User-Comfort Oriented Bidding Strategy for Electric Vehicle Parking Lots

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***Abstract*—The number of electric vehicles (EVs) has been gradually increasing over the last decades. In order to eliminate the concerns related to charging demand in power systems, the appropriate integration of EVs to the grid is of great importance. Electric vehicle parking lots (EVPLs) offer a crucial occasion to manage the charging process of EVs. Further, EVs are capable of either charging from the grid or supplying power to the grid due to the vehicle-to-grid (V2G) features. Through an agent, namely an aggregator, EVPLs can participate in the electricity market and a considerable amount of profit can be obtained in terms of EVPLs, EV owners, and aggregators by energy selling. However, EV owners may not be willing to participate in this structure due to the concerns related to their comforts. In this context, a model in which EVPLs can bid for energy selling to the grid through an aggregator is proposed in this study. Additionally, the comfort violation of EV owners is taken into account. In order to validate the effectiveness of the devised model, various case studies are also performed.**

***Index Terms*—Aggregator, bidding, electric vehicle, electric vehicle parking lot.**

NOMENCLATURE

The abbreviations, sets and indices, parameters, and variables used throughout the study are stated below.

A. Abbreviations

EV	Electric vehicle
EVPL	Electric vehicle parking lot
SoE	State of energy

B. Set and Indıces

k	Set of electric vehicle parking lots.
m	Set of electric vehicles.
s	Set of scenarios.
t	Period of the day index in time units [min].

C. Parameters

CE_m^{EV}	Charging efficiency of EV m.
DE_m^{EV}	Discharging efficiency of EV m.
CR_m^{EV}	Charging rate of EV m [kW].
DR_m^{EV}	Discharging rate of EV m [kW].
$P_{s,t}^{bid}$	Power bidding to the grid during period t for scenario s [kW].
$SoE_{des,m}$	Desired SoE of EV m [kWh].
$SoE_m^{EV,ini}$	Initial SoE of EV m [kWh].
$SoE_m^{EV,max}$	Maximum SoE of EV m [kWh].
$SoE_m^{EV,min}$	Minimum SoE of EV m [kWh].
$T_{k,m,s}^{a}$	Arrival time period of EV m in EVPL k for scenario s.
$T_{k,m,s}^{d}$	Departure time period of EV m in EVPL k for scenario s.
$\varDelta T$	Time granularity.
π_s	Probability value of scenario s for reference power profile.
t_1	Starting period of the bidding.
t_2	Ending period of the bidding.

D. Variables

$P_{k,m,s,t}^{EV,ch}$	Charging power of EV m in EVPL k during period t for scenario s [kW].
$P_{k,m,s,t}^{EV,disch}$	Discharging power of EV m in EVPL k during period t for scenario s [kW].
$P_{s,t}^{grid}$	The power drawn from the grid during period t for scenario s [kW].
$u_{k,m,s,t}^{EV}$	Binary decision variable for charging and discharging.

I. INTRODUCTION

A. Motivation and Background

The transportation sector is mostly carried out by using conventional fuels such as petroleum and oil. These types of sources are in danger of being depleted in the near future and cause greenhouse gas emissions. However, the problems due to the greenhouse gas emissions can be largely eradicated with the integration of electric vehicles (EVs) into the current power systems [1]. It should also be stated that EVs have great benefits such as providing the penetration of locally renewable energy and lower operating costs [2].

According to the revealed report [3], the total number of EVs in the world increased by more than 50% in comparison with 2016 and exceeded 3 million. Since it is estimated that this number will increase more in the near future, efficient integration of these vehicles into the power system has become an important issue due to possible power outages, voltage fluctuations, overloading of transformers and increased energy losses.

On the other hand, EVs can be considered as a flexible load because their batteries can be controlled. Hence, in the case of managing EVs as a flexible load during participation in the electricity market, significant opportunities can be achieved in an operational manner [4]. A single EV, however, cannot join the electricity market with relatively small energy and power capacity. In this respect, multiple EVs are coordinated through an aggregator for participation in the electricity market, afterward the related aggregator bids in the appropriate electricity market [5], [6].

When the daily movements of EVs were examined, it is founded that EVs are parked about 93% to 96% of a day. The situation of charging and discharging EVs in only place can facilitate control and management. Electric vehicle parking lots (EVPLs) offer a good opportunity to charge EVs. Also, after EV owners have parked their EV to the EVPL, they can monitor the state-of-energy (SOE) of EV in the EVPL and can control it [7].

The EVPL provides profit to EVPL owners, EV owners, and the aggregator. Selling energy to the grid and making a profit attract the attention of EVPL owners. Nevertheless, the uncertainty of EV owners' behaviors and electricity market prices is a problem for the EVPL owner. EV owners are interested in minimizing their charging costs while EVPL owners also tend to make maximum profit. The aggregator, which is a third-party entity, might allow multiple EVs to participate in the electricity market in order to maximize the profit when meeting the requirements of EV owners. Besides, the collection of EVs in an EVPL is an advantage to the aggregator compared to the dispersed situation of EVs. Last but not least, the distribution system operators (DSOs) are responsible to supply power to the end-users and the sustainability of the power. Thus, the management of EVPLs can give an opportunity to the DSOs so as to prevent peak load due to overcharging [8].

B. Literature Review

In recent years, there has been an increasing amount of literature on investigating the impact of the charging process of EVs on the power systems from the various point of views.

Sarker et al. [9] proposed a structure in which the aggregator manages a group of EVPLs and participate in day-ahead markets. However, it should be underlined that the problem was addressed in terms of profit maximization. Additionally, an energy storage system was evaluated in the proposed model so as to enhance the total income.

Chukwu et al. [10] created a mathematical model to estimate the power capacity of a parking lot with a PV-based renewable energy source, which is capable of selling energy to the main grid. Neyestani et al. [11] conducted a study on the participation of EVPLs in the reserve markets with the objective of maximizing total profit. It is worthy to underline that the comfort of the EV owners was neglected in this study. Farzin et al. [12] examined the effect of the parking lots on the distribution system reliability. The developed model considered the municipal parking areas as a distributed energy storage system with the aim of minimizing the cost of energy. Akhavan-Rezai et al. [13] developed an online intelligent decision-making strategy for public EVPLs where the aggregator manages the charging process of EVs. The devised model prioritized the charging of EVs taking certain conditions into account. Notwithstanding, any energy bidding concept was not noticed in the scope of the study.

Vayá et al. [14] proposed a model in which the aggregator meets the flexible demand of EVs and participates in the day-ahead electricity market to minimize the cost of charging. It is worthy to highlight that EVPL concept and energy selling option was not addressed. Shafie-Khah et al. [15] proposed a two-stage model for managing the EVPL, considering the uncertainties of EV owners' behavior and renewable energy sources. While the objective function was determined as minimizing of the cost, the comfort violation of EV owners was neglected in the developed model.

Gil et al. [16] suggested a model that reflects the impact of different sizes of renewable-based energy systems on the profit and behavior of the EVPL in the reserve and electricity markets. Although EVPL was able to sell energy back to the grid, the comfort of EV owners was not considered. Pourbabak et al. [17] presented an algorithm to determine the optimal power allocation of different EVPLs with the aim of maximizing the total income. Moreover, the demand mismatches were satisfied by power exchange among the EVPLs. However, energy selling option of the EVPLs and comfort violation of EV owners were not evaluated. Yao et al. [18] proposed a structure in which the aggregator participates in the day-ahead and real-time market by contracting with an independent system operator to provide frequency regulation services. It should be underlined that neither EVPL concept nor comfort violation was taken into account. Chen et al. [19] proposed a program called eVoucher to encourage the participation of EVPLs with many EVs in the retail electricity market. Nonetheless, the comfort of EV owners was not addressed in the propounded model.

These aforementioned studies, together with the many others not referred to here have introduced significant improvements about the charging interactions of EVs in order to enhance operational flexibility with the aid of the demand response concept. However, none of them did evaluate the EVPLs by taking into account the comfort violation which is actually the segregation of this study from the existing literature.

C. Contributions and Paper Organization

A mixed integer linear programming (MILP) model of scheduling EVs charging process in different EVPLs is proposed by taking the uncertain behavior of the EV owners into account. Owing to the vehicle-to-grid (V2G) feature of the EVs the DSO is supported from the EVPLs through the aggregator by considering an energy bidding program. The main contributions of this study can be emphasized as follows:

- The EVPLs can sell energy to the grid by participating in the bidding program. Thus, the EVs are provided to be taken part in electricity markets indirectly.
- In order to enhance compatibility with the real life, the SoE of EVs and the arrival times to EVPL are considered as a scenario-based stochastic model.
- The total comfort violation is intended to be minimized after charging and discharging of EV batteries due to the bidding program.

The rest of the paper is organized as follows. The mathematical model of the proposed structure is detailed in Section II. Afterward, Section III clarifies the case studies with different scenarios and provides a comparison of the related results. Finally, Section IV highlights the important conclusions and future studies.

II. METHODOLOGY

The proposed aggregator based EVPLs structure is shown in Fig. 1. As can be seen from Fig. 1, EVPLs are capable of performing bidirectional energy flow through the distribution system. In the devised model, the charging process of the EVs is conducted by the EVPLs; further, the responsible aggregator is able to be supplied the energy to the grid after bidding operation. It is an assumption that the related EVs are enriched with V2G option to provide energy during participation in the energy market. The required information interaction between the aggregator, EVPLs, and the DSO is achieved by the bidirectional communication system. Furthermore, EVPLs are coordinated by the aggregator that provides the participation of them in the electricity markets. However, the key point related to the EVPLs is to handle the uncertain arrival times of the EV owners. Due to the mobility of the EV loads, the charging process in the EVPLs is needed to be properly scheduled. The EV owners may also not want to participate in this type of program because of the possible deteriorations in the EVs' batteries. In this respect, it is assumed that a contract between the EV owners and the EVPLs is arranged. Thus, it should be noted that the battery degradation is not included in this study.

The aim of the study is to minimize the total comfort violation of the EV owners in terms of the departure SoE during the participation of the EVPLs in bidding program. The objective function that represents the total comfort violation of the EV owners is given in (1). It is stated as the percentage change in total SoE level according to the desired SoE before the departure time. In the case of taking a negative value, it means that there is no inconvenience in terms of total comfort. Equation (2) states that the power drawn from the grid is equal to the sum of the charging power of the EVs.

$$min \sum_k \sum_m \sum_s \sum_t \pi_s \cdot \left(\frac{SoE_{des,m} - SoE^{EV}_{k,m,s,t}}{SoE_{des,m}} \right) \cdot 100, \quad t = T^d_{k,m,s} \tag{1}$$

$$P^{grid}_{s,t} = \sum_k \sum_m P^{EV,ch}_{k,m,s,t}, \quad \forall s, \forall t \tag{2}$$

The power sold to the grid by bidding is equal to the sum of the discharging power of the EVs in the related EVPL as given in (3).

$$P^{bid}_{s,t} = \sum_k \sum_m \left(P^{EV,disch}_{k,m,s,t} \cdot DE^{EV}_m \right), \quad \forall s, t \in [t_1, t_2] \tag{3}$$

Equation (4) provides that the charging power cannot be greater than the charging capacity of related EV. Similarly, (5) expresses that the discharging power cannot exceed the discharging capacity of related EV. Moreover, $u^{EV}_{k,m,s,t}$ is a binary decision variable so as to prevent the occurrence of the charging and discharging interaction at the same time.

$$P^{EV,ch}_{k,m,s,t} \leq CR^{EV}_m \cdot u^{EV}_{k,m,s,t}, \quad \forall k, \forall m, \forall s, t \in [T^a_{k,m,s}, T^d_{k,m,s}] \tag{4}$$

$$P^{EV,disch}_{k,m,s,t} \leq DR^{EV}_m \cdot (1 - u^{EV}_{k,m,s,t}), \quad \forall k, \forall m, \forall s, t \in [T^a_{k,m,s}, T^d_{k,m,s}] \tag{5}$$

The SoE of an EV at time t is modeled by (6), which is obtained by summation of the SoE at the previous time *(t-1)* with either the charged energy amount from the grid or the energy amount sold to the grid.

$$SoE^{EV}_{k,m,s,t} = SoE^{EV}_{k,m,s,(t-1)} + CE^{EV}_m \cdot P^{EV,ch}_{k,m,s,t} \cdot \Delta T - P^{EV,disch}_{k,m,s,t} \cdot \Delta T, \quad \forall k, \forall m, \forall s, t \in \left[T^a_{k,m,s}, T^d_{k,m,s}\right] \tag{6}$$

The SoE of EVs when they arrive at the EVPL after the trip is considered as the initial SoE of the related EV before the plug-in to port, as pointed out in (7).

$$SoE^{EV}_{k,m,s,t} = SoE^{EV,ini}_m, \quad \forall k, \forall m, \forall s, t = T^a_{k,m,s} \tag{7}$$

Inequalities (8) and (9) ensure that the SoE of each EV must be between the maximum and the minimum energy capacity of the related EV.

$$SoE^{EV}_{k,m,s,t} \leq SoE^{EV,max}_m, \quad \forall k, \forall m, \forall s, \forall\, t \tag{8}$$

$$SoE^{EV}_{k,m,s,t} \geq SoE^{EV,min}_m, \quad \forall k, \forall m, \forall s, \forall\, t \tag{9}$$

In addition, EVs are not to be charged and the power drawn from the grid must not take a value during the bidding program period, as given in (10) and (11). The preventing of charging and discharging of EVs when they are not in an EVPL is provided by (12) and (13), respectively.

$$P^{grid}_{s,t} = 0, \quad \forall s, t \in [t_1, t_2] \tag{10}$$

$$P^{EV,ch}_{s,t} = 0, \quad \forall s, t \in [t_1, t_2] \tag{11}$$

$$P^{EV,ch}_{s,t} = 0, \quad \forall s, t \notin [T^a_{k,m,s}, T^d_{k,m,s}] \tag{12}$$

$$P^{EV,disch}_{s,t} = 0, \quad \forall s, t \notin [T^a_{k,m,s}, T^d_{k,m,s}] \tag{13}$$

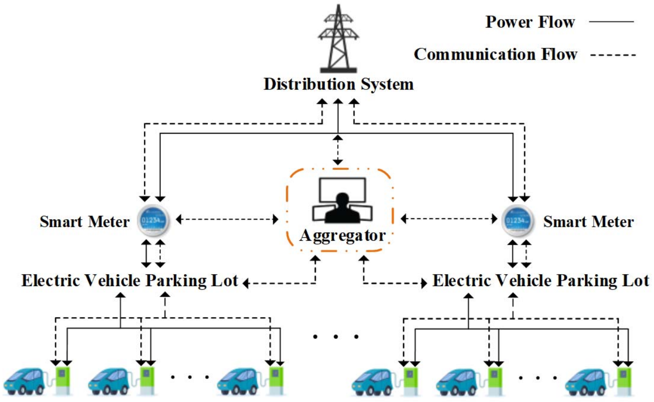

Figure 1. The proposed structure that the EVPLs through an aggregator bid energy selling to the grid via EV batteries in the EVPLs.

III. TEST AND RESULTS

In this study, a model in which EVPLs bid for energy selling to the grid via EV batteries through the aggregator is modeled by using MILP. The objective function is to minimize the total comfort violation of EV owners. The proposed strategy is tested in GAMS v.24.1.3 software. Commercially available CPLEX v.12 is used as the solver. The problem can be solved in 1.14 seconds in a Dual Core Laptop with 1.7 GHz CPU and 6 GB RAM. In following subsections, input data, simulation results, and discussions are given. The optimization model has been tested on a daily horizon with 5 mins time granularity for each case. On the other hand, the communication among the assets are not evaluated.

A. Input Data

In order to investigate the impact of different bid levels on the total comfort of EV owners, different cases according to the amount of the bid and selling time interval are analyzed. The uncertainty of initial SoE of EVs and the arrival time of EVs to the related EVPL are taken into account as a stochastic problem. In order to ensure the compliance to real life, four different scenarios are created considering real driving cycles in terms of the arrival times and the initial SoE values before the plug-in. In order to express the reality of the addressed scenarios, the distribution of the arrival times of EVs to the related EVPL in a day period is demonstrated in Fig. 2 for each of the scenarios. Furthermore, EVPL is assumed to enter into an agreement with the EV owners to participate in the bidding program. Thus, EV owners are required to remark their departure time.

In the forming of the load pattern of EVPLs, ten commercially available EV types with different specifications are considered, which are detailed in Table I. In all scenarios, there is a total of 400 EVs, 40 from each EV model. It is assumed that EV owners want to leave at least with a SOE of 80%. The EVs remain in the EVPL during at least minimum charging time, which corresponds to a charge level of 80%. However, the SoE of EVs is determined by EVPL at the departure time. EVs may only be discharged during the bidding interval, are not charged in this time interval.

The EVPLs can sell/buy energy to/from the grid in the study by using the EV's batteries so that they can participate in electricity markets. It is assumed that the EV owners have agreed to sign a contract and allowed their batteries to be used by the aggregator.

B. Simulation Results and Discussion

In order to validate the effectiveness of the proposed model, four different case studies have been conducted in this study as follows:

- *Base Case:* EVs are not discharged and there is no bid to grid.
- *Case-1:* EVPLs bid for 434 kW to the grid through the aggregator from 11:00am to 2:30pm.
- *Case-2:* EVPLs bid for 500 kW to the grid through the aggregator from 12:00am to 2:00pm.
- *Case-3:* EVPLs bid for 600 kW to the grid through the aggregator from 11:00am to 2:30pm.
- *Case-4:* EVPLs bid for 600 kW to the grid through the aggregator from 12:00am to 2:00pm.

The EVPLs sell energy to grid 1.505 MWh, 1 MWh, 2.1 MWh, and 1.2 MWh in Case-1, Case-2, Case-3, and Case-4, respectively. Table II presents the comparison of the results obtained for the evaluated case studies in detail. According to the results it can be seen that Case-3, which has 5.7016 value, is the worst case in terms of total comfort of EV owners.

TABLE I. ELECTRICAL CHARACTERISTICS OF THE CONSIDERED ELECTRIC VEHICLES

EV Types	Battery Capacity [kWh]	Charging Power [kW]
Volkswagen E-Golf [20]	36	7.2
BMW i-3 [21]	33	7.7
Mercedes B-Class [22]	28	10
Tesla Model-S [23]	100	10
Fiat 500E [24]	24	6.6
Ford Focus Electric [25]	23	6.6
Kia Soul EV [26]	27	6.6
Mitsubishi i-MiEV [27]	16	3.6
Chevy Volt [28]	18	3.6
Nissan LEAF [29]	40	6.6

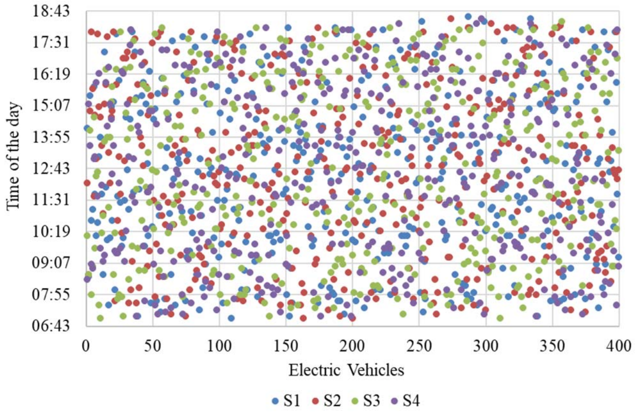

Figure 2. The distribution of arrival times in a day for 400 EVs according to 4 different scenarios.

There is no deterioration deduced in the total comfort of EV owners in the Base Case, Case-1, Case-2, and Case-4. The best case is the base case where there is no bidding to the grid considering the objective function. In that case, all EVs are charged fully before the leaving from the EVPL. For the same bidding period, the higher bid amount reduces the comfort, as seen in the comparison between Case-1, Case-3 and Case-2, Case-4. In Case-3, the value of total comfort reduces by increasing the bid value from 430 kW to 600 kW according to Case-1.

A similar reduction in total comfort is seen if Case-2 is compared to Case-4. As a result, if the EVPLs increase the amount of the energy sold between the same bidding periods, the comfort of EV owners dramatically worsens. In this respect, it is important to select the amount of the bid in such a way that there is no deterioration in total comfort. It is clearly deduced from Table II that an increase in bid amount and/or time interval of bid increases the comfort violation. The optimum case is Case-1 in terms of comfort violation and bid amount as any comfort violation does not occur and at the same time, 1.505 MWh energy is sold to the grid.

It should be clarified that the total comfort violation can be interpreted according to amounts of bids for the same time intervals, while the total comfort violation for the same bid amount at different time interval cannot be estimated. Because the number of arriving and leaving EV varies at different time intervals. So, it may change the total comfort value despite the same bid amount.

Figure 3 illustrates the SoE change of the EV named as NIS7 during the time spent for parking in EVPL-2 for Case-1 and Case-3. In selected cases, the energy is sold to the grid from EVPLs between 11:00 am and 2:30 pm. The NIS7 arrives at EVPL-2 before the starting period of the bidding in Case-1 and Case-3, and it leaves the parking lot after the ending period of the bidding program. For both cases, the NIS7 leaves from EVPL with a lower energy level than the desired SoE level that is 32 kWh. The discharging energy amount of the EV is smaller in Case-1. However, it appears to be discharged for a longer period in Case-3 which is the case where the comfort violation is the highest. Besides, the EV is not charged within the bidding periods.

The power drawn from/sold to the grid in Case-2 and Case-3 for Scenario-1 is demonstrated in Fig. 4. The mentioned figure is illustrated to reveal that the sold energy is directly linked up to the amount of the bidden power and the bidding time period. For the sake of clarity, only Case-2 and Case-3 are selected. As can be seen in Fig. 4, an average energy of approximately 120 kWh and 150 kWh is sold to the grid during the bidding periods in Cases 2 and 3, respectively.

The power drawn from the grid in the Base Case and Case-1 is demonstrated in Fig. 5 for scenarios 1 and 4. For better representation, the further zoomed subfigure in Case-1 for Scenario-4 is also provided. Compared to Case-1 and Base Case for the Scenario-1, it is seen that the peak load after the ending period of bidding is remarkably increased.

TABLE II. COMPARISON OF DIFFERENT CASE STUDIES

Case Studies	Amount of Bid [kW]	Bidding Period	Comfort Violation Value
Base Case	-	-	-25
Case 1	430	11.00am-2.30pm	-0.15602
Case 2	500	12.00am-2.00pm	-11.6896
Case 3	600	11.00am-2.30pm	5.7016
Case 4	600	12.00am-2.00pm	-9.7206

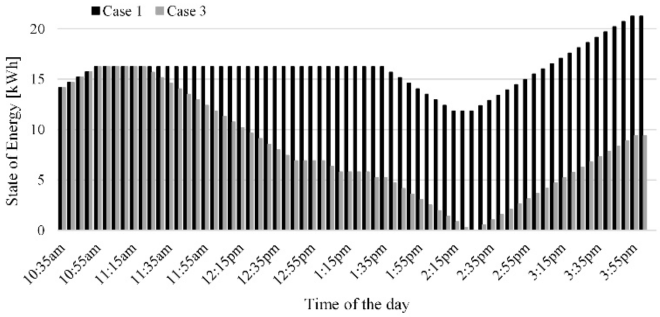

Figure 3. The SoE change of NIS7 in EVPL-2 for Case-1 and Case-3 in Scenario-3.

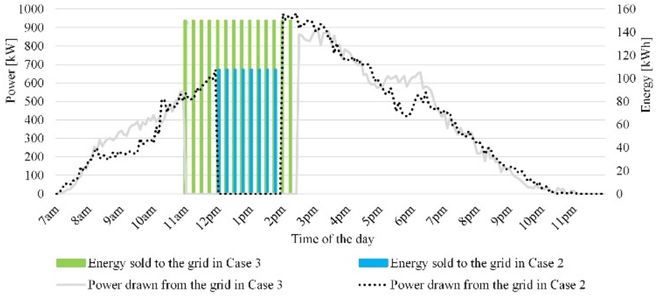

Figure 4. The power drawn from the grid and the energy sold to the grid in Case-2 and Case-3 for Scenario-1.

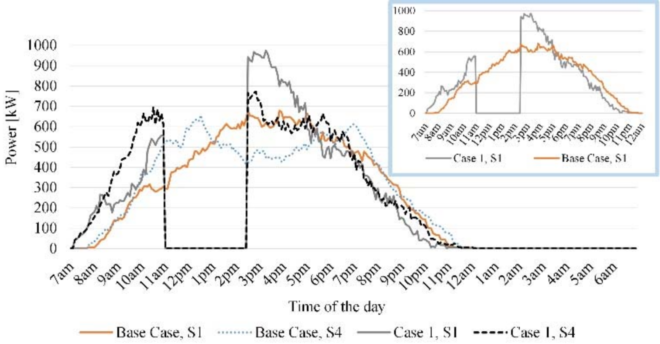

Figure 5. The comparison of power drawn from the grid for the Base Case and Case 1 in each scenario.

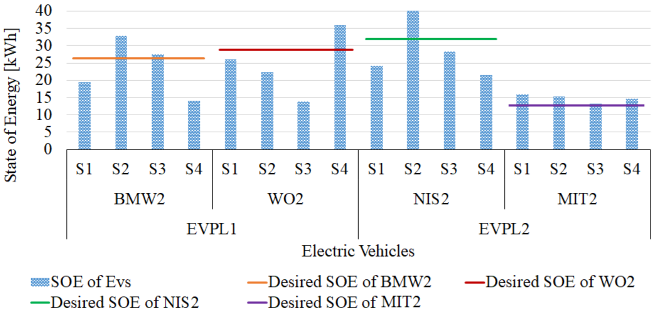

Figure 6. The comparison of SOE at departure times of some EVs and desired SOE of these EVs in each scenario for Case 3.

The DSO should also take necessary precautions in order to prevent to face any problem on sustainability. Figure 6 shows the SOE of BMW2, WO2, NIS2, and MIT2 vehicles when they leave the EVPL in Case-3 for each scenario. It is observed that the SOE of some vehicles has remained below the desired SoE level. It should be reminded that the desired SoE level demonstrated in the mentioned figure is equal to 80% of the battery capacity for each EV. Despite the same bid amount, different scenarios cause the energy level of the vehicle batteries to be different. Due to not to be provided the desired SoE at the departure time, EV owners may experience a problem in the subsequent driving.

IV. CONCLUSION

A single EV cannot participate in the electricity market with a relatively small capacity. Through an aggregator, the EV in an EVPL can have an opportunity to take part in the electricity market. In this way, the aggregator, EVPL owner, EV owner and DSO can make a profit. A single EV is a price taker; however, an aggregator may be in a price maker position in the electricity market. If numerous EVs are managed as a flexible load for the participation in the electricity market, significant opportunities for power systems can be achieved. Motivated by this fact, in this study, a model in which EVPLs bid for energy selling to the grid through an aggregator via EV batteries is proposed. It is seen that the effect on the total comfort of EV owners can be reduced together with the amount of the bid and the selling time determined by the EVPLs. The discharging operations cause degradation in the batteries of EVs. Furthermore, EV owners generally expect a departure with full charge from the EVPL. Due to these challenges, EV owners may not want to participate by considering their comfort and battery degradation. In order to facilitate the participation of EV owners to this structure, incentive payments can be considered, and degradation rates of the batteries can be compensated.

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