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A Model for Scheduling of Electric Vehicles Charging in a Distribution Network using Multi-agent Model

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ABSTRACT

This study has been conducted aiming at improvement of a multi-agent model whose task is planning and energy management of a power distribution system based on electric vehicles and their aggregators. In this work, the wear of automobile batteries is considered as an inhibitor agent for electric vehicle owners which affects other agents. Therefore, the aggregator agent should consider the cost as encouragement for the owners of electric vehicles. The agents used in this paper are: 1) Technical agent distribution system operator 2) Distribution System Operator market agents 3) Electric vehicle aggregator agents. This paper proposes a strategy for the aggregation agent of electric vehicles in a competitive electricity market, taking into account market reservations. This model provides a way to reimburse vehicle owners for battery burnout over the consumption cycle and it helps to increase the desire of electric vehicles to charge and sell electricity to the market and increase the profits of vehicle agents and owners.

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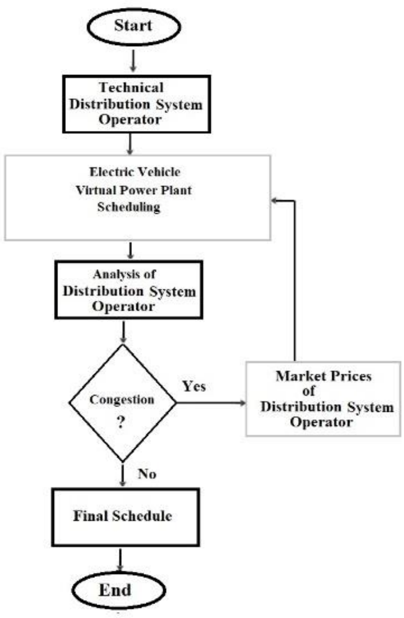
Graphical Abstarct



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1. INTRODUCTION

Various methods have been proposed to minimize costs in power distribution networks (1). Today, electricity exchanges in most countries take place through the electricity market and by considering the economic performance of power systems by the system operator, which is required to maintain an acceptable level of security (2). The technology of electric vehicles, or those with battery-powered vehicles, can be divided into two general categories of EVs and Plug-In Hybrid Electric Vehicle (PHEVs). Among these technologies, PHEVs are generally more attended due to the ability to work simultaneously with two internal combustion and electric engines (3, 4).

On the other hand, PHEVs can solve many power system problems as a potential electric energy store and causes the possibility of electric energy storages with high capacity, but sporadic, and random-behavior. Introducing an appropriate aggregator for these types of vehicles and defining its relationships with other power system organizations can help them grow faster. An aggregator is an agent as an interface between the system operator and the consumer. The aggregator helps to facilitate the use of electric vehicles and maximize the profit of operator and vehicles (5). The existence of batteries in these vehicles as their main characteristic, as well as the ability to charge and discharge electricity power through the global power grid lead to change the attitude to these vehicles from an electrical load to a moving electrical energy storage. Managing battery charging and discharging electric vehicle batteries is one of the most important issues in electric vehicle-based smart grids. In fact, the management of vehicle charging and the timing of consumed electricity traffic should be such that the profit of all market participants reaches its optimal level and reduces network costs (6). One of the most basic needs for a healthy competition is the monitoring on parties' performance by the neutral factor. In the electricity market, this task is performed by the Independent System Operator (ISO). Independent system operator is responsible for maintaining the security of the system. This operator acts in market environment independently and does not discriminate between them in encouraging or penalizing participants. It is at the same time responsible for operating the power system and operating from the ultimate market. Generation companies (Gencos) produce and sell electrical energy. They also provides additional ancillary services such as frequency regulation, voltage control and reserve for which the operator needs. A generation company can own one or more power plants with different technologies. Generation companies may also be called Independent Power Producers (IPPs). Transmission companies (Transcos) are the owners of transmission line equipments. These companies use their own equipment in accordance with the independent operating system instructions. Distribution companies (Discos) are the owners and operators of the distribution network. In this paper, the focus is on production and transmission and, distribution network is not used. Virtual power plants are agents of power system without power generation; but they can store electrical power at some times and return it to the grid at other times. In this work, electric vehicles are considered as virtual power plants.

In this paper, a way to optimize the planning of electric vehicle charging is proposed. The proposed model will be a complete model of smart grids that will include all the participants. Participants in the proposed model will include electric vehicles, distributed generation resources and aggregators. Each of the existing agents is trying to maximize its profits in the electricity market. Therefore, various agents must be able to estimate market conditions by predicting load and prices, and present their best offerings for market participation; this is done with the help of a hierarchical multi-agent control system and CPLEX optimization methods with the GAMZ software.

The second section focuses on theoretical foundations and provides the background to the proposed research. The third section, the proposed model is presented. In section 4, the results obtained are analyzed. In section 5, we will present the discussion. in section 6, the conclusion is presented.

2. RESEARCH BACKGROUND

Multi-agent system models were first introduced and used to control the components of smart grids (7), which are most commonly used for large area grids. An example is the use of these models in intelligent energy markets (8-16). The multi-agent system is a new computational model in which several inputs interact with other inputs in an environment (10, 17).

The application of multi-agent systems is divided into two groups: solving the problems of large power systems with the goal of reducing computations (11, 12, 18, 19). Controlling power systems by dividing the system into smaller subsystems and increasing decision-making power (13, 14, 20).

A multi-agent system model is discussed in literature [15-18,21] for managing a distribution system comprising a large number of electric vehicles. The main reason is the use of the power system and, this agent modifies the program with the control and study of the network and informs them.

Hamidi and Moradi (19) presented a multi-agent system is where the charging time of electric vehicles is determined in a way that occurs at the lowest cost of electricity. In this work, the capacity of the transmission lines has been considered as a limiting factor for decision making. It should be kept in mind that the transmission lines should not be loaded more than their capacity.

Hamidi et al. (21) also provided a way to charge vehicles when the network price is the lowest. In this work, electricity prices are also affected by the time of charging vehicles. In other words, the time of minimum price is a function of the time of charging vehicles, and the time of charging vehicles should also occur at the lowest market price. With this in mind, the two variables should be optimized in terms of each other.

Hu et al. (22) provided a multi-agent method according to which, in the environment including electric vehicles, the filling of transmission lines is managed and prevented.

Multi-agent systems are used for a variety of electricity network optimizations. The hierarchical agent-oriented control system is shown in Figure 1.

It is assumed in this work that four agents are considered. These agents are as follows:

1. Technical Distribution System Operator (Technical DSO)
2. Market Distribution System Operator (Market DSO)
3. Electric Vehicle Virtual Power Plant (EV VPP)
4. Dispersed Energy Resources (DER)

In Figure 1, the relationship between these agents is completely identified. The task of technical DSO is to control the technical agents of the network, such as filling lines. The market DSO also optimizes system economic affairs. Also, the task of electric vehicles or EV VPP is the control and management of electric vehicles (23-28).

3. MODELLING

In this paper, electric vehicles owners give the responsibility of charging and discharging their batteries

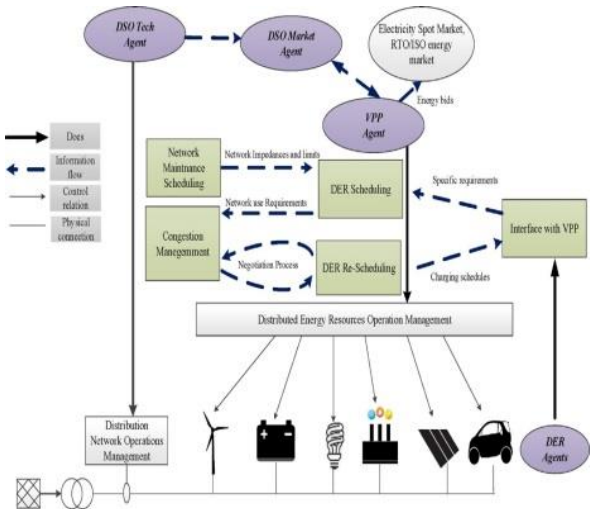

Figure 1. The relationship between various agents in the distribution system (22)

to the aggregators. Aggregators can charge batteries at low power prices and in the high-load hours, additional and unused charge of these vehicles will bring back to the grid. The battery charging by the grid is called Grid-to-Vehicle (G2V), and the return of energy from the vahicle's battery to the grid is called Vehicle-to-Grid (V2G). The owner of any electric vehicle has the ability to or not to participate in the market with the binary variable $\alpha_{t,v} \in \{1,0\}$. If the vehicle is capable of charging and discharging, this variable will show the number 1 and if there is no ability for any reason, such as failure or absence in the parking, then the corresponding variable represents the zero number. This variable specifies the state of the device *v* at *t*.

If the EV is ready for charging or discharging, it must behave according to the program that the aggregator specifies and, if necessary, receives energy from the grid, and in other times it will provide energy to the grid. This will increase the owner's profit, electric vehicle aggregator as well as the power system.

The aggregator maximizes its profits by planning electrical vehicles. The aggregator profit is obtained from difference in revenue from services provided to the grid and costs incurred on the grid. One of the charges made in the network is the cost of wearing out electric vehicle batteries. In this work, it is assumed that the aggregator participates in both the regulation up and regulation down market and offers proposals in both. If aggregator offer are accepted by Independent System Operator (ISO), it is necessary to participate in the market and provide the services required by the Independent System Operator. Otherwise, it will suffer damage. Figure 2 shows the decision tree made by the aggregator in the day ahead market. It can be better to see the probabilities in Figure 2. The aggregator offering in the market is that it offers two numbers, one for the price, and one for the market share. To accept the aggregator proposal, a probability is defined which is shown with π^a. Also, the probability of deployment in the market is also shown with the variable π^d. In the event of winning by the aggregator in the market, two powers are defined; One P^{cap}, which means the aggregator suggested power that specifies the proposed capacity and one P^{accept}, which means its accepted power in day ahead regulation market by ISO.

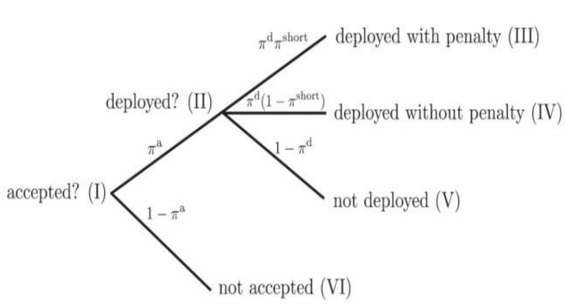

Figure 2. Decision tree for market interactions

In branch (I), the capacity offer is accepted with probability π^{a}. In the following, and after admission to the market, the potential established by SO may be ranged from zero to p^{accept}, in this case:

$$0 \le p^{depl} \le p^{accept} \quad (1)$$

This happens with the probability π^{d} and is indicated in Figure 2. Also, the aggregator must realize that the power demanded by the SO can be higher than the expected power, and therefore the shortened power or p^{short} must be considered. An ideal case without a penalty factor has been shown in (a) from Figure 3. In this aggregator, the λ^{cap} is established for the accepted capacity p^{accept} and λ^{RT} is paid for p^{depl}.

In branch (V), the aggregator expects that his proposal to be accepted with probability π^{a}, but not deployed in the RT market. In this case, no gain is achieved, and only the offer placed on the market next day is received at the price of λ^{cap}. In branch (V), the offer is accepted and it is expected that all accepted capacity is not used in RT market. In this case, there is no benefit to participation in the RT market, and not the risk for the aggregator. In fact, in this case, only the offer to participate in the day ahead market and with the price of λ_{cap} is accepted.

In this model, an aggregator which decides to maximize its profit is considered. The objective function of this problem is written as follows.

$$\max\{r^{em} + r^{cap} + r^{depl} - c^{regup} - c^{regdn} - c^{deg}\} \quad (2)$$

In relation 2, the symptoms are as follows:

r^{em} *: Profit from the participation on the day ahead energy market*

r^{cap} *: Profit from the participation on the day ahead energy market*

r^{depl} *:The expected profit in the real time market for up and down regulations are respectively obtained with the probabilities π^{a} and ϕ^{a}. Also, the deployment and implementation of a proposal offered in the RT market occurs with probabilities π^{a} and ϕ^{a}.*

c^{regup} *: The cost of up regulation services*

c^{regdn} *: The cost of down regulation services*

c^{deg} *: Battery Depreciation Costs*

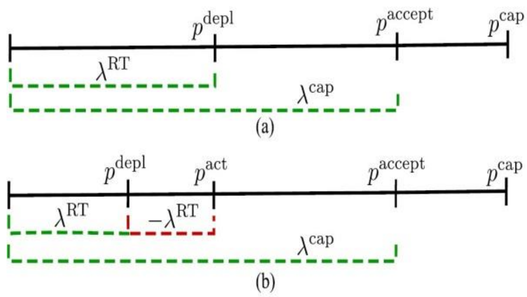

Figure 3. Actual profit and costs for a) a non-penalty b) penalty cases

In the model proposed in this paper, it is assumed that the energy and reserve market are closed by the system operator based on the power pool market. The system operator identifies generators' produced power program by doing Unit Commitement (UC) program. In this work, the energy and reserve market is closed in two steps. In the first stage, the energy market is implemented and the reserve market will be exploited in the second stage.

After closing day ahead market, during the operation of the system, it may happen that there is a need for more or less planned energy. For this reason, there is a need for interaction of RT market. If the required power is greater than the planned power in the DA market, up regulation is required and unsupplied energy is provided. Also, if the load is less than production, this excess power will be sold at up regulation.

In this work, the market price is provided in step form and the price and quantity of power accepted in market are also in step form. Each of the power values and prices offered to them is accepted on the market with different probabilities. Figure 4 shows the total of this process and the final ordered pair of value-price.

It is necessary to define its various variables in order to obtain the objective function,. At first, r^{em} or profit from the DA market is obtained.

The relation 3 of the profit from the day ahead market is as follows:

$$r^{em} = \Delta t \sum_{t \in T} \sum_{v \in V} \lambda_{t}^{DA} (\eta_{v}^{dsg} . p_{t,v}^{emdsg} - p_{v,t}^{emchg}) \quad (3)$$

in relation to 3:

λ_{t}^{DA}	The electricity price at the hour t of the day ahead market
η_{v}^{dsg}	Battery discharge efficiency v
$p_{t,v}^{emdsg}$	Battery dischargable power v at hour t

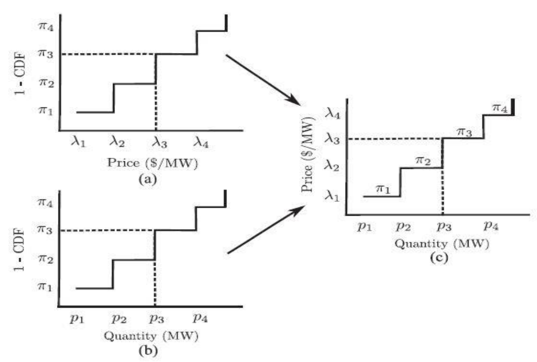

Figure 4. Capacity and price accepted in the market (a) Prices and acceptance probabilities for each price (b) Power values and acceptance probabilities for each value (c) Ordered pair of power- price, which is obtained from the combination of two graphs (a and b)

$p_{v,t}^{emchg}$	Power stored in battery v at hour t
Δt	Study interval for calculating profit

Also, the day ahead regulation market profit is calculated according to relation 4:

$$r^{cap} = \sum_{t\in T} \sum_{b\in B}[(\omega_{t,b}^{up}\lambda_{t,b}^{up})\pi^a p_t^{up} + (w_{t,b}^{dn}\lambda_{t,b}^{dn})\Phi^a p_t^{dn}] \tag{4}$$

In relation 4, the values are as follows:

$\omega_t^{up\backslash dn}$	:	A binary variable that indicates whether step b of price-value-probability curve is active or not.
$\lambda_{t,b}^{up\backslash dn}$	:	Regulation price at time t and step b.
π^a	:	The acceptance probability (winning) in the regulation up market
Φ^a	:	The acceptance probability (winning) in the regulation down market
$p_t^{up\backslash dn}$	:	Regulation power suggestion at hour t

The mentioned relationship involves only profits from capacity market commitment. If the system operator needs to use the offered offer in the capacity market, it is necessary to buy at RT market price.

The profit from this work is in the form of a relation 5:

$$r^{depl} = \pi^a\pi^d\eta^{dsg}\sum_{t\in T} \sum_{v\in V} \sum_{b\in B} (v_{t,b}^{up}\lambda_{t,b}^{RT})(e_{t,v}^{regup} + e_{t,v}^{stopdsg}) \tag{5}$$

In relation 5, $\lambda_{t,b}^{RT}$, the RT market price is obtained from the curve of Figure 4. $e_{t,v}^{regup}$ is also the energy that is expected to be deployed and used in the market for regulation up. Also, $e_{t,v}^{stopdsg}$ is the energy is scheduled for energy discharging in the regulation up service. The r^{depl} benefit discussed in this section is shown in branch (III) of Figure 2. The aggregator must install a part of the capacity offer in order to obtain this benefit, regardless of the risk of consumption more than the proposed power. This will likely result in the aggregator being forced to pay the costs due to lack of capacity. This cost is shown in relation 6.

$$C^{regdn} = \Phi^a\Phi^d(1-\Phi^d)\sum_{t\in T} \sum_{b\in B} (v_{t,b}^{up}\lambda_{t,b}^{RT}) (p_t^{dn} - \Phi^a\Phi^d p_t^{dn}) \tag{6}$$

$$C^{regup} = \pi^a\pi^d(1-\pi^d)\sum_{t\in T} \sum_{b\in B} (v_{t,b}^{up}\lambda_{t,b}^{RT}) (p_t^{up} - \pi^a\pi^d p_t^{up}) \tag{7}$$

In relation 7, the difference between the suggested capacity p_t^{up} and the power expected to be used indicates the power shortage. This power shortage should be purchased by an aggregator on the RT market. The probability of this power shortage is $\pi^a\pi^d(1-\pi^d)$. The term $(1-\pi^d)$ is called the power shortage probability or π^{short}. This probability has been shown in branch (IV) of Figure 2.

Now, if the power purchased is more than used or deployed, the excess amount should be sold in the RT market. This is called regulation down. Charging and discharging the vehicle batteries will cost the owners of electric vehicles. As a result, they do not want to adjust the charge and discharge of vehicles by the aggregator. Therefore, in order to encourage this, the aggregator should consider a cost as encouragement for them. This amount should be such as to compensate the wear of the batteries due to charge and discharge. Relation 8 is used for wear of the battery of existing electric vehicles:

$$c^{deg} = \sum_{v\in V} C_v^{bat}\left|\frac{m_v}{100}\right|\left[\frac{\Delta t\sum_{t\in T}\left(p_{t,v}^{emdsg}+p_{t,v}^{emchg}\right)-\xi_v}{BC_v} + \frac{\sum_{t\in T}\left(\pi^a e_{t,v}^{regup}+p_{t,v}^{emchg}\right)}{BC_v}\right] \tag{8}$$

In the relationship 8:

BC_v	Battery capacity of vehicle v
C_v^{bat}	Battery cost of vehicle v
m_v	The linear estimate of battery life of vehicle v based on the number of charge and discharge cycles
ξ_v	Total energy for movement of vehicle v

In relation 8, the aggregator is obliged to compensate the owners of electric vehicles, to transfer energy to the network and wear of the batteries. This amount of compensation is dependent on the discharge power shown with $p_{t,v}^{emdsg}$. For excess energy received from the grid, compensation should also be considered. But this compensation is paid for the excess energy on the use of the vehicle for moving. For example, if energy ξ_v is required for a vehicle to move, wear compensation for battery is considered for the energy that is more than this charge. It should be noted that for regulation services, the energies $e_{t,v}^{regdn}$ and $e_{t,v}^{regup}$, which cause the wear of the batteries, are considered and the number of charge times does not matter and it does not burn out the battery of the electric vehicle. The objective function mentioned at the beginning of the modeling has constraints and limitations that are discussed below.

The relations 9 and 10, respectively, indicate the proposed capacity of regulation up and down.

$$p_t^{up}\pi^d\Delta t = \sum_{v\in V} (e_{t,v}^{regup} + e_{t,v}^{stopchg}) \quad \forall t\in T \tag{9}$$

$$p_t^{dn}\Phi^d\Delta t = \sum_{v\in V} (e_{t,v}^{regdn} + e_{t,v}^{stopcdn}) \quad \forall t\in T \tag{10}$$

Now, if the extra capacity of the batteries is taken into account, the aggregator can, by utilizing and scheduling, perform the regulation up and down and do not have to buy the RT market. The constraints of this work are shown in relations 11 to 12:

$$soc_{t,v} = soc_{t-1,v} + \eta_v^{chg} p_{t,v}^{emchg} \Delta t - p_{t,v}^{emdsg} \Delta t - \xi_v \left(\frac{S_{t,v}}{\sum_{t \in T} S(t,v)} \right) \ \forall t \in T, v \in V \qquad (11)$$

$$soc_{t,v} \geq \xi_v \left(\frac{S_{t,v}}{\sum_{t \in T} S(t,v)} \right) \quad \forall t \in T, v \in V \qquad (12)$$

$$0 \leq e_{t,v}^{regdn} + e_{t,v}^{stopdsg} \leq SoC_v^{Max} - soc_{t,v} \quad \forall t \in T, v \in V \qquad (13)$$

$$0 \leq e_{t,v}^{regup} + e_{t,v}^{stopchg} \leq soc_{t,v} - SoC_v^{Min} \quad \forall t \in T, v \in V \qquad (14)$$

In all of the equations and relationships mentioned above, it should be noted that the capacity of the batteries is less than the minimum and does not exceed the maximum. Therefore, the relationship 15 for the batteries is considered:

$$SoC_v^{Min} \leq soc_{t,v} \leq SoC_v^{Max} \quad \forall t \in T, v \in V \qquad (15)$$

A constraint should also be taken into account that to put the battery energy at the end of the day at the constant amount at the beginning of the day. This constraint is considered in relation 16:

$$soc_{t=|T|,v} = SoC_v^{init} \qquad v \in V \qquad (16)$$

4. ANALYSIS

Given the hypotheses of the problem, a unique mathematical model was identified for the problem. Finally, mathematical relations were extracted and formulated according to the proposed model. According to the proposed model, its results are analyzed using the GAMS software and using the CPLEX method. In this work, the system consisting of 100 electric vehicles have been considered which are controlled by an aggregator. The system is equipped with aggregating agents for electric vehicles or virtual power plants (VPP), electric power consumers, electric vehicles and system operators. Electric vehicle information is assumed as follows:

Battery capacity of each vehicle is 24 kWh. The maximum battery charge is 95% and its discharge depth is 15%. The internal energy of the batteries is initially considered as random numbers for each battery. The battery wear rate or gradient, or m_v for each battery, is considered to be -0.015. A similar step curve is used for market offerings. The probabilities π^a and Φ^a equal to 0.9 and the probabilities π^d and Φ^d equal to 0.8. The curve used in this study has four steps, which are represented by the set b. The stepwise prices for all four steps λ^{dn} for 24 hours are shown in Table 1.

TABLE 1. Market price for regulation down

Hours	Step1	Step2	Step3	Step4
1	6	7	8	9
2	6	7	8	9
3	7	8	9	10
4	7	8	9	10
5	8	9	10	11
6	8	9	10	11
7	8	9	10	11
8	8	9	10	11
9	9	10	11	12
10	10	11	12	13
11	11	12	13	14
12	12	13	14	15
13	13	14	15	16
14	14	15	16	17
15	13	14	15	16
16	12	13	14	15
17	11	12	13	14
18	10	11	12	13
19	12	13	14	15
20	13	14	15	16
21	14	15	16	17
22	12	13	14	15
23	10	11	12	13
24	8	9	10	11

Also λ^{up} or the price of each step for regulation up is shown in Table 2.

TABLE 2. Market price for regulation up

Hours	Step1	Step2	Step3	Step4
1	6	7	8	9
2	6	7	8	9
3	7	8	9	10
4	7	8	9	10
5	8	9	10	11
6	8	9	10	11
7	8	9	10	11
8	8	9	10	11
9	9	10	11	12
10	10	11	12	13

Hours	Step1	Step2	Step3	Step4
11	11	12	13	14
12	12	13	14	15
13	13	14	15	16
14	14	15	16	17
15	13	14	15	16
16	12	13	14	15
17	11	12	13	14
18	10	11	12	13
19	12	13	14	15
20	13	14	15	16
21	14	15	16	17
22	12	13	14	15
23	10	11	12	13
24	8	9	10	11

Regulations up and down at different hours of the day are shown in the Figures 5 and 6.

Regulation down energy is shown negatively in Figure 6. Also, in 24 hours a day and for all electrical vehicles in the grid, the sum of the energies $e^{stopchg}$ and total energies $e^{stopdsg}$ are summarized in Table 3.

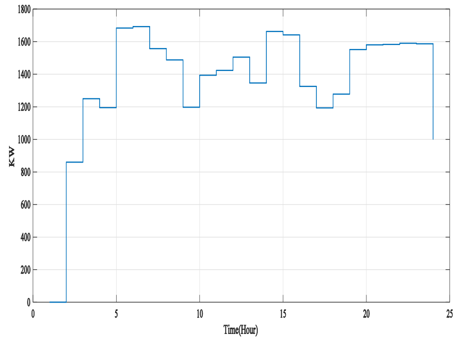

Figure 5. Regulation up energy

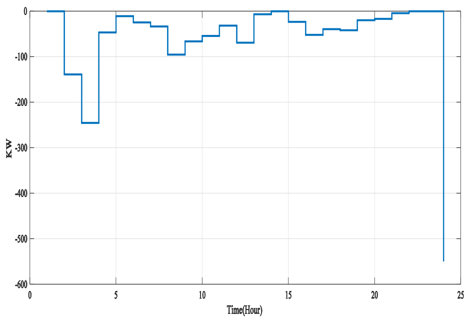

Figure 6. Regulation down energy

TABLE 3. Energies $e^{stopdsg}$ and $e^{stopchg}$

Energy	Value (KWh)
$e^{stopchg}$	32586
$e^{stopdsg}$	1570

The total aggregator profit is obtained from the algebraic sum of revenues and expenses. Revenues and costs and, ultimately, the profits earned by the aggregator are presented in Tables 4 and 5.

$$\text{Costs - Income = Aggregator Benefit} \tag{39}$$

Using the relationship 39, the profit from participating of aggregator in the market is the numerical value of \$ 2.9 × 10^6, in the reference paper, the total cost which aggregator pays for the regulation market is equal to 2.436 × 10^6. In the research, the total regulation costs are about 1.33 × 10^5. The reason for this difference is in three cases. The aggregator can achieve huge profits by using only electric vehicle battery capacity and accurately scheduling battery charging and discharging. In fact, the resources that lead to profits for the aggregator are vehicle batteries which acts as virtual power plants (VPP). Now, if the capacity of these batteries changes, the capacity of the VPPs has actually changed and it is expected that this change will strongly affect the energy exchanges and grid financial transactions and aggregator of electric vehicles.

Table 6 shows the effect of battery capacity on aggregator financial transactions. The effect of the battery capacity on the aggregator's profit is shown in Figure 7. As shown in Figure 7, increasing the capacity of the batteries increases the available power of the aggregator and increases its maneuverability. This increased maneuverability will increase its profits.

TABLE 4. Revenue from aggregator participation in markets

Revenues (Income)	Abbreviation	Value($)
Profit from the participation on the day ahead energy market	r^{em}	$5.2*10^4$
Profit from the participation on the day ahead energy market	r^{cap}	$2.2*10^6$
Income from the deployment of power in the RT market	r^{depl}	$8.1*10^5$

TABLE 5. Costs that the aggregator pays

Costs	Abbreviation	Value ($)
The cost of up regulation services	c^{regup}	$8.7*10^4$
The cost of down regulation services	c^{regdn}	$1.3*10^4$
Battery Depreciation Costs	c^{deg}	$3.3*10^4$

TABLE 6. Effect of battery capacity on aggregator profit

Each vehicle's battery capacity (KWh)	Aggregative profit ($)
12 KWh	$1.97*10^6$
15 KWh	$2.43*10^6$
18 KWh	$2.76*10^6$
21 KWh	$2.89*10^6$
24 KWh	$2.96*10^6$

According to Figure 7, it is clear that with increasing battery capacity, profit will be increased but profit growth will decrease.

5. Discussions

In fact, when the price of electrical energy in the grid is low, the aggregator can charge the available vehicle battery with proper planning and when the price of electricity in the grid is high it sells the excessive energy stored in batteries to the grid. In addition to making big profits, the aggregator can pay the owners of electric vehicles to encourage and to compensate the wear batteries. On the other hand, the network's electricity price is high during peak hours and is low during low hours. However, if vehicles get electricity from the grid at low load hours and they bring this energy back to the grid at peak times, help for peak shaving or flattening the load profile. With this, the costs of investment, operation, repair and maintenance of the network also significantly improve. The participation of electric vehicles in the electricity market depends on their charging status. Table 7 and Figure 8 show the status for all vehicles within the next 24 hours.

How to charge a vehicle has an inverse relationship with power consumption and its price. As shown in Figure 8, during the hours when the electricity price is low (early and late hours), the charge status of vehicles is higher than when the price of electricity is high (mid-day hours). The reason for this is that vehicles prefer to deliver power to the grid in the time of expensive electricity and when it's cheap, buy electricity from the electricity grid. In fact, the management of vehicle charging and the timing of electricity consumption should be such that the profits of all market participants reach their optimum level and reduce network costs. This issue has always been an important topic for electric vehicles and attracted experts' attention.

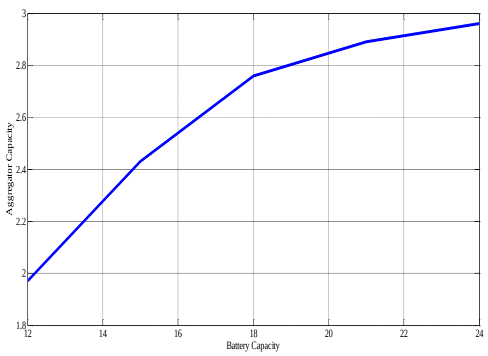

Figure 7. The Effect of Battery Capacity on Aggregator Profit

TABLE 7. Charging status of electric vehicles

hours	Charging vehicles	hours	Charging vehicles
1	1235.667	13	2055.978
2	1840.482	14	1942.5
3	1889.484	15	1861.837
4	2075.37	16	1865.619
5	2043.889	17	1933.543
6	1972.539	18	1998.315
7	1917.485	19	1991.335
8	1867.943	20	1960.806
9	1917.572	21	1922.909
10	1933.761	22	1870
11	1963.472	23	1786.667
12	1944.741	24	1200

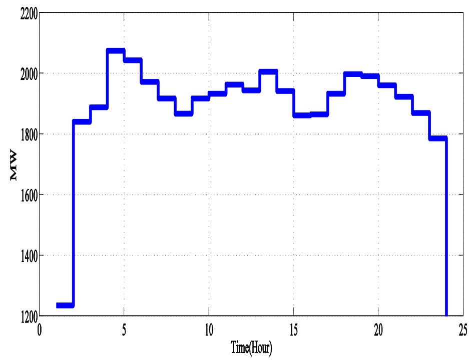

Figure 8. Charging status of electric vehicles

6. CONCLUSION

In this work, the focus was on multi-agent model technology for power management of electric vehicle systems. In the electricity market, there are agents or participants that facilitate the exchanges and operation of the electricity grid. These factors are usually identified as follows:

• The agent of Distribution System Operator (DSO)

• Market agents of the distribution system operator who are responsible for the economic activity of the system.
• Agents of virtual power plants of electric vehicles (in this case electric vehicles are considered as virtual power plants).
• Electric vehicle agents

Considering the relationship between these agents and market participants has led to a comprehensive model governing the electric vehicle-based markets. The proposed model is a multi-agent model and is a topic that is less of a concern for researchers. For this reason, with the advancement and increase of electric vehicles in the urban structure, there are many problems that, despite the many advantages of electric vehicles, makes it even more difficult to use these vehicles. Therefore, it is necessary to provide a comprehensive and optimal plan for the interaction between the agents and the optimum charging of vehicles considering the complete structure of the multi-agent systems. It can also provide relative safety and welfare for the grid and owners of electric vehicles while optimizes the profitof all market participants.

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Persian Abstract

چکیده

هدف از این مقاله، بهبود یک مدل چندعاملی است که وظیفه آن برنامه‌ریزی و مدیریت سیستم توزیع انرژی الکتریکی با محوریت خودروهای الکتریکی و تجمیع کنندگان آن‌هاست. در این کار فرسودگی باتری خودروها به‌عنوان یک عامل بازدارنده، برای صاحبان خودروهای الکتریکی در نظر گرفته‌شده است که عامل‌های دیگر را تحت تأثیر قرار می‌دهد. لذا عامل تجمیع کننده، باید هزینه‌ای به‌عنوان مشوق برای صاحبان خودروهای الکتریکی در نظر بگیرد. عوامل استفاده‌شده در این مقاله عبارت‌اند از:1) عامل فنی بهره‌بردار سیستم توزیع 2) بهره‌بردار بازار توزیع 3) تجمیع کنندگان خودروهای الکتریکی . این مقاله، استراتژی پیشنهاددهی برای عامل تجمیع کننده‌ی خودروهای الکتریکی، در بازار برق رقابتی و با در نظر گرفتن رزروهای بازار را انجام می‌دهد. این مدل، راهکاری برای غرامت دادن به صاحبان خودروهای الکتریکی برای فرسودگی باتری‌ها در طول چرخه‌ی مصرف ارائه می‌کند و کمک می‌کند که تمایل بهره‌برداری از خودروهای الکتریکی برای شارژ و فروش برق به بازار بیشتر شده و سود بهره‌بردار و صاحبان خودروها افزایش یابد.