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# Integrated scheduling of renewable generation and electric vehicles parking lot in a smart microgrid

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ABSTRACT

Integration of Electric Vehicles (EVs) and Renewable Energy Sources (RESs) into the electric power system may bring up many technical issues. The power system may put at risk the security and reliability of operation due to intermittent nature of renewable generation and uncontrolled charging/discharging procedure of EVs. In this paper, an energy resources management model for a microgrid (MG) is proposed. The proposed method considers practical constraints, renewable power forecasting errors, spinning reserve requirements and EVs owner satisfaction. A case study with a typical MG including 200 EVs is used to illustrate the performance of the proposed method. The results show that the proposed energy resource scheduling method satisfies financial and technical goals of parking lot as well as the security and economic issues of MG. Moreover, EV owners could earn profit by discharging their vehicles' batteries or providing the reserve capacity and finally have desired State Of Charge (SOC) in the departure time.



## 1. Introduction

The concept of microgrid (MG) is proposed to improve the local reliability and flexibility of electric power systems, which is defined as a group of Distributed Energy Resources (DERs), loads, and energy storage units. MG can operate in both gird-connected mode and islanded mode [1]. The idea supporting the formation of the MG is that a paradigm consisting of a cluster of distributed generations and aggregated loads is adequately reliable and economically viable as an operational electric system [2,3]. Due to increasing shortage of the fossil fuel and the environmental concerns, the governments are motivated to utilize renewable energy resources. A MG combined with Renewable Energy Sources (RESs) can be a preferable solution to the raised energy crises as well as environmental concerns [4]. In a centralized controlled microgrid, microgrid central controller (MGCC) makes bids of energy and spinning reserve to electricity market based on forecasting of market prices, renewable power output and load. Day-ahead deterministic unit commitment would be settled according to collected information of market price, power forecasts and status of units. In this way, MGCC settles the bids of energy and spinning reserve, the setpoint of controllable DGs, the charging/discharging states of energy storage system and the interruption of load. Moreover, the dispatch and bidding strategy in MGCC should maximize the total financial income of microgrid including revenue from electricity market and local consumers subtracting operation cost of generating unit and payback cost of load curtailment [5].

On the other hand, Electric Vehicle (EV) is another important component of electric power network in the near future. The widespread deployment of EVs may introduce a solution to the world fossil fuel shortage as well as the air pollution crisis [6,7]. The emission reduction goal is achieved by proper and optimum utilization of the EVs as energy storages and loads in power system integrated with RESs [8–10]. Beyond these advantages, the anticipation of connection of EVs into the power network may bring up many technical challenges that need to be addressed properly. With the widespread adoption of EVs, the power system may face significant challenges due to the huge electricity demand of these loads [11]. Also, a MG is impacted by a growing penetration of EVs, which represents a new dimension for MG management and huge amounts of energy storage will be injected to the grid through millions of EVs [12].

Vehicle-to-Grid (V2G) is a new concept related to an energy storage technology that has the capability to allow bidirectional power flow between a vehicle's battery and the electric power grid [13]. With V2G capability, the state of charge of an EV's battery can go up or down, depending on the revenues and grid's demands. Through V2G, EV owners can make revenue while their cars are

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parked; it can provide valuable economic incentives for EV owners. On the other hand, utilities significantly support V2G by having increased system flexibility and reliability as well as energy storage for intermittent RESs such as wind and solar. In order to participate in energy markets, aggregators integrate the large numbers of EVs stored energy and submit their offers to the power market [14,15]. In order to maximize customer satisfaction and minimize grid disturbances, intelligent parking lots can be of great worth [16,17]. In these type of parking lots, customers by providing the desired parameters will charge their EVs and moreover, have the opportunity to sell their stored energy to the local electric loads or the upstream grid and earn money [18]. As the owners of EVs usually use their vehicles in few hours during a day and their vehicles stay in parking lots without using in the rest of the day, the batteries of EVs can be considered as energy storage systems. So, EVs can be considered as a new player to provide the reserve capacity of the system. In [19], the mechanism of participating EVs in spinning reserve market has been developed.

Some studies proposed an energy management system for energy scheduling in a MG in order to realize the V2G concept. Using a suitable control and energy dispatch strategy, the stored energy in EVs' batteries can enhance the stability of power grid, mitigate peak loads and improve behaviors of intermittent renewable generation [20,21]. The randomness of the renewable energy resources causes great difficulty in the planning of MGs, and is a hot topic in MG design research [22–24]. Although generating electricity from renewable energy resources offer clean alternatives to fossil fuels, they are uncertain and variable. Therefore, their large scale integration into an electric power system poses challenges to system operators and planners. Spinning reserve is one of the important ancillary services that is essential to ensure the secure and reliable operation of the power system with high penetration of intermittent renewable generation [25,26].

Some recent literatures discussed about the EVs impacts on power grids [27,28]. In [27], a method for determining the optimal places of plug-in hybrid electric vehicles' (PHEVs) parking lots which provide V2G power as distributed generation has been proposed. Utilizing an optimization algorithm to maximize the advantages of using EVs' batteries as energy storage systems in power grids has been presented in [28].

In [16], the charge/discharge management of a fleet of EVs in a smart parking lot has been carried out where the method aimed at maximizing the state of charge (SOC) of each EV's battery. The charge/discharge strategy has been analyzed with and without considering the constraint of batteries lifetime of EVs. However, the charge/discharge scheduling of EVs in a parking lot without considering the external electricity grid has only been taken into account. Also, the capability of EVs in providing reserve capacity has not been studied in this work.

In [29], an Estimation of Distribution Algorithm (EDA) to schedule large number of EVs charging in a parking lot has been proposed. The method optimizes the energy allocation to the EVs in real-time while considering various constraints associated with EV battery and utility limits. The paper has only proposed charging of EVs and the V2G option is not taken into account. The authors in [30], proposed a Simulated Annealing (SA) approach and heuristic technical validation of the obtained solutions to solve the energy resources scheduling. A case study considering 1000 V2G units connected to a 33 bus network managed by a Virtual Power Plant (VPP) has been presented. In the model, EVs have been distributed through the distribution network and there is no centralized parking lot. In [27], wide use of aggregated EVs in parking lots has been presented to overcome the small storage capacity of an EV. EV parking lots are considered as new players whose roles are collecting the EVs in order to reach high storage capacity from small battery capacity of EVs, affecting the grid. In [31], an optimization problem of scheduling EV charging with energy storage for the day-ahead and real-time markets has been proposed. Also, a communication protocol for interactions among different entities including the aggregator, the power grid, the energy storage, and EVs was considered. The paper focused only on the scheduling EV charging and discussed about utilization of EVs and energy storages together.

In traditional power systems, spinning reserve was generally supplied by free capacity of committed generators. However, after deregulation of the power system, in addition to the generation units, some other resources, such as demand side resources and aggregators can participate in the spinning reserve scheduling. In this study, in addition to MG generation resources, electric vehicles aggregator offers reserve capacity in order to provide the spinning reserve requirement. The model presented here, in contrast to the models from [14,32,33], uses intelligent parking lot as an aggregator to facilitate the managing of EVs, which as shown in [16] is a more practical representation. Moreover, in this paper, the influence of forecast errors corresponding to renewable energy resources is addressed.

In [34], an energy management algorithm for a grid-connected charging park has been developed. The charging park involves PHEVs as well as a photovoltaic system. The energy management algorithm aimed at reducing the overall daily cost of charging the PHEVs, mitigating the impact of the charging park on the main grid, and contributing to shave the peak of the load curve. However, the capability of charging park in providing reserve capacity, and compensating the intermittent nature of RESs has not been taken into account.

To the best of our knowledge, no energy and reserve scheduling model in which the EVs can participate in providing reserve capacity in a MG has been reported in the literature. In addition, the integration of intermittent renewable generation and EVs charge/discharge has not been considered in most of previous studies. In this paper an intelligent parking lot is considered in order to aggregate the stored energy of EVs. Moreover, the role of EVs in providing the reserve for compensating the renewable power forecasting error is studied. The Proposed method considers system constraints and EVs owners' preferences. Moreover, the elapsed time of the EV's battery life is taken into account as a criterion for making decision. A weighting factor is also proposed to prioritize the EVs charging/discharging procedures in the parking lot. The innovative contributions of the proposed method are highlighted as follows:

- Evaluate EVs participations in both energy and reserve scheduling.
- Integrated scheduling and management of intermittent renewable generation and EVs in a MG.
- Using intelligent parking lot as an aggregator to facilitate interaction between EVs owners and microgrid operator.

The rest of the paper is organized as follows: in Section 2, system topology is introduced. Section 3 presents the problem formulation; including the resources and network constraints. A case study and analysis of the results are shown in Section 4. Finally, the most important conclusions of the work are presented in Section 5.

## 2. System topology

This section presents a topology for the proposed MG including an intelligent parking lot, multiple microsources such as photovoltaic (PV) system, wind turbine (WT) system, microturbine (MT) and fuel cell (FC), as shown in Fig. 1. In addition, there is a single