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

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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

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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

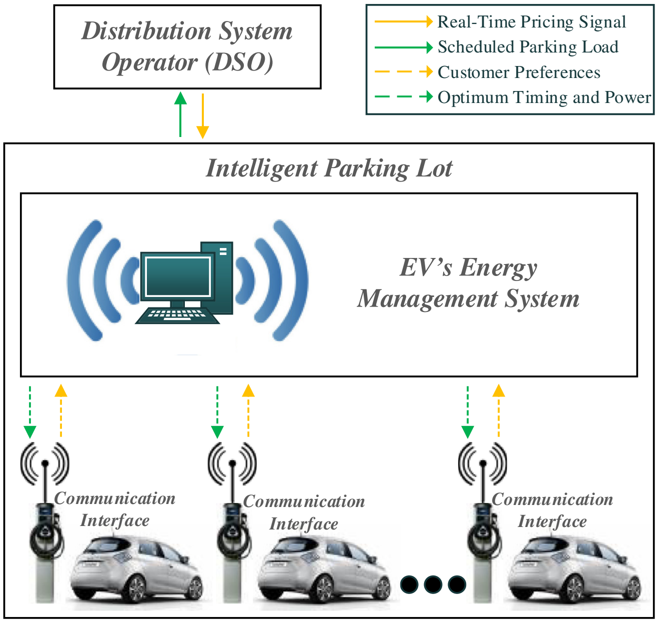

Fig. 1. The proposed intelligent parking lot.

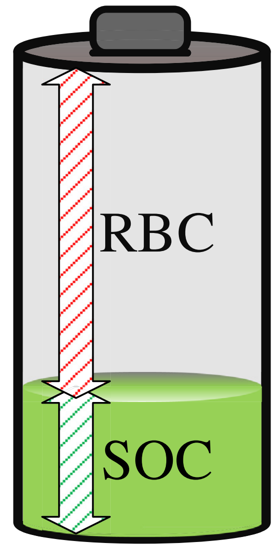

Fig. 2. The definition of RBC and SOC.

charging/discharging mode of each EV at each period. A weighting factor is also proposed within the model to prioritize the EVs in the parking lot that is defined as follows:

$$W^{i,t}_{\text{Charging}} \propto \left\{ \text{RBC}^{i,t}, \text{Price}^{i}_{\text{Charging}}, \frac{1}{\text{RT}^{i,t}}, \frac{1}{\text{AOB}^{i}} \right\} \tag{1}$$

$$W^{i,t}_{\text{Discharging}} \propto \left\{ \text{SOC}^{i,t}, \text{Price}^{i}_{\text{Discharging}}, \text{RT}^{i,t}, \frac{1}{\text{AOB}^{i}} \right\} \tag{2}$$

$$\text{RBC}^{i,t} = \left(1 - \text{SOC}^{i,t}\right) \tag{3}$$

where $W^{i,t}_{\text{Charging}}$ and $W^{i,t}_{\text{Discharging}}$ are the charge and discharge weighting factors of the ith EV at time step t, respectively; $\text{Price}^{i}_{\text{Charging}}$ and $\text{Price}^{i}_{\text{Discharging}}$ are the desired charging and discharging price limit of the ith EV, respectively; $\text{RBC}^{i,t}$ and $\text{SOC}^{i,t}$ represents the remaining battery capacity and the state-of-charge of the ith EV at time step t indicated in Fig. 2; $\text{RT}^{i,t}$ is the remaining time of charging/discharging period of the ith EV at time step t; AOB^{i} is the age of the ith EV's battery which indicates the elapsed time of each EV's battery life; and Cap^{i} is the battery capacity of the ith EV.

As the effective parameters in the charge/discharge weighting factor are not in the same scale, they need to be normalized.

The OBJ (objective function) that should be maximized is given as follows:

$$\text{OBJ} = \sum_{t} \sum_{i} W^{i,t} \times \Delta\text{SOC}^{i,t} \tag{4}$$

where $\Delta\text{SOC}^{i,t}$ is the difference between $\text{SOC}^{i,t}$ and $\text{SOC}^{i,t-1}$ which indicates the charging/discharging rate of the ith EV at time step t.

In this paper, a simplified battery model which consists of voltage source expressing open circuit voltage and internal resistance is taken into account [23].

$$\Delta\text{SOC}^{i,t} = \eta \times I^{i,t} \tag{5}$$

where η is the charging efficiency of the battery and $I^{i,t}$ is the charging/discharging current of the ith EV at time step t.

The battery OCV (open circuit voltage) is given as follows [24]:

$$\text{OCV}^{i,t} = V_n + \alpha \frac{RT}{F} \ln\left(\frac{\text{SOC}^{i,t}}{C_n - \text{SOC}^{i,t}} \right) \tag{6}$$

where V_n and C_n are the nominal voltage and the capacity of battery respectively; R, T and F is gas constant, battery temperature, and Faraday constant, respectively; and α is the sensitivity parameter between the $\text{SOC}^{i,t}$ and the $\text{OCV}^{i,t}$.

$$\text{CCV}^{i,t} = \text{OCV}^{i,t} + R_{\text{in}} \times I^{i,t} \tag{7}$$

$$P^{i,t}_{\text{EV}} = \text{CCV}^{i,t} \times I^{i,t} \tag{8}$$

where $\text{CCV}^{i,t}$ is the battery closed circuit voltage of the ith EV at time step t; R_{in} is the internal resistance of the battery; $P^{i,t}_{\text{EV}}$ is the charging/discharging power allocated to the ith EV at time step t.

Substituting $\text{CCV}^{i,t}$ into Eq. (8) yields.

$$P^{i,t}_{\text{EV}} = \text{OCV}^{i,t} \times I^{i,t} + R_{\text{in}} \times \left(I^{i,t}\right)^2 \tag{9}$$

As the main decision variable is the power allocated to each charger, calculating $I^{i,t}$ with $P^{i,t}_{\text{EV}}$ using Eq. (9) results in:

$$I^{i,t} = \left(\frac{-\text{OCV}^{i,t} + \sqrt{\text{OCV}^2 - 4R_{\text{in}} \times P^{i,t}_{\text{EV}}}}{2R_{\text{in}}} \right) \tag{10}$$

Substituting $I^{i,t}$ into Eq. (5) yields.

$$\Delta\text{SOC}^{i,t} = \eta \times \left(\frac{-\text{OCV}^{i,t} + \sqrt{\text{OCV}^2 - 4R_{\text{in}} \times P^{i,t}_{\text{EV}}}}{2R_{\text{in}}} \right) \tag{11}$$

Finally, the objective function becomes Eq. (12).

$$\text{OBJ} = \sum_{t} \sum_{i} W^{i,t} \times \eta \times \left(\frac{-\text{OCV}^{i,t} + \sqrt{\text{OCV}^2 - 4R_{\text{in}} \times P^{i,t}_{\text{EV}}}}{2R_{\text{in}}} \right) \tag{12}$$

2.2. Constraints

The maximization of the objective function is subjected to the following constraints. The status of available EVs in the parking lot is determined by comparing the desired charging/discharging price limits and electricity price of open market received from the DSO (distribution system operator). Each EV parked in the parking lot is situated at one of three charging/discharging/idle modes shown in Fig. 3. The proposed flowchart to determine the value of charging/discharging/idle mode of the i th EV at time step t ($M^{i,t}$) and the number of switching between charging and discharging mode of the i th EV (D^i) is depicted in Fig. 4.

- EVs charge and discharge are not simultaneous:

$$\mathrm{CH}_{\mathrm{EV}}^{i,t} + \mathrm{DCH}_{\mathrm{EV}}^{i,t} \leq 1; \mathrm{CH}_{\mathrm{EV}}^{i,t}, \mathrm{DCH}_{\mathrm{EV}}^{i,t} \in \{0,1\} \tag{13}$$

where $\mathrm{CH}_{\mathrm{EV}}^{i,t}$ and $\mathrm{DCH}_{\mathrm{EV}}^{i,t}$ are binary variables that represent the status of charging and discharging of the ith EV in period t, respectively.

- Limits of charging/discharging power allocated to each EV:

$$P_{\mathrm{EV}}^{i,t} \leq P_{\mathrm{G2V,max}}^{i} \times \mathrm{CH}_{\mathrm{EV}}^{i,t} \tag{14}$$

$$-P_{\mathrm{EV}}^{i,t} \leq P_{\mathrm{V2G,max}}^{i} \times \mathrm{DCH}_{\mathrm{EV}}^{i,t} \tag{15}$$

where $P_{\mathrm{G2V,max}}^{i}$ and $P_{\mathrm{V2G,max}}^{i}$ are the maximum charging and discharging power of the ith EV, respectively.

- Limits of SOC for each battery:

$$\mathrm{SOC}_{\mathrm{min}}^{i} \leq \mathrm{SOC}^{i,t} \leq \mathrm{SOC}_{\mathrm{max}}^{i} \tag{16}$$

where $\mathrm{SOC}_{\mathrm{max}}^{i}$ and $\mathrm{SOC}_{\mathrm{min}}^{i}$ are the maximum and minimum SOC of each EV, respectively.

- Limits of charging/discharging rate of each EV:

$$-\Delta\mathrm{SOC}_{\mathrm{max}}^{i} \leq \Delta\mathrm{SOC}^{i,t} \leq \Delta\mathrm{SOC}_{\mathrm{max}}^{i} \tag{17}$$

where $\Delta\mathrm{SOC}_{\mathrm{max}}^{i}$ is the maximum allowable rate for charging/discharging of EV i.

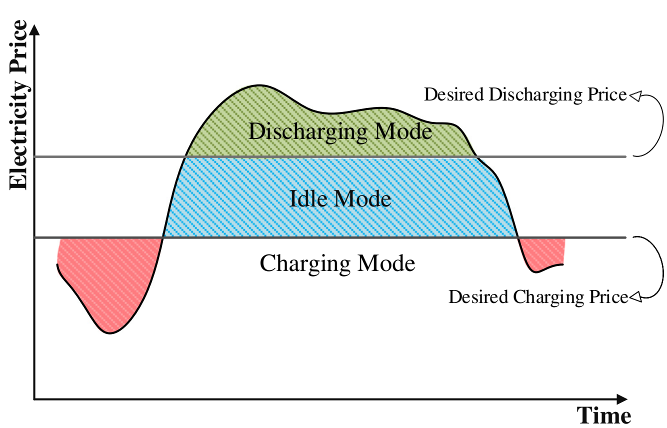

Fig. 3. Three modes of a typical EV.

- Departure SOC constraint:

As the primary and main duty of an EV is to be driven, the battery of EV should be charged enough during its parked time. So, the EV's owner needs to ensure that his/her vehicle has been enough charged in order to be driven for a determined distance.

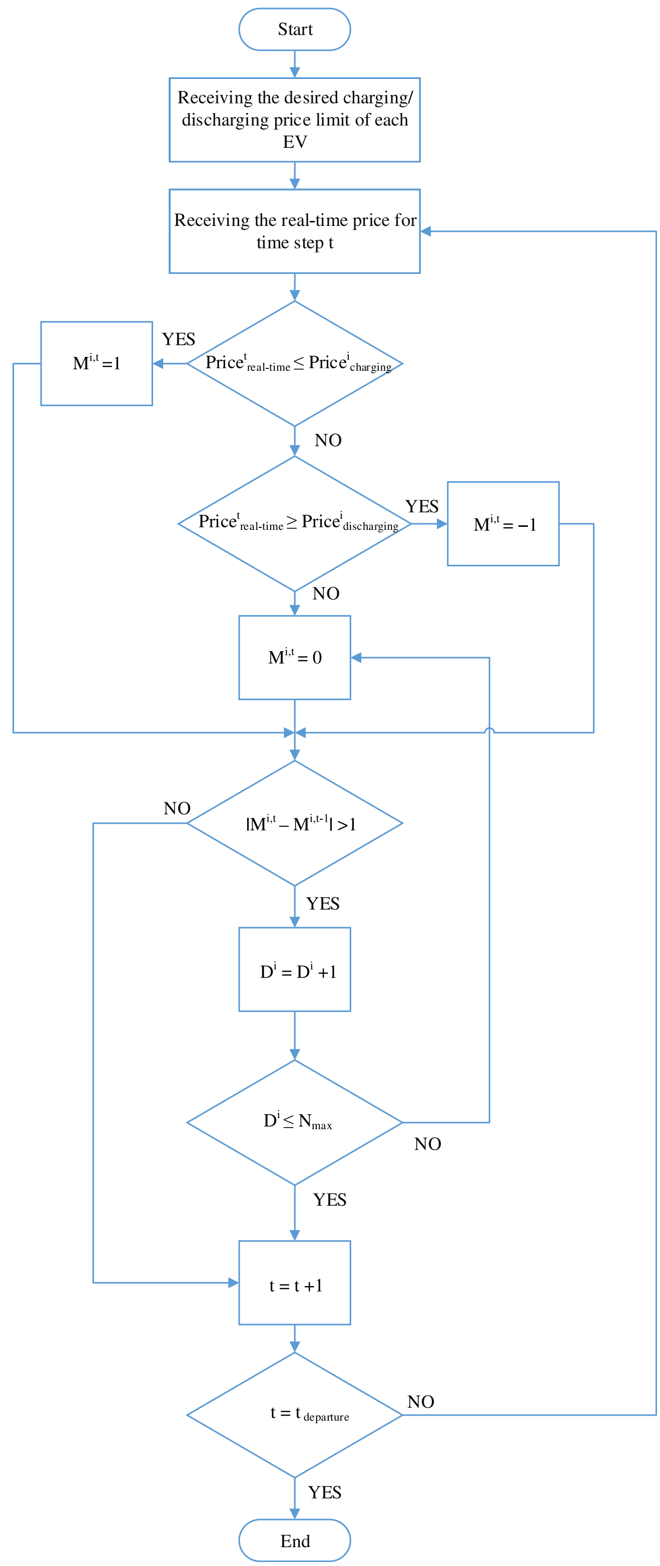

Fig. 4. The flowchart of status determination.

Therefore, in the proposed model, an extra constraint was considered to ensure a reasonable SOC at the departure time for each EV.

$$\mathrm{SOC}^i_{\mathrm{Departure}} \geq \mathrm{SOC}^i_{\mathrm{Arrival}} + \Delta\mathrm{SOC}^i_F \tag{18}$$

where $\mathrm{SOC}^i_{\mathrm{Departure}}$, $\mathrm{SOC}^i_{\mathrm{Arrival}}$ and $\Delta\mathrm{SOC}^i_F$ are the departure SOC, initial SOC and the required additional SOC at departure time of the ith EV, respectively.

- The number of switching between charging and discharging:

The maximum number of switching between charging and discharging is determined by the elapsed time of the EV's battery life.

$$D^i \leq N_{\max} \tag{19}$$

where D^i represents the number of switching between charging and discharging mode during parked period; $N_{\max}$ is the maximum number of switching between charging and discharging.

- Duration of presence in the parking lot:

$$\sum_{t=t^i_a}^{t^i_d} \left| M^{i,t} \right| = T^i_p \tag{20}$$

where t^i_a and t^i_d are the arrival time and the approximate departure time, respectively; T^i_p is the approximate duration of presence of the ith EV in the parking lot.

- The limit of battery charging:

$$P^{i,t}_{\mathrm{EV}} \cdot M^{i,t} \cdot \eta_{\mathrm{G2V}} \cdot \Delta t \leq \mathrm{RBC}^{i,t-1} \cdot \mathrm{Cap}^i \tag{21}$$

where η_{G2V} is the charging efficiency.

- The limit of battery discharging:

$$P^{i,t}_{\mathrm{EV}} \cdot M^{i,t} \cdot \frac{1}{\eta_{\mathrm{V2G}}} \cdot \Delta t \leq \mathrm{SOC}^{i,t-1} \cdot \mathrm{Cap}^i \tag{22}$$

where η_{V2G} is the discharging efficiency.

The proposed model is solved using NLP (nonlinear programming) solver CONOPT under GAMS on a Pentium IV, 2.6 GHz processor with 4 GB of RAM.

3. Case study

A case study of an intelligent parking lot with capacity of 500 EVs is carried out in this paper. The Arrival and departure times of EVs are assumed as random variables. The intelligent parking lot is supposed to be located in an urban area. Based on a statistical study on some parking lots on weekdays in Tehran city carried out by authors, the hourly parking utilization duration illustrated in Fig. 5 has been obtained.

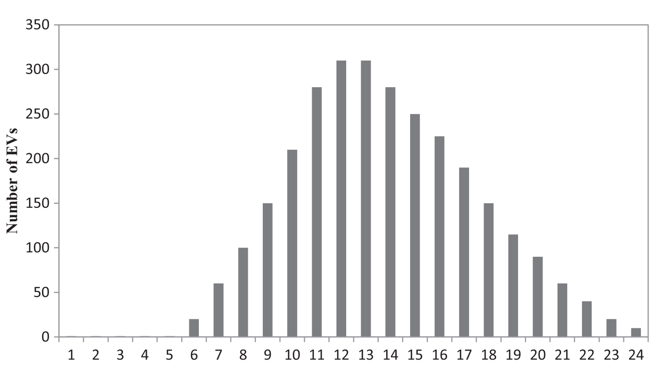

Fig. 5. The statistical parking utilization information.

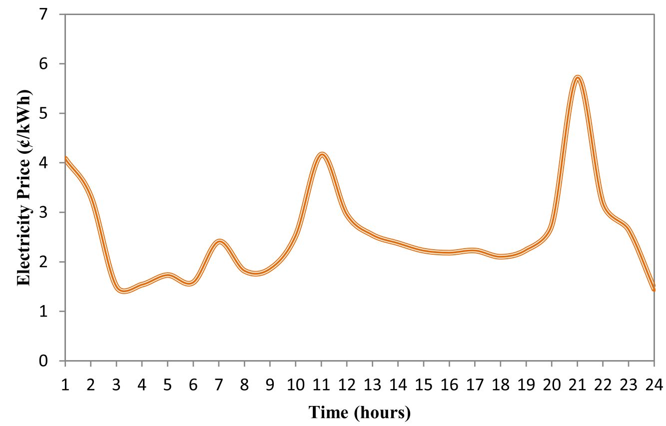

Fig. 6. The hourly electricity price of open market.

The software of the intelligent parking lot prioritizes the charging/discharging procedure of each EV considering its arrival time, approximate duration of presence in the parking lot, hourly electricity price signal, and price offers of other EVs. All EVs supposed to be Chevy Volt [25], so the batteries were assumed to be identical for all EVs with the capacity of 16.5 kWh.

The initial SOC of each EV is considered as a continuous uniform random number between 0.1 and 0.7. The arrival time is assumed between 6:00 AM and 6:00 PM. Also, the approximate duration of presence in the parking lot is considered as a continuous uniform number between 2 and 8 h.

The charging price that the EV owner is willing to pay is considered as a continuous uniform random number between 2.5 and 4.5 ¢/kWh. The discharging price that the EV owner is willing to sell the stored energy is considered as a continuous uniform random number between 3 and 5 ¢/kWh. The sample time (Δt) is set to 900 s since it is a reasonable decision making time for 500 EVs. Fig. 6 is the hourly energy price from IESO (independent electricity system operator) of Ontario's power system on 13 Jun 2013 [21].

Table 1 presents the relationship between the AOB (age of the battery) and the number of switching between charging and discharging. For example, old batteries have the lowest number of switching between charging and discharging.

To evaluate the proposed model, two scenarios are considered. In scenario 1, the age of the EV's battery is not considered and each battery can charge and discharge without any technical considerations. In scenario 2, the elapsed time of the EV's battery life is taken into account as a constraint in EVs charging and discharging procedure.

3.1. Scenario 1

In this scenario, the software of the intelligent parking lot doesn't consider the number of switching between charging and discharging mode as a constraint; in other words, each EV can charge and discharge as much as possible without any constraint.

Table 1
The relation of AOB and the number of allowed charging/discharging procedure.

Age of the battery (year)	AOB $<$ 4	4 $\leq$ AOB $<$ 6	6 $\leq$ AOB $<$ 8	8 $\leq$ AOB
Number of allowed charging/discharging procedure	8	6	4	2

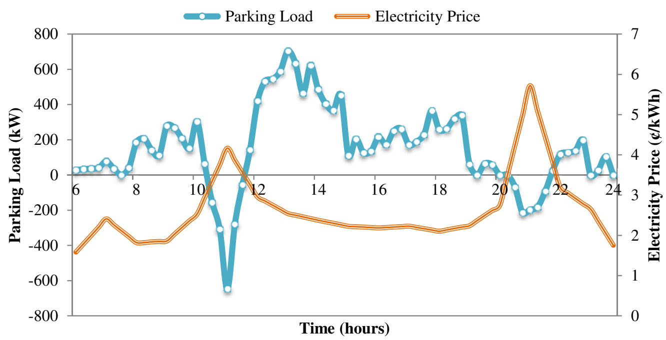

Fig. 7. The hourly scheduled parking electricity demand and electricity price in scenario 1.

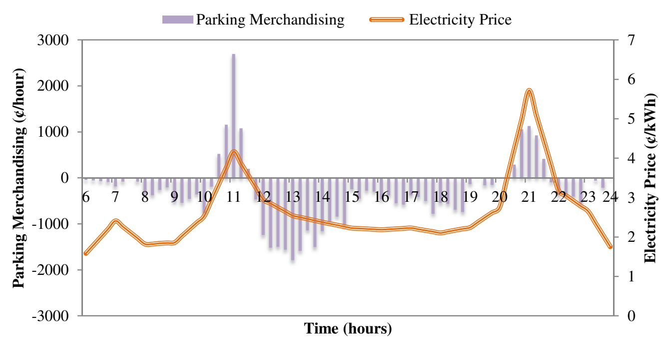

Fig. 8. The hourly parking merchandising and electricity price in scenario 1.

Fig. 7 shows the hourly scheduled parking electricity demand. As shown, the parking sells the EV's stored energy to the grid in peak hours while in off-peak hours it purchases electricity from the grid. Although the night peak price is bigger than that one in the morning, the total sold energy is less; because the most of the EVs left the parking in night hours.

Fig. 8 shows the total merchandising of the intelligent parking lot. As shown, in the hours when the electricity price is high, it is preferred to sell the electricity stored in EVs to gird. The parking load and consequently parking purchased energy increase dramatically between 12:00 and 15:00, due to high electricity prices between 10:00 and 12:00. So, all of the EVs tend to sell energy to the grid and the average SOC of the existing EVs in the parking decrease significantly. On the other hand, by approaching the final hours of EV's presence in the parking lot and low electricity prices, the software of intelligent parking lot changes the mode of the most EVs to charging mode; therefore, a peak load is appeared during hours 12:00-15:00.

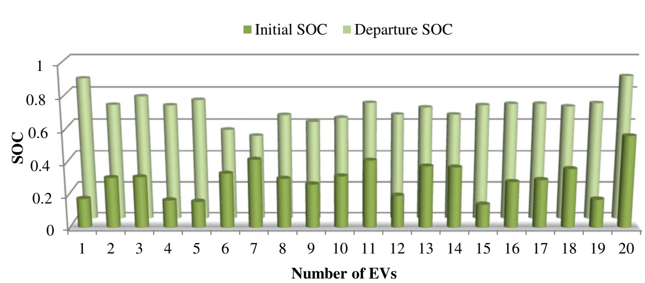

Fig. 9. Initial and departure SOC of 20 EVs in scenario 1.

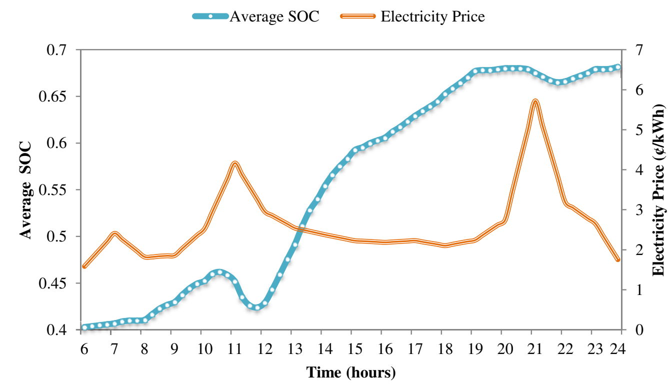

Fig. 10. Average SOC for existing EVs in the intelligent parking lot in scenario 1.

Fig. 9 shows the initial and departure SOC for 20 randomly selected EVs. As shown, the EV's SOC in the departure time has a reasonable quantity despite participation of EVs in V2G discharging program. Whatever the EV's owner is willing to pay higher price for charging and staying longer in the intelligent parking lot, the software allocates more power to the EV's charger and as a result, the EV reaches the higher SOC at plug-out time.

Fig. 10 shows the average SOC for existing EVs in the intelligent parking lot. The average SOC starts to grow at hour 12:00 until hour 20:00 when the electricity price is relatively low. When the electricity prices grows up during hours 10–12 and 21–22, the intelligent parking lot aggregates the stored energy in the EVs' batteries and sells to the grid and in this way play a role as an energy storage. On the other hand, during hours with low electricity prices, the parking lots play a role as a controllable load which its load varies with the price.

3.2. Scenario 2

In this scenario, the software of the intelligent parking lot asks customers for the age of their EV's battery in order to impose limitation for the number of switching between charging and discharging.

Fig. 11 shows the hourly scheduled parking electricity demand. Comparing with scenario 1, the parking load decreased because the software of the intelligent parking lot has fewer choices and the batteries main charging/discharging procedure occurs in low/high energy prices.

Fig. 12 shows the merchandising of the intelligent parking lot. Similar to the scenario 1, due to the peak prices at hours 10:00–12:00 and the final hours of EV's presence in the parking lot, a peak appears in the parking lot electricity demand at hours 12:00–14:00.

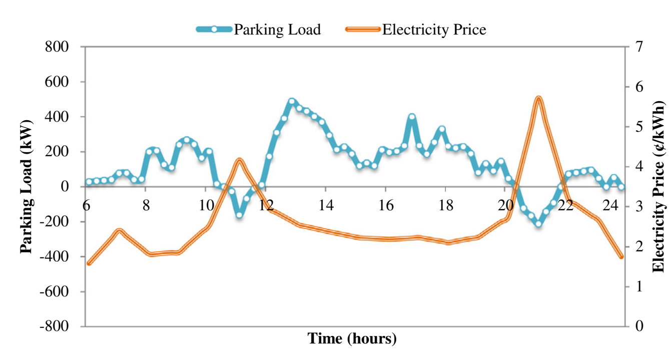

Fig. 11. The hourly scheduled parking electricity demand and electricity price in scenario 2.

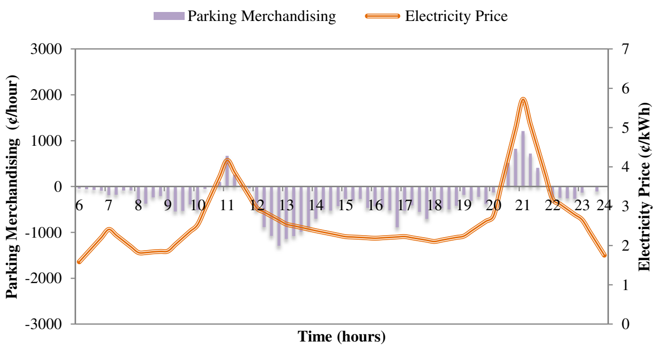

Fig. 12. The hourly parking merchandising and electricity price in scenario 2.

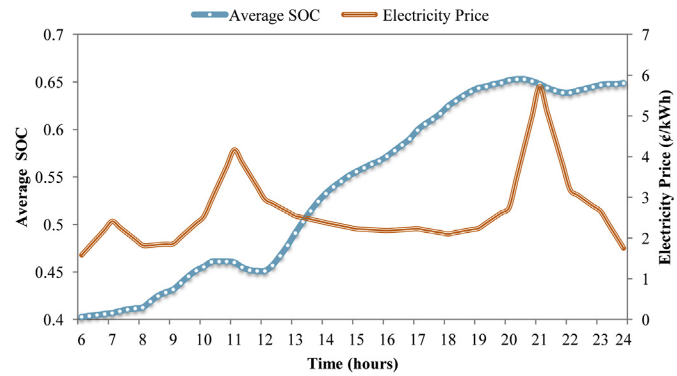

Fig. 14. Average SOC for existing EVs in the intelligent parking lot in scenario 2.

In this scenario, unlike the scenario 1, the parking lot doesn't have wide choices for charging/discharging of EVs and therefore the peak electricity demand and supply of the parking lot are reduced.

Fig. 13 shows the initial and departure SOC for 20 randomly selected EVs. In this scenario, the battery lifetime was considered as a constraint, so the departure SOC of each EV has been affected. By limiting the number of switching between charging and discharging modes, the EVs' departure SOC compared with the one in scenario 1 is less but still reasonable.

Fig. 14 shows the average SOC for existing EVs in the intelligent parking lot. As in this scenario the battery condition is considered, the fluctuations of average SOC decreased. This strategy increases the EVs' battery lifetime [26].

4. Conclusion

The integration of EVs in the power networks makes new challenges; accordingly, there is a growing necessity to address the implications of this technology on the power network. In this paper, a new scheduling EVs charging/discharging model for implementing in an intelligent parking lot has been proposed. The economical and technical aspects of EVs charging/discharging are simultaneously taken into account. In the proposed model several constraints such as the battery charging limit, the arrival and departure time of each EV, and desired charging/discharging price have been considered. The proposed model helps the intelligent parking lot to play a role as a VPP or an aggregator in order to collect the dispersed EVs in an accumulated area and manage their energy demand to prevent unexpected overloads in the power system. The results showed that the charging was carried out in the hour with lower electricity prices while in the hours with higher electricity prices the proposed model preferred to discharge the EVs to sell the stored energy to the DSO. The intelligent scheduling and control of charging and discharging of EVs introduces a great opportunity for evolving a sustainable integration of electrical and transportation system. Through V2G, EVs' owners can make revenue while their cars are parked; it can provide valuable economic incentives for EV owners. In addition, utilities significantly support V2G capability and benefit from dispersed energy storages in the grid. Simulation results evidenced that the use of intelligent parking lot for managing of the charging/discharging of EVs has eliminated the risk of an electricity demand growth during the peak load of the network. Furthermore, intelligent parking lot provided an infrastructure for aggregating the stored energy of the EVs' batteries and selling it to the grid during the peak hours when the electricity prices were high. Also, considering the lifetime of battery as a constraint affected the charging/discharging scheduling of EVs.

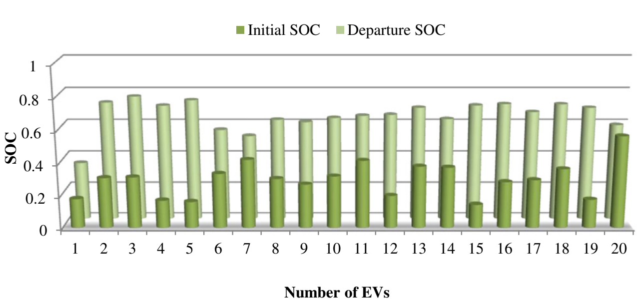

Fig. 13. Initial and departure SOC of 20 EVs in scenario 2.

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