesh network to increase robustness	✓ ✓

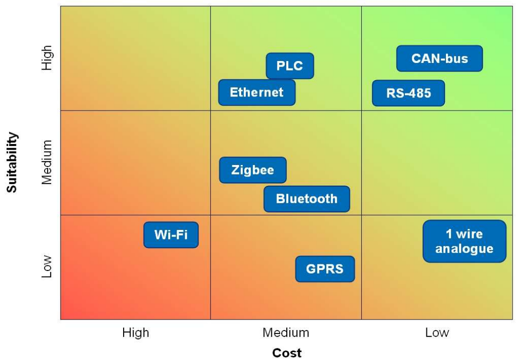

Fig. 2 Evaluation matrix for communication methods between EV and CP.

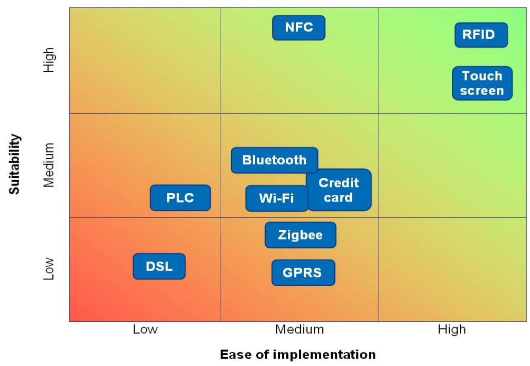

Fig. 3 Evaluation matrix for authentication methods.

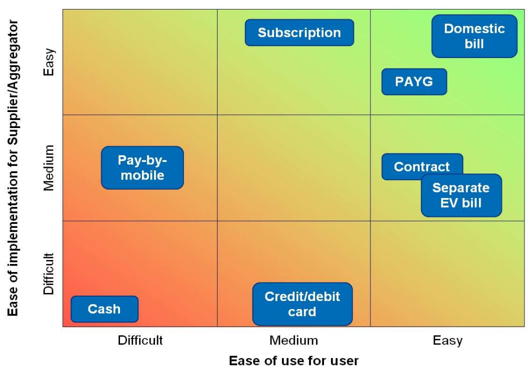

Fig. 4 Evaluation matrix for payment methods in a domestic location.

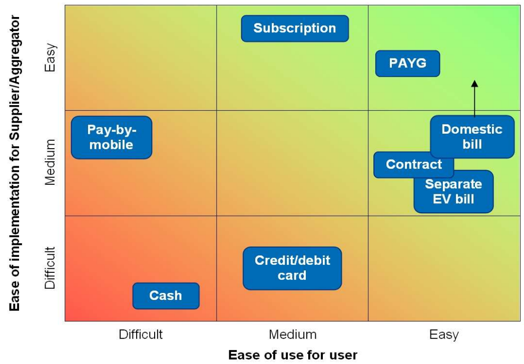

Fig. 5 Evaluation matrix for payment methods in non-domestic locations.

3. The role of smart metering technology

The requirements for plug-and-play charging of EV, in terms of power and ICT infrastructure, will be supported by smart metering technology. Smart meters (SM) have the potential to support the integration of EV with the infrastructure by providing a diverse set of functionalities for the interaction of the EV with the electric grid.

The smart metering concept was cradled from concepts such as automated meter reading (AMR) and automatic meter management (AMM), which were introduced in order to have a more detailed characterisation of energy consumption. This idea has motivated the enhancement of metering infrastructures. It extends the previous concepts to the advanced metering infrastructure (AMI) that includes the supporting hardware and software that can measure, store and process energy data for both consumers (e.g. charging EV) and producers of energy (e.g. EV delivering power back to the grid) **(1).**

Although the definition of SM can be broad, it is widely accepted that they are AMI which offer additional functionalities when compared to traditional meters in particular to handle EV integration under different scenarios **(2)**. They are electronic boxes with communication links **(3)**, designed to provide utilities and customers with real time information based on energy costs. One of the roles of the smart metering is to allow customers to be aware of their energy consumption profile and incentivise them to use energy more efficiently. Smart metering also provides a two way communication channel between the meter and the utility infrastructure, for automated reading and control, allowing advanced energy services to be exchanged between customers and the grid. **(1)**

3.1. High level requirements

The importance of smart metering is clear when defining high level requirements for future metering infrastructures. The MERGE project defined high level requirements that SM should guarantee:

1) Interoperability and public communications standards;
2) Common communication architecture;
3) Service lifecycle management;
4) Event support and alarm handling;
5) Combination of different business and market services.

Since metering systems are to be massively deployed, creating a complex system, different layers of interoperability need to be accounted for, not only in terms of communication technologies but also in terms of procedures for participating in different business transactions. Hence, it is very important to define standards for communications, as they will be the basis of the interoperability in mass markets for smart metering technologies, where a single solution is unlikely to meet all requirements.

Nonetheless, common communication architectures should be designed to ensure the necessary performance of data exchange in terms of availability, reliability, security and speed. It must allow unconstrained participation of customers in a dynamic tariffs environment.

From the point of view of the lifecycle management of SM, the development of new services or the updating of existing ones, according to different configurations and parameters, have to be accounted for. Enhanced lifecycle management strategies can significantly reduce the impact of technology changes.

Given the potentially high number of events generated in the electric grid, it is necessary to rely on an event and alarm management system that is able to provide an overview of the status of the network. Alarms generated by SM can signal critical events that could adversely affect the electric system operation.

SM can support the participation of EV in the complex power market through the combination of market services in different business cases. The role of the SM is to enable the market participation of EV as individual units and aggregated sets.

3.2. Charging Strategies

A particular role of smart metering technology is the integration of different charging strategies of EV as those defined in the MERGE project **(4)**, as illustrated in Fig. 6.

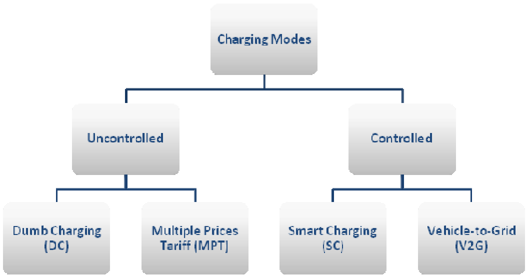

Fig. 6 Charging modes for EV.

Different functionalities that SM need to provide were defined in the project to tackle both less demanding charging approaches, such as dumb charging (DC) and multiple prices tariff (MPT), and also elaborated charging schemes, like smart charging (SC) and vehicle-to-grid (V2G). This led to the definition of different versions of SM to be considered in the MERGE project, for domestic and public environments, according to the defined charging modes.

3.3. Smart Meters as Gateways of Services

Smart meters represent a unique opportunity towards a more efficient and detailed approach to demand side management (DSM). As a concentrator and manager of information related to the energy exchange of each consumer, SM are able to offer energy services both to the customer and to the grid while promoting DSM strategies.

As gateways, SM are responsible for the local management of available generation or loads, in particular EV, establishing the necessary communications to provide universal metering and control functions in order to achieve a high level of coordinated energy management.

3.4. Smart Metering in V2H

The role of smart metering in integrating distributed generation and controllable loads is clear. EV as controllable loads and potential suppliers of energy to the grid can be integrated in the domestic environment under the Vehicle-to-Home (V2H) concept **(5)**.

Since SM act as gateways of services, they are responsible for the establishment of the communication infrastructure. Thus in a domestic environment, they can be responsible for the setup of a Home Area Network (HAN) for the interconnection of appliances. This will enable SM to support three V2H use cases, which were identified in the MERGE project **(4)**. In the first and simplest use case, the smart metering infrastructure is responsible for the local management of controllable appliances and EV. The second use case introduces available microgeneration to the first use case, adding increased complexity to the energy management infrastructure. In the third use case, unlike the previous cases, the domestic environment is considered to be electrically isolated from the grid. In such situations SM are not able to offer services to the grid, but they can ensure energy supply according to a priority list of domestic appliances.

4. Smart grid opportunities

The integration of EV in smart grids is a challenging issue due to their complex and stochastic behaviour compared to other energy resources. Their contribution to the intelligence of the future grids can be based on the fact that EV can behave as flexible loads, considering the different charging scenarios (dumb / multiple prices tariff / smart charging) or as distributed storage devices (V2G concept). The latter case is characterised by fast dynamic response which enables grid support, in terms of peak shaving and reserve/regulation provision. Moreover, EV are mobile energy resources which can connect at different points of the grid while the connection period varies according to the EV owners' needs. Thus, a stochastic representation of EV should be considered when integrating EV in smart grids.

The EV stochastic behaviour and duality in their operation dictate the need for a new aggregating entity that will provide market visibility and EV charging controllability. As referred to in Section 2, this entity can be a S/A which will serve as the intermediary between the EV and the upstream network. The S/A combines the functions of managing the EV load and offering the EV electricity in the retail market, considering always the EV owners' requests. The management of a large amount of grid connected EV, which are dispersed in a large geographical area, is enabled by a hierarchical management structure, as shown in Fig

7. EV can be connected to the grid either as individual entities or as clusters controlled by different aggregation layers.

Two innovative distribution network infrastructures have been proposed to achieve efficient DER aggregation: Microgrids (MG) and Virtual Power Plants (VPP). The integration of EV in both structures requires the synergy of a technical management and market operation framework, as presented in Fig. 8. When operating the grid in normal conditions, EV will be managed and controlled by the different aggregation layers, as shown on the right hand side of Fig. 8. In case of abnormal or emergency situation, the DSO takes control in order to handle violation of grid operational restrictions.

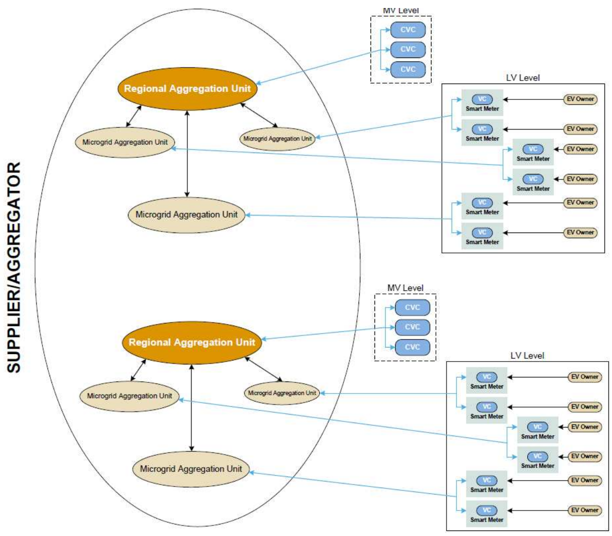

Fig. 7 Supplier/Aggregation hierarchical management **(6).** (MV: Medium Voltage. LV: Low Voltage. CVC: Cluster of Vehicles Controller. VC: Vehicle Controller)

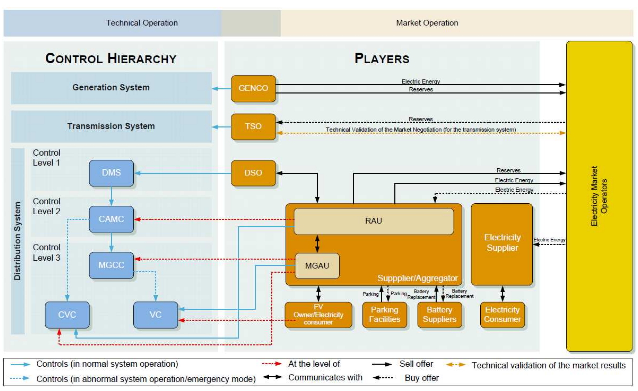

Fig. 8 Technical management and market operation framework for EV integration into electric power systems **(7)**, **(8)** (GENCO: Generation Company. TSO: Transmission Systems Operator. DSO: Distribution System Operator. RAU: Regional Aggregation Unit. MGAU: Microgrid Aggregation Unit. DMS: Distribution Management System. CAMC: Central Autonomous Management Controller MGCC: Microgrid Central Controller.)

The interaction between the VPP control centre and the VPP resources, including EV, is shown in Fig. 9.

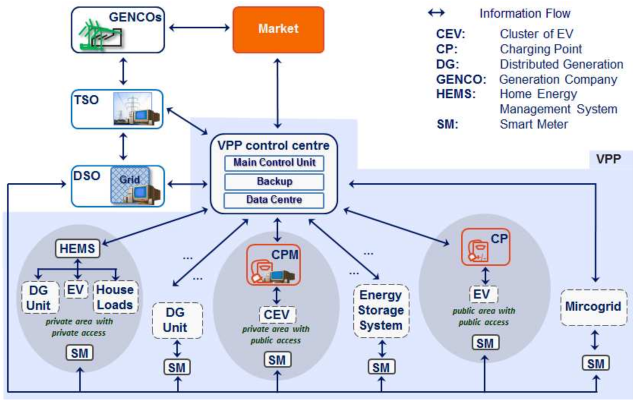

Fig. 9 Interaction between the VPP control centre and the VPP resources in the direct control approach **(9)**

5. Consumer attitudes and behaviours

The identification of traffic patterns and human behaviours relating to the use of EV has been investigated by the MERGE project. This study examines how conventional vehicles are currently used and the potential impact the widespread introduction of EV would have on the grid.

A detailed consumer behaviour questionnaire was distributed in eight languages to a range of distribution lists by all partners in the MERGE consortium. Over 1600 responses were obtained from a cross-section of the European population providing a sound basis from which to draw conclusions and perform analysis.

The studies focussed in particular on Germany, Great Britain, Spain, Greece, Portugal and Ireland. The questionnaire responses provided statistics on the proportion of responders that would participate in the different EV charging modes addressed in the MERGE project, as well as potential usage patterns.

The survey found that a significant majority of responders would participate in smart control of charging, if tariff electricity rates were to incentivise it. It also found that most drivers would prefer to recharge an EV at home, although there was no trend as to the regularity with which they would choose to recharge, suggesting the practicalities of limited range and recharging opportunities are difficult to conceive without actually owning an EV.

The study found that electric vehicles would serve the needs of 85% of responders, assuming that they could access an electricity supply to recharge the vehicle; however, only 57% responders said that they could provide electricity to their vehicle where it is parked for the longest period of the day.

The questionnaire data have also been used in basic models of the energy requirements of EV under different 'dumb' and 'smart' charging scenarios as shown for Germany in Fig. 10 and Fig. 11 respectively.

The analysis showed that with a 10% penetration of electric vehicles using a dumb charging strategy (with no smart control of charging) and all vehicles charging as soon as they return from their last journeys of the day, the daily peak demand levels would increase by between 6% and 12% compared to the baseline peak demand and that the peaks would occur at a different time to that of the baseline peak demand.

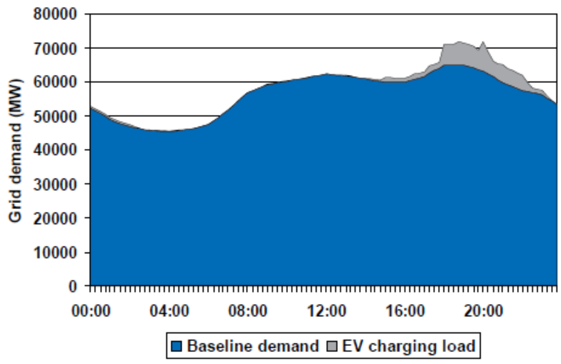

Fig. 10 Example of German grid demand with a dumb charging scenario - EV charging load increases the peak load **(4)**

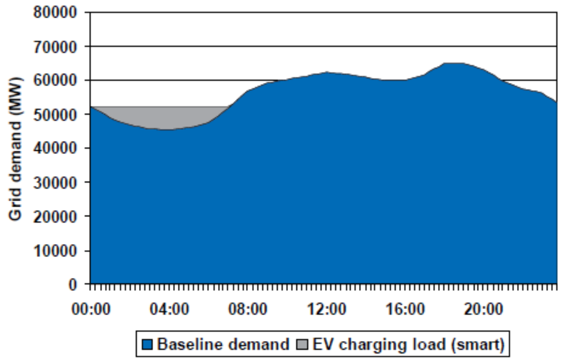

Fig. 11 Example of German grid demand with a smart charging scenario - EV charging load fills the night-time 'valley' **(4)**

The analysis further showed that a 10% penetration of electric vehicles, with an ideal smart charging strategy with all EV charging load moved to the night-time 'valley' periods, would cause no change to the baseline peak demand levels. In addition, the peak EV charging load is also reduced, unless the charging is already spread over a long period of the day.

The daily variation from minimum to peak demand was shown to increase significantly for the 'dumb' charging scenario and reduce significantly for the 'smart' charging scenario.

The data obtained in the questionnaire, along with the dumb and smart charging load change models, will be used in further analyses as the work of the MERGE project continues.

6. Conclusions and Recommendations

From the initial research performed in this project, one can conclude that large scale EV deployment requires the adoption and the development of a new set of concepts, and control / management architectures in order to minimise the need to reinforce the electrical generation, transmission and distribution infrastructures. The adoption of controlled charging strategies involving the adherence of the new consumers to this concept is fundamental for the success of the EV deployment.

EV grid interfaces also need to be enhanced, in order to help local control of the participation of EV in delivering ancillary services to the power system. This can be performed either by installing additional functionalities on board of EV or by installing these functionalities at the EV point of connection. This requires the update of the existing standards on the charging of electric vehicles.

A new set of agents, like the supplier/aggregator is envisaged to help manage the integration of this new type of consumers – the EV batteries. This should also be done by exploiting smart metering infrastructures that are presently being deployed. In fact, such infrastructure, if properly designed, can support the communication needs and the EV energy billing requirements.

In addition, it is very important to understand that in the future Distribution System Operators will have to play a critical role in this new scenario, by validating the EV batteries' charging profiles before the aggregators present their biddings on EV consumption needs to the market.

From the studies performed so far in the MERGE project, it is possible to conclude that large scale EV deployment can be performed without major concerns if one adopts an intelligent based approach, involving full use of ICT, to manage and control the presence of EV consumers in the electrical network.

References

(1) Rua, D.; Issicaba, D.; Soares, F.J.; Almeida, P.M.R.; Rei, R.J.; Lopes, J.A.P.; "Advanced Metering Infrastructure functionalities for electric mobility," Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES, pp.1-7, 11-13 Oct. 2010.

(2) Hatziargyriou, N., et al: Mobile Energy Resources in Grids of Electricity: the EU MERGE Project, SGM - 2nd European Conference SmartGrids and E-Mobility, Brussels, Oct. 2010.

(3) Venables, M.; "Smart meters make smart consumers [Analysis]," Engineering & Technology, vol.2, no.4, pp.23, April 2007.

(4) Bending, S., et al: MERGE Project. WP1, TASK 1.1, 1.2, 1.5, Deliverable D1.1. "Specify Smart Metering for EV", Aug 2010, http://www.ev-merge.eu/

(5) G. Haines, A. McGordon, P. Jennings, "The Simulation of Vehicle-to-Home Systems – Using Electric Vehicle Battery Storage to Smooth Domestic Electricity Demand", EVER 2009, Monaco, 2009.

(6) MERGE Deliverable D1.2 "Extend concepts of MG by identifying several EV smart control Approaches to be embedded in the smartgrid concept to manage EV individually or in clusters", June 2010, http://www.ev-merge.eu/

(7) J. A. Peças Lopes, F. J. Soares, P. M. Rocha Almeida, "Integration of Electric Vehicles in the Electric Power System", Proceedings of the IEEE, vol. 99(1), pp. 168-183, Jan. 2011.

(8) F. J. Soares, J. A. Peças Lopes, P. M. Rocha Almeida, "A Technical Management and Market Operation Framework for Electric Vehicles Integration into Electric Power Systems", presented at the 2nd European Conference on SmartGrids and E-Mobility, Brussels, Belgium, October, 2010.

(9) MERGE Deliverable D1.3 "Controls and EV Aggregation for Virtual Power Plants", October 2010, http://www.ev-merge.eu/