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Economic benefits from the coordinated control of Distributed Energy Resources and different Charging Technologies of Electric Vehicles in a Smart Microgrid

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Abstract

In the near future, Electric Vehicles (EVs') penetration is expected to rise, making the study of their local level effects imperative. EVs is a new, promising, technology which will offer cleaner and more effective means of transportation. On the other hand, EVs can also act as storage devices, thus offering ancillary services to the grid. The optimum operation of Low Voltage (LV) grids, with special emphasis on Smart Microgrids (SM), must be ensured and the financial viability of EVs' penetration is to be assessed. Smart Microgrids seem to be the best solution for the management of modern LV grids with Distributed Energy Resources (DER). The main purpose of this paper is to investigate the economic benefits that can arise from the coordinated control of DER and EVs in SM operation. Absence of distributed resources, and therefore satisfaction of the full load from the upstream network, is considered as the base case. Various pricing policies based on System Marginal Prices (SMPs) are considered. For each scenario, three different charging technologies are examined. All different cases are compared between them to determine which one is the most advantageous in terms of operational cost.

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Keywords: Electrical Vehicles; Microgrids; Distributed Energy Resources; Renewable Energy Sources; Microturbine; Fuel Cell; System Marginal Price; Economic Dispatch

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1. Introduction

The notion of Smart Grids refers to the evolution of electricity grids. A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that assume both roles – in order to efficiently deliver sustainable, economic and secure electricity supplies, [1]. Now, distribution grids are being transformed from passive to active networks, in the sense that decision-making and control are distributed, and power flows bidirectional. This type of network eases the integration of Distributed Generation (DG), Renewable Energy Sources (RES), Demand Side Integration (DSI) and energy storage technologies, and creates opportunities for novel types of equipment and services, all of which would need to conform to common protocols and standards [2].

The realization of active distribution networks requires the implementation of radically new system concepts. Smart Microgrids, also characterized as the "building blocks of smart grids", are perhaps the most promising, novel network structure. The organization of Microgrids is based on the control capabilities over the network operation offered by the increasing penetration of DERs including Microturbines (MT), Fuel Cells (FC), Wind Turbines (WT) and photovoltaic (PV) arrays, together with storage devices, such as flywheels, energy capacitors, batteries and controllable (flexible) loads and EVs, at the distribution level. These control capabilities allow distribution networks, mostly interconnected to the upstream distribution network, to also operate when isolated from the main grid, in case of faults or other external disturbances or disasters, thus increasing the quality of supply. Overall, the implementation of control is the key feature that distinguishes Microgrids from distribution networks with DG. In more details, Microgrids issues are described in references [2]-[9]. The structure of the Microgrid with the control of the production units and the load is presented in Fig. 1a.

Nowadays, a significant number of EVs use power grids around the world to charge their batteries. There are several categories of EVs. The Battery Electric Vehicles (BEVs) store electrochemical energy in their batteries in order to achieve the desirable motion. Another category of EVs is the Fuel Cell EVs. They store energy in the form of hydrogen, which supplies a Fuel Cell with atmospheric oxygen to produce electricity using the process of electrolysis, with heat and water as products of this reaction. Hybrid Electric Vehicles (HEVs) use an electric motor as well as an internal combustion engine for propulsion. Finally, Plug-In Hybrid Electric Vehicles (PHEVs) have at least an extra electric motor added at their power train, in addition to the conventional internal combustion engine, in order to achieve the desirable propulsion, [10]-[14]. This interconnection urges the need to examine several issues such as the impact on the grid, the way that EVs should charge and the limitations of this process as well as the benefit of the grid operator in such conditions. EVs can macroscopically pose some issues to the grid because of the additional loads they introduce. However, in the level of distribution, they can introduce various problems in operation, [15]. The effects of the incorporation of EVs have to be taken into consideration with care, since it may result in unfeasible operations for the grids. Furthermore, when the SM's operation is focused on the economic optimization of its DER, it becomes crucial to know for example where and how many EVs could connect, when it would be better to connect and under what rules they should charge and which is the best charging technology. Several papers have been developed introducing strategies for the EVs' charge, [16]-[21].

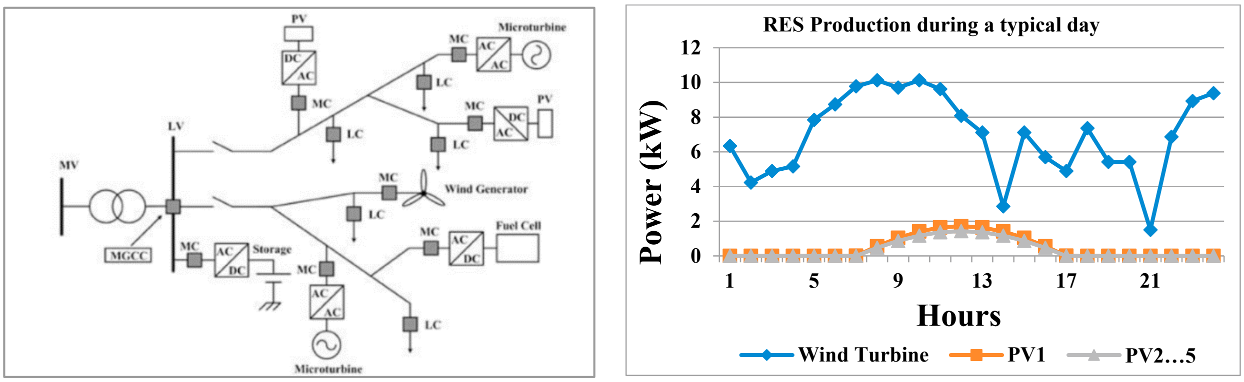

Fig. 1. (a) Structure of the Microgrid; (b) Production of WT and PVs for a typical day;

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