Energy xxx (2014) 1–12

Contents lists available at ScienceDirect

Energy

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

Real-world based approach for optimal management of electric vehicles in an intelligent parking lot considering simultaneous satisfaction of vehicle owners and parking operator

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ARTICLE INFO

Article history:
Received 28 May 2014
Received in revised form
4 August 2014
Accepted 6 August 2014
Available online xxx

Keywords:
Intelligent parking lot
Electric vehicle
Optimal energy management
Transparency of financial transactions

ABSTRACT

In this paper, an optimal energy management system for EVs (electric vehicles) parking is proposed. The presented model has the capability of management and optimal scheduling of charging and discharging of a large number of electric vehicles while considering technical and economic aspects. This model takes parking operator's benefit as well as vehicle owners' benefit into considerations, simultaneously. The benefit of parking operator is maximized by considering total daily costs and income of the parking lot. Furthermore, in order to maximize vehicles owners' profit and satisfying them, lost opportunity cost and penalty cost functions have been introduced. The parking lot is fined if requested final state of charge by vehicle owners is not met. In Addition, financial transactions of parking operator with vehicle owners and distribution system operator are accurately investigated. The obtained results imply that the presented energy management system provides maximum profits for parking operator and meanwhile it fulfills preferences of vehicle owners.

1. Introduction

Nowadays, electric vehicles are attracting attention to address problems such as pollution, reduction of natural oil and fossil fuel reserves, and rising petrol costs [1,2]. For instance, it is expected that the number of EVs in the United States will increase to almost 1 million till 2015 [3]. Hence, in recent years, researchers have focused on different aspects of EVs. These studies mainly discuss issues including charge and discharge scheduling, effect of EVs on the grid [4–10], and optimal placement of EVs parking [11–15]. This study is related to charge and discharge scheduling category in an intelligent parking. In the following, some of the prominent issues as well as related works in this context are presented.

Despite the numerous advantages of EVs, high penetration rate of these vehicles and their uncontrolled charge and discharge might impose overload on the grid during peak hours. Usage of the intelligent control strategies provides a possibility of load supply during peak hours [16]. Also, the results of research presented in Ref. [17] revealed that smart charge strategies reduce charge costs on average by more than 32%. In Ref. [18], the effects of the incentive programs on EV owners' charge behavior and peak shaving are shown. In order to optimize energy consumption profile and also to reduce peak load of building, smart charging and discharging process of EVs in the building garage introduced in Ref. [19]. The authors in Ref. [19] propose a utility function for each PHEV (plug-in hybrid electric vehicle) and define it as negative total energy payment to the building. Then, based on a distributed algorithm, each vehicle chooses the best strategy to charge, independently; so that the utility function could be maximized. Authors of Ref. [20] investigated how changes in the price of fuel (which is needed for electricity generation) affect the optimal management of PHEV power. It is demonstrated that electricity price may considerably influence characteristics related to optimal control policy. In order to obtain optimal charging control in a deregulated electricity market, two algorithms are presented in Ref. [21] based on

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http://dx.doi.org/10.1016/j.energy.2014.08.026
0360-5442/

predicting future electricity price. The first one avoids overload on the grid. Also, it decreases daily cost of energy by optimizing charge and discharge time and energy flow. The second algorithm also avoids overload on the grid; while it increases the income of vehicle owners through the participation of EVs in the ancillary service market and taking part in V2G (vehicle-to-grid). Since, the regulatory intervention depends on the local context, so, its more realistic if the hypothesis of regulated electricity markets is taken into account. V2G is referring to the situation where EVs provide reserve power for the grid. In this condition, the battery of vehicles is discharged and injects power to the grid [22].

Ref. [23] has investigated the effect of uncertainty of the renewable energy, the EV arrival, the charging energy of each EV, and the grid power price on scheduling of EVs. Moreover, in order to maximize the average SOC (state of charge) for all EVs, the EDA (estimation of distribution algorithm) has used for smart scheduling of EVs charging and discharging [24]. In this scheduling, some constraints such as electricity price, remaining battery capacity and remaining charging time are considered. Moreover, in Ref. [25], an optimal charge scheduling model is presented to maximize the SOC of batteries in which some other constraints such as charge and discharge price and battery life (age of the battery) are considered. In Ref. [26], a scheduling model for PEV (plug-in electric vehicle) charge is presented using concepts of non-cooperative games. In this model, it is assumed that PEVs are cost-minimizing and they are weakly coupled through a common electricity price. In Ref. [27], a multi-objective approach for scheduling of electric vehicles in a smart distribution system is presented in which the environmental and economic issues as well as various driving patterns of EVs owners are taken into account.

In Ref. [28], a communication protocol is introduced for interactions between aggregator, an energy storage device, the grid, and EVs. It investigates charge scheduling of EVs from the electricity market viewpoint. Moreover, in Ref. [28], the aggregator energy trading in day-ahead and real-time markets are taken into consideration, simultaneously. Also, Ref. [29] has presented a conceptual model to facilitate the participation of small aggregators in the management of new residential complexes consisting of a smart building and an intelligent parking lot for EVs. The presented model in Ref. [29] promises higher income for sub-aggregators and less energy not charged for EVs while ensuring the convenience for residents.

In summary, conducted researches in this field have focused on the optimal management of charging and discharging of EVs and parking profit maximization. It is worth noting that in aforementioned literature vehicle owners' rights are not taken into consideration perfectly. Although in some research works vehicle owners' preferences such as the effect of charging and discharging on battery life, constraints of charging and discharging price and requested final SOC (charge level when vehicle departures the parking lot) are taken into considerations, the financial transactions and the approach of profit allocation have not been investigated so far. Vehicle owners and parking operator have mutual obligations. Besides, each of them has rights which should be acquired that have not been properly investigated so far.

In this paper a novel energy management system for EV parking lots is presented in which practical constraints are considered. The proposed model is capable of scheduling and managing numerous EVs. This model aims to provide maximum profits for parking lot, transparency of transactions between parking operator with the vehicle owners and the distribution system operator as well as satisfying vehicle owners. In order to maximize profits of the parking lot, total daily costs and income of parking are modeled and then resulted profit function is maximized. In addition, two cost functions for lost opportunities and the penalty due to requested final SOC failure are introduced to maximize vehicle owners' profits and bring them satisfaction. This model considers vehicle owners' preferences such as limitations of charging and discharging price. Moreover, costs of charged and discharged power per hour, lost opportunities costs and the fine due to the missing requested final SOC are calculated and the receipt is issued at the end of the day. Furthermore, the amount of money which is paid to or received from the distribution system operator is calculated while the permissible range of power injection and absorption of the distribution system are considered.

The remainder of this paper is organized as follows: In Section 2, the structure of the proposed intelligent parking is presented and the corresponding rules and assumptions are described. Problem formulation, introduction to the proposed objective function and constraints related to the charge and discharge scheduling problem is presented in Section 3. Simulation results are discussed in Section 4. Finally, the discussion and conclusion is given in Sections 5 and 6, respectively.

2. Intelligent parking lot

In this section, structure, rules and assumptions related to the proposed intelligent parking lot model are presented.

2.1. Structure

Here, a smart energy management system is introduced which can be used in parking lots. This system is capable of automatic and simple data exchanging and establishing communication between parking lot operators and the distribution system operator. As a result, it is able to manage charge and discharge of a large number of EVs. Fig. 1, indicates the conceptual structure of intelligent parking, and data/information flow between different players (EV's energy management system, EVs' owners and the distribution system operator).

As can be seen in Fig. 1, EV's energy management system consists of four sections; information center, information processor, optimization software and accounting unit. The energy management system communicates with parking lot, vehicle owners and the distribution system operator through the information center. The information center receives the characteristics of EVs such as arrival time, departure time, initial SOC and battery specifications. It also receives vehicle owners' preferences such as maximum charge price, minimum discharge price and desired final SOC. In addition, it receives the hourly electricity price signal from the distribution system operator (or open market). Received data is considered as input. The information processor unit analyzes received data regarding the desired final SOC. If the desired final SOC is not accessible according to price limitations imposed by vehicle owners, the information processor unit determines the permissible range for final SOC and sends it to the information center. Information center informs vehicle owners about these permissible ranges, so that they either change announced maximum charge price and minimum discharge price or choose the final SOC value from acceptable range and send it to the information center. Next, the optimizer unit performs optimal charge and discharge scheduling using received data from the information center. In case of inaccuracy of data announced by vehicle owners such as arrival time, departure time, initial SOC and battery specifications, parking lot operator informs information center. When charge and discharge procedure has finished, accounting unit, issues receipt of each vehicle and sends it to the information center.

Please cite this article in press as: Mirzaei MJ, et al., Real-world based approach for optimal management of electric vehicles in an intelligent parking lot considering simultaneous satisfaction of vehicle owners and parking operator, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.08.026