Plug-in Electric Vehicles (PIEVs) Aggregator as a Source of Spinning Reserve

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Abstract- **Because the owners of private vehicles use their vehicles in some hours in a day and their vehicles stay in parking lots without using in the rest of the day, the batteries of plug-in electric vehicles (PIEVs) can be considered as a source of energy storage. This paper takes the perspective of an aggregator that manages the participation of PIEVs fleet in the spinning reserve (SR) market and presents a mathematical model for optimal charging and discharging of the PIEVs, based on driving patterns of the fleet. The aggregator maximizes its profit in SR market subject to a number of technical and contractual constraints. The said problem is a nonlinear and mixed integer problem which is solved using simulated annealing (SA) algorithm.**

Keywords- Aggregator; Plug-in Electric Vehicle (PIEV); Spinning Reserve (SR) Market

I. INTRODUCTION

In recent years, automotive companies have developed technologies to produce vehicles that use electricity instead of gasoline. If these vehicles become commercially practical, they have the potential to significantly decrease oil consumption and provide huge environment benefits. Internal combustion cars emit greenhouse gases and in addition, have very low efficiency as compared with electric vehicles (EVs). In other words, instead of using fossil fuels in engine of low efficiency internal combustion cars to move, the fuel can be used in power plants, converted to electrical energy and finally led to move vehicles with efficient motors of EVs. Therefore, it will lead to save the energy and also lead to reduce greenhouse gases emission into the atmosphere, accordingly. On the other hand, the fuel price has risen sharply, following crises of the lack of energy in the past decades. Governments have begun to expand the use of EVs due to limited fuel reserves and also to reduce dependence on foreign sources of fossil fuels. But unfortunately EVs have some disadvantages such as bulk energy storage source, inability to go a long distances due to lack of appropriate technology for saving more energy in batteries, high duration battery charging and low lifetime of batteries as compared to internal combustion cars.

EVs have an energy storage capacity which is rather small for each individual vehicle, but when the number of vehicles is large, a significant energy storage capacity will be yield. Plug-in electric vehicles (PIEVs) have one fundamental characteristics of interest to this paper. PIEVs have batteries on board that can both generate and store electricity and therefore they can be treated as bi-directional EVs. While the PIEVs charge their batteries acts as a load and receive energy from grid (grid-to-vehicle (G2V)) and also they can supply the energy to grid (vehicle-to-grid (V2G)) by means of special hardware installed in PIEVs and parking lots. Now, by increasing the number of PIEVs and their connection to the power grid, the need for planning for efficient use of energy storage source is necessary more than before. So, if we don't have a compiled program for utilization and management of PIEVs, not only connection of these vehicles to the grid will not help the situation of the power system, but also their charge time may coincide with the demand peak and create more acute problems for the power system. Recently, federal energy regulatory commission (FERC) emphasized the urgent need to accomplish this integration for the future health of the system [1]. At any given time, at least 90% of the vehicles are theoretically available for V2G [2]. If a significant number of PIEVs connect to the grid under intelligent and coordinate control and management of an aggregator, they can act as a small power plant having high start-up speed and without any starting cost. In other words, the aggregator can achieve a large source of capacity and stored energy according to the value of batteries charged in PIEVs. The technical and economical relationship among aggregator, independent system operator (ISO) and PIEVs is shown in Fig. 1.

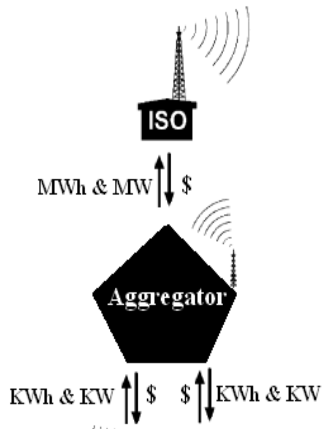

Fig. 1 The technical and economical relationship among aggregator, ISO and PIEVs

The aggregator can participate in a variety of ancillary service market such as regulation market, spinning reserve (SR) market etc., according to the quantity of energy stored in batteries of connected PIEVs. Also, according to its temporal predicts towards the amount of energy stored in the batteries of PIEVs and also meet all requirements of the

PIEVs' owners for their batteries charging, the aggregator can participate in the SR market and discharge the vehicles' batteries and inject energy to the grid (V2G) when being called by ISO.

Reference [3] proposes a method for scheduling usage of available energy storage capacity from plug-in hybrid electric vehicle (PHEV). Unit commitment (UC) with V2G for cost and emission reduction in power system is presented in the [4-6]. In [7, 8] experience of use of PIEVs are described. References [9-11] have proposed an aggregator that makes use of the distributed power of electric vehicles to produce the desired grid-scale power for V2G frequency regulation services. The cost arising from the battery charging and the revenue obtained by providing the regulation have investigated and represented.

The present paper is organized as follows. In the Section II the main notations used throughout the paper have been listed. Section III presents the problem formulation, while in Section IV the proposed algorithm is offered. The simulation studies and results analysis are driven in Section V. Finally, Section VI concludes the paper.

II. NOMENCLATURE

The main notations used throughout the paper are stated below for quick reference.

$AggDV(t)$: Value (1/0) of aggregator decision vector at Hour t;

$Bid(t)$: Amount of bid (MW) of aggregator to ISO at Hour t;

$CDtoAgg(t)$: Connection duration (hour) of PIEVs to the aggregator when connect at Hour t;

$C_{PIEV}(i)$: Amount of capacity (KWh) related to battery of PIEV;

$Ch_{PIEV}(i, t_{Disconnect})$: Amount of charge (KWh) of battery of i'th PIEV when disconnecting from the aggregator;

$Demand(t)$: Amount of demand (MW) of aggregator at Hour t;

$E_{G2V}(i,t)$: Amount of energy (MWh) injected to battery of PIEV at Hour t;

E_k: Internal energy of molten metal related to the SA algorithm;

FOR_{Agg}: Forced outage rate of aggregator;

i: Index of PIEV;

$MCDtoAgg$: Minimum connection duration (hour) of PIEV to the aggregator;

MBC: Minimum battery charge of PIEV in KWh while PIEV disconnecting from the aggregator;

N_{PIEV}: Total number of PIEVs;

$NtoAgg(t)$: Number of PIEVs connected to the aggregator at Hour t;

$PIEV_{tot}$: The whole of PIEVs connected to aggregator;

$\Pr ob_{call}(t)$: Probability calling of aggregator by ISO at Hour t;

$\Pr ofit$: Net profit ($) of aggregator resulted by participation in SR market in a day;

RR_{Ch}: Ramp rate of charging (pu/h) related to batteries of PIEVs;

RR_{Disch}: Ramp rate of discharging (pu/h) related to batteries of PIEVs;

$SOCtoAgg(t)$: State of capacity (SOC) of PIEVs batteries while connecting to the aggregator at hour t;

T: Total hour of a day;

T_k: Temperature of molten metal related to the SA algorithm;

t: Index of Hour t;

$t_{Connect}(i)$: The time that i'th PIEV connects to the aggregator;

$t_{Disconnect}(i)$: The time that i'th PIEV disconnect from the aggregator;

$t_{Full}(i)$: The time that i'th PIEV have full charge of batteries;

$U(i)$: Binary number equal to 1, when owner of PIEV respect to MCDtoAgg and equal to 0, otherwise;

α: Coefficient of gradual decreasing the temperature of molten metal related to the SA algorithm;

$\lambda_E(t)$: Forecasted energy market price ($/MWh) at Hour t;

$\lambda_{spot}(t)$: Forecasted spot market price ($/MWh) at Hour t;

$\lambda_{SR}(t)$: Forecasted SR market price ($/MWh) at Hour t.

III. PROBLEM FORMULATION

The most important constraint of the problem is the minimum connection duration of PIEVs to the aggregator (MCDtoAgg). In other words, to benefit from this type of charging, owners of PIEVs should not disconnect their vehicles from aggregator earlier than the desired MCDtoAgg. In order to ensure the owners of PIEVs about desired batteries charge while disconnecting from the aggregator, aggregator must follow and observe the desired minimum battery charge (MBC) of PIEVs. In other words, the batteries of PIEVs which owners have respected MCDtoAgg, must have desired MBC when disconnecting from the aggregator.

In this paper, the aggregator aims at maximizing his/her profit. The mathematical formulation of the problem is as follows:

$$\max\{Profit\} = \max \sum_{t=1}^{T}\{-Cost_1(t) - Cost_2(t) + Income_1(t) + Income_2(t) + Income_3(t)\} \quad (1)$$

$$Cost_1(t) = \sum_{t=1}^{T} Demand(t).AggDV(t).\lambda_E(t) \quad (2)$$

$$Cost_2(t) = \sum_{t=1}^{T} Bid(t).FOR_{Agg}.Prob_{del}(t).\lambda_{spot}(t) \quad (3)$$

$$Income_1(t) = \sum_{t=1}^{T} Bid(t).\lambda_{SR}(t) \quad (4)$$

$$Income_2(t) = \sum_{t=1}^{T} Bid(t).\lambda_E(t).Prob_{del}(t) \quad (5)$$

$$Income_3(t) = \sum_{i \varepsilon PIEV_{tot}} \left[\sum_{t=t_{Connect}(i,s)}^{t=t_{Full}(i,s)} \left[\lambda_E(t).E_{G2V}(i,t)\right]\right].(1-U(i)) \quad (6)$$

$$U(i) = \begin{Bmatrix} 1\_if\,(t_{Connect}(i) - t_{Disconnect}(i) + 1) \geq MCDtoAgg \\ 0\_otherwise \end{Bmatrix} \quad (7)$$

$$\left[Ch_{PIEV}(i, t_{Disconnect}) \geq MBC\right] \times U(i) \quad (8)$$

The first term of the objective function (Equation (2)) is related to the purchase cost of electrical energy from the energy market in order to charge the batteries of PIEVs. The second term of the objective function (Equation (3)) is related to the purchase cost of electrical energy from the spot market in order to meet the aggregator obligations while recalling by ISO for energy generation in SR market. The third term of the objective function (Equation (4)) related to aggregator income resulted by participation in SR market. The fourth term of the objective function (Equation (5)) is related to the aggregator income resulted by being called by the ISO in order to generate electrical energy in SR market. The fifth term of the objective function (Equation (6)) is related to the income resulted by receiving the batteries charging cost from owners of PIEVs who have not respected the MCDtoAgg. The cost received from this group of owners of PIEVs is in accordance with energy market price. The constraints (Equation (6)) are related to the desired MBC of PIEVs, and these limitations must be met by the aggregator for the owners of PIEVs who respected the MCDtoAgg.

In order to forecast the hourly spot price, a random based method is used [12, 13]. The hours between 18 and 22 are considered as the peak period. To present the price spike in the peak hours, a number of spikes are randomly generated using Frechet Distribution [14].

IV. THE PROPOSED ALGORITHM

Participation or non-participation of an aggregator in the SR market at different hours of a day converts problem to a mixed-integer programming (MIP) problem. Non-linear behaviour of the owners of PIEVs for times of connection to and disconnection from aggregator cause the problem to become a non-linear problem. So, the problem is a non-linear mixed-integer problem and we must use an intelligent optimization algorithm to solve such problem. In this paper, we have solved the problem by using simulated annealing (SA) algorithm. In this algorithm, we defined the inverse value of aggregator profit as an internal energy of molten metal and then try to minimize the internal energy of molten metal. The proposed algorithm consists of several steps that are explained in the following. Also, the flowchart of the proposed algorithm has been shown in Fig. 2.

Step 1: in this step, the input data of the problem are defined.

Step 2: in Step 2, essential information for designing of SA algorithm like initial molten metal temperature, the number of generation of new state for variables of problem at any temperature, coefficient of gradual reducing the temperature of molten metal (α) are obtained. And also, an initial random state for variables of the problem (AggDV) is generated.

Step 3: generate a new random state for AggDV in the vicinity of previous state.

Step 4: check the problem constraints: if the any of limits is violated, Step 3 is repeated; otherwise the next step is run.

Step 5: according to the metropolis acceptance standard, the acceptance probability of new state in the inaccurate cases is as follow:

$$\min\left\{1, e^{\frac{-(E_{k+1}-E_k)}{T_k}}\right\} \geq random[0,1) \quad (9)$$

Where E_k is the internal energy of molten metal (defined as the inverse value of aggregator profit), T_k is the molten metal temperature and $random[0,1)$ is the function of MATLAB software to generate normally distributed random number between 0 and 1.

Step 6: in this step, the number of generated states in the current temperature of molten metal is checked and if enough number of states has been generated, the next step is implemented, and otherwise Step 3 is repeated.

Step 7: if the molten metal is not still frozen, the molten metal temperature decreases according to schedule and the algorithm continues from Step 3, otherwise, the algorithm is terminated. The schedule for gradual decreasing the temperature of molten metal is considered as:

$$T_{k+1} = \alpha \times T_k \tag{10}$$

Where α is the coefficient of molten metal temperature gradual decreasing.

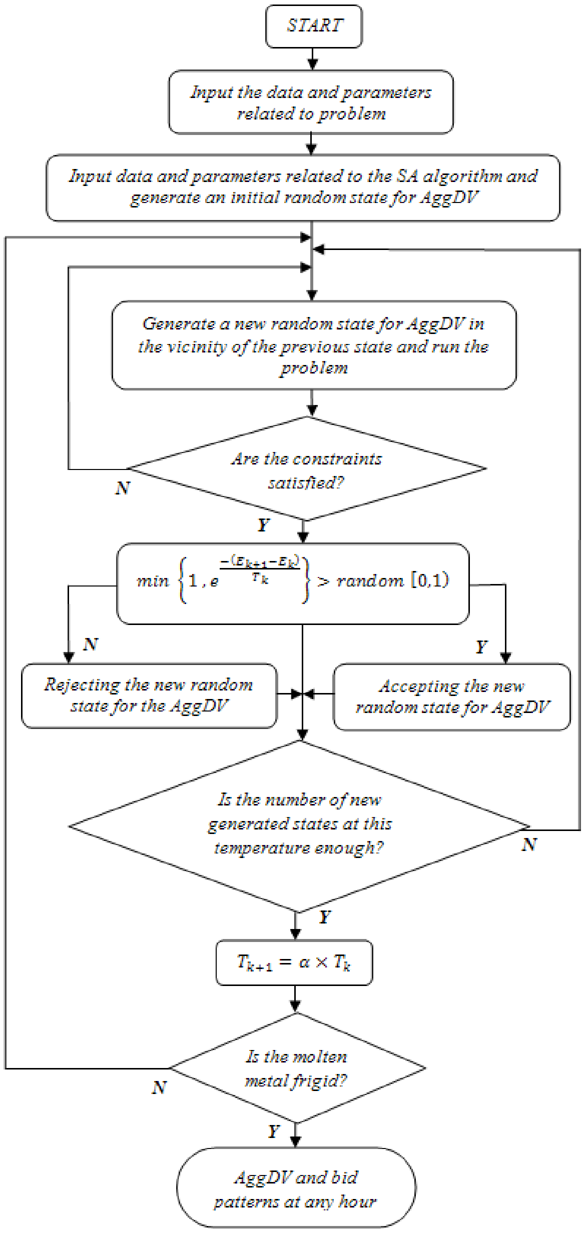

Fig. 2 The flowchart of the proposed algorithm

V. THE SIMULATION STUDIES

In this paper, to encourage the owners of PIEVs to connect to the aggregator, the cost of batteries charging is considered zero. Also, to take advantage of economic benefits of connection to aggregator, owners of PIEVs only must obey the MCDtoAgg. The input parameters used in the simulation studies are stated in Table 1.

TABLE I INPUT DATA FOR SIMULATION OF ALL PARTS OF THE PROBLEM

FOR_{Agg}	RR_{Ch}	RR_{Disch}	$MCDtoAgg$	MBC	C_{PIEV}
0.01	0.2 pu/h	0.2 pu/h	5 hour	0.8 pu	50 KWh

In this section, we plan to examine the effect of some parameters of the problem such as SOCtoAgg, the probability of calling of aggregator (ProbCall) by ISO, energy market price and SR market price on the amount of aggregator bid, the aggregator profit and also on the profit of owners of PIEVs. In this section, we assume that the quantity of SOCtoAgg is 0.6 per unit. Hourly NtoAgg, CDtoAgg, forecasted prices for the energy and SR market and hourly ProbCall are shown in Table 2.

TABLE III HOURLY NTOAGG, CDTOAGG, FORECASTED PRICES FOR THE ENERGY AND SR MARKET AND PROBABILITY OF CALLING OF AGGREGATOR

t	NtoAgg	CDtoAgg	λ_E	λ_{SR}	$Prob_{call}$
1	100	6	102	56	0.01
2	100	5	90	58	0.01
3	150	4	88	80	0.01
4	190	3	72	140	0.01
5	100	2	60	160	0.01
6	170	1	64	130	0.01
7	0	9	72	140	0.04
8	9000	8	76	158	0.06
9	9300	7	162	172	0.06
10	9100	6	172	56	0.06
11	9500	5	74	56	0.07
12	4400	4	80	80	0.08
13	3350	3	84	20	0.09
14	2300	2	76	188	0.09
15	2250	1	84	20	0.05
16	0	16	158	10	0.04
17	9300	15	76	188	0.07
18	9500	14	78	90	0.12
19	9500	13	88	100	0.15
20	8400	12	94	20	0.16
21	6300	11	104	76	0.14
22	4250	10	170	20	0.11
23	1200	9	130	26	0.08
24	1030	8	100	20	0.07

As it can be seen in the Table 3, we have defined a coefficient vector in order to design five scenarios. First entry of coefficient vector is related to coefficient of SOCtoAgg, second entry is SR market price coefficient, third entry is energy market price coefficient and the forth one is coefficient of ProbCall.

TABLE IIII VALUE OF COEFFICIENT VECTOR IN EACH SCENARIO

-	Sc.1	Sc.2	Sc.3	Sc.4	Sc.5
$\begin{bmatrix} \alpha_{SOCtoAgg} \\ \alpha_{\lambda SR} \\ \alpha_{\lambda E} \\ \alpha_{Probcall} \end{bmatrix}$	$\begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$	$\begin{bmatrix} 1.33 \\ 1 \\ 1 \\ 1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0.5 \\ 1 \\ 1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 1 \\ 2 \\ 1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 1 \\ 1 \\ 3 \end{bmatrix}$

Simulation results have been shown in the following tables and figures considering the value of coefficient vector in each scenario.

The hourly demand of aggregator in each scenario has been shown in Table 4. As it can be seen, the demand of aggregator in some hours is low or zero. Because in these hours there is few connected PIEV to the aggregator or the charge of PIEVs' batteries are full.

TABLE IVV HOURLY DEMAND (MW) OF AGGREGATOR IN EACH SCENARIO

t (h)	Sc.1	Sc.2	Sc.3	Sc.4	Sc.5
1	1	1	1	1	1
2	1	1	1	1	1
3	2.5	1.5	2.5	2.5	2.5
4	4.4	1.9	0	0	3.4
5	2.9	1	4.4	0	2.9
6	2.7	1.7	4.6	6.1	2.7
7	0	0	0	0	0
8	90	90	90	90	90
9	183	93	183	183	183
10	0	0	0	0	184
11	279	186	279	279	186
12	230	44	230	230	139
13	77.5	33.5	77.5	77.5	77.5
14	56.5	23	56.5	56.5	56.5
15	45.5	22.5	45.5	45.5	45.5
16	0	0	0	0	0
17	93	93	93	93	93
18	188	95	188	188	188
19	190	95	190	190	190
20	179	84	179	0	179
21	0	31.5	0	0	147
22	0	0	0	0	74
23	0	0	0	0	0
24	127.8	127.8	128.8	211.8	127.8

The hourly bid of aggregator to ISO in each scenario has been shown in Table 5. As it is shown, there is no offer presented by aggregator at 7, 8, 16, 17 hours (in all scenarios) and at 9 and 18 hours (in all scenarios except the second scenario). Since in the said scenarios SOCtoAgg is not 1 pu, so the aggregator has to wait for charge the PIEVs batteries according to ramp rate charging of batteries, and then can offer to ISO for participation in SR market.

TABLE V HOURLY BID (MW) OF AGGREGATOR TO ISO IN SR MARKET

t (h)	Sc.1	Sc.2	Sc.3	Sc.4	Sc.5
1	491	491	491	491	491
2	491	491	491	491	491
3	491	492	491	491	491
4	492	493	492	492	492
5	493.5	495	492	492	493.5
6	495.4	496	493.5	492	495.4
7	0	0	0	0	0
8	0	0	0	0	0
9	0	90	0	0	0
10	90	183	90	90	90
11	90	183	90	90	183
12	183	369	183	183	274
13	369	413	369	369	369
14	413	446	413	413	413
15	446	469	446.5	446.5	446.5
16	0	0	0	0	0
17	0	0	0	0	0
18	0	93	0	0	0
19	93	188	93	93	93
20	188	283	188	188	188
21	283	367	283	188	283
22	283	430	283	188	367
23	283	430	283	188	430
24	283	430	283	188	430

As it is extracted from the simulation studies and presented in the Table 6 and Fig. 3, the total demand of aggregator in the Scenario 2 has minimum value and in the Scenario 5 has maximum value. Because in the Scenario 2, the SOC of batteries of PIEVs is high. Therefore, the aggregator has low demand in this scenario. Also, in the Scenario 5 the probability of calling of aggregator in SR market in order to inject energy to the market is very high. So, the aggregator has tendency to purchase more energy and store in the batteries of PIEVs.

TABLE VI AMOUNT OF TOTAL DEMAND AND TOTAL BID OF AGGREGATOR, AGGREGATOR AND PIEVS OWNERS' PROFITS ($) IN ALL SCENARIOS

-	Sc.1	Sc.2	Sc.3	Sc.4	Sc.5
Total Demand (MWh)	1753.8	1026.4	1752.8	1654.9	1973.8
Total Bid to ISO (MWh)	5957.4	7334	5955	5573.5	6520.4
Aggregator profit per year (Million $)	137	202	50	100	226
PIEV owner profit per year ($)	1286	741	1286	2438	1268

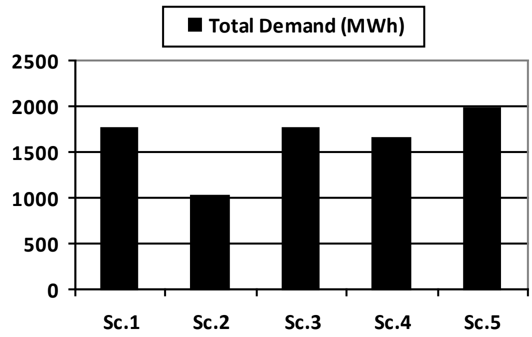

Fig. 3 The total demand of aggregator (MWh) for a day in each scenario

As it is shown in the Table 6 and Fig. 4, the total bid of aggregator to ISO in the Scenario 4 has minimum value and in the Scenario 2 has maximum value. Because in the Scenario 4 the price of energy is high and the aggregator prefers to purchases less energy. Therefore, the aggregator can't bid more reserve. And also, in the Scenario 2 as it said the SOC of batteries of PIEVs is high. So, the aggregator has more stored energy in the batteries of PIEVs and can bid more spinning reserve to ISO.

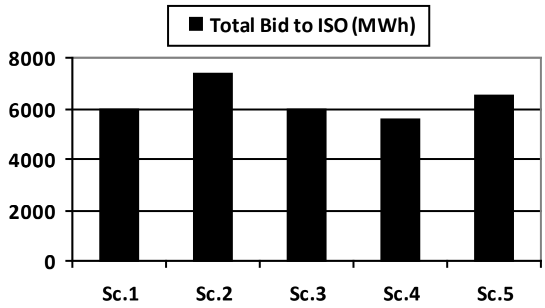

Fig. 4 The total Bid of aggregator (MWh) to ISO for a day in each scenario

As it can be seen in the Table 6 and Fig. 5, the aggregator benefit obtained from participation in the SR market depends on all four parameters. High quantity of SOCtoAgg causes to increase profit of aggregator. Because the aggregator will have less need to purchase energy to recharge batteries. Low SR market price reduces the profit of the aggregator, since low price in the SR market reduces the aggregator revenue. High energy market price reduces the profit of the aggregator, because the aggregator pays more cost to buy energy from the energy market in order to charge the batteries of PIEVs. High quantity of ProbCall causes to increase profit of aggregator, since the aggregator can act as V2G and inject the stored energy in batteries of PIEVs to the grid while being called by ISO.

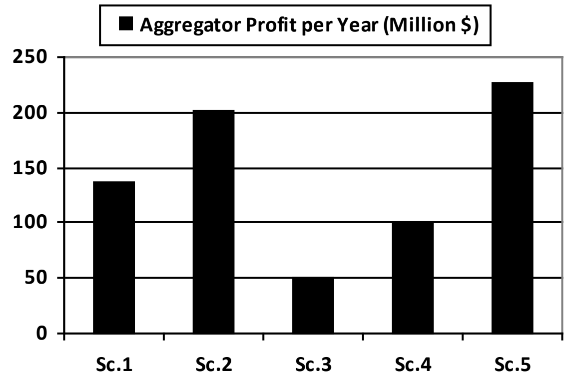

Fig. 5 The aggregator profit per year (Million $) due to participation in SR market in each scenario

As it is shown in the Table 6 and Fig. 6, the benefit of PIEVs owners which respected MCDtoAgg is independent from SR market price and ProbCall and in fact, it only depends on energy market price and SOCtoAgg. When the energy market price increases and also when SOCtoAgg decreases, the benefit will be increased. Because the aggregator is obliged to supply the batteries of PIEVs which respected MCDtoAgg at zero price, so when the SOCtoAgg reduces and also energy market prices increases, the benefit of owners of PIEVs will increase.

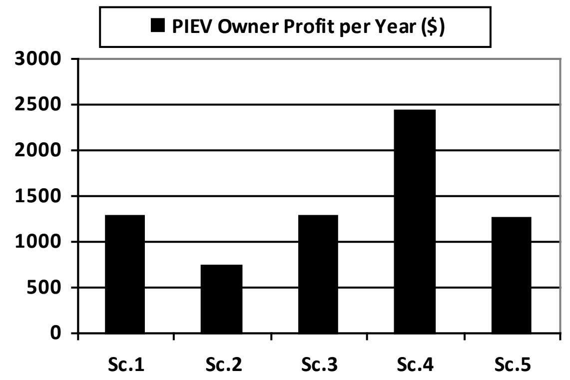

Fig. 6 The PIEV owner profit per year ($) due to respect to the MCDtoAgg in each scenario

VI. CONCLUSION

High value of SOCtoAgg causes to increase aggregator profit, because aggregator is less likely need to buy energy for batteries charging. Low SR market price reduces aggregator profit, because it causes to reduce aggregator income. The more energy market price increases, the less aggregator makes a profit, because the aggregator has to pay more money to market for purchasing the energy to charge the batteries of PIEVs. If aggregator is more likely to be recalled by ISO in order to generate energy in SR market, its profit will be increased accordingly, because in addition to make money by participating in the SR market, aggregator can inject energy stored in batteries of PIEVs to the grid (V2G) and earn money from energy market.

The profit obtained by owners of PIEVs connected to aggregator is higher when energy market price increases and also when SOCtoAgg is low. Because aggregator is bound to supply batteries charge of PIEVs which is respected MCDtoAgg at zero price, thus the less value of SOCtoAgg and the more energy market price increases, the more benefit for owners of PIEVs will be obtained.

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