MANAGING A MULTI-PURPOSE PARKING LOT FOR ELECTRIC VEHICLES

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REZUMAT. Soluţia aparentă pentru reducerea emisiilor de gaze cu efect de seră din industria transporturilor este înlocuirea vehicolelor cu ardere internă cu maşini electrice, o soluţie în strânsă legătură cu industria energiei electrice. Succesul acestei tehnologii depinde foarte mult de existenţa unor locuri unde încărcarea vehicolelor electrice să se poată face la un preţ redus. În această lucrare se analizează modalitatea în care vehicolele electrice interacţionează cu piaţa de energie electrică (PZU) şi modalităţi de management energetic pentru reducerea costurilor cu încarcarea bateriilor maşinilor electrice.

Cuvinte cheie: masini electrice, parcare, management energetic, V2G, G2V.

ABSTRACT. The apparent solution for reduction of emissins of greenhouse gases in transportation industry is the replacement of traditional vehicles with electric vehicles, a solution in close connection with electricity industry. Electric Vehicles succes is closely linked with the existence of places where charging can be done at convenient prices. This paper studies how the electric vehicles interact with the electricity market through the parking lot operator and how to apply an energy management strategy for the benefit of drivers and the parking lot as a whole.

Keywords: Electric Vehicles (EV), parking lot, energy management, V2G, G2V

1. INTRODUCTION

Currently our planet faces major climate changes due to global warming, which in turn is one of the consequences of emissions of greenhouse gases. In transports industry the apparent solution is a wide spread of electric vehicles (EVs), a solution in close connection with the electricity industry. The spread of electric vehicles in everyday life causes appearance of a distributed energy storage capacity in the distribution network. On the other hand, EVs success is closely linked to the price of electricity; the cheaper the electricity, the more successful EV technology. This distributed energy storage can be used in both directions charging the cars and increasing the amount of stored energy inside the batteries of EV (G2V), and discharging the vehicles for the electrical grid benefit (V2G). The succes of the EV tehnology, G2V and V2G use of the storage capacity of EV's are directly linked with their contribution to energy markets around the world. In this paper is presented and studied an EV designated parking lot which is buying it's energy from the Day Ahead Electricity Market (DAM) and is selling this energy to EVs.

Recent approaches in V2G and G2V technology include modeling a big number of EVs in a parking lot as a group and analyze and optimize energy consumption while these vehicles are parked [1]. The litaerature also presents studies of the impact tp the energy market in cases of sudden appearance of a big number of EVs [4]. Other studies refer to the grid influence in case of a wide spread of EV technology [3] and to the benefits and problems of EVs [2].

In this paper, the case of a parking lot for EVs is considered for an economical analysis, approaching a strategy based on the churching-discharging cycle of EVs in direct connection with the electricity market. The location of the parking lot (near a mall and office buildings) provides us with a view on the specific approximate behavior of EVs, which in turn transposes into an electric power demand inside the parking lot. If the number of EV passing through the parking lot is big enough there is a need for a smart management strategy applied by the parking lot operator, so that EVs can be charged at convenient costs for the benefit of the drivers and of the parking lot as a whole.

This paper is an introduction into a study of behavior of the electric vehicles in a competitive local energy micro-market, which would ensure benefits for both the micro-market operator and the drivers of EVs. The interest of this work is not the study of the impact of EVs spread, but to study the behavior of EVs as generators/consumers with the general idea of reducing the price of distance traveled.

2. ELECTRIC VEHICLES MODEL

Based on the interest of this paper, the EV passing through the parking lot where separated in three categories:

1. Vehicles belonging to the maintenance personnel of the parking lot and the personnel working at the mall.
2. Vehicles belonging to the people working in the office building.
3. Vehicles which belong to the people coming to the mall.

From the point of view of the parking lot operator this separation shows the posibilty of usage of these vehicles in his interest. The vehicles from the first category are vehicles that stay parked longest and they appear in the parking lot first and leave the parking lot last, which means that if the operator has electrical energy available at that time he can charge this vehicles fast with the advantage of low energy cost at that time. These vehicles can also be discharged when there is energy shortage to supply other vehicles that are parked. Approximately the same thing happens with the vehicles from the second category with the difference that these appear and leave around the same time during the day. The vehicles from the third category are the vehicles which stay the shortest time in the parking lot and cannot realy participate as V2G.

The vehicles from all of the three categories where modelled as follows:

1. The vehicle appears in the parking lot with an amount of energy stored in the battery. This caracteristic is ilustrated in State of Charge (*SOC*) parameter, SOC_{init} vector, and the total battery storage capacity, *CAP* vector.
2. The driver announces the parking lot operator how long he thinks he is going to stay. This caracteristic is stored in *Tprom*.
3. Given the time period the car is going to be parked, the parking lot operator agrees to an energy price *Pr*, and asks the driver how much energy at this price he would like to buy. The price *Pr* is calculated in steps. This caracteristic is stored *WN* vector.
4. The parking lot operator then asks the driver if he would be interested in buying extra energy at a lower price. This is ilustrated in a boolean vector *EXW*.

Having this caracteristics the charging of EVs starts at the next point of time simulated. The simulation was conducted for a total time interval of 7:00 till 23:00, with simulation executed every 10 minutes, which means 97 points of time were studied.

The EV have the following limitations which should be considered while building the model:

1. The vehicles that can be used as energy storage devices cannot discharge lower then 35% *SOC*, as the discharging process under this limit leads to a shorter lifetime period of batteries.
2. All EVs cannot be charged to a *SOC* bigger then 95 % from the same considerations.
3. The devices cannot have a *SOC* bigger then 100%.
4. EVs cannot have a *SOC*<0%.

After colecting all this data we can build an EV model used in this paper.

First of all we initialize the variable $SOC_{act}(t,j)$ which represents the actual *SOC* of the car *j* at the moment of time *t*, by using 1. SOC_{act} along with the vector *CAP(j)* represents the amount of energy stored in the vehicle and it is used as a starting point for calculating the $P_{ch}(j)$, which represents the charging electrical power of the vehicle *j*.

$$SOC_{act}(t,j) = SOC_{init}(j) \tag{1}$$

The second step is calculating the minimum *SOC* of each vehicle, as desired by the driver. Practicly these values are calculated using eq. (2).

$$SOC_{\min}(j) = \frac{SOC_{init}(j) \bullet \mathrm{CAP(j)} + WN(j)}{CAP(j)} \tag{2}$$

3. PARKING LOT MODEL AND ENERGY MANAGEMENT

The parking lot simulated in this paper has 1000 parking spaces from which 50 are designated to the maintenance personnel, 250 parking spaces designated for the people working in the office building, and 700 spaces designated for mall shoppers.

The parking lot participates at the day ahead energy market with the office building and the mall. Since energy consumption in the office building and the the mall varries if analized in short period of time, the interest of these three consumers is avoiding of participation in the Ballancing Market (BM). An EVs parking lot comes in handy in this situation. By using V2G and G2V technology the parking lot operator can compensate the shortage or surplus of energy.

The parking lot has one important characteristic, namely the number of parking spaces available for vehicles and the number of ocupied places. This characteristic is stored in a boolean vector *LOC*, which has value 1 if the space is ocupied and 0 if the space is free. By defining the *LOC* we can always keep track of the number of the vehicles parked.

At each moment of time the operator has to go through the following steps to ensure a good energy management:

1. Identifies the vehicles that need charging.
2. Calculates the medium electrical power needed for each vehicle, so that vehicle can be charged to the *SOC* needed at the moment of time in which this Vehicle is supposed to leave the parking lot by using eq. (3). At the same time the parking lot eliminates from charging the vehicles with *SOC* bigger then 95%. By defining P_{mn} as shown in (3) we practically skiped another if bloc in the management algorithm, and to be specific the comparison between $SOC_{min}(j)$ and $SOC_{act}(t,j)$. As defined in (3) with the time flow and as $SOC_{act}(t,j)$ is approaching the value of $SOC_{min}(j)$, and the value P_{mn} approaches 0.

$$P_{mn}(t,j) = \frac{(SOC_{\min}(j) - SOC_{act}(\mathrm{t},j)) \bullet \mathrm{CAP}(j)}{CAP(j) \bullet (\mathrm{Tprom}(j) - \mathrm{t})} \quad (3)$$

3. Calculate the total needed power by suming the power needed by each vehicle, as in eq. (4).

$$P_{tn}(t) = \sum_{j=1}^{1000} P_{mn}(t,j) \quad (4)$$

4. The next step is calculating the charging power for each car. Preparing this paper we studied a number of algoritms for calculating the charging power and decided that the charging power should be divided between the electric vehicles equally. The idea is to charge the electric vehicles non-discriminatory. At the same time when an electric vehicle arrives in the parking lot, the operator assumes the responsability of charging the vehicle to a minimum *SOC*. And because of this we decided to introduce a threshold power at which the needed charging power of this vehicle $P_{ch1}(j)$ is set to the medium power needed $P_{mn}(j)$.In this paper, the threshold power is set to 15 kW.
5. After calculating the total power needed for charging the vehicles present in the parking lot we need to compare this power with the power available P_{av} for charging the vehicles.
6. If $P_{tn} \le P_{av}$ we calculate the charging power for all the vehicles by applying eq. (5), with consideration of P_{ch1}. This means if the $P_{ch1}(j) \neq 0$, $P_{ch}(t,j) = P_{ch1}(j)$.

$$P_{ch}(t,j) = \frac{P_{av} - \sum_{j=1}^{1000} P_{ch1}(j)}{\sum_{j=1}^{1000} LOC(j) - \mathrm{NrF}(t)} \quad (5)$$

7. If $P_{tn} > P_{av}$ we need to calculate the power needed by the cars in the mall section of the parking lot using eq. (6).

$$P_{TMall}(t) = \sum_{j=1}^{700} P_{mn}(t,j) \quad (6)$$

8. If $P_{TMall} \le P_{av}$, the power needed for charging the EVs in the parking lot is calculated by using (5), mentioning that the electrical power needed for charging the electrical vehicles in the office biulding section and maintenance personnel section are set to zero.
9. If $P_{Tmall} > P_{av}$, the power needed by the EVs n the mall section is calculated using (7). Since $P_{Tmall} > P_{av}$ the power for the vehicles parked in the office building section and maintenance personnel section is calculated by using (8). We have to mention that practically we wanted to avoid introducing another variable in the algorithm. And if the electric power charging the EVs is negative as defined in (8) this means that the vehicles parked in the office building section and maintenance personnel section are discharging, covering the energy shortage between the power demanded by the parking lot and the power available for charging EVs. It is possible that at one moment of time, the amount of power needed by the mall section of the parking lot can not be covered by the EVs parked in the office building and maintenance personnel sections, in this case the parking lot operator takes the power shortage from the balancing market. This power shortage is calculated using eq. (9).

$$P_{ch}(t,j) = \frac{P_{TMall}}{\sum_{j=1}^{1000} LOC(j) - \mathrm{NrF}(t)} \quad (7)$$

$$P_{ch}(t,j) = \frac{P_{av} - P_{TMall}}{\sum_{j=1}^{300} LOC - NrU} \quad (8)$$

where:
NrU – the number of vehicles unavailable for discharging because their $SOC_{act} < 35\%$.

$$P_{bal}(t) = P_{TMall} - P_{av} \quad (9)$$

where:
P_{bal} – the power needed for charging the mall section of the parkig lot.

10. After calculating the charging power needed for each vehicle the next step is calculating the SOC in the next time step for each vehicle. This is done by applying (10). In this paper the study time interval is set for 10 minutes which in the formula coresponds to 1/6.

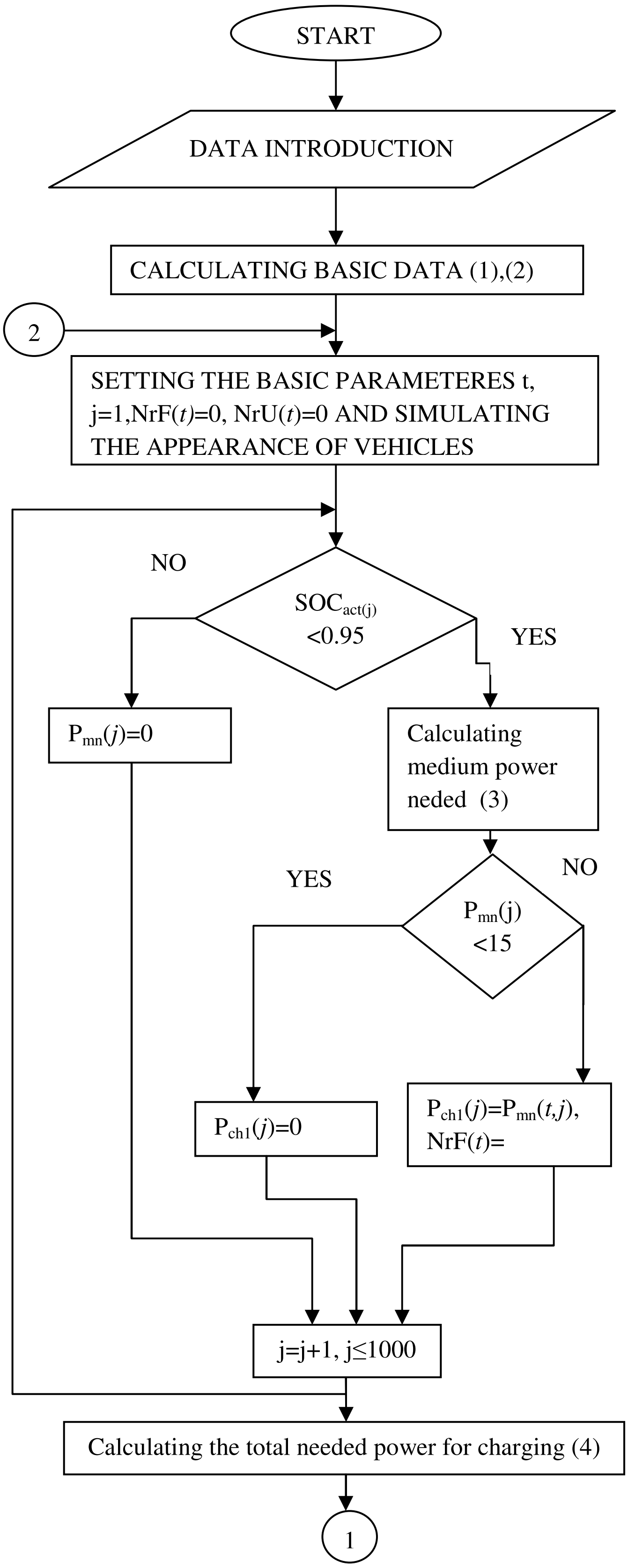

Fig. 1 The computing scheme of parking lot energy management procedures (part 1).

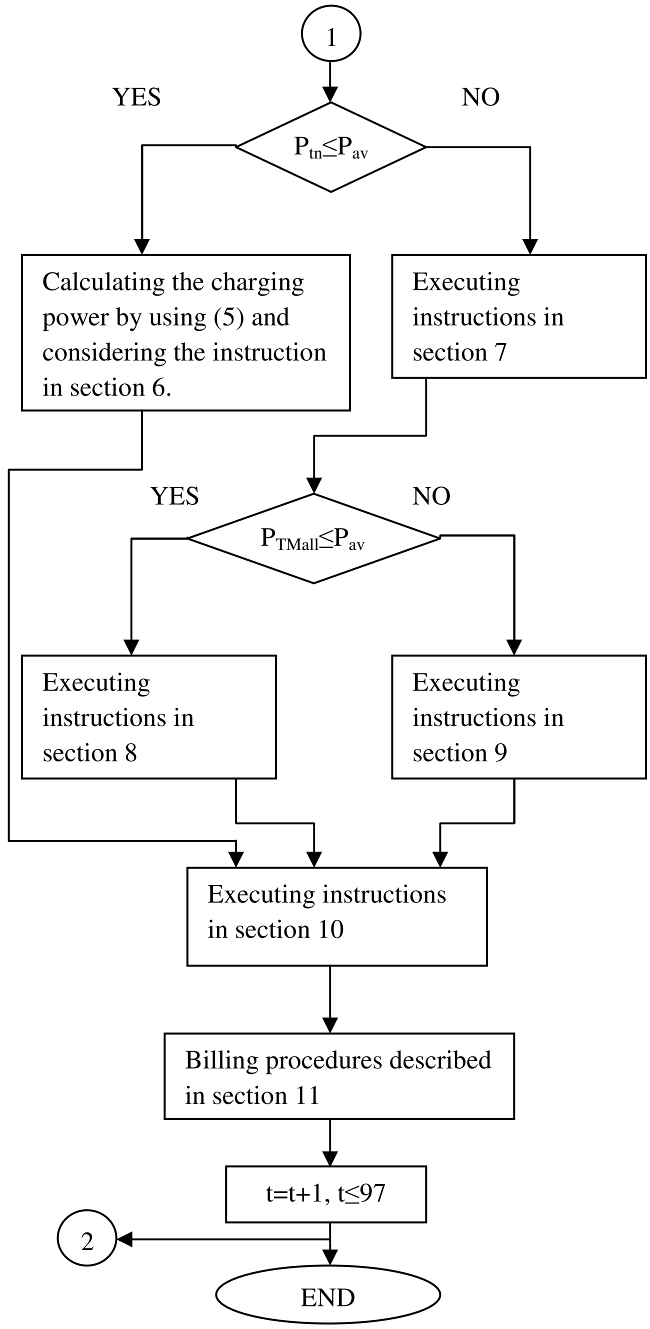

Fig. 1 The computing scheme of parking lot energy management procedures (part 2).

$$SOC_{act}(t+1,j)=\frac{SOC_{act}(t,j)\bullet \text{CAP(j)}+P_{ch}(t,j)\bullet \frac{1}{6}}{CAP(j)} \quad (10)$$

11. In each time point the parking lot operator identifies the vehicles which are supposed to leave, and of course emits the invoice for each vehicle when leaving. This is computed using (11), (12) and (13). The total bill for each EV includes 2 components: the amount of energy sold at the agreed price *Pr*, and the extra sold

energy at price *Pr2*, if the driver agreed as described in chapter 2.

$$\mathrm{Bill}_1(t,j)=(\mathrm{SOC}_{\min}(j)-\mathrm{SOC}_{init}(j))\bullet \mathrm{CAP(j)}\bullet \mathrm{Pr} \qquad (11)$$
$$\mathrm{Bill}_2(t,j)=(\mathrm{SOC}_{act}(t,j)-\mathrm{SOC}_{\min}(j))\bullet \mathrm{CAP(j)}\bullet \mathrm{Pr}_2 \qquad (12)$$
$$\mathrm{Bill}_T(t,j)=\mathrm{Bill}_1(t,j)+\mathrm{Bill}_2(t,j) \qquad (13)$$

12. By computing this algorithm from t=1 to t=T we can study the influence of EVs over the energy market and calculate the revenue of the parking lot operator, as it is done in this paper.

The logical diagram of the parking lot energy management procedure adapted to the case study is illustrated in Fig.1.

4. CASE STUDY

The parking lot simulated in this paper has 1000 parking spaces from which 50 are designated to the maintenance personnel, 250 parking spaces designated for the people working in the office building, and 700 spaces designated for mall shoppers.

All the cars arriving in the parking lot have the following characteristics:

- total battery capacity between 16 and 80 kWh, these values are randomly generated, there are a lot of vehicle manufacturers and the capacities are the upper and the lower limits of EVs currently manufactured around the world;
- depending on the length of the period of time ΔT in hours the cars will spend parked in the parking lot, the agreed price *Pr* is computed the following way:
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    - 1<ΔT<2 Pr=0.5 Lei/kWh;
    - 2≤ΔT<4 Pr=0.4 Lei/kWh;
    - 4≤ΔT<8 Pr=0.3 Lei/kWh;
    - 8≤ΔT Pr=0.2 Lei/kWh;

The behavior of the parking lot energy managemnt procedure is studied over 97 points of time, coresponding to the time period of 7:00 to 23:00. The maintenance personnel should be working at 7:00 which tells us that at the first point of time there are 50 EVs parked in the parking lot.

The people working in the office building start arriving at 8:00 till 9:00, in a continuos manner. This tells us that at 9:00 all 250 parking spaces designated by the parking lot operator are ocupied. Similar, the spaces ocupied in this section of the parking lot will be available for mall shoppers after 17:00.

Simulation of arriving mall shoppers was done using a stochastic method. Which means that at one moment t if a parking space is free there is a 30% chance that a car will arrive. With the arrival of each car in this section the vehicle characteristics listed in chapter 2 are randomly generated, with the following limitations:

- the time ΔT the car is spending in the parking lot is between 1 and 4 hours;
- the maximum amount of energy the driver can buy is set to 20kW·ΔT.

In interest of creating a more complex study case the power available for charging the vehicles $P_{av}(t)$ was created randomly, taking in consideration the number of cars in the parking lot.

The evolution of available power is shown in fig. 2. As it is seen in this figure, the available power varies in the limits 14.6 kW and 3000 kW. The total amount of energy sold to vehicles is 16701 kWh.

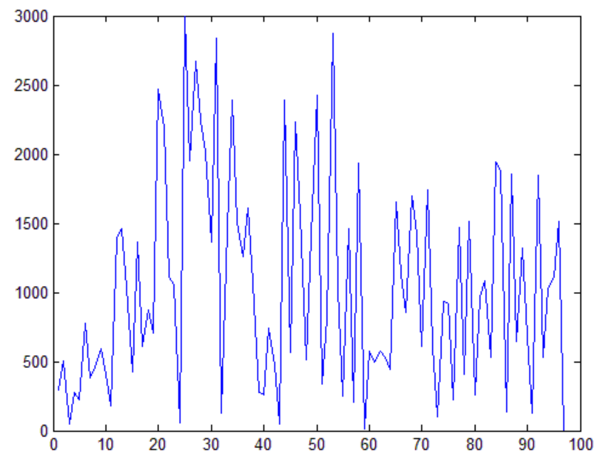

Fig. 2 Evolution of available power for charging the EVs parked.

The evolution of money billed for the electric energy used for charging the EVs is shown in fig.3. The total amount billed for the electric energy is 5834 Lei. The energy purchased by the operator on the day ahead market costs 3597 Lei. The energy prices that where taken into account are the oficial day ahead closing market prices available for the 06.09.2013.

The number of cars passing through the parking lot during the simulated day is 3584. Taking into account that a big number of cars needs a small amount of energy for charging.

The analisys of data obtained after running the described algorithm shows that the energy bought from the balancing market was P_{bal}=0 kWh.

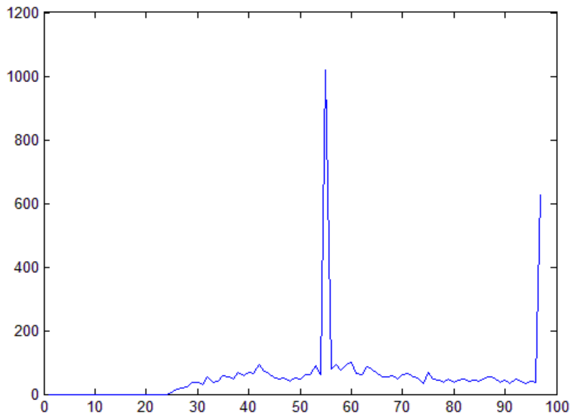

Fig. 3 Evolution of money billed to the EVs owners .

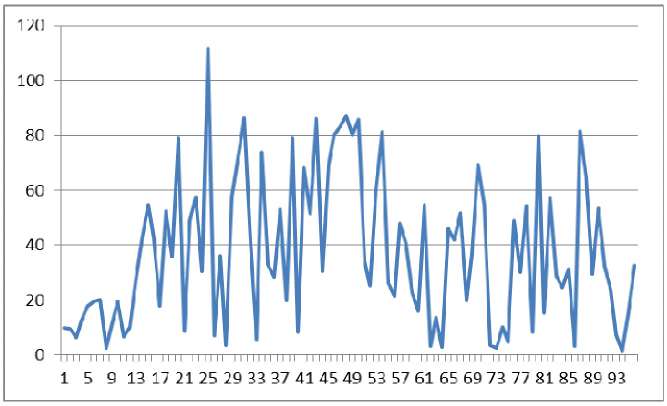

Fig. 4 Evolution of money paid by the operator to the day ahead market for the electrical energy used for charging the vehicles.

5. CONCLUSIONS

✓ The energy management strategyc of the parking lot proposed in this paper, reduces the costs of charging of EVs.

✓ The proposed model brings financial benefits to the drivers of EVs, and the operator of the parking lot at the same time.

✓ Even though the lowest unitary prices applied for calculating the bill for the electric energy is low 0.2 Lei/kWh the operator of the parking lot makes profit.

✓ The proposed energy management algorithm allows the operator not to participate in the balancing market.

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