Energy 65 (2014) 572–579

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Optimal scheduling of electric vehicles in an intelligent parking lot considering vehicle-to-grid concept and battery condition

Masoud Honarmand, Alireza Zakariazadeh, Shahram Jadid*

Center of Excellence for Power System Automation and Operation, Dept. of Electrical Engineering, Iran University of Science and Technology, P. O. Box: 1684613114, Tehran, Iran

ARTICLE INFO

Article history:
Received 10 August 2013
Received in revised form
12 November 2013
Accepted 17 November 2013
Available online 16 December 2013

Keywords:
Battery condition
Electric vehicle
Energy management
Intelligent parking lot
Vehicle-to-grid

ABSTRACT

The anticipation of a large penetration of EVs (electric vehicles) into the market brings up many technical issues. The power system may put at risk the security and reliability of operation due to uncontrolled EV charging and discharging. It is necessary to carry out intelligent scheduling for charging and discharging of EVs. In this paper, a smart management and scheduling model is proposed for large number of EVs parked in an urban parking lot. The proposed model considered practical constraints such as desired charging electricity price, remaining battery capacity, remaining charging time and age of the battery. The results show that the proposed parking lot energy management system satisfies both financial and technical goals. Moreover, EV owners could earn profit from discharging their vehicles as well as having desired SOC (state of charge) in the departure time.

1. Introduction

The widespread implementation of EVs may introduce a solution to the world fossil fuel shortage as well as the air pollution crisis. Currently, there are three types of EVs prepared to be launched in the markets: fully EVs, fuel cell EVs, and hybrid EVs. Battery and fuel cell EVs are driven only by electric power while available hybrid EVs have also an internal combustion engine [1]. The anticipation of connection of EVs into the power network may bring up many technical drawbacks that need to be addressed properly. In the near future, a huge number of EVs will add a large-scale energy demand to power systems. An emerging issue is that a large number of EVs simultaneously will be connected to the grid that may put at risk the overall power system quality and stability.

EVs with V2G (vehicle-to-grid) capability can reduce emission from the transportation industry. The emission reduction aim is achieved by proper and optimum utilization of the EVs as energy storages and loads in power system integrated with RESs (renewable energy sources). Moreover, with increasing shares of renewable energy resources in the electricity system, the economic benefit of EVs is expected to be enhanced through avoiding the construction and management cost of peak generators and absorbing excess electricity operated under smart control strategies [2–4]. The intelligent scheduling and control of EVs as loads or sources have great potential for evolving a sustainable integrated electricity and transportation infrastructure. V2G is a new concept that is 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 [5]. Using the V2G technology increases the power grid operation flexibility and reliability due to better utilization of intermittent RESs. 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 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, the V2G capabilities of many EVs are combined by aggregators and then bid into the appropriate markets [6,7]. Using the potential benefit of EVs, an aggregator can convert some threats to changes in electricity market environments and there have been opportunities to increase the profit, enhanced the EV's owners and even the market efficiency [8]. With the widespread adoption of EVs, the power system may face significant challenges due to the huge electricity demand of these loads. For example, if 30% of conventional vehicles in the US were replaced by EVs, the total charging load would be 140 GW, which accounts for 18% of the US summer peak load of

* Corresponding author. Tel.: +98 21 77491223; fax: +98 21 77491242.
E-mail addresses: honarmand@elec.iust.ac.ir (M. Honarmand), zakaria@iust.ac.ir (A. Zakariazadeh), jadid@iust.ac.ir (S. Jadid).

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http://dx.doi.org/10.1016/j.energy.2013.11.045

780 GW [9]. In Ref. [10], the effect of unmanaged charging of EVs has been carried and the results showed that the peak grid load increased. The paper proposed a way that shifts load to a more desirable time in which no effect on the mobility of the EV's owners has been reported. Technologies as well as the interest of governments for widespread use of EVs, lead to system operators think about how to address the integration and management of these new loads. Large numbers of EVs have the potential to put at risk the stability of the power network. For example, the aggregated load in a parking lot needs to be managed very carefully in order to avoid interruption when several thousand EVs are introduced into the system over a short period of time. Also, due to various requirements of the EVs parked in the parking lot at any given time, the demand pattern will also have a considerable impact on the electricity market [11]. In order to maximize customer satisfaction and minimize grid disturbances, intelligent parking lots can be of great worth. In this parking, customers by providing the desired parameters will charge their EVs and moreover have the opportunity to sell their stored energy to the grid and earn money. In Ref. [11], an EDA (estimation of distribution algorithm) 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 proposed charging of EVs only and the V2G option is not taken into account. The authors in Ref. [12] proposed a SA (simulated annealing) 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 VPP (virtual power plant) has been presented. In the model, EVs have been distributed through the distribution network and there is no centralized parking lot. In Ref. [13], a distributed DR (demand response) algorithm for EVs charging requirement has been proposed in which the concept of congesting principle in the internet traffic control has been employed. In the recent literature, a number of scheduling schemes for EV charging and discharging have been proposed. The scheduling schemes proposed in Refs. [14,15] only dealt with battery charging without considering V2G capability. The V2G scheduling models proposed in Refs. [16,17] tried to optimize the charging and discharging powers to minimize the cost. In charging and discharging scheduling, the scheduler tries to optimize the bidirectional energy flows between the grid and EV's Battery. These papers applied essentially centralized algorithms, which may not be suitable for the EV charging and discharging systems with a large population and dynamic arrivals.

In Ref. [18], 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 using EVs and energy storages together. In EVs management model, different types of objective functions have been presented in the literatures. For example, the objective could be to minimize the cost and emission reductions for a sustainable integrated electricity and transportation infrastructure by maximum utilization of RESs using EVs [19]. If the aggregated EV batteries are considered as a potential energy storage, another objective could be to maximize the capability of this aggregated battery to mitigate the unpredictable fluctuations of renewable energy [20]. A novel objective function could be to maximize the average SOC (state of charge) for all vehicles at the next time step [11].

In summary, the above works have paid attention to the charging/discharging management of EVs and did not consider the customer preferences. In addition, the battery life constraint has not been considered in most works. Though some research works have tried to explore the different objective function, most works did not focus on the technical aspect of EVs. The proposed model, with proper managing of the number of charging and discharging, not only satisfies the customers' preferences and increases their revenue but also enhances the lifetime of EVs' batteries. Intelligent parking lots integrated with the proposed charging/discharging model offers many benefits to utilities and consumers. In this parking, customers by providing the desired parameters will charge their EVs and, moreover, have the opportunity to sell the stored energy in their EVs' batteries to the grid and earn money.

In this paper, a new EVs energy management system for an intelligent parking lot is proposed. The proposed model is capable of controlling charging/discharging procedure of large number of EVs. This model considers system constraints and customer's preferences. Moreover, the elapsed time of the EV's battery life is considered as a criterion for making decision. A weighting factor is also proposed to prioritize the EVs charging/discharging procedures in the parking lot.

The rest of this paper is organized as follows: The problem formulation for maximizing the charging/discharging rate and related decision making parameters and system constraints are presented in Section 2. Simulation data and results are presented and discussed in Section 3. Finally, the conclusion is given in Section 4.

2. Problem formulation

In this paper an intelligent parking lot energy management system is presented to manage the charging/discharging scheduling of EVs. The intelligent parking lot compared to conventional ones is creating new opportunities for electric vehicle owners as well as utility. Intelligence refers to the ability of parking lot energy management system for automatically receive and send data to vehicles and make a wise decision about charging and discharging the EVs. This parking lot receives several parameters from each EV's owner, such as desired charging/discharging price limits, approximate duration of presence in the parking lot, and the elapsed time of the EV's battery life. These parameters are considered as the input data. By receiving the elapsed time of the EV's battery life, an extra constraint is considered for the charging/discharging of EVs. The information flow and architecture of proposed intelligent parking lot is indicated in Fig. 1. The objective function and constraints of proposed methods are described in this section.

The assumptions used in the proposed model are as follows:

- The intelligent parking lot is allowed to access the day-ahead open market electricity price for following 24-h scheduling [21].
- EVs' owners submit their desired parked time period and charging option for next 24-h to the intelligent parking lot by a cell phone program or an internet portal [22].

2.1. Objective function

This study focuses on the maximization of charging/discharging rate for all EVs. The main goal of the proposed scheduling model is to allocate maximum profit to each EV owner by means of charging and discharging in a proper time. Moreover, the SOC level of each EV should be maximized. The proposed objective function covers both financial and technical goals. In the proposed model, the software of the intelligent parking lot receives the hourly electricity price of open market, desired charging/discharging price limits, charging period, initial SOC, and the elapsed time of the EV's battery life as the input data in order to optimally determine the