Electric Vehicles Grid Integration Under the MicroGrid Concept

J. A. Peças Lopes[1], **P. M. Rocha Almeida**[1], **F. J. Soares**[1], **N. Hatziargyriou**[2]

[1] Instituto de Engenharia de Sistemas e Computadores do Porto (address: Campus da FEUP, Rua Dr. Roberto Frias, 378, 4200 - 465 Porto, Portugal) and Faculdade de Engenharia da Universidade do Porto, Porto, Portugal (e-mails: jpl@fe.up.pt; filipe.soares@fe.up.pt; pedro.almeida@fe.up.pt).

[2] Technical University of Athens (Zografou Campus, Athens, Greece) (email: nh@power.ece.ntua.gr).

I. Introduction

Future massive adoption of Electric Vehicles (EVs), replacing the conventional ones, will provoke considerable impacts in electric power system design and operation. When parked and plugged into the electric grid, EVs' batteries can be considered as:

- Simple loads, e.g. when EVs' owners simply define that the batteries must be charged at a certain rate;
- Dynamic loads/storage devices, if EVs' owners define a time interval for the charging to take place. From the grid point of view, this approach yields more benefits once it provides elasticity to these new loads, allowing even the battery to inject active power into the grid when such action is needed.

The latter is the distinctive feature of the Vehicle-to-Grid (V2G) concept, allowing the provision of several ancillary services like peak power and spinning reserves. However, to fully exploit EVs capabilities, a hierarchical management structure will be required to control EVs activities, either individually (connected at the Low Voltage (LV) level) or as clusters of distributed storage devices (connected directly to the Medium Voltage (MV) level, in fleet charging or fast charging stations).

As the MicroGrid (MG) and Multi-MicroGrid (MMG) concepts already contemplate the adoption of such a management mechanism, the most logical action to take is to embed the EVs management procedures into the MG and MMG hierarchical management structure and concepts. On one hand, a synergetic approach between MGs and EVs will allow a massive integration of this kind of vehicles, while avoiding expenditures in network reinforcements. On the other hand, the clear symbiosis existing between MGs and EVs can be exploited to leverage the shift from a centrally operated electric power system to a decentralized paradigm, composed by a set of MMGs. Furthermore, EVs may be the solution for the MG frequency's related problems, when operating in islanded mode. EVs' dynamic charging management and storage capability can be used to help managing the network in some emergency conditions, by participating in the primary frequency control.

This paper's main goal is to present an enhanced architecture of the MGs and MMGs hierarchical control structure, capable of properly accommodating EVs connections, and define the guidelines to use EVs, featuring V2G, namely in emergency operating modes. In addition, a comparative study will be presented about the dynamic behaviour of typical MG suddenly subjected to a load increase, during islanding operation, in two distinct situations: a) when EVs are only in a dumb charging mode and b) when EVs participate in primary frequency control. Additionally to the loads, the test system used for this purpose includes also dispersed photovoltaic (PV) panels, 2 micro wind generators and 2 industrial micro Combine Heat and Power (CHP) units. Dynamic simulations are performed for a feasible EVs integration scenario, taking into account the results obtained in the study described in [1].

II. Architecture

MicroGrid with EVs

A MG is defined as a LV grid where electrical loads and small generation systems (fuel cells, microturbines, wind generators, PV panels), together with storage devices (like flywheels and batteries), coexist through an embedded management and control system [2, 3]. When connected at the LV level, a MG Central Controller (MGCC) can take care of the control of loads, through Load Controllers (LC), microgeneration, through Microgeneration Controllers (MC) and also of the charging/discharging of the batteries of each EV through specific Vehicle Controllers (VC), requiring specific electronic interfaces for grid connection, as described in Fig. 1.

Multi-MicroGrid with EVs and Charging Stations

The MMG is related to a higher level structure, formed at the MV level, consisting of several LV MGs and Distributed Generation (DG) units connected on adjacent MV feeders. The possibility of having a large number of controllable MGs, DG units and MV loads under active Demand Side Management (DSM) requires the use of a hierarchical control scheme that enables an efficient control and management of this kind of system [4].

In order to get a clear picture on the control hierarchy of a system composed by several MGs where EVs are to be connected, Fig. 2 describes its several possible levels of control. In this architecture there are more elements to control besides the Vehicle Controllers (VC), present on the LV networks, and the Clusters of Vehicles Controllers (CVC), connected to MV networks, which represent the EV fleet charging and battery fast charging stations.

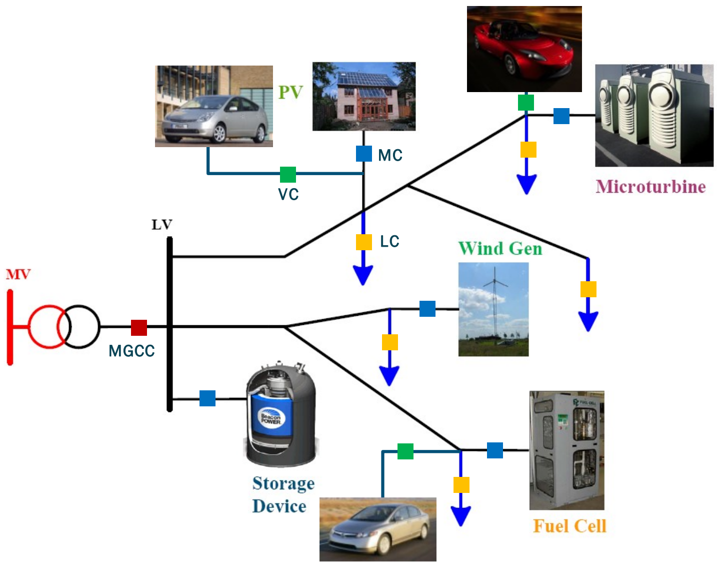

Fig. 1 – Structure and elements of a Microgrid that includes EV

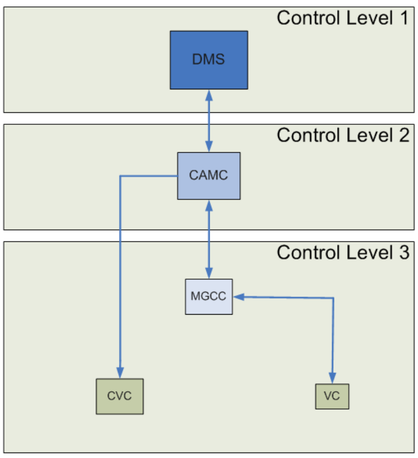

Fig. 2 - Hierarchical control architecture of a Distribution Network with large deployment of microgrids and electric vehicles

In this architecture the elements of the MV grid, including MGs, can be managed from a so called Central Autonomous Management Controller (CAMC) installed at a High Voltage (HV)/MV substation level. The CAMC will be the entity responsible for managing a large amount of EVs when connected to the grid. The MGCC should be capable of recognizing the presence of EVs in the grid and can serve as an aggregator agent, intermediating between the CAMC and the control of the EVs, by sending set-points to the corresponding VC, related with rates of charge, adjustment of operation droops or requests for provision of ancillary services. The amount of data to be exchanged between these elements is small, which makes the communication simple to be established.

A large amount of EVs, with storage capabilities, connected to a MG will allow an increase in the volume of microgeneration integration, since they can be used to store local surplus of generated energy. If proper control solutions are adopted, EVs' batteries can also provide load dynamic control capability and storage capabilities for balancing the MG, allowing in this way MG islanding operation and black start without the need of installing extra storage devices.

The implementation of these control and management architectures and concepts is easy to be done under the smart metering development trend, since the smart meter communication and control infrastructure provide the bed for such development.

Grid Interface for EVs

The way how active power is absorbed/injected into the grid by EVs' batteries requires the use of inverters with specific control solutions, capable of properly interfacing them with the network. Therefore, defining inverter control is a key issue to ensure stable MG operation, namely in emergency modes and in the presence of load variations. Inverter control strategies can be generally divided in two types [5]:

- PQ inverter control: the inverter is used to assure a given active and reactive power injection, following a given set-point. The inverter is not able to form the grid itself by imposing a voltage waveform with suitable amplitude and frequency.
- Voltage Source Inverter control: the inverter is controlled to supply the load with pre-defined values for voltage and frequency. In this case, the inverter is capable to establish the voltage wave form with suitable amplitude and frequency.

III. Emergency Operation

On one hand, when a cluster of Micro-Sources (MS) is operated within a MG and the main power supply (the MV network) is available, all the inverters can be operated in PQ mode, because they have voltage and frequency references [6]. On the other hand, when dealing with the MG in islanded mode, a VSI can be used to provide a reference for frequency assuring islanding operation without changing the control mode of any inverter.

However, when EVs are dispersed within the MG their storage capacity and load controllability features can be explored in order to reduce or even eliminate the needs for a dedicated storage capability, controlled by the VSI, housed in flywheels or dedicated batteries.

During islanded operation, the power injected by the storage devices is proportional to MG frequency deviation. Therefore, correcting permanent frequency deviation during islanded operation should be considered a key objective in any control strategy in order to avoid storage devices to keep injecting (or absorbing) active power whenever MG frequency deviation differs from zero. The combination of primary frequency regulation provided by storage devices, dynamic load control schemes for less important loads and dynamic control of EVs' batteries are the key for successful MG islanded operation. With the presence of EVs this concept gains extra interest from the technical and the economical perspectives.

Islanding may occur under programmed circumstances, like maintenance of the MV/LV transformers, or under faulty situations, such as a fault on the upstream grid.

IV. Simulation

In this work the dynamic behaviour of a MG, in islanding mode, with several EVs connected is addressed. A typical LV network was used to illustrate the MG dynamic behaviour. Several MS compose the MG generation capacity: 2 micro CHP units of 150 kW each, 2 micro wind turbine of 20 kW each and several PV panels with a total installed power of 40 kW. The CHP units are synchronous machines, which enables the MG to be operated without dedicated storage devices. For the purposes of this study, EVs penetration corresponds to a total of 55 kW, but only some EVs are charging [1], which results in a 20 kW load.

A model of the network was created in Matlab/Simulink, using a 4th order model for the synchronous machines and a common induction generator model for the micro wind generators. Two scenarios were then assessed, one with EVs in charging mode only (not controllable) and the other with EVs' batteries participating in frequency regulation. For both scenarios a sudden increase in load was imposed, while in islanded mode, and the results compiled in figures 3, 5 and 6.

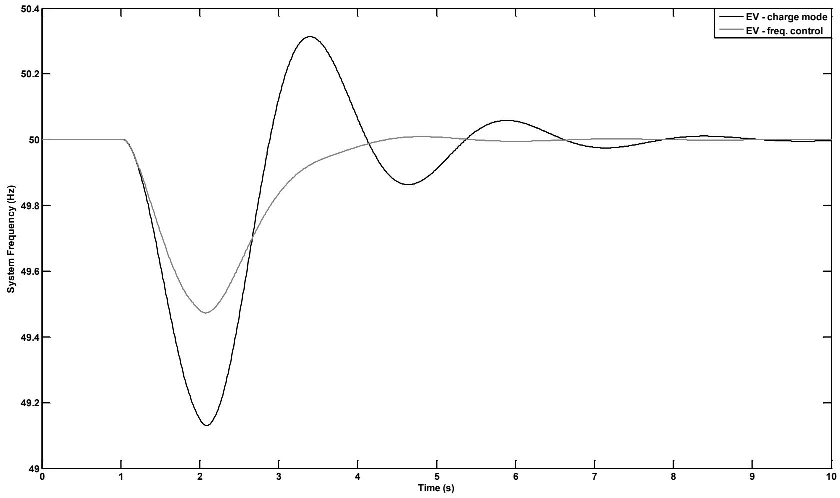

Fig. 3 – Frequency of the MG

Fig. 3 shows how frequency varies with and without EVs participation in the primary control. As it can be seen the under damped response from the synchronous units is smoothened by EVs reaction when interfaced through inverters that operate in a modified PQ mode, where the active power set-points are defined from a droop control mode responding to frequency, as described in Figure 4 [7]. Moreover, with EVs presence the maximum frequency deviation drops from approximately 0.8 Hz to 0.5 Hz.

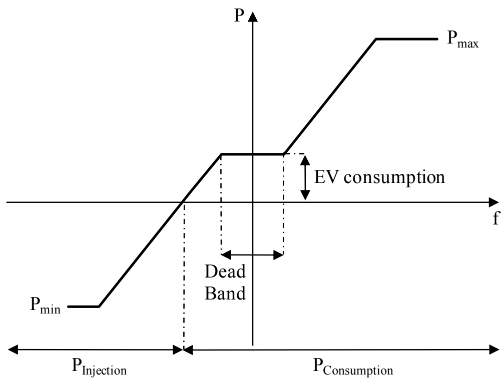

Fig. 4. Droop control for EVs [7]

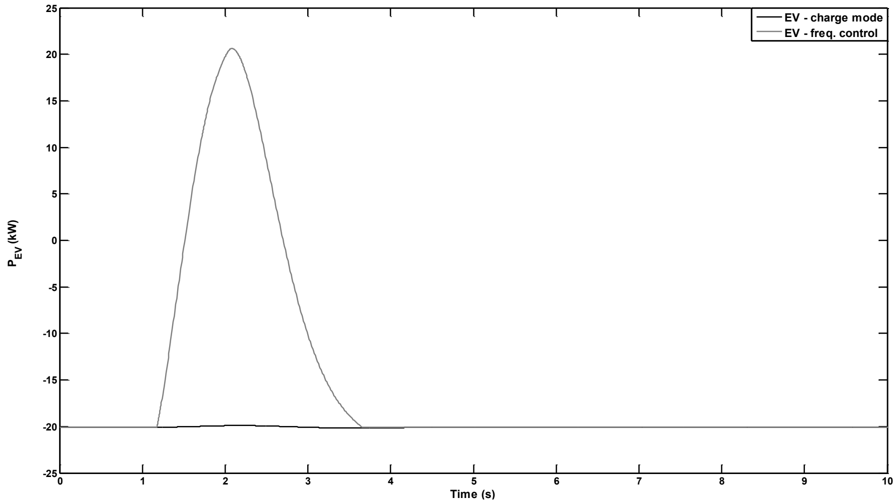

Fig. 5 – Active power from the EVs

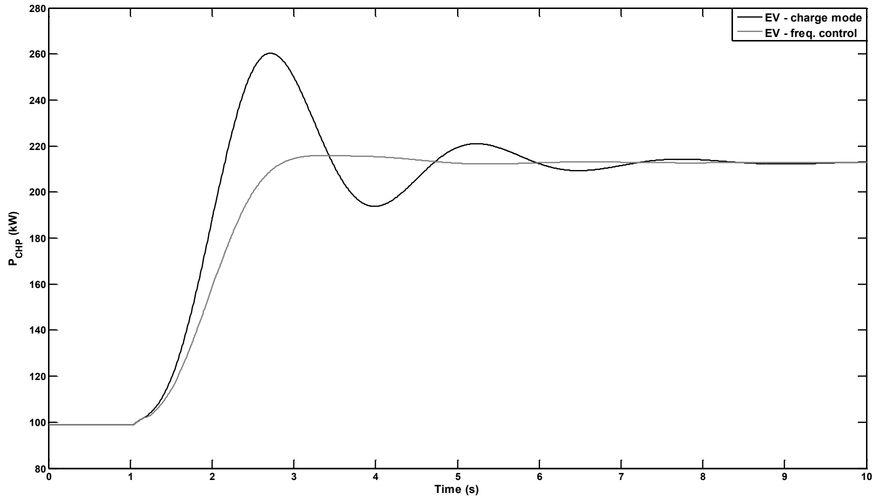

Fig. 6 – Active power from the CHP units

Fig. 5 and 6 depict the EVs active power contribution for frequency deviation control and the micro CHP units behaviour, respectively. As the frequency drops the EV batteries decrease their consumption until they reach a point where the vehicles start to inject stored power into the grid, under a V2G concept. The micro CHP units react slower than for the dumb battery charging situation due to a small integral control loop contribution of the synchronous generators.

V. Conclusions

Electric vehicles interfaced with the grid in a smart way can increase robustness of operation to power system dynamic behaviour. From a purely technical level, the use of batteries, like those that serve as storage for EVs, together with power electronic interfaces that are capable of responding very fast to frequency deviations can improve considerably the global system dynamic behaviour regarding participation in primary frequency control. In addition, the dispersed storage capacity provided by EVs, as well as their load controllability, can be explored in order to reduce or even eliminate the needs for the dedicated storage in a MG. Nevertheless, in order to fully exploit EVs capabilities, a hierarchical management structure will be required to control EVs activities, either individually or as clusters of distributed storage devices. As the MGs and MMGs concepts already contemplate the adoption of such a management mechanism, a synergetic approach including EVs and MGs/MMGs should be pursued in order to make the concepts of MGs and MMGs more attractive regarding technical and economical issues.

From the results presented in this paper, it was possible to verify that the MG improved dramatically its performance when EVs were used to help in frequency control.

VI. References

[1] J. A. Peças Lopes, F. J. Soares, P. M. Rocha Almeida, “Identifying Management Procedures to Deal with Connection of Electric Vehicles in the Grid”, to be presented at the PowerTech’2009, Bucharest, Romania, June/July 2009.

[2] J.A. Peças Lopes, J. Tome Saraiva, N. Hatziargyriou, N. Jenkins, "Management of Microgrids", Proceedings of the IJECC 2003, Bilbao, Spain, 2003.

[3] J. A. Peças Lopes, C. L. Moreira, F. O. Resende, “MicroGrids Black Start and Islanded Operation”, Proceedings of the 15th PSCC, Liege, 22-26 August 2005.

[4] N. J. Gil, J. A. Peças Lopes, “Hierarchical Frequency Control Scheme for Islanded Multi-Microgrids Operation”, Proceedings of IEEE Lausanne Power Tech 2007, Lausanne, Switzerland, July, 2007.

[5] S. Barsali, M. Ceraolo, P. Pelacchi, and D. Poli, "Control techniques of dispersed generators to improve the continuity of electricity supply." in Proceedings IEEE Power Engineering Society Winter Meeting, 2002.

[6] J. A. Peças Lopes, C. L. Moreira, A. G. Madureira, “Defining Control Strategies for MicroGrids Islanded Operation”, IEEE PWRS - IEEE Transactions on Power Systems, vol.21, no.2, pp.916-924, June 2006.

[7] J. A. Peças Lopes, P. M. Rocha Almeida, F. J. Soares, “Using Vehicle-to-Grid to Maximize the Integration of Intermittent Renewable Energy Resources in Islanded Electric Grids”, to be presented at the International Conference on Clean Electrical Power, Capri, Italy, June 2009.