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Two-objective Approach for Electrical Vehicles Parking lot Participation in Joint Energy, and Ancillary Services Markets

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***Abstract*— In response to having a green transport sector and increasing sustainable energy alternatives, it is expected that electric vehicles (EVs) will be a considerable energy consumer in the near future. In order to cover the problems related to their charging demand, the integration approaches between the EVs and the grid should be optimized. Electric vehicle parking lots (EVPLs) are an exceptional solution for managing the charging process of EVs. Moreover, vehicle-to-grid (V2G) feature has the potential of increasing the reliability of the power system, the profit of EVPLs (by providing ancillary services (AS)), and reducing the cost of EVs owners. In this paper, an incentive-based two-objective approach is suggested for optimizing the profit of EVPLs and EV owners (each vehicle individually) by participating in day-ahead (DA) electricity and AS markets at the same time. Probability distribution functions (PDF) and random data are used to cover uncertainties. The suggested method is tested using the real word data by GAMS solvers.**

Keywords*— *Ancillary services, Electrical vehicles parking lot, Optimal bidding, Regulation up, Regulation down

NOMENCLATURES

Parameter	
γ	Price
δ	Parking profit percentage from the sale of energy to the EVs
∂	Maximum EVPL profit ($/ kW)
$Chrate$	Charging rate
Pd	Desired (required) power
Soc	State of charge
dpr	Departure time
arr	Arrival time
β	Discount
Cap	Battery capacity
$Chrate_i^{Max}$	Maximum possible charging rate of each EVs
$Dchrate_i^{Max}$	Maximum possible discharging rate of each EVs
μ	Charging efficiency
ζ	Discharging efficiency
$Soc_{i,t}^{min}$	Minimum allowed Soc (state of charge)
$Soc_{i,t}^{max}$	Maximum allowed Soc (state of charge)
Variables	
$Sch/Sdch$	Charging/Discharging state of EVs
P	Power
W	Importance weighting of each objective
mu	Mean of Normal PDF
sigma	Standard deviation of Normal PDF
R	Revenue

Indices	
i	EV
pl	Electrical vehicle parking lot
t	Time
E	Energy market
g	Grid
ru	Regulation up
rd	Regulation Down
as	Ancillary services
en	EVs participation state in AS markets

I. INTRODUCTION

A. Background

Conventional fuels (petroleum and oil) are the main source of energy for vehicles. Due to an array of reasons (greenhouse gas emissions, limited and expensive resources, etc), many societies prefer to use electric energy in the transportation industry[1]. Therefore, EVs have been developed rapidly in the past decades [2]. According to the expansion of EVs, it is expected that they will have a significant impact on the electric grid [3]-[4]. Studies discussed that the development of EVs can cause many challenges for the electrical grid (voltage fluctuations, energy shortages, increasing energy losses in distribution networks, overloading of transformers) [5]-[8]. However, later studies claimed that the capacity of cars can be used to maintain the stability of the distribution network. They focused on the providing regulation services for this purpose. The limited capacity of a single EV for taking part in the wholesale markets is not enough [11]. Therefore, EVPL can manage an array of EVs and make profit by participation in energy and AS markets [12].

B. Literature review

EVPLs participation in different markets is examined in some articles that are presented in this section. In [13], EVs are used to reduce the operation cost of the system by providing energy and frequency regulation. Similar to the previous study, [14] suggests a business case about solving imbalance and overload problem of the Dutch AS markets by considering the operational and investment costs of smart charging pool of EVs. Aim of [15] is maximizing the expected profit of the EV aggregator in frequency control reserve in Eastern Denmark by using the data from the PARKER project (the mentioned data is constant according to table I of the[15]). [16] suggests an optimization model for the aggregation agent to take part in the day-ahead and AS markets by considering truncated Gaussian PDF for battery capacity, slow charging rated power, energy consumption and initial battery Soc. Naïve forecast and scenario generation approaches are used to cover uncertainties.

EV aggregator optimal stochastic participation in energy and AS markets is investigated in [17]. Scenario generation, truncated Gaussian and uniform distributions are used in this paper for characteristics of EVs. [18] discusses a probabilistic approach. Technical possibilities are used for providing AS by V2G technology. Normal distribution is used for arrival and departure time, and EV type and capacity are considered random. Optimal bidding method of EV aggregators in energy and AS markets is the aim of [19] by considering truncated normal distribution functions for arrival and departure time. Monte Carlo Simulation is used to cover uncertainties. The stability of the distribution grid and minimizing the EVs charging cost are the main purpose of [20]. Normal PDF is used to model arrival and departure time of EVs. A linear formulation is considered for modeling the demand of EVs and their driving patterns (a stochastic pattern is presented for driving pattern). EVPLs bidding model for selling energy to the grid through an aggregator is proposed in [12]. Additionally, the comfort violation of EV owners is taken into account. In order to validate the effectiveness of the model, various case studies are also performed.

Some studies solved the presented problem in two stages (first stage is maximizing the profit of the EVLP, and the second level is minimizing the cost of EVs). Moreover, some of them developed the model by adding incentives to the previous ones. A bi-level stochastic model for maximizing the revenue of the virtual power plant and an array of PEVs participation in DA energy market (EM) is suggested in [21]. The EV owners and the aggregator are placed in lower and upper level, respectively.

[22] suggests an incentive-based two-stage approach for EVs in workplace parking lot to take part in energy and regulation markets. According to this paper, the incentive can change individual vehicles behaviors such as arrival time, departure time, and desired Soc. A new approach is suggested in [23] for optimal participation of parking-lot charging infrastructures in EM by considering different incentives (fixed, according to charging demand and both charging demand and parking duration) for EVs.

C. Contributions

A novel incentive based two-objective approach for EVPL participation in energy and AS markets is presented in the paper. Minimizing the cost of EVs and maximizing the profit of EVPL at the same time are the main goals of the model; these goals can be achieved by considering the integration of EVs participation rate, incentives, cost of EVs and parking profit. To the best of the authors' knowledge, in the paper a novel integrated method is presented for estimating the participation rate of EVs in the AS market. In the presented method, incentives of EV owners are: making a direct profit from participating in AS market and a discount on the price of energy.

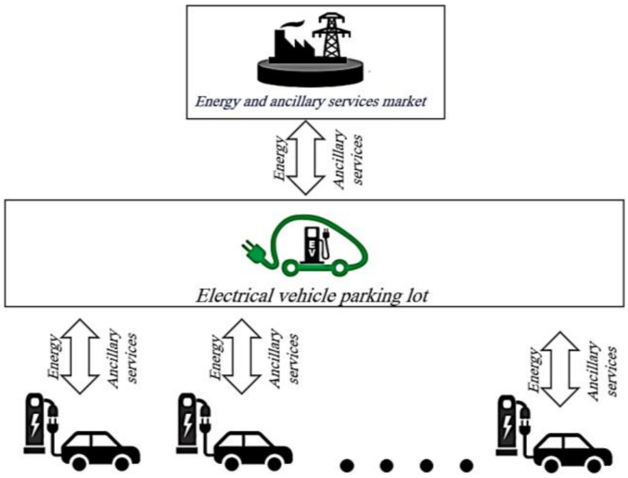

Fig. 1. EVPL test system

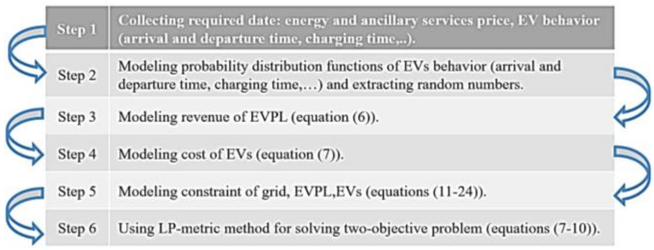

Fig. 2. Schematic diagram of the proposed strategy

II. Problem Description and Mathematical Modeling

A. Revenue of AS

Revenue of regulation up and regulation down markets are described in (1).

$$R_{as} = P_{as} \times \gamma_{as} \tag{1}$$

B. EVs participation rate and pricing method

The authors of this paper present an approach for sharing the profit of participation in the AS markets between EVPL and EVs. If (100-α) % of the profit (of AS markets)belongs to the EVPL and α% belongs to the EVs, Fig. 3 shows the relationship between α and the participation rate of EVs in AS markets (by increasing α, the profit of EVs in As markets increase. therefore, the number of EVs that take part in AS markets rise. consequently, the participation rate goes up). This is a novel approach; it is not tested on a real EVPL; therefore, Fig. 3 is assumed. As a similar method, paper [22] uses a formulation that indicates incentives change the behavior of EVs. EVs are separated into two groups: EVs of the first group do not participate in the AS markets, and EVs of the second group participate in the AS markets. It is clear that the EVs of the second group are more profitable for EVPL; therefore, their desired power can be supplied with less profit. Equation (2) indicates the selling price of energy to the first group. This is determined according to EVs desired charging rate. ∂ is the EVPL profit per kW ($\partial$is constant) , and δ_i can be calculated according to Fig. 4. The parking-lot chooses charging hours of EVs according to the energy price and the parking capacity in the most optimal mode. By decreasing the charging rate, EVPL has more time for charging EVs and EVPL can share its capacity in different hours. Consequently, EVPL decreases the δ_i . As a result, the cost of the EVs decreases. The charging rate can be calculated as (3).

The calculation of the energy price for the EVs of the second group is the same as the first group with the difference that a discount should be considered according to their battery capacity and their maximum charging/ discharging rate (these two factors play an important role in providing regulation service). By increasing each of these factors, EV has more capacity for participating in AS markets and makes profit for EVPL. The amount of discount (β_i) is calculated by (4) and Fig. 5(σ_i has a direct relation with β_i). This discount is reduced from δ_i (is calculated by Fig. 4 and (3)). The price of energy for second group is calculated by (5).

$$\gamma_{i,t}^{E} = \gamma_{g,t}^{E} + (\partial * \delta_i) \quad (2)$$

$$Chrate_i = (Pd_i - Soc_{i,arr})/(dpr_i - arr_i) \quad (3)$$

$$\sigma_i = Cap_i \times Chrate_i^{Max} \quad (4)$$

$$\gamma_{i,t}^{E} = \gamma_{g,t}^{E} + (\partial * (\delta_i - \beta_i)) \quad (5)$$

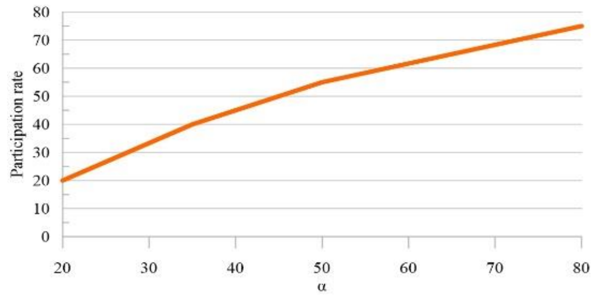

Fig. 3. EVs participation rate curve

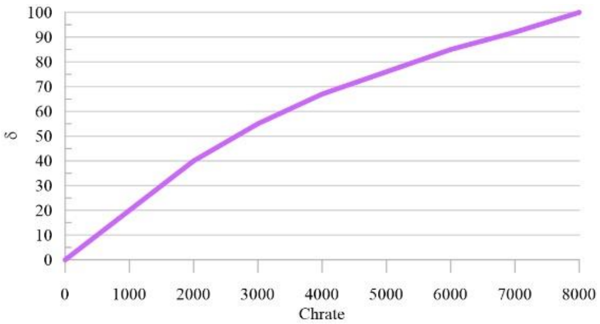

Fig. 4. Charging rate and parking profit curve

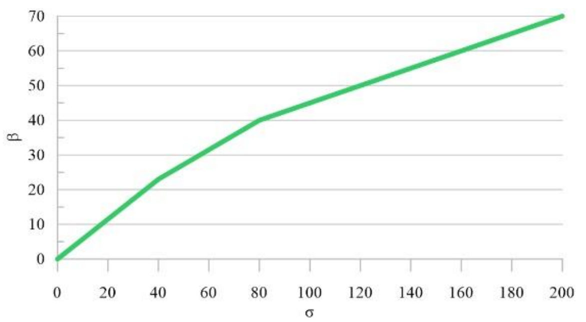

Fig. 5. EV discount curve

C. Objective function

$$Obj1 = \sum_{0}^{i} \sum_{0}^{t=24} (\gamma_{i,t}^{E} \times P_{i,t}^{E}) + (\gamma_{g,t}^{ru} \times (1-\alpha) \times P_{pl,t}^{ru}) + (\gamma_{g,t}^{rd} \times (1-\alpha) \times P_{pl,t}^{rd}) - (\gamma_{g,t}^{E} \times P_{pl,t}^{E}) \quad (6)$$

$$Obj2 = \sum_{0}^{i} \sum_{0}^{t=24} (\gamma_{i,t}^{E} \times P_{i,t}^{E}) - (\gamma_{i,t}^{ru} \times a \times en_i \times P_{i,t}^{ru}) - (\gamma_{i,t}^{rd} \times a \times en_i \times P_{i,t}^{rd}) \quad (7)$$

The goal of (6) is to maximize the difference between revenue and cost; consequently, profit of EVPL maximizes. This equation contains four parts. The first part indicates the income of selling energy to EVs (as described in part II.B, the energy price for each EV is specific to it). Part two and three indicate the income of taking part in AS markets. Finally, the last part describes the cost of importing energy from the grid. The cost of EVs minimized by (7). This equation includes three parts. The first part is cost of buying energy from the EVPL. Second and third parts describe the profit of taking part in AS markets. en_i presents part two and part three are active for EVs that are willing to take part in regulation markets. To solve the multi-objective problem, LP-metric method is used in this paper. These will transform the mentioned problem to a single function [25]-[26].

$$Obj = W_1 \frac{(Obj_1 - Obj_1^*)}{Obj_1^*} - W_2 \frac{(Obj_2 - Obj_2^*)}{Obj_2^*} \quad (8)$$

$$W_1 + W_2 = 1 \quad (9)$$

$$0 \le W_1 \;,\; 0 \le W_2 \quad (10)$$

In this method, each objective function is solved separately (obj_1^*, obj_2^*). Then, (8) is used for combining two objective functions with considering (9) and (10). W_1 and W_2 represent the importance of each objective function.

D. Constraints

Equation (11)-(12) indicate the maximum charging and discharging power of the EVs. In these equations, t can be smaller than one hour. It is possible to charge (observing energy in EM and regulation down) for some minutes, and to discharge (taking part regulation up market) in other minutes (not at the same time according to (13)). Equation (14) ensures that each EV will leave the parking lot with the required power. Equation (15) ensures that EVs cannot participate in any market when they are not present in the parking. Equation (16) limits the Soc of the EVs [15][23]. Equation (17) presents the Soc of the each EV at each hour. Inequality (18) limits the P^{rd} of the EVs.

$$Chrate_i^{Max} \ge (P_{i,t}^{E} + P_{i,t}^{rd}) \times Sch \quad (11)$$

$$Dchrate_i^{Max} \ge P_{i,t}^{rd} \times Sdch \quad (12)$$

$$Sch + Sdch \le 1 \quad (13)$$

$$Pd_i = Soc_{i,dpr} - Soc_{i,arr} = \sum_{t=T_{arr_i}}^{t=T_{dpr_i}} \mu \times P_{i,t}^{E} + \mu \times P_{i,t}^{rd} - \frac{P_{i,t}^{ru}}{\zeta} \quad (14)$$

$$\sum_{t=dpr_i}^{t=arr_i} P_{i,t}^{E} = 0 \ , \quad \sum_{t=dpr_i}^{t=arr_i} P_{i,t}^{ru} = 0 \ , \quad \sum_{t=dpr_i}^{t=arr_i} P_{i,t}^{rd} = 0 \quad (15)$$

$$Soc_{i,t}^{max} \geq Soc_{i,t} \geq Soc_{i,t}^{min} \quad (16)$$

$$Soc_{i,t+1} = \sum_{t=arr_i}^{t=dpr_i} Soc_{i,arr} + \mu \times P_{i,t}^{E} + \mu \times P_{i,t}^{rd} - \frac{P_{i,t}^{ru}}{\zeta} \quad (17)$$

$$P_{i,t+1}^{rd} \leq Soc_{i,t} \quad (18)$$

Equation (19)-(21) indicate the summation (total amount) of EVs share in electricity and AS markets that will be traded by EVPL. Equation (22) limit the total importing and exporting power capacity of the parking. Equation (23) and (24) limit the total allowed (by the grid) regulation up and regulation down power of the EVPL.

$$P_{pl,t}^{E} = \sum_{0}^{i} P_{i,t}^{E} \quad for\ each\ t \quad (19)$$

$$P_{pl,t}^{ru} = \sum_{0}^{i} P_{i,t}^{ru} \quad for\ each\ t \quad (20)$$

$$P_{pl,t}^{rd} = \sum_{0}^{i} P_{i,t}^{rd} \quad for\ each\ t \quad (21)$$

$$P_{pl,t}^{E} + P_{pl,t}^{ru} + P_{pl,t}^{rd} \leq P_{pl}^{Max} \quad (22)$$

$$P_{pl,t}^{ru} \leq P_{pl,t}^{ru,Max} \quad (23)$$

$$P_{pl,t}^{rd} \leq P_{pl,t}^{rd,Max} \quad (24)$$

III. CASE STUDY

In this part, the electric market of Finland is simulated with real world data on 26th January 2023.

A. *Data of grid and EVPL*

The limits of grid and EVPL are present in Table I.

Table I. Data of grid and EVPL

$P_{pl,t}^{ru,Max}$	100kw
$P_{pl,t}^{rd,Max}$	100kw
P_{pl}^{Max}	200kw
ζ	0.9
μ	0.9
∂	10$/ kW

B. *Market price*

Fig. 6 is the reference of price dataset [27]. The price of energy and AS markets of Finland in (26.1.2023) are shown in Fig. 6.

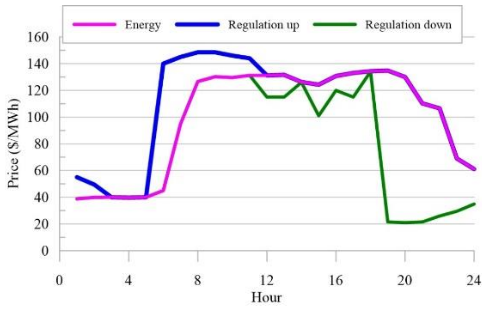

Fig. 6. Energy and AS price ($/MWh)

C. *EVs behavior*

EVPL decisions is completely dependent on the behavior of the EVs and the physical characteristics of their batteries. The vehicle's arrival information, the length of stay, the initial Soc of the batteries at the time of entry, the amount of required power, the total capacity and the maximum rate of charging/ discharging of the batteries must be available. In this paper, the information of 10000 random EVs of a workplace EVPL are extracted from a big dataset of EVs in [28]. Then Easyfit software is used for calculating the PDFs of the mentioned dataset. These PDFs are presented in the Table II.

Table II. PDFs of EVs behavior

	Arrival	Stay length (h)	Required power	Charging / Discharging rate
mu	7.0964	3.6443	14.282	3.3487
sigma	5.8227	2.878	13.365	5.5948

MATLAB is used for generating random data from the information of Table II. Table III presents this random data (the output data of MATLAB is modified to have compatibility with other ones).

Table III. Data of EVs behavior

EV	Arrival (h)	Stay length (h)	Initial Soc	Required power	Charging / Discharging rate	Battery capacity
11	7	3	0.1012	13.5558	8.9	17
15	7	9	0.1947	13.3101	5.8	24
20	7	6	0.1111	13.9420	7	18
38	10	8	0.1241	10.1471	3.3	15
47	15	6	0.1785	14.1666	10	20
49	19	3	0.2588	14.4162	8.9	21

D. *Result*

Fig. 7 indicates EVPL participation in energy, regulation up and regulation down markets. The amount of EVPL participation is the summation of present EVs participation in each market. Despite the fact that charging of EVs in the regulation down market does not have energy importing cost for parking, according to the Fig. 7, a large part of the cars is charged through the importing energy in the EM. The reason can be found in the Fig. 3, (2) and (4).

(1-α) decreases as the number of vehicles participating in AS markets increases; consequently, parking has a smaller share of AS markets revenue (according to Fig. 3, EVs participation in AS market will increase by increasing α).

The optimal mode for EVPL has been selected according to the behavior of EVs. The Fig. 8 shows the participation or non-participation state of EVs in the AS market. 28 of EVs (56 %) participate in the AS markets, matching this number with the Fig. 5, α is about 0.55.

Fig. 9 presents EVs participation in energy and AS markets.

The most optimal mode of activity of EV15 in EVPL is presented in Fig. 9 by considering all the constraints. This EV enters the EVPL at 7 o'clock and stays in the EVPL for 9 hours. In this simulation, all of the mentioned constraints are considered. For example, the power stored in the battery does not exceed its maximum capacity at any moment; the summation of energy, regulation up and regulation down does not exceed the maximum charging/ discharging rate. Fig. 9 indicts this issue (EV15 battery capacity is 24 kW, charging/ discharging rate is 5.8kW per hour). The figure indicates this EV absorbs a great part of its required power from regulation down without any cost. Considering about 55% (α) of the profit of the participation in the regulation down market for the EVs is a golden opportunity for this EV to take part in this market with maximum power at the peak hours of the regulation down market price. EVPL takes into account that this EV has enough time in the coming hours to charge its battery.

The optimal planning of EV 38 is shown in the Fig. 9. Like the EV15, all the constraints have been met for this EV. It seems that the mentioned EV could charge at the first hour and then participate in the regulation up market. Behavior of EV47 is like previous ones. It sells a great part of its power at 19 o’clock. The reason for this issue can be found in the Fig. 6; at this time the price of regulation up market is higher than other hours. Therefore, EV47 tries to sell as much power as possible in this hour for making maximum profit. It worth noting that reaching the required power is the first priority of the EVs.

According to Fig. 8 about half of the EVs participate in the AS markets, and the rest of them do not participate in these markets. Providing their required power at the lowest price is the most important point for these EVs; so, they should absorb power when the energy is at its cheapest. According to Table III, EV11 enters the EVPL at 7 o'clock and stays in the EVPL for 3 hours. Since the price of energy starts to increase after 5 o'clock, this EV absorbs the required power in the early hours. Therefore, it absorbs power at 7 o'clock with the maximum charging rate, and the remaining power is charged at 8 and 9 o'clock. EV49 is another example that enters the EVPL at 19 o'clock and stays in the EVPL for 3 hours. This car absorbs a great part of the power it needs in the last hour of its presence because the price of energy is lower in this hour than other hours.

Fig. 10 indicates the profit of EVPL for different W_1 (in (8)). According to this picture, with the increase of W_1 (focus on the profitability of EVPL), the profit of EVPL will increase. According to this figure, after $W_1 = 0.3$, the slope of the increase in the profit of EVPL decreases. It is worth mentioning that some parts of (6) and (7) are the same. By combining them in (8), these parts are affected by both W_1 and W_2 ($W_1 + W_2 = 1$). Therefore, the variation range of this equation is limited.

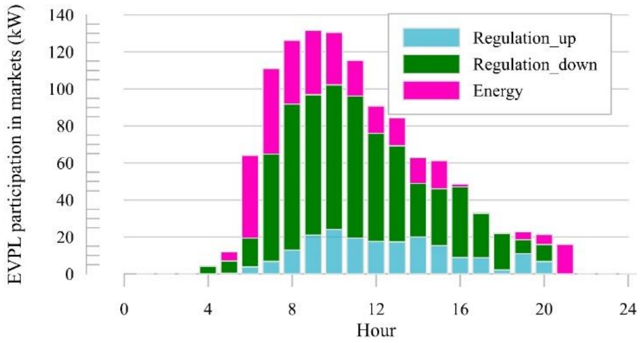

Fig. 7. EVPL participation in markets

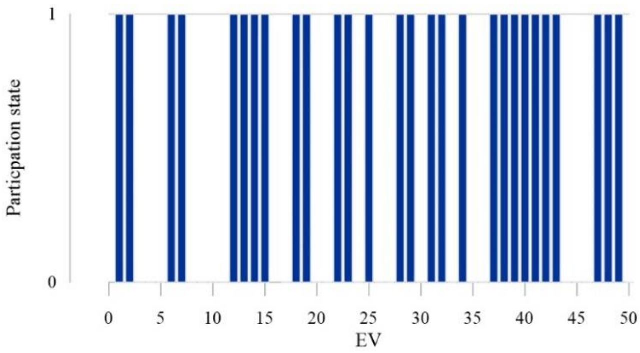

Fig. 8. Participation state of EVs

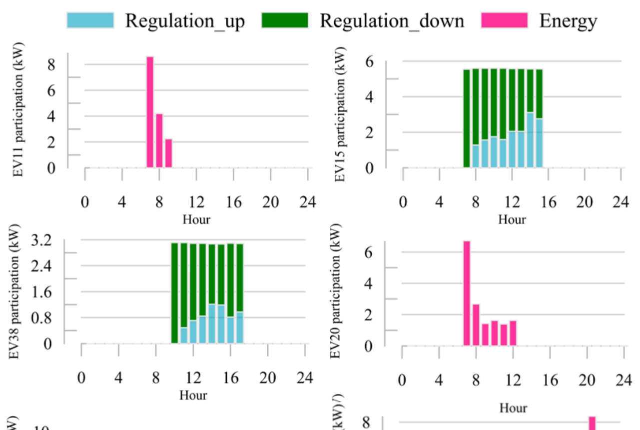

Fig. 9. Participation of EVs

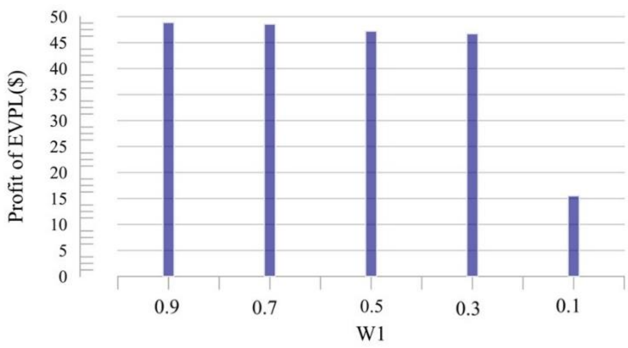

Fig. 10. Profit of EVPL for different W1

IV. Conclusion

In this paper, a novel model for EVPL (workplace) optimal participation strategy in energy, and AS market is presented. Combination of new pricing and discount approach, novel two-objective function and AS are used to maintain reliability and stability of power system, increase revenue of EVPL and reduce the cost of EVs. PDFs are used for generating data of arrival time, stay length, demand (required power) and charging rate. Battery capacity and initial Soc are randomly extracted from a parking data base. Results present EVPL will select optimum α for maximizing its profit. A new pricing method is presented in the current paper. In this method, by increasing the ratio of required power to the duration of EVs present time in the EVPL, the cost of EVs increases; therefore, EVs are encouraged to stay longer in the parking lot. At the same time, the greater the ability of the EVs to participate in the AS markets (higher battery capacity and higher charging and discharging rate), the more discount the EVPL gives to the EVs.

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