Assessment of PEV Owners' Preferences Impact on PEV Parking Lot Transactions

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Abstract—**The inevitable need of new infrastructures for encouraging plug-in electric vehicles (PEVs) penetration into the system has drawn various attentions towards the required studies. In this regard, the PEVs parking lot (PL) has shown to have proper potentials. Other than providing a charging place for the PEVs, PLs can be considered as an integrated form of PEV batteries and act as storage in the system. However, the accuracy of PL's operation can be enhanced through detailed modeling of various affecting factors such as PEV's preferences on using the charging capability of the PL. In this study, a new model to add the PEVs' preferences in the PL's market participation problem is proposed. Various categories of PEVs are considering based on their arrival/departure pattern, duration of stay in the PL, and charging requirements. The results showed a considerable difference in PL's strategy in market participation, with and without considering PEVs' preferences.**

Index Terms— *energy and reserve market, mixed integer linear programming (MILP), parking lot (PL), plug-in electric vehicle (PEV).*

NOMENCLATURE

Subscripts

h	Duration of stay in PL
t	Time interval
ω	Scenario and scenario set

Superscripts

ar	Arrived PEVs to the PL
Cat	PEVs categories
Cha	Charging mode
$dCha$	Discharging mode
del	Delegated energy (probability of reserve call)
dep	Departed PEVs from the PL
EM	Energy Market
EV	Electric vehicle
fix	Fixed SOC requirement
$flex$	Flexible SOC requirement
$G2V$	Grid to Vehicle
in	Power injected into the PL
out	Output energy from PL
PL	Parking Lot
Re	Reserve
RM	Reserve Market
Sc	Scenario
$Tariff$	Tariff from PEV owners entering PL
$V2G$	Vehicle to Grid

Variables and Parameters

C	Capacity of a PL (kW)
Cd	Cost of equipment degradation
FOR	Forced outage rate (%)
n, N	Number of parked PEVs
r, R	Reserve (kW)
soc, SOC	State of Charge (kWh)
β	Coefficient determining the share of each PEV category from hourly vehicle departure
θ	Coefficient determining the share of each PEV category from total PEVs in the PL in each hour
ϕ	Coefficient determining the minimum departure SOC requirement of each PEV category
γ	Charge/Discharge rate
ρ	Probability
η	Efficiency
π	Price

Remark: An underlined (overlined) variable is used to represent the minimum (maximum) value of that variable.

I. INTRODUCTION

The electrification of transportation has been recently a subject of interest in power system studies as well as urban planning studies. The benefits that can be achieved through encouragement of plug-in electric vehicle (PEV) penetration in the system have been investigated in various studies [1]. Other than that, different papers have been dedicated to various aspects of the subject, such as battery design and manipulation, level of PEV penetration, and PEV charging schedule. However, the most important issue in this matter is to provide appropriate and sufficient infrastructure for users to get encouraged for switching from regular vehicles to PEVs. This can be achieved through incentive-based programs or loan aids on PEV purchase and utilization. Nevertheless, these methods can provide a short-term solution to the problem. For longer vision into deployment of PEVs' advantages in the system, long-term solutions and permanent results should be proposed.

In this regard, PEV parking lots (PL) have been a trending attempt. Like regular vehicles, the owners of PEVs need a place to park their vehicles during the working hours of the day.

Needless to emphasize that a PL is a requirement of the urban system, a PL can also be a place for the PEVs to charge and discharge as well. When the PL is equipped with the required facilities for charge/discharge of the PEV battery further benefits can be obtained from PEVs staying in the parking. As shown by [2] and [3], the system can benefit from the longer stay of PEVs in the PL and provide the vehicle to grid (V2G) mode of the PEVs and act as a resource in the system. By this means, electric system can have an extra resource, urban planner can benefit from a centralized charging system instead of individual charging stations, and the PEVs can have a motivation of using PL as they can benefit from selling their state of charge (SOC) to the upstream network.

Although PL can be beneficial from different points of view, however, it should be noted that in the operation of PLs the PEVs usage pattern, traffic pattern, and owners' preferences can have significant effects. There are some references such as [4-6] that have focused on PL concept, but they did not address the PEV owner preference on the PL behavior. In [7], the PL behavior in transaction with the upstream energy and reserve markets have been investigated, but the only preference of the owner which is considered in that paper is the minimum departure SOC.

Authors in [8] used a real-time procedure for charging/discharging of PEVs considering the temporal variations of PEVs arrival/departure. A study on the SOC evaluation for PEVs due to their traffic pattern is in [9]. The uncertain behavior of the users is modeled through controlled and uncontrolled charging in [10]. PEV fleet characterization due to PEV travel between system buses is considered in the system operation [11]. Various levels of PEV penetration in the system and their behavior uncertainties along with distribution system uncertainties are studied in [12]. However, the previous studies have mostly considered the effect of PEV behavior on their individual charging or considered the travel pattern in the system on the PEVs consumption. In this paper, the purpose is to assess the effect of PEV owner preferences on their both aspects: flexible load and storage resource.

A PL can be considered as a flexible load due to a variable charging state of PEVs in the PL. On the other hand, while the PEVs agree to participate in the V2G mode, the PL can benefit from the potential resource that the PEV batteries' SOC provide for the PL. With this SOC the PL can participate in both energy and reserve markets. However, regarding the PEVs' preferences on their required SOC and their preferred stay duration in the PL, different strategies can be adopted by the PL operator for charging/discharging the PEVs. In this paper, various preferences of PEV owners when entering the PL are considered to limit the operation of the PL according to these requirements.

The rest of the paper is organized as follows. In Section II, the PEVs are categorized based on their preferences. The implementation of the PEVs' preferences on PL transactions is modeled in Section III. Two case studies are investigated for the numerical results in Section IV. Finally, in Section V, the conclusion of the study is presented.

II. CATEGORIZING PEVS' PREFERENCES

In general, vehicles that use a parking place, especially in public areas, tend to spend a couple of hours in the parking. The same can be considered for the PEVs.

The main requirement of PEVs in the system is to have a place to enable the charge needs of the PEVs. Therefore, when the PEVs enter the PL, the owners mainly expect to be charged. However, if they agree to participate in V2G mode, the PL can act as a resource in the system. In this case, the owners are also paid for providing this opportunity to the PL. Hence, further interest will be offered to the owner.

In this regard, in this paper the PEVs are categorized mainly into two groups: the first group who only wants to charge their vehicles while in the PL (G2V group); and the second group PEVs that agree to participate in the V2G mode as well as the G2V (V2G group). In other words, the owners can have the option of participating in G2V or V2G group by considering their own needs and duration of stay as well as the battery degradation of their vehicles.

On the other hand, when an owner decides to use a PL, it may have other plans for consumption of its charge or the amount of SOC that it needs for its next probable travel. Therefore, it should have the choice to limit its charging or discharging status. In order to categorize this preference of the owners, it is considered that all the PEVs can have the choice of fixed or flexible SOC. This means that the PEVs can determine that they need a certain amount of SOC when they are departing the PL. This will limit the PL's transaction, both with the PEV owner and the upstream grid. Besides, some other PEVs may agree to have a flexible amount of SOC on their departure. In this case, the PL will have more flexibility both as a flexible load and resource.

On the above premises, overall of four categories are defined in this study: G2V mode with fixed SOC, G2V mode with flexible SOC, V2G with fixed SOC, and V2G mode with flexible SOC. Note that by V2G mode, it is meant that the PEVs participate in both G2V and V2G mode.

In order to implement the categories of the PEVs in the PL model some coefficients are defined in this study. These coefficients and their values can be found in Table I and II. As mentioned before, the PEVs can determine their SOC requirement on their departure. This value is shown by coefficient as the percentage of their battery capacity. This value is influenced by the duration of their stay in the PL [13]. Therefore, for different durations different values are specified. Moreover, it should be determined that what is the percentage of the PEVs that belong to each of the previously defined categories. For this determination the coefficient β is defined. The values for β are shown in Table II. All these values are derived from real data and surveys on possible PEV owners' behavior as in [14] and [15].

TABLE I.   VALUES OF ϕ FOR DIFFERENT PEV CATEGORIES

Mode	Departure SOC Requirement	Duration of stay (hours)		
		1-3	4-7	9-12
G2V	Fix	0.6	0.8	0.9
	Flex	0.4	0.6	0.6
G2V+V2G	Fix	0.4	0.5	0.6
	Flex	0.3	0.4	0.5

TABLE II.   VALUES OF β FOR DIFFERENT PEV CATEGORIES

Mode	Departure SOC Requirement	Duration of stay (hours)		
		1-3	4-7	9-12
G2V	Fix	0.56	0.32	0.08
	Flex	0.14	0.08	0.02
G2V+V2G	Fix	0.06	0.12	0.18
	Flex	0.24	0.48	0.72

From another point of view, the PEVs with their categories provide PL with different opportunities and limitations. Therefore, the PL also should treat them proportionate to the level of opportunity and/or limit that they put on the PL. In this regard and for encouraging higher levels of participations, the PL trade with each category with different price. These prices are relative to their level of flexibility. For example, a flexible V2G PEV provides the highest level of flexibility for the PL. Therefore, the PL will reduce from the price that they should pay for their charging and these PEVs will receive an incentive for V2G mode participation as well.

III. PL MATHEMATICAL MODEL

After determination of the PEV categories, in this section the mathematical model for the PL transaction with the upstream energy and reserve market is discussed. It is assumed that a PL purchases energy from the upstream network for charging the PEV batteries. On the other hand, it presents the SOC of PEVs to upstream energy and reserve market. The PL also has financial transactions with the PEV owners based on their category and the tariffs assigned to each category.

Consequently, the objective function of the problem is to maximize PL's profit as in (1).

$$profit^{PL} = \sum_t \left(\rho_\omega^{PL} \sum_\omega \left(profit_{\omega,t}^{EM,PL} + profit_{\omega,t}^{RM,PL} + profit_{\omega,t}^{PEV,PL} \right) \right) \quad (1)$$

where ω is the scenario for various PEVs' arrival and departure scenarios. Based on (1), the profit of the PL consists of its profit from the upstream energy market, upstream reserve market, and its transactions with the PEVs for charging/discharging their batteries. The detailed terms of the objective function are presented in the following equations.

$$profit_{\omega,t}^{EM,PL} = \left(p_{\omega,t}^{out,V2G} \right) \pi_t^{out,PL} - \left(p_{\omega,t}^{in,V2G} + p_{\omega,t}^{in,G2V} \right) \pi_t^{in,PL} \quad (2)$$

$$profit_{\omega,t}^{RM,PL} = r_{\omega,t}^{PL} \pi_t^{Re,PL} + r_{\omega,t}^{PL} \rho_t^{del} \pi_t^{out,PL} - r_{\omega,t}^{PL} \rho_t^{del} FOR^{PL} \pi_t^{out,PL} \quad (3)$$

$$profit_{\omega,t}^{PEV,PL} = \left(\phi_{\omega,t}^{fix1} \beta_{\omega,t}^{fix1} C_{\omega,t}^{dep,PL} - SOC_{\omega,t}^{dep,fix1,Sc} \right) \pi_t^{G2V1}$$
$$+ \left(soc_{\omega,t}^{dep,flex1} - SOC_{\omega,t}^{dep,flex1,Sc} \right) \pi_t^{G2V2}$$
$$+ \left(\phi_{\omega,t}^{fix2} \beta_{\omega,t}^{fix2} C_{\omega,t}^{dep,PL} - SOC_{\omega,t}^{dep,fix2,Sc} \right) \pi_t^{G2V3}$$
$$+ \left(soc_{\omega,t}^{dep,flex2} - SOC_{\omega,t}^{dep,flex2,Sc} \right) \pi_t^{G2V3} \Big|_{SOC_{\omega,t}^{dep,flex2,Sc} < soc_{\omega,t}^{dep,flex2}} \quad (4)$$
$$- \left(soc_{\omega,t}^{dep,flex2} - SOC_{\omega,t}^{dep,flex2,Sc} \right) \pi_t^{V2G} \Big|_{SOC_{\omega,t}^{dep,flex2,Sc} \geq soc_{\omega,t}^{dep,flex2}}$$
$$- \left(p_{\omega,t}^{out,V2G} + p_{\omega,t}^{in,V2G} + r_{\omega,t}^{PL} \rho_t^{del} \right) Cd^{PL}$$
$$+ N_{\omega,t}^{PL} \pi^{Tariff} - r_{\omega,t}^{PL} \rho_t^{del} \pi_t^{V2G}$$

As shown in (4), there are four prices for all four categories of PEVs who enters the PL. The trade between PL and PEV is based on the amount of SOC that remains in the battery when they are departing the PL compared to their initial SOC (the amount of SOC that they enter the PL with) and their required amount of SOC. Note that V2G PEVs are paid a battery degradation price (Cd^{PL}) to compensate their battery depreciation while discharging.

In the model, it is shown that the PL profit is calculated on an hourly basis; however, the coefficients defined for PEVs' preferences were based on their requirements and stay duration.

Thus, in order to make the coefficients applicable to the model their hourly values are calculated using (5) and (6).

$$\beta_{\omega,t}^{Cat} = \frac{\sum_h \beta_{\omega,h}^{Cat} N_{\omega,t,h}^{dep,Cat}}{N_{\omega,t}^{dep,PL}} \quad (5)$$

$$\varphi_{\omega,t}^{Cat} = \frac{\sum_h \varphi_{\omega,h}^{Cat} \beta_{\omega,h}^{Cat} N_{\omega,t,h}^{dep,Cat}}{\sum_h \beta_{\omega,h}^{Cat} N_{\omega,t,h}^{dep,Cat}} \quad (6)$$

In (5), the hourly value for coefficient β is calculated based on the proportion of total number of PEVs on each category multiplied by the β value to the total number of PEVs departing the PL in each hour. The same procedure is employed for calculating the hourly values of . However, in computation of the hourly   values it should be determined that what the share of each category is from the number of departing PEVs in each hour. In this regard, (7) and (8) determines the share of the G2V and V2G PEVs from the total departed SOC in each hour, respectively.

$$soc_{\omega,t}^{dep,G2V} = \phi_{\omega,t}^{fix1} \beta_{\omega,t}^{fix1} C_{\omega,t}^{dep,PL} + soc_{\omega,t}^{dep,flex1} \quad (7)$$

$$soc_{\omega,t}^{dep,V2G} = \phi_{\omega,t}^{fix2} \beta_{\omega,t}^{fix2} C_{\omega,t}^{dep,PL} + soc_{\omega,t}^{dep,flex2} \quad (8)$$

Moreover, the SOC of the PL in each hour can be calculated from (9) and (10). It should be noted that as there are two different types of PEV modes in the PL, the SOC related to each mode should be calculated separately. The reason is that only the V2G mode PEVs provide the opportunity of upstream energy and reserve market participation for the PEV. Therefore, it is necessary to determine the potential of PL for market participation. This can be done through estimation of the SOC in the PL.

$$soc_{\omega,t}^{PL,G2V} = soc_{\omega,t-1}^{PL,G2V} \Big|_{t>1} + SOC_{\omega,t_0}^{PL,G2V} \Big|_{t=1}$$
$$+ soc_{\omega,t}^{ar,G2V} - soc_{\omega,t}^{dep,G2V} + p_{\omega,t}^{in,G2V} \eta^{cha,PL} \quad (9)$$

$$soc_{\omega,t}^{PL,V2G} = soc_{\omega,t-1}^{PL,V2G} \Big|_{t>1} + SOC_{\omega,t_0}^{PL,V2G} \Big|_{t=1} + soc_{\omega,t}^{ar,V2G}$$
$$- soc_{\omega,t}^{dep,V2G} + p_{\omega,t}^{in,V2G} \eta^{cha,PL} - p_{\omega,t}^{out,V2G} / \eta^{dcha,PL} \quad (10)$$

All the PEVs with flexible departure SOC requirement still needs their minimum SOC preferences to be maintained in their battery. On the other hand, the maximum charging of a battery is also limited to the limit of its capacity. These restrictions are modeled through (11) and (12) for both categories of the flexible PEVs.

$$\phi_{\omega,t}^{flex1} \beta_{\omega,t}^{flex1} C_{\omega,t}^{dep,PL} \leq soc_{\omega,t}^{dep,flex1} \leq \overline{soc}^{EV} \beta_{\omega,t}^{flex1} C_{\omega,t}^{dep,PL} \quad (11)$$

$$\phi_{\omega,t}^{flex2} \beta_{\omega,t}^{flex2} C_{\omega,t}^{dep,PL} \leq soc_{\omega,t}^{dep,flex2} \leq \overline{soc}^{EV} \beta_{\omega,t}^{flex2} C_{\omega,t}^{dep,PL} \quad (12)$$

When charging the PEVs, the PL should consider the maximum possible capacity of the PEV battery. This amount can change in different vehicles due to their battery specifications. Therefore, the PL transactions should also be limited by those specifications. For the G2V mode, (13) limits the maximum charging of the G2V PEVs; but for the V2G mode as the possibility of discharge also exists, a minimum restriction should also be defined to bound the PL's discharge (14).

$$soc_{\omega,t}^{PL,G2V} \leq n_{\omega,t}^{G2V,PL} C_{\omega,t}^{PL} \overline{soc}^{EV} \qquad (13)$$

$$n_{\omega,t}^{V2G,PL} C_{\omega,t}^{PL} \underline{soc}^{EV} \leq soc_{\omega,t}^{PL,V2G} \leq n_{\omega,t}^{V2G,PL} C_{\omega,t}^{PL} \overline{soc}^{EV} \qquad (14)$$

The charging stations installed in the PL also restrict the trading of the PL by its charging/discharging rate (γ^{PL}). As a result, the maximum power exchange of the PL is limited to this rate as in (15) and (16). In addition, the PL's output which includes the V2G energy output and the reserve should also be in the range of charging limit as in (17).

$$0 \leq p_{\omega,t}^{in,G2V} \leq \gamma^{PL} N_{\omega,t}^{G2V,PL} \qquad (15)$$

$$0 \leq p_{\omega,t}^{in,V2G} \leq \gamma^{PL} N_{\omega,t}^{V2G,PL} \qquad (16)$$

$$0 \leq p_{\omega,t}^{out,V2G} + r_{\omega,t}^{PL} \leq \gamma^{PL} N_{\omega,t}^{V2G,PL} \qquad (17)$$

IV. NUMERICAL RESULTS

The model proposed in this study has been implemented on two case studies. In Case I, the PEVs that enter the PL are considered to be categorized and follow certain preferences. In Case II, the preferences of the PEVs are not considered. The only limitation that the PEV owners impose on the PL in Case II is their choice on participation in G2V/V2G mode. The energy and reserve prices employed in this study are obtained from the Spain electricity market [16].

The market prices for energy and reserve markets used in this study are shown in Fig. 1. As the voltage level of this study is considered to be the medium voltage, the expenses of the transmission network consumption is added to the market prices based on [17]. The PL is considered to be installed in a commercial area and mainly used by the employees who tend to have their PEVs stay in the PL for longer hours. The problem is modeled as a Mixed Integer Linear program and solved using GAMS solver CPLEX12.
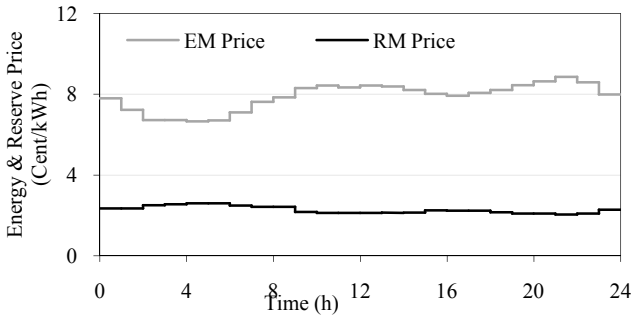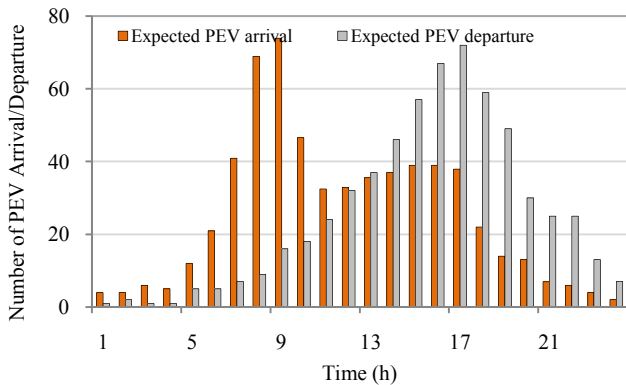
A. Case I: Categorized PEV entrance to PL

In this case, the aforementioned categories are considered as the entering PEVs to the PL. It is assumed that the arrival/departure pattern of the PEVs in/out the PL is like Fig. 2. Considering this pattern the PL will try to maximize its profit through participation in energy and reserve markets. The input power to the PL for charging the PEV batteries is shown in Fig. 3.

As illustrated in Fig. 3, during the early hours of the day, the PL starts to charge its PEVs based on the duration that they intend to stay in the PL. It is shown that the PL charges the PEVs who agree to participate in the V2G mode for two reasons. Firstly, according to Fig. 2, there are a large number of PEVs arriving between hours 6 to 10 who are mainly the employees of the commercial sector and need to stay in the PL for a longer period.

Therefore, the PL can benefit from their SOC and offer them in energy and reserve market. On the other hand, as the total percentage of flexible V2G mode PEVs is higher in the vehicles that tend to stay longer, the PL can also benefit from selling more energy to the PL owners. However, for hours 11, 13, and 14 the energy price is rather high comparing to previous hours, therefore, the PL decides not to charge the PEVs during those hours.

Although in Fig. 3 it is shown that no energy is injected from the PL into the grid but Fig. 4 shows that the PL participates in the reserve market and has a considerable reserve provision from its SOC. The reason is that the benefits from the reserve market can be twofold: first, as it does not discharge the PEV batteries, it does not have to pay to the PEV owners for their discharge; second, the PL can benefit both from selling energy to the PEV owners and also from reserve declaration to the reserve market. As a result, in this situation it is more profitable for the PL to take part only in the reserve market.
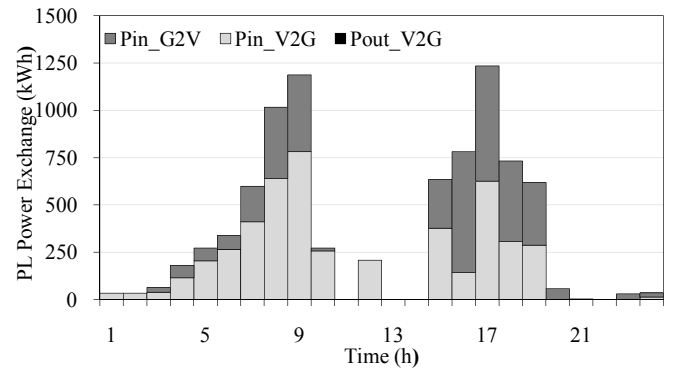

Fig. 1. Energy and Reserve Market prices.

Fig. 2. Expected arrival and departure of PL.

Fig. 3. Input power to PL in Case I.
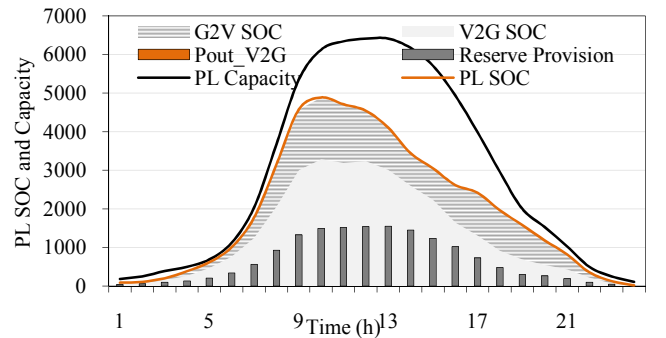

Fig. 4. SOC of PL in Case I.

Fig. 5. SOC of PL in Case I.

Fig. 6. Input power to PL in Case II.
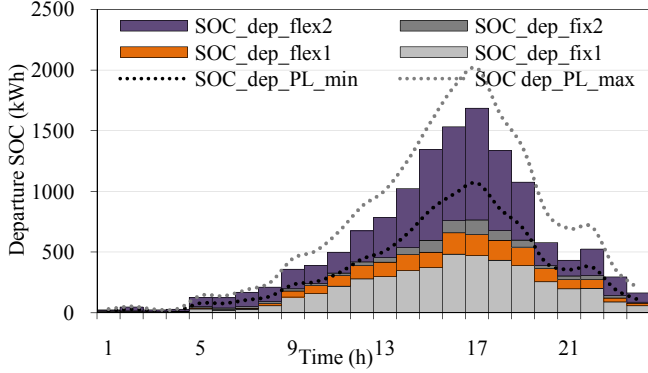
In Fig. 3, the share of G2V and V2G PEVs from total SOC of the PL is shown. Moreover, Fig. 5 shows the share of each PEV category from the total SOC that departs from the PL in each hour. It is observed that the highest share belongs to category flex2 (PEVs with flexible requirement in V2G mode). The reason is that they have brought the highest level of flexibility to the PL. In trade, the PL considers discount for selling energy to this category to maintain their participation in this category.

B. Case II: Uncategorized PEVs

In this case, although the previously discussed restricting categories are not considered, the choice of PEV owners in whether participating in the V2G mode still exists. Moreover, the minimum requirement of each PEV on their departure SOC is also taken into account.

The results for the energy exchange of the PL in this case are shown Fig. 6. Regarding Fig. 6, it is seen that the hourly input power to the PL is higher compared to the correspondent hour in Case I. This occurs due to the fact that in this case the PL is not limited by the fixed category PEVs to maintain the SOC of the departing PEVs at a certain level. On the other hand, it is shown that in hour 14, when in Case I no energy trade occurred the PL charges the V2G PEVs.

In addition, in hour 12, in contrary to Case I where only the V2G PEVs were charged, in this case more G2V PEVs are involved by the PL in the charging procedure. The reason is that in Case I the PL has restrictions on maximum possible charging of the PEVs; therefore, it will charge only its flexible V2G PEVs to take benefit of their SOC in its reserve provision. In contrary in Case II, the PL tends to charge the V2G mode PEVs to make benefit through selling energy to these PEVs.

From another point of view, during PL's peak charging hours (i.e., hours 8, 9, and 16-18) the input energy to the PL in Case II is higher than Case I. This overestimation in charging behavior of PL, which is caused by not considering the PEVs' preferences, can lead to overdesigning of the distribution network and impose undesirable extra costs to the electrification progress of the transportation system.

Comparing figures 4 and 7 it can be seen that although the SOC of the PL in Case II is higher than the Case I, the amount of reserve provision is not changing considerably. This occurs due to the fact that the PL should compromise between the penalty of not being available for the reserve call, the limit of PEVs on their departure, the excess payment for purchasing energy from the upstream, and the value it should pay to the PEVs for their V2G mode.
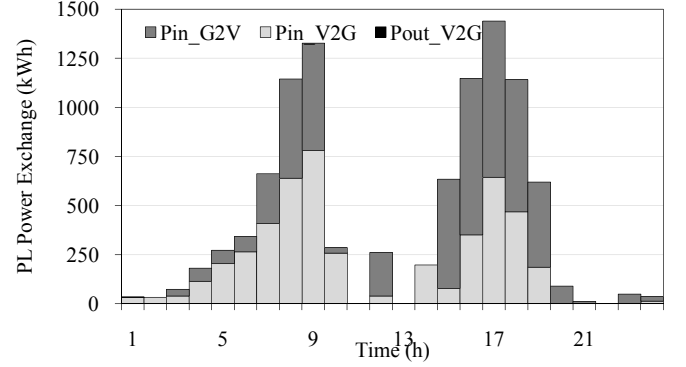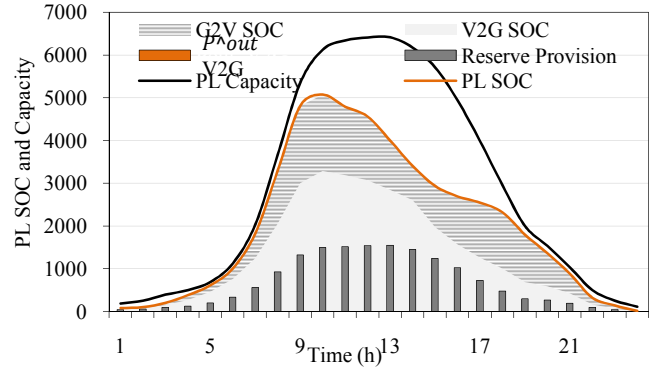

Fig. 7. SOC of PL in Case II.

All these compromises cause the PL to act with a safe margin regarding the reserve provision.

However, these two figures show that the total SOC increases in Case II as the limits of PEVs' preferences on their departure is neglected.

V. CONCLUSION

In this paper a new model for considering the PEVs preferences in the PL's energy and reserve transactions was proposed. It was shown that PEVs preferences can be applied to the PL's mathematical model through certain defined coefficients restricting the energy trade of the PL by the owners' preferences. In this model, the owners' tendency to participate in G2V or V2G mode was considered as well as their departure SOC requirement. These preferences were assigned to the PEVs based on their duration of stay in the PL. The results showed that the restrictions on PL due to the PEVs' preferences can significantly change the behavior of the PL and its strategy in market participation. It is also deduced that the PL is limited by the total energy input, which can also affect the operation of other system components. Moreover, the strategy of the PL on market participation was influenced by the PEVs preferences and was propelled to a way which was beneficial both for the PEV owner and the PL. The study confirmed that for increasing the penetration of electric vehicles and encouraging the active participation of PEV owners, it is necessary to consider them in the system model, as neglecting them will cause the overestimation of the possible benefits obtained by the PL. On the other hand, it was revealed that prices and tariffs with which the trades between the PEVs and PLs are made have been playing important roles on the mutual effects of PEVs' owners and the PLs. This matter can be the subject of future studies.

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