Pricing G2V/V2G Modes through Characterizing the PEVs Traffic Behavior

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***Abstract*—In this paper, a mixed-integer linear programing (MILP) model for characterizing the traffic behavior of plug-in electric vehicles (PEVs) in an urban environment is proposed. The paper proposes the procedure to mathematically model the uncertain behavior of the PEVS. As the PEV's traffic pattern affects the potential of PEV parking lot (PL) in terms of available capacity and state of charge, the characterized PEVs are employed to provide the proper pricing schemes for the PEVs in PL. The results discuss the mutual effect of PEVs behavior on the profit of PL, as well as the effects of PL's tariffs on motivating PEVs to provide more flexibility for the PL. The results show that with a proper pricing scheme both parties (i.e., PEV owners and PL) can earn higher profits, while the charging requirements are met based on the preferences of the owners.**

***Index Terms*—Charging station, parking lot, plug-in electric vehicle, traffic pattern, urban transportation.**

I. 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: Capital letters denote parameters and small ones denote variables.

II. INTRODUCTION

A. Motivation and Aim

Encouraging higher penetration of plug-in electric vehicles (PEVs) in the system necessitated the development of further infrastructures in the network to facilitate their deployment. One of the main requirements of the PEVs in the system is the availability of the charging stations in urban areas. The parking lots (PLs) in a network can provide an aggregated form of the PEV batteries in a system; therefore, requires further studies.

The PL is a medium between the PEV owners and the upstream network. Therefore, the interactions of the PL should be strategically operated considering the objectives of all the involved parties. Therefore, it is necessary to comprehensively study the various aspects of a PL's interactions in both directions. One of the main factors affecting the PL's behavior is the pattern of the PEVs arriving to or departing from the PL. The number of available PEVs in the PL and their available capacity along with their charging requirement on their departure will define the charging level of the PL. On the other hand, the PEVs' stay duration will affect the PL's decision on participating in the energy or reserve market in the vehicle-to-grid (V2G) mode.

As a result, it is important to characterize various types of PEVs, their preferences, and their requirement with a mathematical model to be incorporated in the operation model of the PL.

In this regard, this study presents a comprehensive study of the PEVs characteristics on their PEV PL usage pattern including their arrival/departure pattern, stay duration, and G2V/V2G preferences.

B. *Literature Review*

There are several aspects regarding the integration of the PEVs in the system, however, the most important of them all is to be able to have a more accurate model of how they are behaving in the system. Various studies have been dedicated to model the PEVs in the system, but a few have focused on modeling the PEVs' traffic flow behavior. Some of the previous studies have employed the data from the common vehicles commute and adapted that the PEVs travel behavior to it. In [1], the travel survey of the vehicles in the UK [2] is used to determine the amount of the PEVs' required load in the system. The authors in [1] assumed that the only role for the PEVs in the system would be as a load. A purpose-based travel assumption using the same survey from UK is adapted in modeling the PEVS in [3]. The 2009 National Highway Travel Survey [4] has been used by several previous studies such as [5] to model the travel profile of the PEVs.

The management of power needed in hybrid PEVs based on the trips they travel is studied in [6]. As the traffic behavior affects the location of charging stations, in [7] these effects are studied in a planning time horizon. Other studies such as [8]-[10] have considered the driving distance and SOC requirement of PEVs in their work. The study in [11] analyzed the regulation on charging the PEVs having in mind the cost and benefit of the PEV as well the system operator. In [12] a combined PEV charging and demand management is proposed to enhance the user's preferences.

Most of the previous studies have considered an aggregator as the interface of the PEVs with the market. However, when dealing with the PEV PL, several factors should be taken into account. The limited number of charging stations and the uncertain arrival/departure to the PL will affect its behavior. In the meantime it should be noted that a PL also provides a parking space for the PEVs. This means that despite the aggregation of charging stations, the PEVs are not going to necessarily leave the PL soon after their charging is finished. As a result, the difference in the characteristics of the PL in comparison to PEV aggregators necessitates a comprehensive and specific look to the PL.

On the other hand, the potential that the PEVs' batteries bring to the PL is affected by their preference on their operation modes (G2V/V2G) as well as their charging requirements. The traffic behavior is the factor that changes the potential in the PL. This potential is the component that alters the PL's profit. As a result, the PL should treat this potential in accordance with the profit that PEVs provide for it. This matter has not been addressed in the previous studies and is the main intention of this paper. Using the proposed method to drive the behavior of the PEVs, the effect of V2G/G2V tariffs is tested on the profit of PL.

C. *Contributions*

In order to address the need for incorporating more accurate models of PEVs traffic pattern in PL's behavior determination, this study provides a model to mathematically derive the PL's traffic pattern based on the PEVs commute. Deploying the traffic pattern of PEVs (from various real-case surveys), an algorithm is proposed in this paper to compute the number of the PEVs in the PL. This step is necessary due to limited number of charging points inside a PL in comparison to the total number of PEVs in the network. Moreover, different coefficients are defined to determine the hourly share of different PEV categories and preferences in the PL. Finally, the derived mathematical model is employed in the proposed optimization model of the PL to assess the effect of PEVs preferences on the operation of PL. Through the discussions of this study's results, a pricing scheme can be deduced for PL's G2V/V2G tariffs.

The proposed framework in this work is a complementary to the previous works of the authors presented in [13]. The contribution of this current work can be added to other works with other objectives. The main contributions of this study are:

1. To mathematically characterize the traffic pattern of PEVs in the PL based on their arrival/departure, stay duration, and operation mode preferences;
2. To propose a flowchart to derive the PL's commute pattern based on PEVs arrival/departure scenario;
3. To propose a method to optimally determine the G2V/V2G tariffs based on the PL's profit.

D. *Paper Organization*

The rest of the paper is organized as follows. In Section III, the proposed model for the PEV characterization is discussed. The interaction model of the PL with the integrated PEV characteristics is shown in Section IV. The numerical results are presented in Section V. Finally, the conclusion of the work is in Section VI.

III. PEV CHARACTERIZATION MODEL

One of the main issues regarding the manipulation of PEVs in the system as a resource is how to manage to meet the grid's need while maintaining the PEV owners' preferences at their satisfaction level. However, the owners of these vehicles may also have preferences other than the limitations of PEV. When considering the PL as a place to charge the vehicles, these concerns become more critical. In a charging station, the management of charging can be in owners' hands; conversely, in a PL, the PEVs are mostly left in the stations for a couple of hours. Therefore, the owners will have the least control on the (dis)charging of their vehicles. This matter in long term may result in fewer tendencies towards using the PL. As a result, a procedure of acquiring owners' preferences and including them in the strategy determination of the PL is necessary.

In this paper, it is assumed that the PEVs that enter the PL can submit their preferences when entering the PL. The PL, on the other hand, also needs to compromise with the preferences of the PEV owners and its own profit. The PEVs should be treated relative to the opportunities or restrictions they bring for the PL. This can be through different tariffs attributed to different preferences.

For this purpose, the PEVs that enter the PL are categorized into four groups based on their operational flexibility and preference:

1. G2V mode with fixed departure SOC;
2. G2V mode with flexible departure SOC;
3. Both G2V, V2G mode with fixed departure SOC;
4. Both G2V, V2G mode with flexible departure SOC.

It is assumed that all the vehicles will provide this data when entering the PL. Now, if the PL operator wants to implement different tariffs to different PEVs, it needs to determine the number of PEVs in each category in each hour of arrival, and when they depart. Besides, it was considered that all PEVs will determine their minimum requirement of SOC when departing the PL. This preference is applied to the objective of the PL through coefficient φ which determines the minimum departure SOC requirement of each PEV category. The PEVs are categorized based on their duration of stay into three groups with different time intervals. The values to determine the share of each category from the total departed PEVs are presented by coefficient β. It is necessary to determine the share of each category from departing PEVs, because the amount of trade with each of these PEVs and PL should be calculated for the payments of PEVs on their departure. From another point of view, the PL should be aware of its capacity to participate in the market. This means that it should have enough information on how many PEVs take part in G2V or V2G mode. For this purpose another coefficient is defined as θ which determines the share of each PEV category from total PEVs in the PL in each hour. The hourly amounts of θ are calculated from the stay duration pattern and β. It should be noted that for each scenario of PL number, a scenario for θ is also generated.

In this study, a PL with 250 stations in a commercial area is considered. The arrival/departure patterns of the PEVs are derived from survey in [5] and are shown in Fig. 1. The scenarios for the arrival of PEVs in the PL are generated using the lognormal distribution function as described in [14]. Using the data from the survey, the expected stay durations of PEVs are derived and is shown in Fig. 2. As it is assumed that the PL is in a commercial center, the PEVs that enter the PL may stay from 1 to 12 hours in the PL. Therefore, the total PEVs can be classified into different groups based on their stay duration. Fig. 3 shows the number of PEVs in each class.

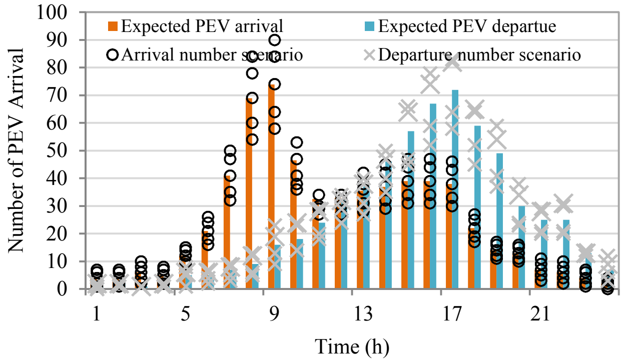

Figure 1. Total number of PEVs in the PL in each hour based on their expected stay duration.

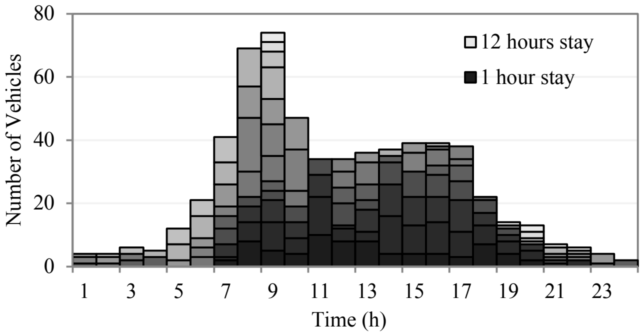

Figure 2. Total number of PEVs in the PL in each hour based on their expected stay duration.

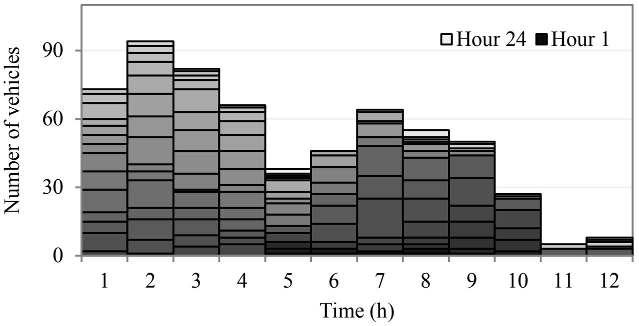

Figure 3. Classification of PEVs based on their stay duration.

At this stage, the preferences of PEVs on their stay duration are the PL is derived. However, when these preferences are considered as the inputs of the PL, it will affect the commute pattern of the PL. Therefore, the commute pattern of the PL should be determined in accordance to the preferences of the PEVs. The challenging part is to relate the departure scenarios of the PL to the arrival scenarios of the PEVs based on their stay duration. Moreover, due to the fixed number of stations in the PL, the scenarios generated for departure may result in the number of PEVs' in the PL more than the PL's station capacity. To prevent this, the flowchart shown in Fig. 4 is proposed.

From the data derived from Fig. 1, Fig. 3, and the β coefficient, an initial number of PEVs in the PL ($n_{\omega,t}^{PL}$) is calculated. This amount is equal to remainder PEVs in the PL from the previous hour and the arrived PEVs in each hour minus the departed PEV. Then this amount is checked with the total number of available stations in the PL.

If the computed value exceeds, the number of excess PEVs (n_t^{surp}) is reduced from the arrival scenario on that hour. Now, the arrival scenarios need to be changed which causes the change in the number of PEVs in each category and consequently the number of PEVs in each stay duration class. Considering the discrete distribution of stay duration pattern (Fig. 3), the new arrival scenario and stay duration scenario is formed. Based on the new arrival and stay duration scenario, the new departure scenario is generated. Once again the number of PEVs in PL is calculated. The procedure is performed until the PL's number scenario does not exceed the total PL's station number (Fig. 4).

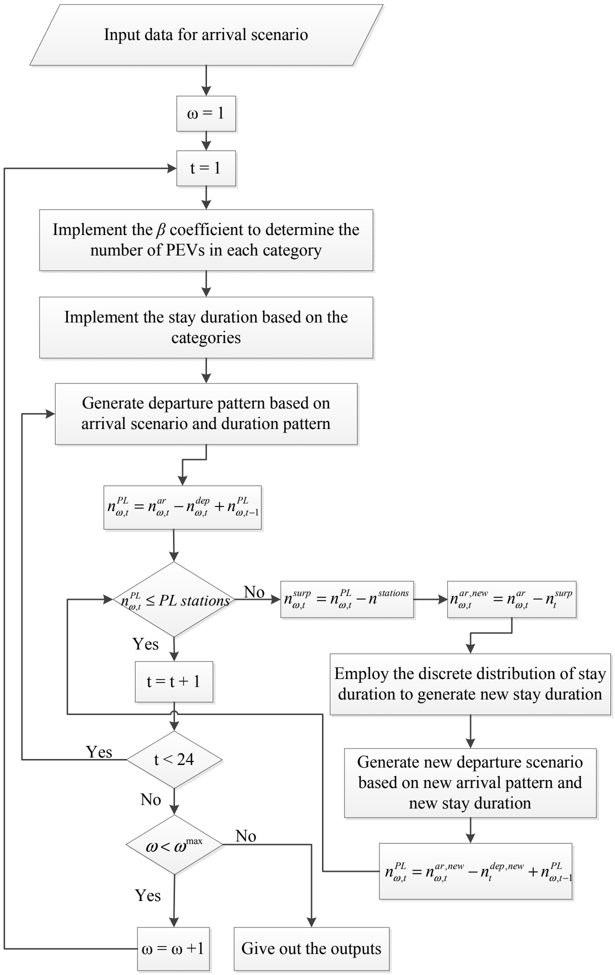

Figure 4. Flowchart of generating scenario for PEVs' number in PL.

IV. PL PROFIT MODEL

The characterized PEVs pattern is employed as the input for modeling the PL's profit calculations. The PL can make profit through various interactions. One of PL's main interactions is with PEVs and selling energy to them. On the other hand, a PL may also participate in energy and reserve market.

Therefore, the objective function of the problem would be based on the profit the PL can make through its interactions as presented 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 denotes scenario for various PEVs' arrival and departure scenarios. The detailed terms of the objective function are presented in the following equations. The profit of the PL through its energy market interaction consists of the revenue from injecting the PEVs power in V2G mode to the grid and the cost of purchasing the required energy for both G2V and V2G PEVs (2).

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

The profit of the PL through reserve market participation includes the cost of PL's penalization in case of not being available for the reserve call and the revenues for being available in the reserve market as well as the revenue upon reserve call (3).

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

The most important part of the problem is to model various terms of PL-PEV interaction while considering the different preferences of the PEV. The PL-PEV interaction is the term that reflects the effects of PEVs' preferences along with the pricing scheme of the PL. The proposed model is shown in (4).

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

As can be seen all the coefficients representing the preferences of the PEVs including ϕ to maintain the minimum departure SOC and the β coefficient for the PEVs stay duration is included in the model. Moreover, the PEVs choice on using between G2V and V2G operation modes are also considered in the model through applying different tariffs to each operation mode.

For this purpose, different pricing schemes are applied to each category described in Section III as in follows:

- Category 1 ➔ π_{t}^{G2V1}
- Category 2 ➔ π_{t}^{G2V2}
- Category 3 & 4 ➔ π_{t}^{G2V3}

The operation of the PL is subjected to the various constraints because of the capacity of the PEVs. However, in the proposed model not only the battery capacity should be considered, but also it should be noted that the constraints on each category of the PEVs meet the requirements of that specific category. The SOC of departure for the PEVs in the G2V mode is different from those in V2G mode and are computed from (5) and (6). These equations show the equality constraints for flexible categories of PEVs. For the fixed category the same reasoning and approach can be deployed.

$$soc_{\omega,t}^{dep,G2V}=\phi_{\omega,t}^{fix1}\beta_{\omega,t}^{fix1}C_{\omega,t}^{dep,PL}+soc_{\omega,t}^{dep,flex1} \quad (5)$$

$$soc_{\omega,t}^{dep,V2G}=\phi_{\omega,t}^{fix2}\beta_{\omega,t}^{fix2}C_{\omega,t}^{dep,PL}+soc_{\omega,t}^{dep,flex2} \quad (6)$$

The hourly amount of SOC for those PEVs in the G2V mode is affected by the SOC brought by the arrival of new PEVs, charging the batteries, the remainder of SOC from the previous hour minus the amount of SOC which is departed from the PL on that hour (7). However, for those PEVs in the V2G mode, another factor which is the possibility of discharging is also considered (8).

$$soc_{\omega,t}^{PL,G2V} = soc_{\omega,t-1}^{PL,G2V}\Big|_{t>1} + SOC_{\omega,t_0}^{PL,G2V}\Big|_{t=1} + soc_{\omega,t}^{ar,G2V} - soc_{\omega,t}^{dep,G2V} + p_{\omega,t}^{in,G2V}\eta^{cha,PL} \tag{7}$$

$$soc_{\omega,t}^{PL,V2G} = soc_{\omega,t-1}^{PL,V2G}\Big|_{t>1} + SOC_{\omega,t_0}^{PL,V2G}\Big|_{t=1} + soc_{\omega,t}^{ar,V2G} - soc_{\omega,t}^{dep,V2G} + p_{\omega,t}^{in,V2G}\eta^{cha,PL} - p_{\omega,t}^{out,V2G}\Big/\eta^{dcha,PL} \tag{8}$$

Another main constraint on the PL's operation is the maximum capacity of charging. It determines that the SOC of PL should not pass the maximum available capacity of vehicles in the PL multiplied by the maximum possible SOC of each EV. The equation for G2V PEVs is shown in (9). For the V2G vehicles, as the PL has the control to discharge the PEVs' batteries a minimum limit also should be bounded by the SOC of PL in each hour (10). More constraints on the operational model of the PL can be found in [13].

$$soc_{\omega,t}^{PL,G2V} \le \theta_{\omega,t}^{PL} C_{\omega,t}^{PL}\overline{soc}^{EV} \tag{9}$$

$$\left(1-\theta_{\omega,t}^{PL}\right)C_{\omega,t}^{PL}\underline{soc}^{EV} \le soc_{\omega,t}^{PL,V2G} \le \left(1-\theta_{\omega,t}^{PL}\right)C_{\omega,t}^{PL}\overline{soc}^{EV} \tag{10}$$

V. NUMERICAL RESULTS

Based on the approach presented in Section III the PEVs under study are characterized and consequently the PL's number of PEVs, hourly capacity, and SOC will be derived. The hourly share of each PEV category from the total arrival/departure PEVs in the PL, as well as the total number of existing PEVs in the PL are calculated based on the predefined coefficients. After that, the interaction of the PL with the electricity market and the PEV owners are analyzed in order to examine the effect of different pricing schemes on the PLs behavior in the market. In this study, different pricing types are also employed for different operation modes of PEV (G2V/V2G). The problem was modeled using the mixed integer linear programming (MILP) and solved using the CPLEX 12 solver through GAMs software.

The results for the various pricing schemes are evaluated. In Fig. 5, the variation in PL's behavior on charging the PEVs in accordance with different G2V2 prices is shown. It is observed that the PL's behavior changes both with the variation of time and the variation of G2V2 price. It shows that with all amount of G2V2 price, the PL tends to charge during early hours of the day due to lower energy prices. However, on lower amounts of the G2V2, as the PL cannot make much profit through selling energy to the PEVs in G2V mode (category #2), it charges the vehicles on the V2G mode so that it can make profit through participating in the reserve market.

Moreover, the variation of the profit of the PL through reserve market participation is shown in Fig. 6. It can be seen that at highest levels of G2V2 the profit of the PL will not change with the change in G2V3 price. On the other hand, when the G2V2 price decreases from a certain amount, the variation of the G2V3 price can affect the level of the profit. The reason is that with higher G2V2 prices, as the PL is sure that it can make profit through selling the energy to the PEVs it will purchase higher amount of energy from the market. Consequently, it will have higher amount of SOC available in the PEVs with V2G mode. As a result it will make higher profit through participating in the reserve market. This compromise is made until the G2V2 price reaches 11 cents. From this point it is not profitable for the PL to charge the PEVs. The lowest amount of profit is reached when both G2V2 and G2V3 have the lowest amounts.

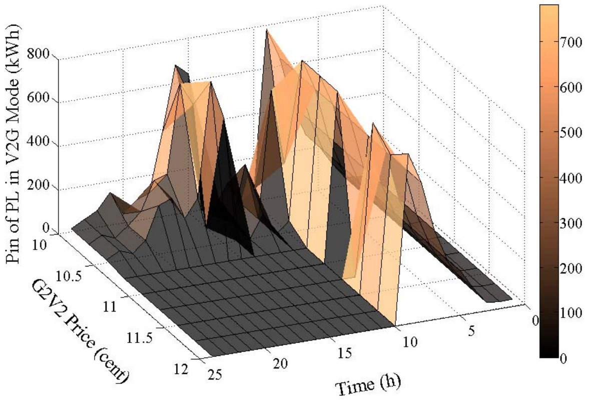

Figure 5. Variation of the input power for V2G mode vs. G2V2 prices

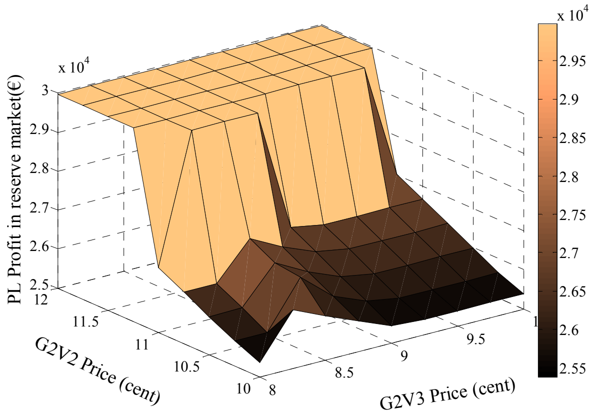

Figure 6. Variation of the PL profit vs. variation of G2V2 and G2V3 prices

VI. CONCLUSION

This paper has proposed a procedure and model to integrate the PEVs traffic behavior and vehicle owner's preferences in the modeling of the PL's commute pattern. The choice between two operation modes of G2V/V2G is assumed to be available for the PEVs. Hence, two different pricing schemes for the mutual interaction of PEV-PL were proposed. Based on the level of flexibility provided by the PEVs, the cost of charging in the PL would be considered different.

The results showed that at different hours, different pricing schemes can have significant effects on the behavior of PL. Although the interaction of PL with PEVs is affected by the energy/reserve price of the market, the G2V/V2G tariff will also have a critical role in defining the PL's strategy in market participation. As shown in the results, the PL's behavior on how to charge the PEVs having V2G operation mode is affected by the price of their charging mode. As participating in the reserve market is a potential source of making profit for the PL, encouraging PEVs to be willing to participate in the V2G operation mode through proper pricing schemes can be obtained. The outcomes of this study can be employed by the PL operator or the regulatory entities to derive an appropriate pricing scheme for the PEVs energy interaction.

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