The Value of Reserve for Plug-in Electric Vehicle Parking Lots

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Abstract—**The introduction of plug-in electric vehicles (PEVs) in the electrical system is bringing various challenges. One of the recent solutions to deploy the potentials of PEVs in the system is through PEV parking lots (PL). The PLs not only provide a place for the PEVs charging requirements, but also give the possibility of exploiting the vehicle-to-gird (V2G) potential of PEVs in a more efficient manner comparing to PEV aggregators. On the other hand, the V2G mode gives the reserve market possibility to the PL operator, which can be a source of income other than selling energy to the PEV owners. However, the willingness of participating in the V2G mode may be low due to exposing battery degradation and not sufficient departure state of charge (SOC). As a result, this study investigates the behavior of PL on deploying the V2G mode of PEVs in reserve market participation considering the PEVs' traffic behavior.**

Index Terms—**Parking lot, plug-in electric vehicle, reserve market, traffic pattern.**

I. NOMENCLATURE

Capital letters denote parameters and small ones denote variables.

Subscripts

ω, Ω	Scenario and scenario set
t, h	Time interval

Superscripts

ar	Arrived PEVs
Cat	Categories of travel Purposes
$Cha/dcha$	Battery charging/discharging
del	Delegated energy (probability of reserve call)
dep	Departed PEVs
E	Energy
EV	Electric vehicle
$Fuel$	Energy consumed as the fuel for the vehicle
$G2V$	Grid to Vehicle
in/out	Input/output to/from PL
$Loss$	Loss of SOC
$Line$	Power line
PL	Parking Lot
Re	Reserve
Sc	Scenario
$Tariff$	Tariff paid by PEV owners arriving at the PL
TOU	Time of use energy price
$V2G$	Vehicle to Grid
vac	Vacant charging points in PL

Variables and Parameters

C	Capacity
Cd	Cost of equipment depreciation
FOR	Forced outage rate (%)
L	Travel distance between zones
n, N	Number
ns, NS	Number of PEV stations
p, P	Active power (kW)
r, R	Reserve (kW)
soc, SOC	State of Charge (kWh)
β	Division of input between PLs
κ	PEVs participation ratio in reserve market
Γ	Charge/discharge rate in stations of urban/PL
Φ	Requirement of PEV owner for minimum SOC
λ	SOC loss due to travel within the zone (%)
η	Charge and discharge efficiency (%)
ρ	Scenario probability (%)
π	Price (€)

II. INTRODUCTION

A. Motivation and Aim

The introduction of plug-in electric vehicles (PEVs) in the electrical system is bringing various challenges. One of the recent solutions to deploy the potentials of PEVs in the system is through PEV parking lots (PL). The PLs not only provide a place for the PEVs charging requirements but also introduce new possibilities that can be employed in the system. The operation of PEVs in the vehicle to grid mode (V2G) is an evolving procedure for better deployment of the PEVs' potentials. However, it should be taken into account that the PEV owners' requirements on departure state of charge (SOC) prevent the PL to fully employ the capacity of the PEVs batteries. As a result, a better approach for the PLs operator is to participate in the reserve market to make a profit through having the possibility of V2G operation.

From another point of view, the PEVs traffic pattern and preferences on how they want to use the PL is a key factor affecting the behavior of the PL in the energy and reserve markets. The traffic patterns of PEVs define the hourly potential that is available for the PL operator to deploy in its market participation strategy.

Therefore, it is important to have a comprehensive model which incorporates the traffic pattern of the PEVs in the market participation of the PL. As a result, this paper proposes a new model for the PL's market participation incorporating the PEVs traffic pattern.

B. *Literature Review*

Although the electric vehicles have been the subjects of many previous studies, there are few studies that have focused on the traffic flow of PEVs in a system. The trips travelled by PEVs affect their required energy. As a result, when dealing with the operation of the PL the travel behavior of the vehicles before entering the PL and their requirement for their future travel after leaving the PL should be taken into account. The management of PEVs' power requirement for hybrid PEVs based on the trips they travel is studied in [1]. With different traffic behavior, the charging in each charging station will be different, thus affecting its location in the grid. In [2], these effects are studied in a planning time horizon. The authors in [3] also provided the planning scheme considering the urban traffic flow of the EVs. In addition, [4] derives the behavior of the PL to be employed in its allocation problem. Moreover, in [5] the traffic criteria are added to distribution system planning to provide a coupled electric and traffic network plan. In [6] the locational energy requirement of PEVs is studied by considering their random driving pattern.

Some of the previous studies such as [7] has discussed the effect of the traffic flow on the power flow of the network due to a varying charging requirement. Moreover, in [8], an integrated traffic and power network is proposed and the charging scheme for the PEVs based on their driving patterns is presented.

Most of the previous studies except for [2] have only considered the grid-to-vehicle (G2V) operation of PEVs. However, the V2G potential of the PEVs has also proved to be an effective component in the future system. In [9], in the planning procedure of the distributed energy resources the V2G potential and traffic pattern of PEVs are studied. Although many studies have used the PEVs as their main concern of study, only a few contributions have addressed the specific effect of the PEVs V2G mode in the market strategy participation of the PL. From the PL owner's point of view, the benefits which it can take from the PEV's potential should be assessed. One of these potentials is the capacity that the PEVs' batteries give to the PL if the PEVs would be willing to participate in the V2G mode. This matter has not been addressed in the previous works. As a result, this paper discusses a cost-benefit analysis for the PL's incentives for the PEVs in the V2G mode and the profit it gains from reserve market participation through having the opportunity of the V2G mode operation.

C. *Contributions*

In this paper the effect of PEVs' operation mode on the PL's profit through market participation is studied.

It is analyzed how much the PL can profit from taking part in reserve market employing the V2G operation mode of the PEVs. In order to motivate the PEVs to participate in the V2G mode and meet their charging requirements, the model considers different pricing schemes for G2V/V2G operation as well as mathematically imposing the PEVs preferences on PL's operation model. The profit and energy balance of two PL with two different market strategies (with or without reserve participation) are compared to determine the value of the reserve market participation for the PL.

In order to examine the limits that the PEVs preferences may put on the operational behavior of the PL, various travel purposes are considered. Different arrival/departure patterns scenarios for each travel purpose are considered and the PL's energy interaction in each of these travel purposes in a system with or without reserve market participation is analyzed. In summary, the contributions of the work can be summarized as follows:

1. Evaluating the PEVs' operational mode (G2V/V2G) on the PL's market strategy;
2. To mathematically model the arrival/departure pattern of PEVs based on their travel purposes and to add it to the PL's operation model as an affecting factor on the PL's market potential.

D. *Paper Organization*

The rest of the paper is organized as follows. In Section III, the main problem is described. In Section IV, the mathematical proposed model for the PL's objective in market participation is shown. The obtained numerical results and discussions are provided in Section V. Finally, section VI concludes the paper.

III. PROBLEM DESCRIPTION

With the PEV PL solution fostering the deployment of the electric vehicles, it becomes critical to examine various aspects regarding the operation of PLs; not only the network effects of the PL but also their possible role in future electricity markets. The potential of PLs in participating in the electricity markets is considerably dependent to the availability of PEVs' state of charge in the PL. Higher numbers of PEVs demanding the charge affect the profit of the PL owners through selling energy to the PEV owners: In addition, the willingness of PEVs to participate in the V2G mode operation, offering their level of SOC in the market, increases the profit of PLs through selling energy or reserve to the electricity market. In this regard, a proper estimation of PL's hourly potentials will help the PL operator to design a better market participation strategy.

There are various aspects affecting the potential of PL in the market, such as the number of PEVs in the PL, the PEVs stay duration and state of charge, the number of PEVs available for V2G, etc.

The main factors affecting all these aspects are the traffic behavior of the PEVs, as well as the preferences of the PEV owners on how they are going to use their battery status. Therefore, the role of PEV's traffic pattern in PEV's market strategy becomes more dominant.

Taking into account the above considerations, this paper investigates the effect of traffic pattern of PEVs on the PL's participation in the market. In particular the profit gained by the PL in the reserve market is investigated. It is assumed that in an area two types of PLs are present. One of the PLs only provides the G2V operation mode for the PEVs and its profit is only through its interactions with the PEV owners. The other PL in the area operates its PEVs in both G2V and V2G modes. In order to motivate the PEVs to participate in the V2G operation mode this PL will be using different pricing schemes for the PEVs who agree to participate in the V2G mode rather than those who only participate in the G2V mode.

Deploying the potential of injecting to the grid, the PL which uses the V2G mode of the PEVs will participate in the regulating reserve market. The PL will be paid by the reserve price for the amount of reserve capacity that it provides for the market. However, upon being requested by the market operator the PL should inject the required amount of energy into the grid and will be paid based on the according price of energy. If the PL owner should fail in providing the promised amount of reserve capacity, it will be penalized by the market operator. In order to incorporate the traffic pattern of the PEVs, various types of travels are considered that enter the area of the PL. Different travel purpose will affect the arrival/departure pattern of the PEVs and their stay duration in the PL. These key factors determine the flexibility that the system operator will have in its market participation strategy acquisition. In order to assess this effect the various behavior of PL in the market is analyzed for different travel purposes. More particularly, the PL's profit through reserve market participation is computed. In this study, four types of travel purposes are considered: a) residential, b) commercial, c) industrial, and d) complex (i.e., combination of all above purposes), where the expected arrival capacity of these categories is shown in Fig. 1.

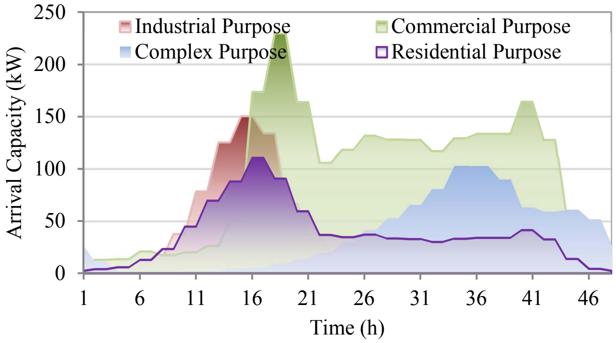

Figure 1. The capacity of arrived PEVs with different travel purposes.

IV. PL'S OBJECTIVE MODEL

It is assumed that the PLs in this study take part in the energy and reserve market to provide the required energy for charging the vehicles as well as providing energy and reserve to the grid in case of using the V2G mode operation. The objective function for the PL with reserve market participation is to maximize its profit through its market interactions and is shown in (1). The objective function for the PL without reserve does not include the profit from reserve market participation and the penalties caused by not being available for the reserve call.

$$
\begin{aligned}
& Profit^{PL} = [\mathrm{Re}venue^{PL} - Cost^{PL}] \\
& \sum_{\omega} \rho_{\omega} \sum_{t} \Big[p_{\omega,t}^{out,PL} \pi_t^E - p_{\omega,t}^{\mathrm{in},PL} \pi_t^E + r_{\omega,t}^{out,PL} \pi_t^{\mathrm{Re}} + r_{\omega,t}^{PL} \rho_t^{del} \pi_t^E + n_{\omega,t}^{PL} \pi^{Tarrif} \\
& -\left(p_{i\omega,t}^{out,PL} + r_{\omega,t}^{PL} \rho_t^{del} \right) Cd - r_{\omega,t}^{PL} \rho_t^{del} FOR^{PL} \pi_t^{Con} - r_{\omega,t}^{PL} \rho_t^{del} \pi_t^{V2G} \\
& + p_{\omega,t}^{in,PL} \ \pi_t^{G2V} - p_{\omega,t}^{out,PL} \ \pi_t^{V2G} \Big]
\end{aligned}
\tag{1}
$$

Based on the objective, the revenues and costs of the PL are from its interaction with the market as well as the PEV owners. The cost of the PL includes buying energy from the market for charging the PEVs, paying for the degradation rate of the PEV batteries, penalty of not being available upon reserve call, and the payment to the PEV owners for discharging in their batteries in V2G mode. On the other hand, the PL can make profit through selling energy to upstream network, reserve market participation, PL's tariff, and selling energy to PEVs in the PL. It is assumed that the energy sold to PEVs in the PL without reserve has the same price as energy market price while the energy sold to PEVs with the price of (π_t^{G2V}) is lower than the market price. The PL tariff and G2V/V2G prices may be determined by the PL operator in a manner to motivate the PEVs to be willing to provide more flexibility to the PL operator.

The objective of the PL is subjected to constraints such as maximum and minimum power, charging/discharging rate, total available capacity, etc. However, as in this paper the traffic pattern of the PEVs as well as their preferences on charging requirements are considered, first, the traffic behavior of the PEVs should be mathematically modeled. The modeled deployed in this paper is adapted from the previous works of the authors in [10] and [11].

However, the challenging part in considering those models with the current assumption is to compute the division of the PEVs number, capacity and SOC between the two PLs in the area under study. For this purpose, a coefficient β is defined to calculate the share of each PL from the total input of PEVs in the area. This coefficient is also used to determine each category of PEVs based on their travel purposes.

In each time interval, the arrived PEVs to the PL cannot exceed the total available capacity of the PL.

Therefore, in each our, the number of vacant charging points in the PL is computed and based on that the hourly number of arrived PEVs to the PL is determined as in (2) and (3).

$$n_{\omega,t}^{vac,PL} = NS^{PL} - n_{\omega,t}^{PL} \tag{2}$$

$$n_{\omega,t}^{ar,PL} = \begin{cases} n_{\omega,t}^{vac,PL} & if\ \beta_t^{Cat} N_{\omega,t}^{in,Cat} > n_{\omega,t}^{vac,PL} \\ \beta_t^{Cat} N_{\omega,t}^{in,Cat} & if\ \beta_t^{Cat} N_{\omega,t}^{in,Cat} \le n_{\omega,t}^{vac,PL} \end{cases} \tag{3}$$

Consequently, the available number of PEVs in the PL will determine the available capacity of the PL. The available capacity is an affecting factor on the PL's strategy in market participation. Higher values of capacity will enable the PL to make higher profit through reserve market participation. The capacity of the PEVs arriving to the PL is calculated from

$$c_{\omega,t}^{ar,PL} = \begin{cases} \left(n_{\omega,t}^{ar,PL} \Big/ N_{\omega,t}^{in,\mathrm{Cat}} \right) C_{\omega,t}^{in,\mathrm{Cat}} & if\ \beta_t^{Cat} N_{\omega,t}^{in,\mathrm{Cat}} > n_{\omega,t}^{vac,PL} \\ \beta_t^{Cat} C_{\omega,t}^{in,\mathrm{Cat}} & if\ \beta_t^{Cat} N_{\omega,t}^{in,\mathrm{Cat}} \le n_{\omega,t}^{vac,PL} \end{cases} \tag{4}$$

In a given time interval, the SOC of the PL is affected by the charging and discharging of the PEVs as well as the arrival/departure SOC of the PEVs (5).

$$\begin{aligned} soc_{\omega,t}^{PL} = {} & SOC_{i,\omega,t_0}^{PL}\Big|_{t=1} + soc_{\omega,t-1}^{PL}\Big|_{t>1} + p_{\omega,t}^{in,PL}\eta_i^{cha,PL} \\ & - p_{\omega,t}^{out,PL} \Big/ \eta_i^{dcha,PL} + soc_{\omega,t}^{ar,PL} - soc_{\omega,t}^{dep,PL} \end{aligned} \tag{5}$$

The total input power of the PL is constrained by the total number of vehicles in the PL in each time interval multiplied by the charging rate of the PL (6). The maximum possible output power of the PL is limited to the total number of PL multiplied by the discharging rate of the charging point equipment and the departure SOC requirements of the PEV owners (7). The PEVs' preferences on their departure SOC requirements are determined by coefficient (ϕ^{PL}).

$$p_{\omega,t}^{in,PL} \le \Gamma^{PL} n_{\omega,t}^{PL} \tag{6}$$

$$p_{\omega,t}^{out,PL} \le min\left\{ \Gamma^{PL} n_{\omega,t}^{PL}, soc_{\omega,t}^{PL}\phi^{PL} \right\} \tag{7}$$

When the PL is participating in the reserve market as well as the energy market, the summation of PL's energy and reserve output should be less than the minimum of PL's possible charging capacity and the available SOC in the PL to be offered in the market as in (8). Moreover, the term κ^{PL} is the ratio of participation of PEVs in the V2G mode from the total available SOC in the PL. It is assumed that this ratio is known by the PL owner based on the information provided by the PEV owners on their entrance to the PL.

$$p_{\omega,t}^{out,PL} + r_{\omega,t}^{out,PL} \le min\left\{ \Gamma^{PL} n_{\omega,t}^{PL}, soc_{\omega,t}^{PL}\kappa^{PL} \right\} \tag{8}$$

The PL's SOC is limited to the maximum and minimum percentage of total PL's capacity. It is typically determined by the vehicle battery manufacturers. Here in this study it is assumed to be (9).

$$\underline{SOC}^{EV} c_{\omega,t}^{PL} \le soc_{\omega,t}^{PL} \le \overline{SOC}^{EV} c_{\omega,t}^{PL} \tag{9}$$

The number of vehicles in the PL in a given time interval is calculated from (10) and should be less than the total number of charging points in the PL as in (11).

$$n_{\omega,t}^{PL} = N_{\omega,t_0}^{PL}\Big|_{t=1} + n_{\omega,t-1}^{PL}\Big|_{t>1} + n_{\omega,t}^{ar,PL} - n_{\omega,t}^{dep,PL} \tag{10}$$

$$n_{\omega,t}^{PL} \le NS^{PL} \tag{11}$$

V. NUMERICAL RESULTS AND ANALYSIS

Based on the above explanations and assumption, an area with two PLs are considered. One of the PLs will only participate in the G2V mode while the other one will use the V2G mode as well. Two different strategies for both of the PL's are assumed and investigated. In the first strategy, it is assumed that both PL's do not participate in the reserve market. The PL who has the possibility of V2G mode will only benefit from injecting to the grid whenever it is needed for the system. On the second strategy, the PL with V2G option will participate in the reserve market. As a result, it will receive for being available, but it will inject into the grid by the probability of reserve call. The result for the energy interaction of these two PLs and two strategies are presented in Fig. 2 and 3. The energy interaction shown in these figures are the sum of energy interaction for all travel categories and purposes. As can be seen, a significant difference between the behaviors of these two PLs in charging their vehicles occurs. Not only the availability of V2G will affect the PL charging behavior, but also the PL's strategy on participating in the reserve market will change its behavior on charging the PEVs.

As can be seen in Fig. 2, as the only source of income from the interaction with the PEVs for the PL without V2G option is to sell the energy to PEVs, it tends to charge the vehicles while the energy price is higher (based on the assumption made in Section II). On the contrary, the PL with the V2G option will have the opportunity of selling energy to the grid when the energy price is higher. As a result, it charges its vehicles while the energy price is lower, which results in lower cost for the PL. This shows that not only the PL will make an income through higher levels of charging PEVs, but also the PEV owners will benefit from having their vehicles charged when the price of energy is at its lowest. Moreover, the PL with the V2G mode would make profit through selling energy to the grid on hours 22 and 23 when the energy price is at its maximum.

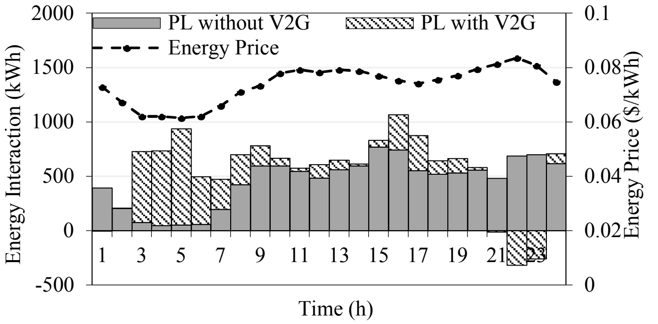

Figure 2. Energy interaction of both PLs without reserve participation strategy.

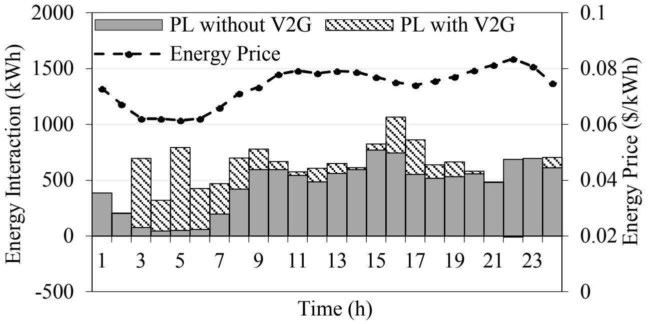

Figure 3. Energy interaction of both PLs with reserve participation strategy.

In Fig. 3 the option of participating in the reserve market is available for the PL with V2G mode. For the PL with G2V mode no change of behavior is observed. However, for the PL with the V2G mode, it can be seen that the level of charging is reduced comparing to Fig. 2. The reason is that in this case, the PL will have the option of making profit through being available in the reserve market. Therefore, it does not need to have the extra cost of purchasing higher levels of energy from the market. As a result, the revenue from selling energy to the PEVs is compensated by the revenue from participating in the reserve market without the cost of buying energy. The costs and profits of both PLs in these two strategies are shown and compared in Table I.

As it can be observed, the profit earned by the PL with the V2G mode in the case where it participates in the reserve market differs considerably with the other cases. It shows that although in this case the costs of charging are at its lowest amount comparing to other cases, the profit is significantly more. The reason is due to the fact that the PL will have extra revenue from being available in the reserve market. Comparing the two cases of with and without reserve for the PL that has the V2G option, it is observed that as no discharging of the batteries occurs, the PL does not need to pay for the battery degradation.

The comparison of operation of PLs with different traffic purpose categories with or without reserve market participation is shown in Fig. 4. It is assumed that the PL in this case has the V2G mode option available. The results compare the energy interaction of the PL.

TABLE I. PROFIT COMPARISON OF DIFFERENT STRATEGIES

	PL with V2G		**PL without V2G**
	With Reserve	***Without reserve***	
Charging Cost	281	323	844
Total Profit	1241.43	317.93	476.8

As it can be observed, due to difference in the behavior of each travel category in terms of stay duration, time of being available in the parking as well as the SOC requirement, different opportunities would be available for the PL encountering each of these travel types. Referring to Fig. 4, PL #1 which has the residential pattern of PEVs has the highest level of charging especially in the early hours of the day comparing to the other cases. The reason is that the PEVs with the residential pattern are available at the parking during those hours when the price of energy is also at its lowest amount. As a result, the PL's strategy is to charge the vehicles during those hours. When the possibility of reserve market participation exists, the PL operator uses the strategy to charge more its vehicles and make profit through higher share in the reserve offer. However, when the reserve market is not available, the PL will use the chance to sell energy to the grid and again take benefit of V2G mode operation as it happens for PL #1. However, the same case cannot be observed for rest of the travel categories. The reason is that during those hours with other types of travel categories (especially commercial and industrial categories), the PEVs are available during the day when the energy price is comparatively higher.

For the rest of the travel patterns, an increase in the charging happens during hours 15 to 20. The reason is that during these hours the PEVs start to depart from the PL. As a result, in order to meet the PEVs requirement of departure SOC as well as making profit through selling the energy to the PEVs, the PL start to charge the PEVs. This strategy is taken by PL #3 and #4 that has the industrial and complex pattern and the departure hour starts from 17. The change in the charging behavior of the PL with or without reserve is also noticeable with different travel categories.

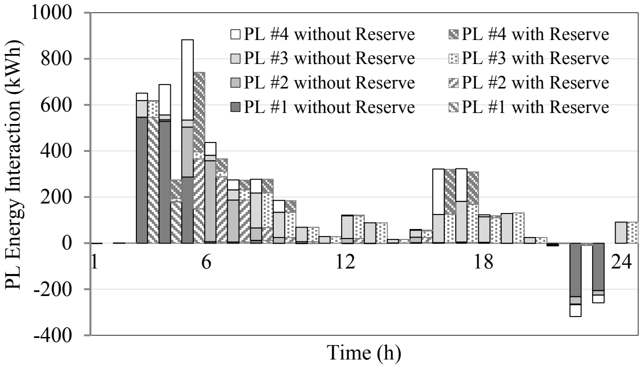

Figure 4. PL's behavior on energy interaction with different travel categories.

VI. CONCLUSION

This paper studied the value of participating in the reserve market for the PLs. A mathematical model for the interaction of the PL with the energy and reserve market as well as the PEVs is proposed. The PEVs' preferences on their charging requirements and operational mode (G2V/V2G) have been added to the mathematical model. The traffic pattern of the PEVs and their arrival/departure behavior is also included in the model through considering four travel purpose categories. These assumptions give a more practical view of the PL's operation and the potential it will have in the market.

The results discussed the PL's strategy in charging its vehicle when the V2G mode and the reserve market options are available. It was shown that the V2G operation mode can be only beneficial for the PL operator if it uses the opportunity of taking part in the reserve market. It was indicated that the extra costs imposed to the PL to motivate the PEVs to participate in the V2G mode makes this case less profitable for the PL operator in comparison to the PL with only G2V mode. A solution for compensating these costs is to participate in the reserve market.

The outcomes of this study show that this approach is fair to both parties of this problem (i.e., PEV owners and PL) as all of the requirements of PEV owners for their level of SOC and preferred stay duration are taken into account. Moreover, the behavior of the PL with different traffic patterns also shows that the reserve solution could be a proper compensation for the PL's cost of V2G. The comparison of cases with and without reserve with various travel patterns indicated that as the travel behavior limits the margin of the PL on charging or discharging the PEVs, the profit of the PL is mostly from being available in the reserve market. On the other hand, in order to share the profit that the PL can make through participating in the reserve market with PEVs who provide this opportunity, the amount of profit can be employed to design the proper incentives for motivating PEVs to participate in the V2G mode and cover their battery degradation costs.

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