Electric Vehicles in Power Systems with Distributed Generation: Vehicle to Microgrid (V2M) Project

Roberto Villafáfila-Robles[1], Pau Lloret-Gallego[1], Daniel Heredero-Peris[1], Andreas Sumper[1,2], Ignasi Cairo[2], Narcís Vidal[3]

1. Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA-UPC)
Universitat Politècnica de Catalunya
EU d'Enginyeria Tècnica Industrial de Barcelona, Electric Engineering Department,
Comte d'Urgell, 187, 08036 Barcelona, Spain
roberto.villafafila@citcea.upc.edu
2. IREC
Catalonia Institute for Energy Research, Barcelona, Spain
3. Endesa
Research, Technology Development and Innovation, Barcelona, Spain

***Abstract*— The integration of electric vehicles into distribution networks will require intelligent systems for managing the charging points and the impact on the grid. Electric vehicles represent an opportunity to manage the power demand allowing shifting the electric load to off-peak periods and to store the excess of generation from renewable generators. In addition, the electric vehicles could be used to improve the reliability and power quality if vehicle to grid (V2G) is deployed. The Vehicle to Microgrid (V2M) project consists on evaluating the impact of electric vehicles into the network and proposing solutions to deal with the challenges that electric vehicles introduce. The results will be validated in a demonstration plant that is a microgrid placed at IREC.**

Keywords: Electric vehicle, V2G, Microgrid

I. INTRODUCTION

Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) are vehicles powered either by electricity (EVs) or a combination of electricity and fossil fuels (PHEVs). The use of electricity in these vehicles allows electricity to become an important fuel in the transportation industry. The gradual transition from oil to electricity as an energy source due to the introduction of EVs presents a major paradigm for power utilities, which will have to be prepared to face the new situation.

Preliminary studies show that grids will not be strongly affected by the use of EVs and PHEVs because the charging of their batteries will take place mainly during off-peak hours. Nevertheless, these studies do not take into account that EVs and PHEVs drivers may charge their vehicles at moments more suitable for them than for the power utility management, which may include peak hours and thus provide an important impact onto the grid. Therefore, it is required to understand the consequences of incorporating the charge of EVs and PHEVs into the grid operation.

In addition, EVs represent a new opportunity to manage the power demand and to avoid curtailments for renewable based generators since most of private vehicles are usually parked more much time than they circulate. It can be manage as an intelligent load that consumes when is required. Moreover, the energy stored in the batteries of EVs and PHEVs could also be used to supply electricity if it is needed, improving the reliability and power quality.

This paper describes the project Vehicle to Microgrid, V2M. It consists on evaluating the impact of EVs in the electric grid and proposing solutions to deal with the challenges that EVs introduce. Fast Charge and possible services related to it are also evaluated. In the long-term objectives, a massive EV penetration in the grid is supposed with millions of deployed units. Under this scenario, the impact in HV/MV/LV grids will be studied and the necessary control of the grid will be analyzed. As a resulting outcome, different scenarios will be considered when analyzing the implications of the connection of EVs and the results will be validated and studied in a demonstration plant (in this case a low-voltage microgrid will be used), which will be installed at IREC facilities.

II. ELECTRIC VEHICLE FRAME

A large number of national and international ongoing projects deal with EVs, both including public and private initiatives, involving organizations such as universities, research centers, system operators, power utilities and automotive industries.

In this frame, the Union of the European Electricity Industry, Eurelectric, has realized an important effort towards the creation of an application of common standards, by means of a declaration for the standardization of Electric Charging Infrastructure [1]. The signatories, 50 representatives of European electricity companies, power distribution system operators and national electricity sector associations, have

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confirmed their determination to cooperate towards the development and application of industry pre-standards until standards have been set by the official standards bodies ISO/IEC [2][3]. The IEC deals with issues related to electric components and electric supply infrastructure whereas the ISO deals with subjects related to EVs.

Among the large number projects and initiatives that are ongoing around the world Europe, the most representative initiatives in Spain, Europe and outside Europe are presented further below.

Finally, the GE-Nissan Project is an international initiative, which involves Japan and the United States, consisting of the study of new technologies to the creation of a smart reliable charging infrastructure for EVs and their integration with homes and buildings [15].

As it concerns to Spain, the MOVELE project, framed in the 2008-2011 Energy Saving and Efficiency Activation Plan with a duration of two years (2009 and 2010), envisages the running of a pilot project introducing EVs in order to demonstrate its feasibility in technical, energy and economic terms in urban environments [16].

The VERDE project, led by the Technical Centre of SEAT is focused on studying and developing technologies that will enable future integration and introduction of PHEVs and EVs in Spain, with duration of three years ending on 2012. The project covers the study of different EVs topologies, energy storage, actuators and interaction between the EV and the distribution grid [17].

The Wind Regulation with Vehicles (REVE) project aims to perform a study thoroughly assessing the key technical challenges and the most relevant economic aspects in order to create a network infrastructure so that EVs may act as energy storing facilities in the electric network while they are not circulating [18].

Smartcity, leaded by Endesa, is a four years project located in the city of Malaga (Spain), which aim is to implement a new model of energy management in cities and increase the consumption of renewable energy [19]. Also, Smartcity encourages the use of EVs, by the installation of recharging sockets and the deployment of a fleet of vehicles.

The Grid for Vehicles (G4V) initiative is a consortium of European partners performing research on the mass integration of EVs included in the 7th Framework Programme of the European Commission [4]. The G4V project aims to develop an analytical method to evaluate the impact of a large scale introduction of electric and plug-in hybrid vehicles into the grid infrastructure, exploring the opportunities consisting in active demand and storage possibilities.

The Electric vehicles in a Distributed and Integrated market using Sustainable energy and Open Networks (EDISON) project is an international research project partly publicly funded through the Danish transmission system operator (TSO) Energinet.dk's research programme FORSKEL[5]. This project will develop optimal system solutions for EV and HEV system integration, including network issues, market solutions, and optimal interaction between different energy technologies [6].

Mobile Energy Resources in Grids of Electricity (MERGE) is a two- year initiative started in early 2010, part-funded by the European Commission (EC) under the 7th Framework Programme [7]. MERGE has as mission the evaluation of the impacts that EVs will have on the EU power systems regarding planning, operation and market functioning. The focus will be placed on EV and SmartGrid/MicroGrid simultaneous deployment, together with renewable energy increase.

The European Green Cars Initiative (EGCI) is one of the three public private partnerships (PPP) included in the Economic Recovery Plan carried out by the EC [8][9]. Its main focus is the electrification of mobility and road transport. The initiative considers the research on electric and hybrid vehicles, especially high density batteries and electric engines, as well as their infrastructure, that is, smart grids and the interfaces grid-vehicles.

The Green eMotion project is included in the EGCI [10]. The project consists of a proposal in order to coordinate a number of demonstrators from various countries, seeking both technical and commercial interoperability.

The Electric Vehicles for Advanced cities (EVA), funded by the EC as part of the EGCI project, proposes the establishment of an integrated European demonstration project on electromobility, and will assess in real life conditions the impact of EVs on user's behavior, the mobility networks and grids [11]. The project will further support the definition of standards, recommendations, scenarios and roadmaps for the deployment of electromobility.

The EV Project in United States aims to develop the required infrastructure to promote the introduction of EVs in this country [12]. The project will characterize the vehicle use in diverse topographic and climatic conditions, evaluate the effectiveness of charge infrastructure and conduct trials of various revenue systems for commercial and public charge infrastructure.

Tokyo Electric Taxi Project, launched in January 2010, is commissioned by the Natural Resources and Energy Agency of the Ministry of Economy, Trade, and Industry [13]. This initiative is a pilot project with the aim to test and operate three interchangeable electric battery taxis for a period of 90 days, to allow the introduction of electric taxis in Japan.

Project Better Place will build the first pilot electric battery rechargeable grid system in Israel [14].

III. V2M PROJECT

The aim of V2M project is to going further than current projects with the objective to create an intelligent system for the integration of EVs into power systems with distributed generation considering the vehicle to grid (V2G). V2G will be able to use EVs as distributed storage for power systems and thus, improving the reliability and quality of power supply.

The general objective of this project is the V2G deployment on power systems operation and regulation within the scope of Spanish electric power sector. In order to cope with this challenge an analysis stage has been defined first. The development of a V2G system is performed in a second stage. Finally, a validation stage in a demonstration plant will be done.

The analysis is considering the benefits and drawbacks of V2G. One of the profits of such systems is that it will increase the integration of renewables into power systems. EVs can perform as storage, charging when there is an excess of renewable generation and injecting the energy stored if there is a lack of generation. Moreover, other advantage is the deferring of investments in infrastructure if an intelligent management of EV's charge-V2G is established.

However, in order to get such benefits some drawbacks have to be overcomed. There is a lack in current regulation to permit V2G. New stakeholders should be defined to manage properly the EV with and without V2G. The management will be possible only if a communication infrastructure is deployed to have a real-time control of network operation. The integration of EVs into power system impacts in its operation and may produce variations in voltage profile and overload power lines. Moreover, as chargers of EVs are power electronics converters, harmonics will be drawn.

Demand side management strategies will be defined for implementing the intelligence management needed to reduce the mentioned impacts on network operation. Such strategies will be established for different time horizons from short-term (where the number of EVs will be low) to long-term (where a mass integration of EVs is expected).

In order to test V2G capability, a V2G system will be developed in the second stage. Such system will consist of power electronics converter that permits injecting the energy stored in the battery into the network. In order to allow the discharge of the battery some facts have to be taken into account as for example, the needs of the user the next time it uses the vehicle and the state of charge of the battery.

The different proposals of demand side management considering the different constraints defined for V2G will be tested at the validation stage using the demonstration plant that is described in next section.

IV. Demonstration Plant

The testing plant is a microgrid placed at the Catalonia Institute of Research (IREC) [20]. It consists of a 40 kW low voltage microgrid connected to the main grid with real systems and has the capability of emulating either loads, generators and storage. Then, it provides the capabilities of integrating the EV both as a load and as energy storage device, and interacts with the rest of the microgrid. The different elements that are part of the microgrid are shown in Fig. 1 and are described below.

A. *Emulation units*

The emulation is performed via hardware. Each three phase hardware emulated unit is composed of two line-frequency phase-controlled AC/DC converters in back-to-back configuration. What is controlled is the active power injected to the grid or consumed from it. It has been considered that a node behaves as a generator (Fig 2.a) when active power flows from the AC side to the DC bus of the lower converter (from now referred as "Emulator"), then from the DC bus to the AC side of the upper converter (from now referred as "Active Front End", AFE) and finally it returns to the grid. On the other hand, it behaves as a consumption, when active power flows from the AFE to the Emulator, and then it returns to the grid (Fig 2.b).

- Generation units: These units of 4 kVA, can be programmed to emulate different sources of renewable energy such as wind or photovoltaic. The dependence on weather conditions of these sources is reflected in their curve response and, therefore, real behavior can be reproduced at the output of the power converter.

- Energy storage unit: This unit also with 4 kVA of power rating can be programmed to follow the charging profile from different energy storage technologies, such as electrochemical batteries Ni-Cd, NaAs, Li-Io, or other type of batteries, such as supercapacitors. The constant current, constant voltage or constant power charging characteristics can be reproduced with these units.

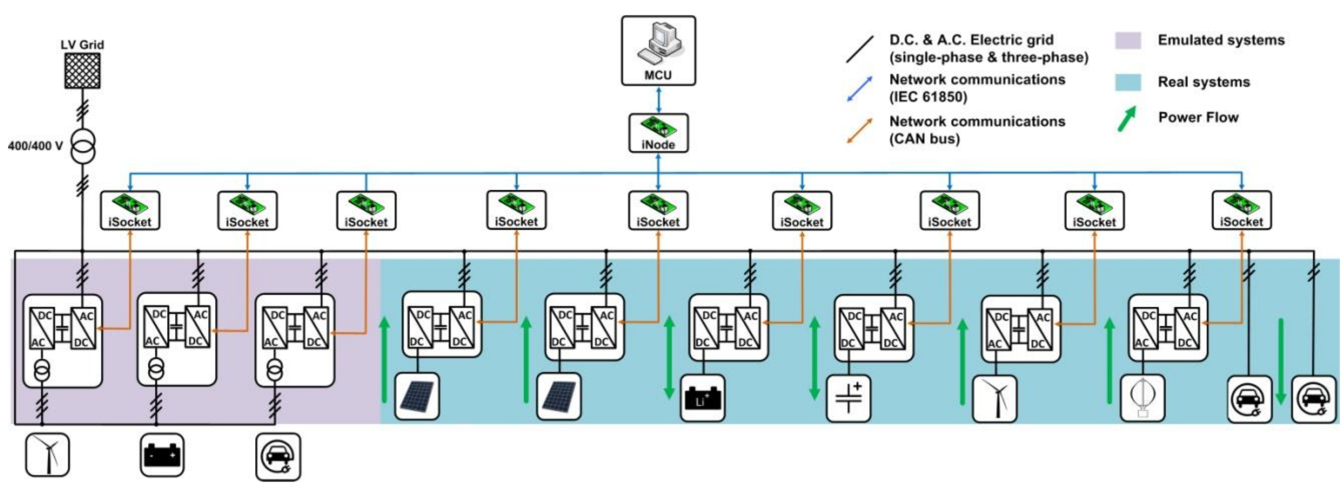

Figure 1. Microgrid connectivity and components.

- Load units: This 4 kVA unit, can emulate the real behavior of different types of consumptions: Sensitive-loads and/or non sensitive-loads, as well as the charging of an electric vehicle.

B. Real systems

- Urban wind turbine power generator (2 x 1 kVA). In order to study the performance of different technologies, both a horizontal and vertical axis micro-windmills are installed and injecting power into the microgrid.
- Photovoltaic generation (2 x 2.5 kW). Also two different kind of photovoltaic panels are installed; monocrystalline and polycrystaline.
- Lithium-ion battery storage (5 kW). The energy supplied by the battery should be enough to support critical loads for at least two hours.
- Ultracapacitors storage (5 kW). These elements are suited for discharging large amounts of energy during short periods of time to cover peaks in demand and, furthermore, they can go through up to hundreds charge/discharge cycles.
- Plug EV. Commercial slow chargers (2 x 3.6 kW) and fast charger (up to 50 kW) will be in the microgrid. The V2G system will be included together with these chargers.

Figure 2. Emulator systems in a back-to-back structure.

C. Management and control unit

The microgrid control units are the iSocket (Intelligent Socket) located in the emulator and the iNode (Intelligent Node), close to the Microgrid Control Unit (MCU). The microgrid is externally managed by an automation system, guaranteeing electric security and stability, reliable power supply with optimal quality and self-healing behavior (automated maintenance and outage prevention).

This management system is hierarchical and 3-layered. At the top layer, the Microgrid Control Unit (MCU) (see Fig. 1) manages the overall microgrid. The iNode and iSockets, which represent middle and bottom layer respectively, perform time critical tasks such as power control, emergency management and logging. For the time being, it has been considered that there is an iSocket for every microgrid's unit, and one single iNode. The MCU is a PC running on Windows XP. The iNode and iSockets are embedded boards based on the Freescale i.MX25 processor (ARM9 family) running on Windows CE 6.0. It has also been fully tested embedded boards with Digi's UNC90 module, which is based on Atmel's T91RM9200 ARM9 microcontroller and runs on an embedded Linux (Linux kernel v2.6 for ARM9 processors).

D. Control algorithm

The control algorithm implemented in the microgrid is based on the independent control of active and reactive power [21].

Two different types of control have been implemented: centralised and distributed. In the centralised mode the iNode is in charge of the decisions and the power of one unit depends on the other's power [22]. On the other hand in the distributed mode the iNode is a bridge between the communications protocol used for the microgrid, that is the IEC 61850 [23] and CAN and the iSocket is the element responsible for taking the decisions. In addition, the power delivered by each unit is independent of the others.

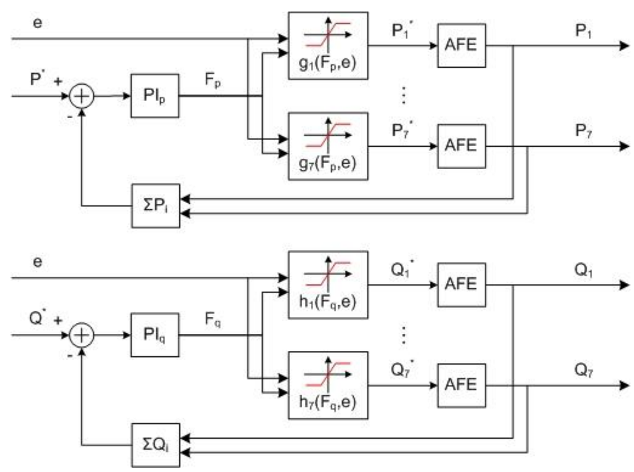

Figure 3. Active and Reactive power closed-loop control.

The iNode, in the centralised control, receives the information of the total P/Q power from all the iSockets and receives the reference value (P* Q*) from the MCU representing the utility control consigns. With these parameters it calculates Fp and Fq, dimensionless parameters whose values range from -100 to +100. These are sent to the iSockets, who with these values, calculate the set value (P^*_i Q^*_j) to send to each converter (Fig. 3).

Another input of the system is the energy price (e), which will be passed over from the iNode to the iSockets.

The iNode uses two independent PI controls to achieve its goal. Meanwhile every iSocket applies a piecewise function to obtain P*i and Q*j as follows:

$$P_i^* = \begin{cases} P_{i\text{-}max} & \beta_{Pi} \\ P_{i\text{-}min} + \frac{P_{i\text{-}max} - P_{i\text{-}min}}{\beta_{Pi} - \alpha_{Pi}} (F_P - \alpha_{Pi}) & \beta_{Pi} \geq \\ P_{i\text{-}min} & F_P < \end{cases}$$

$$Q_i^* = \begin{cases} Q_{i\text{-}max} & \beta_{Qi} < \\ Q_{i\text{-}min} + \frac{Q_{i\text{-}max} - Q_{i\text{-}min}}{\beta_{Qi} - \alpha_{Qi}} (F_Q - \alpha_{Qi}) & \beta_{Qi} \geq F \\ Q_{i\text{-}min} & F_Q < \end{cases}$$

Where $\beta_{Pi} > \alpha_{Pi}$ and $\beta_{Qi} > \alpha_{Qi}$. These parameters are dynamic values that are recalculated depending on the behaviour of each microgrid unit (storage, consumption or generation), energy price and the current state. They can be interpreted as the participation priority of each microgrid unit.

E. Monitoring the microgrid

The use of a Supervisory Control And Data Acquisition (SCADA) software makes configuration and supervision of microgrids easier. Total knowledge of the operating of every Distributed Generation unit (DG), Distributed Storage (DS) unit or Distributed Generation/Storage unit (DG/DS) of the microgrid allows the user to supervise the system at all times and therefore to resolve unforeseen situations quickly

The SCADA used in IREC's microgrid uses a real-time system to calculate energy production (generation and storage) and consumption of each unit. Using this software any electric or physical parameter can be requested in real time, integrating many different electric or physical parameters in one or various systems installed in the same grid, even accessible from external grids (decentralised energy control systems). The communication between software is via LAN or the Internet. This SCADA also acts as a centralising and information management unit. The objective of this software is to process data and prepare reports. Figure 4 shows the current SCADA used to real time monitor the status of the microgrid.

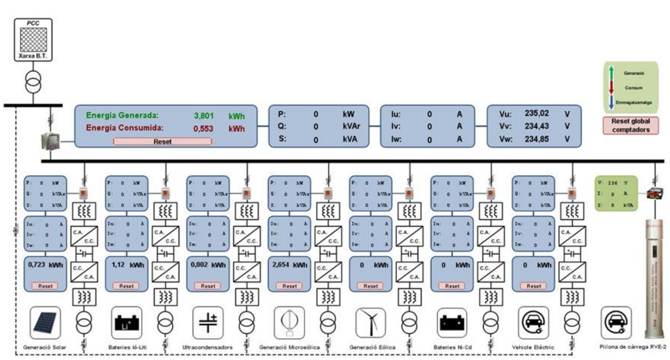

Figure 4. Scada program used for monitoring the microgrid

V. Conclusions

EVs and PHEVs are challenging for power systems. This paper has introduced V2M project that deals with V2G capability and intelligence strategies for improving power systems operation with distributed generation.

Acknowledgment

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