Coordinated Management of EVs Charging Station with a Wide Presence of Renewable Energy Sources

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Abstract-- **Renewable energy generations depend on environmental conditions, and often don't coincide with energy consumptions. In addition, uncontrolled charging of electric vehicles (EVs) leads to technical problems in the grid and economic inefficiency for EVs owners. In this paper, a bi-level energy management algorithm is presented for a distribution network consisting of EVs and renewable energy generations at high penetration level. Energy management at the distribution network level is done centrally by distribution system operator (DSO). In the second level, the parking operator is responsible for providing EVs energy. The parking operator uses the difference in energy prices between the time steps to determine the level of power exchange between EVs and the distribution network in order to reduce the cost of providing energy for EVs in the parking lot. The proposed algorithm coordinates the charging and discharging of EVs with the network conditions and the output of renewable generations while provides financial benefits for vehicle owners. The results indicate the proposed bi-level energy management has been able to use the freedom of the EVs to balance the power of the network and support renewable generations as well as increase the financial benefits of EVs owners.**

Index Terms-- **EVs, Distributed power generation, Financial benefits of vehicle owners, Energy management**

I. INTRODUCTION

Power generation and energy management are some of the most important issues in the policies of today's societies. Several structures have been proposed to provide clean, permanent and low-cost energy. Clean energy is provided by increasing usage of solar, wind, sea waves and etc. On the consumption-side, clean energy consumptions such as electric vehicles (EVs) are replacing fossil fuel vehicles. These EVs are dependent on the power grid to provide power.

Due to dependence on environmental conditions, renewable energy resources are available just for a few hours a day. Also, these resources often do not necessarily coincide with energy consumption, causing imbalances between electricity production and consumption. If renewable power generation exceeds the power consumption, it will lead to overvoltage in the network, followed by a reversal of current power. Conversely, during peak energy consumption periods when the grid does not generate enough renewable power, the grid voltage drops. Hence, increasing the penetration of renewable energy sources is only possible if it is supported by energy consumption [1].

EVs are increasing as new energy consumptions. The presence of a large number of plug-in EVs in the network and the lack of correct management of these EVs can cause problems for the network. The most important of these problems is the creation of a new peak in the distribution network [2].

The plug-in EVs store the required energy for travel in the batteries embedded in the EVs. The battery capacity of every plug-in electric vehicle is not enough to be managed by distribution system operator (DSO). While the aggregation of these EVs in charge parking can create significant capacity for charging or discharging energy, this capacity is sufficient to be used as an energy management program. Therefore, in order to power balancing in the network, DSO can determine policies for EVs parking lots. DSO's policies for power balancing, along with energy pricing policies, can reinforce motivation of owners of EVs to participate in this direction [3].

Several studies have been conducted on the simultaneous control of renewable energy generations and EVs at the distribution network level. Article [4] for the planning of daily energy resources, coordinated with dynamic electricity prices for EVs, presents a stochastic model for solving the challenges of demand and renewable resources. Reference [5] investigates the economic benefits of coordinated control of distributed energy sources and EVs in smart micro grids operation. Impact of electric vehicle customer response to time-of-use rates on distribution power grids is presented in reference [6]. The authors of [3] have investigated the related topics for integrating the EVs into smart grids, as well as integrating renewable energy generations into EVs. Studies present different strategies for charging the EVs in the distribution network are [7,8]. Optimization, control and charging management of EVs fleet in intelligent networks are discussed in reference [9]. In this study, the effects of EVs managed charging on the performance of the transmission system, distribution, local generation, especially renewable energy generations, as well as the profits of EV owners, have been investigated. In [10] the authors study the combination of EVs and wind power sources for peak modification. Reference [11] provides the formulation

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of a hybrid model for optimal allocation of resources for EVs charging stations, renewable energy sources, and energy storage systems in distribution networks.

The reliability of the distribution network consists of renewable generations and EVs was investigated in [12] and it has been proven that increasing the bidirectional power exchanges between the EVs and the network increases the reliability of the distribution network.

Providing the managed power for EVs can reduce daily load fluctuations. Researchers in [13] determine the final capacity of parking lots by performing optimal power flow to balance energy consumption and production, and maintenance the network voltage level within the allowed range. In [14], an innovative and repetitive method is used to provide required energy for EVs by distributed generations. The strategy of this method creates a virtual price, based on the difference between energy consumption and production. The authors in [15] used the concept of filling low load hours to balance energy consumption and production.

Creating coordination between renewable energy generations and EVs as controllable energy consumptions increase the penetration of renewable energy. Researchers in [16] used a dynamic approach to maximize usage of renewable generations to charge EVs. The basis of determining the power levels of EVs is their state of charge (SOC). The authors [17] have used mixed integer linear programming to reduce usage of conventional power generation and increasing penetration of renewable generations. Paper [18] assesses the economic and environmental impacts of providing renewable energy for charging EVs.

Many factors effect in reducing costs of distribution network. Using low-cost power generations and providing energy at low-cost intervals will reduce network costs. Researchers in [19] used extra power of EVs as reserve in the distribution network. The amount of reserve in the grid is based on the difference between energy consumption and generation. In [20], by changing the distribution network structure through reconfiguration, selects the most appropriate structure in terms of energy providing cost for the network. In [21], a mixed-integer non-linear method was used to reduce the cost of network energy. This methodology was presented by the market agent and EVs agent and by making changes in the price of energy.

Unmanaged increasing of penetration level of distributed power generation and EVs (as energy consumptions), cause intensifying the imbalance between energy consumption and production, resulting in the deviation of voltage levels in the network. Researchers in [22] used optimal power flow to determine the level of parking power exchanges under the allowed conditions for network voltage. In addition, the fuzzy management method was used to prioritize EVs and select the most suitable vehicle for charging.

Among the major setbacks in the distribution network energy management formed from renewable energy and EVs is the uncertainty about the behavior of EVs and local generations. Different methods for compensating of the uncertainty inherent in the behavior of EVs and distributed power generations were investigated in [23,24]. Monte Carlo method was proposed to compensate for the uncertainty in the behavior of EVs and renewable generations in [25]. In addition, energy storage for integration of renewable energy and EVs was also used in this reference. Researchers in [26] compensated for uncertainty in the behavior of EVs and renewable generations by expanding power flow at 12-hour time steps. The authors in [27] used the probabilistic method to estimate time to start charging and the time taken to charge of EVs to compensate for the uncertainty in EVs behavior. Paper [28] presented a method for developing interaction between EV parking lots and the distribution system operator in the energy and reserve markets, which considers the uncertainty of load and wind power.

EVs charging / discharging management at the parking lots level provide an opportunity to increase the benefits of EVs. In this regard, the issues and problems of the EVs energy supply by parking lots were thoroughly investigated by the researchers in [29,30]. Researchers in [31] have presented a model for increasing the financial benefits of EV parking lots as a multi-energy system. In this reference, the concept of exchanging power between vehicle and parking lot instead of power exchange between vehicle and network is used. Authors of [32] maximized the number of charged EVs with the lowest cost, using demand response methods.

One of the issues that has been neglected in the studies, is the use of EVs in the parking lot as an electrical energy storage. For this reason, EVs can be used to transfer power between peak hours of local generation and peak energy consumption. EVs, in addition to the controllable capability for providing the required energy, can be used like energy storage due to the freedom of action in terms of available battery capacity (as compared to the required battery capacity) and parking time. Especially when EVs can be integrated into parking lots. In addition, the other issues that have not been addressed are creating dependencies in the profits of EVs to support renewable power generation. In this case, any vehicle that benefits from renewable energy generation to provide its required energy or transfers generated power of renewable energy generation to peak hours of consumption will earn more benefits. In this context, creating an infrastructure that can optimize the benefits of network assets is critical for renewable energy generations alongside the benefits of EVs.

In this paper, an algorithm based on bi-level energy management is proposed to control the combination of renewable energy generation and EVs under high penetration. At the first level, DSO will calculate the tariff energy price as day-ahead, based on the behavior of renewable generations, in order to create coherence between controllable consumptions (EVs) and renewable energy generations. In addition, DSO will change parking lots design capacity by performing optimal power flow, with the goal of reducing the energy providing cost and maximizing usage of renewable generations, as well as satisfying network operation constraints. In the second level, the parking lot operator will determine the ability of EVs to earn the financial benefits, using the price difference in the time intervals that EVs are in the parking lot. Then, by performing linear optimization based on the financial benefits of EVs (depending on difference in energy price), the level of vehicle power exchange with the network will be determined at any time. The innovations of this study are summarized as follows.

1- In this method, due to the available excess capacity of EVs batteries, the parking of EVs is used as energy storage in order to transfer as possible as the energy surplus of renewable energy generations to peak hours of consumptions.
2- To create coordination between controllable consumptions (EVs) and renewable energy generations, tariff energy price has been created based on the behavior of renewable generations. In this case, the benefits of controllable energy consumptions will depend on the exploitation of renewable generations. Additionally, viewpoint from ahead time intervals will be available to the parking operator by the tariff price.
3- In the proposed method, the operation of DSO and parking operator is real-time and is based on hourly electricity production and load balancing. This will cover uncertainties in the behavior of renewable energy generations and owners of EVs.
4- The profitability of EVs is improved in two ways. A) Power transmission from the peak hours of renewable generation to peak hours of consumption. B) Providing energy for EVs at time intervals with low price (the peak of renewable generations).

The paper is organized as follows. In Section II, the energy management mechanism is presented at the distribution network level. The energy management of EVs in parking lots is described in Section III. The results of simulation studies are presented in Section IV and the conclusions are presented in Section V.

II. ENERGY MANAGEMENT AT THE DISTRIBUTION NETWORK

For proper operation of a distribution network consisting of distributed power generation and EVs at high penetration level, a parking capacity management approach is presented with regard to energy price. This method is based on the optimal power flow. In this context, the energy tariff rate will be determined in such a way that energy price will be low for EVs at peak hours of renewable power generations and high at peak hours of energy consumption. This will encourage EVs to supply their energy at peak hours of renewable generations. In addition, based on the imbalance between local power generations and energy consumptions, parking lots capacity will be managed in real time market.

The proposed energy management algorithm is performed at one hour's steps. For this purpose, all parameters are assumed to be constant over a one-hour period. In addition, it is assumed that the initial capacity and location of parking lots of EVs and local power generation are already designed and known.

A. Formation of tariff price

The energy tariff rate for controllable consumptions (EVs) will be calculated by DSO as day-ahead. Electricity tariffs are determined based on forecasts of renewable energy production and energy consumption. For this purpose, the average 24-hour deployment cost per kWh of energy required for electric vehicles is taken as a reference price. Then, according to the difference between the output of renewable generations and energy consumptions, changes in the reference price of energy will be formed (see Fig.1).

The average 24-hours cost of energy needed for EVs can be calculated based on the electricity market rate or the expired cost of energy in the distribution network. The cost of energy in the distribution network is cheaper than energy market rate; because renewable energy generations cover a part of the network's energy consumptions. In this regard, to calculate the reference price of energy, the expired cost of energy in the distribution network is used.

$$\pi_{avg,N} = \frac{\sum_{t=1}^{24}\left[\left(\left(\sum_{j=1}^{N} P_l^{t,j} \pm \sum_{j=1}^{N} P_p^{t,j} - \sum_{j=1}^{N} P_{DG}^{t,j}\right)\cdot\pi^t\right) - \left(\left(\sum_{j=1}^{N} P_{LDG}^{t,j}\right)\cdot\pi_{LDG}^t\right)\right]}{\sum_{t=1}^{24}\left(\sum_{j=1}^{N} P_l^{t,j} \pm \sum_{j=1}^{N} P_p^{t,j} - \sum_{j=1}^{N} P_{DG}^{t,j} - \sum_{j=1}^{N} P_{LDG}^{t,j}\right)} \tag{1}$$

$$\pi_{avg,M} = \frac{\sum_{t=1}^{24}\left(\left(\sum_{j=1}^{N} P_p^{t,j}\right)\cdot\pi^t\right)}{\sum_{t=1}^{24}\sum_{j=1}^{N} P_p^{t,j}} \tag{2}$$

$$\pi_{avg} = \beta \times \pi_{avg,N} + (1-\beta) \times \pi_{avg,M} \tag{3}$$

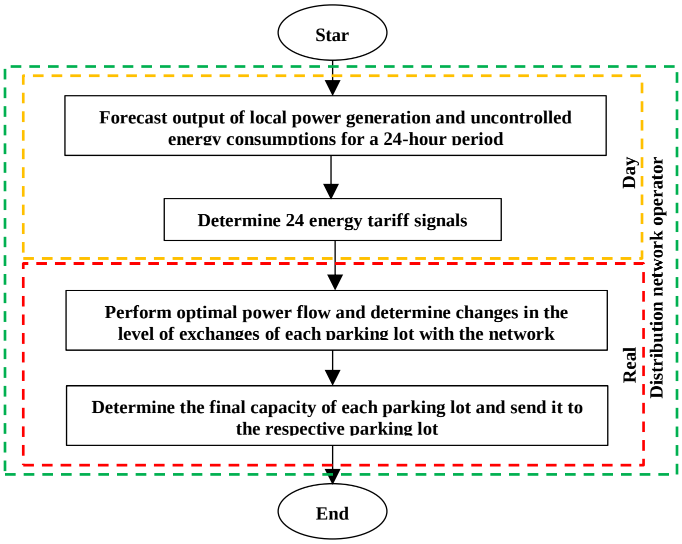

Fig.1. Flowchart of the DSO actions

Equation (1) shows the average cost per kWh of energy in the distribution network. The first term of this equation shows the cost of energy exchanged with the upstream network and the second term shows the cost of energy from non-renewable local production. According to this, the power exchanged with the upstream network is settled at the price of π^t, and the cost of producing non-renewable power is equal to π_{LDG}^t. As mentioned, distributed generation units cover part of the network load, and therefore, in this equation, the amount of electricity production of these units is shown with the opposite sign of the load. The parking lots can also be connected to the network as charging or discharging at any time and have the sign corresponding to electricity production or consumption. In equation (2), the average cost per kWh of energy for parking lots is calculated. In this regard, parking lots can have signs corresponding to electricity production or consumption at any time. In equation (3), the average 24-hour cost of supplying energy needed for EVs is calculated based on the variation in parking design capacity. By changing the β parameter, it is possible to increase the effectiveness of parking lots in the production cost.

Parking lots tariff price rate is based on difference in the output of renewable generations and energy consumptions, as expressed in (4). If renewable energy generations are more than energy consumptions, the cost of energy will be lower for parking lots. In contrast, with increasing energy consumptions, the energy price for parking lots is rising, so parking lots can earn revenue by selling (discharging) energy to the network.

$$\pi_P^t = \pi_{avg} + \gamma \left[\frac{\left[\left(x \cdot \sum_{j=1}^{N} P_l^{t,j} - \sum_{j=1}^{N} P_{DG}^{t,j} \right) \right]}{\sum_{j=1}^{N} P_p^{t,j}} \cdot \pi_{avg} \right] \tag{4}$$

In this equation, coefficient γ is effect of the price of the parking tariff from difference between renewable generation and energy consumption. The value of this parameter is at the discretion of the system operator to reflect impact of renewable resources in supplying the load.

B. Parking lots capacity management

The DSO manages capacity of parking lots in real time market based on information of energy consumptions and power generations for each time step. Renewable energy generations will be used at the maximum available capacity. In addition, parking lots will operate at nearest value to their design capacity. DSOs change parking lot design capacity with the goal of reducing the cost of providing energy for targeted consumption and maintaining grid constraints based on optimal power flow. The imbalance between power consumption and generation in the studied distribution network will be exchanged with the upstream network. In the event of violation of the voltage constraint or grid lines loading limitations, the surplus or deficit will be exchanged with parking lots and will change their design capacity.

As mentioned, the objective function is minimizing the cost of providing energy of covered consumptions:

$$min \left\{ \sum_{j=1}^{N} \left(\left(P_p^{t,j} \cdot \pi_P^t \right) + \left(P_{LDG}^{t,j} \cdot \pi_{LDG}^t \right) \right) + \left(\sum_{j=1}^{N} \left(P_p^{t,j} + P_{DG}^{t,j} \right) - \sum_{j=1}^{N} \left(P_l^{t,j} \right) \right) \cdot \pi^t \right\} \tag{5}$$

Given the following constraints:

$$V_{min} \le V_m \le V_{max} \tag{6}$$

$${p_{ij}}^2 + {q_{ij}}^2 \le {S_{ij,max}}^2 \tag{7}$$

$$P_{p,min} \le P_p^{t,j} \le P_{p,max} \tag{8}$$

$$S_{DG} \le S_{DG,max} \tag{9}$$

$$p_i = V_i \sum_{k=1}^{N} Y_{ij} V_j \cos\left(\delta_i - \delta_j - \theta_{ij}\right) \tag{10}$$

$$q_i = V_i \sum_{k=1}^{N} Y_{ij} V_j \sin\left(\delta_i - \delta_j - \theta_{ij}\right) \tag{11}$$

$$p_{ij} = V_i V_j \left(G_{ij} \sin\delta_{ij} + B_{ij} cos\delta_{ij} \right) - G_{ij} V_i^2 \tag{12}$$

$$q_{ij} = V_i V_j \left(G_{ij} \sin\delta_{ij} - B_{ij} cos\delta_{ij} \right) + B_{ij} V_i^2 \tag{13}$$

The first part of equation (5) represents the cost of energy supplied through parking lots and distributed generation sources. The second part of this equation also shows settlement of the power imbalance with the real time market price of energy.

Constraints (6), (7), (8), and (9) indicate network voltage limitation, lines loading limits, capacity limitation for parking lots, and limitation in local power production, respectively. The active and reactive injection power to the buses in (10) and (11), respectively, and the active and reactive power of the lines in (12) and (13) are visible.

C. Modeling distributed generations

The sources of distributed power generation studied in this paper include photovoltaic and wind power generations as renewable power generation [33], and the power generation sources of micro-turbine and fuel cell as non-renewable power generation [34,35].

$$P_{pv}^{t,j} = \eta_g n A_m G_t \tag{14}$$

Where η_g is the instantaneous PV generator efficiency, A_m the area of a single module used in a system (m^2), G_t the global irradiance incident on the titled plane (W/m^2) and N is the number of modules.

$$P_{wt}^{t,j} = \begin{cases} 0 & v_w^t < v_{min} \; or \; v_w^t > v_{max} \\ \frac{v_w^t - v_{min}}{v_r - v_{min}} & v_{min} \le v_w^t < v_r \\ P_r & v_r \le v_w^t < v_{max} \end{cases} \tag{15}$$

$$P_{DG}^{t,j} = P_{pv}^{t,j} + P_{wt}^{t,j} \tag{16}$$

$$\pi_{LDG}(t) = \left(U^t \middle/ P_{LDG}^t \right) + b \cdot P_{LDG}^t \tag{17}$$

$$P_{LDG}^t - P_{LDG}^{t-1} \le RU \tag{18}$$

$$P_{LDG}^{t-1} - P_{LDG}^t \le RD \tag{19}$$

$$P_{LDG,min}^t \le P_{LDG}^t \le P_{LDG,max}^t \tag{20}$$

The equations (14) and (15) respectively represent the output of photovoltaic power generation and dependence on the solar radiation level and the output of wind power generation, depending on velocity of the wind. Equation (16) shows distributed renewable energy generations at time t and bus j is equal to wind and photovoltaic power generation. Equation (17) expresses the cost of local non-renewable electricity production based on the output power and amount of start-up cost per kilowatt of production. The constraints (18 to 20) are correlated with the rate of power growth, power loss and local generation capacity.

III. ENERGY MANAGEMENT AT THE EVs PARKING LOT LEVEL

The ideal conditions for EVs owners are to provide their energy at the cheapest time steps of vehicle presence in the parking lot. In addition, owners of EVs can earn revenue by doing charge and discharge managed at the other time steps of their presence in the parking lot. Therefore, if the average price of energy at the effective rate of return is taken as the base price, buying energy at a lower price and selling energy at a higher price than the base price increases the economic benefits of electric vehicle owners. Also, the larger the time step price difference from the base price, the more profitable the EV. Thus, by analyzing the state of charge of electric vehicles and analyzing the price of energy charges, the degree of profitability of electric vehicles is determined (see Fig.2).

In the proposed method, the percentage (half) of the financial benefits of EVs is allocated to the owner of the parking lot. On the other hand, due to limited capacity of parking lots, the benefits of all EVs can't be provided. Therefore, the owner of the parking lot is trying to support a vehicle that is more profitable.

A. Determine the level of power exchange between EVs and the network through parking lot

The level of power exchange between EVs and the network (through parking) is optimized by linear programming. The purpose of determining the level of power exchange between EVs with the network based on the financial profitability of EVs is to maximize the revenue of set of EVs inside parking lot.

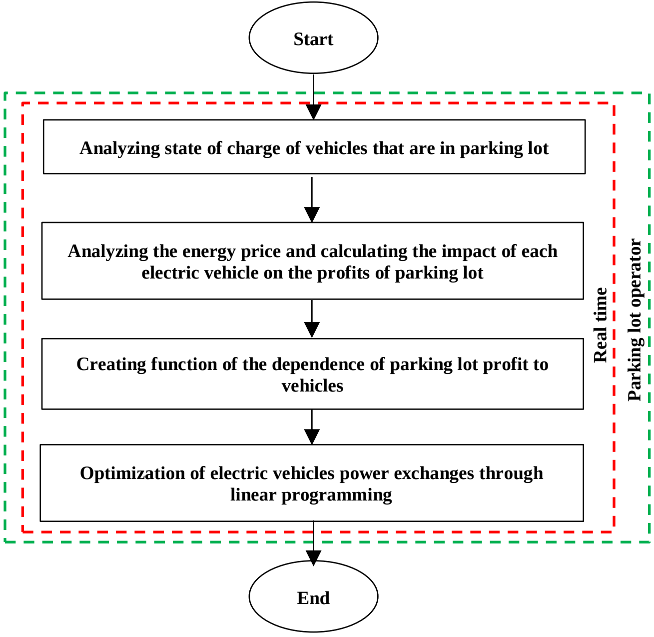

Fig.2. Flowchart of the parking lot operator behavior

$$max\left\{\sum_{e=1}^{n}\left[M_c^{e,t}\cdot P_{EV}^{e,t}\right]-K\left|P_P-\sum_{e=1}^{n}P_{EV}^{e,t}\right|\right\} \tag{21}$$

Constraints of linear optimization method will also be managed with regard to EVs constraints.

$$P_{EV,min}^{e,t}\leq P_{EV}^{e,t}\leq P_{EV,max}^{e,t} \tag{22}$$

Equation (21) expresses the goal of the parking operator in two parts. The first part is related to the financial benefits of EVs inside the parking lot. The second part is guaranteed to maintain parking capacity within the allowed range. K is a great value which puts the greatest benefit of parking in subject to achievement the parking design capacity.

The analysis of the state of charge of EVs shows the amount of power required or the excess energy stored in the battery of EVs for the parking operator. In this regard, final state of charge of EVs is considered as a reference for state of charge. Based on the difference in state of charge of each vehicle from its reference value, the number of required steps one-hour is calculated to provide the vehicle's final energy according to equation (23).

$$T_m^{e,t}=\frac{(soc_{fin}^{e}-soc^{e,t})\times E_{batt}^{e}}{P_{charger}^{e}} \tag{23}$$

The parking lot operator calculates the profitability of existing EVs in the parking lot by analyzing energy price. In this regard, according to the results of the analysis of the state of charge of EVs, the cheapest time steps for the providing of final energy of vehicle are predicted and the average price of other steps will be considered as a reference price. The price deviation of each step compared to the price reference indicates the amount of profitability of the electric vehicle at that time step.

The average energy price in time steps and the charge motive function of the vehicle are presented using equations (24) and (25).

$$C_{avg}^{e,t}=\frac{\sum_{l}\pi_P^{l}}{t_{ex}^{e,t}-T_m^{e,t}}\ ,\ l\in A \tag{24}$$

$$M_c^{e,t}=C_{avg}^{e,t}-\pi_P^{t} \tag{25}$$

B. Modeling of EVs

The most important parameters in modeling the behavior of EVs are battery capacity, state of charge of battery at any time step, and charger power. In this regard, the technical constraints and limitations below are important [36].

$$\left(1-D_{plag}^{e,t}\right)\left(P_{ch}^{e,t}+P_{dis}^{e,t}\right)=0 \tag{26}$$

$$P_{ch}^{e,t}\times P_{dis}^{e,t}=0 \tag{27}$$

$$0\leq \mathrm{Q}_{\mathrm{ch}}^{\mathrm{e,t}}\leq (soc_{max}^{e}-soc^{e,t})\cdot E_{batt}^{e} \tag{28}$$

$$0\leq \mathrm{Q}_{\mathrm{dis}}^{\mathrm{e,t}}\leq (soc^{e,t}-soc_{min}^{e})\cdot E_{batt}^{e} \tag{29}$$

$$P_{ch}^{e,t}\leq P_{charger}^{e} \tag{30}$$

$$P_{dis}^{e,t}\leq P_{charger}^{e} \tag{31}$$

$$soc^{e,t_{ex}}\geq soc_{fin}^{e} \tag{32}$$

$$soc^{e,t+1}=soc^{e,t}+\left(\frac{P_{EV}^{e,t}}{E_{batt}^{e}}\right) \tag{33}$$

$$P_{EV}^{e,t}=P_{ch}^{e,t}+P_{dis}^{e,t} \tag{34}$$

$$P_p^{j,t}=\sum_{e}^{n}P_{EV}^{e,t} \tag{35}$$

Based on (26), EVs have the ability to exchange with the network only if they are connected to the network. Furthermore, EVs do not have the ability to simultaneously charge and discharge, which is modeled (27). The available capacity for charging and discharging EVs is modeled in (28) and (29). Equations (30) and (31) model the charger's limitation and (32) represents a guarantee for the providing energy required for EVs. The charging state of EVs at the end of each step is calculated according to (33). Equation (34) also indicates the power exchanged with each EV at each node. It should be noted that equations (26) to (34) are valid for all nodes. Equation (35) also shows the total power exchanged with each parking lot at any time.

IV. SIMULATIONS AND NUMERICAL STUDIES

In this section, the proposed bi-level energy management method will be tested. In this study, simulation is presented using GAMS optimization software tasted on the standard IEEE 33-bus network [38]. In this regard, in order to verify the validity of the proposed method, the behavior of DSO has been investigated in six states. These states, which depend on the level of penetration of distributed power generation and EVs, are shown in Table I. The second part of the study was done in a sample parking lot and the parking operator's behavior was investigated in three states. In the first and second modes, the ability to change the parking capacity is about 1/4 and 1/8 of parking design capacity, respectively. In the third case, parking constraints are not considered and parking operator behavior is only in order to meet the needs of EVs.

TABLE I
Penetration Level of Local Generation and Evs in Study Scenarios

Study of DSO behavior	**Study states**					
	1	2	3	4	5	6
Penetration level of local generation	66%	66%	66%	33%	33%	33%
Penetration level of EVs	0%	30%	50%	0%	30%	50%

A. Input data

The initial information required to study the behavior of the DSO under the proposed method of energy management involves predicting the behavior of distributed generations, energy price, and energy consumptions. This information is presented in Fig.3 [28, 39].

Initial information on fuel cell and microturbine energy sources is also provided in Table II [34, 35]. Additionally, the allowed voltage deviation is considered to be 0.05 per unit [40]. In this study, half of local power productions are allocated to photovoltaic and 40% to wind resources, and the rest to non-renewable productions. In addition, four parking spaces are located at buss 9, 15, 27 and 32 with a design capacity of 500 KWh and a 25% changeability capability.

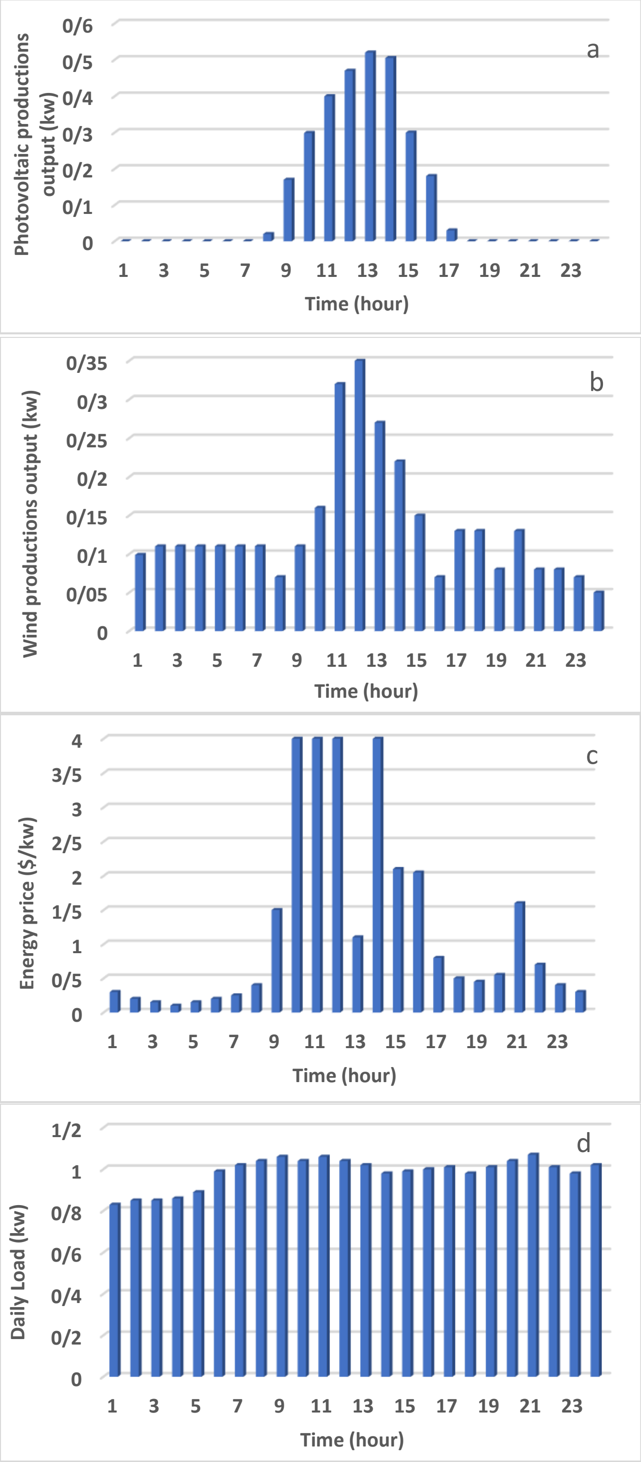

Fig.3. a) Output of photovoltaic power generation. b) output of wind power generation. c) Energy prices at one hour's steps. d) predicted daily load figure

TABLE II
Information of Non-Renewable Local Power Generations

Type	a	b	P_{min}	P_{max}	MUT	MDT	RU	RD
Micro turbine	0.015	0.01	150	700	3	3	350	350
Fuel cell	0.02	0.01	50	300	1	1	150	150

The initial information for EVs is presented in Table III. The EVs in this study use batteries with a capacity between 10 and 30 kWh [41]. In addition, the charger power used for EVs is up to 2.5 kWh. This power is related to parking lots with a voltage level of 208 to 240 V and a current of about 10 A [27]. On the other hand, for the purpose of increasing the battery life of EVs and preventing high discharge, as well as guaranteeing the availability of EVs in an emergency, the minimum state of charge is 30% of the vehicle's battery capacity.

TABLE III
Information of Evs Studied in Sample Parking

Type	Input time(h)	Exit time(h)	Input SOC (%)	Exit SOC (%)	Battery capacity (kWh)	Number
vehicle fleet 1	1	6	30	80	18	260
vehicle fleet 2	2	9	45	85	21	240
vehicle fleet 3	7	13	45	90	18	165
vehicle fleet 4	8	16	30	85	18	150
vehicle fleet 5	13	21	30	80	20	185
vehicle fleet 6	19	24	40	85	24	240

In this study, the fleet of EVs was examined in three categories. The first category of EVs enter the parking lot before the peak of renewable generations. The second and third categories are present in the parking lot during and after the peak of renewables generations. Each of these three categories, according to the input SOC, is grouped into two groups with input SOC and without input SOC.

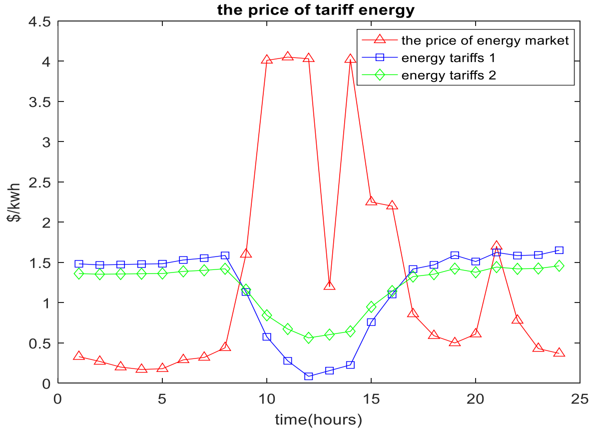

Fig.4. Tariff energy price provided by DSO

B. Results of optimization of DSO behavior

DSO calculates the energy price in the first step. Fig. 4 shows the tariff decision results. On the other hand, as can be seen from the figure, parking lots have low energy costs during 10:00 to 15:00 (the peak of renewable energy generation), and expensive at the peak of energy consumption. In addition, the energy tariff 1 in the peak hours of renewable energy generations is cheaper than the energy tariff 2. Because energy tariff 1 is related to the penetration level of 66% of local generations and energy tariff 2 is related to the penetration of 33% of local generations.

The bus voltage level of the distribution network at peak hours of energy consumption (at 21:00 o'clock) and the peak of renewable generation (at 13:00 o'clock) is shown in Fig.5 and Fig.6.

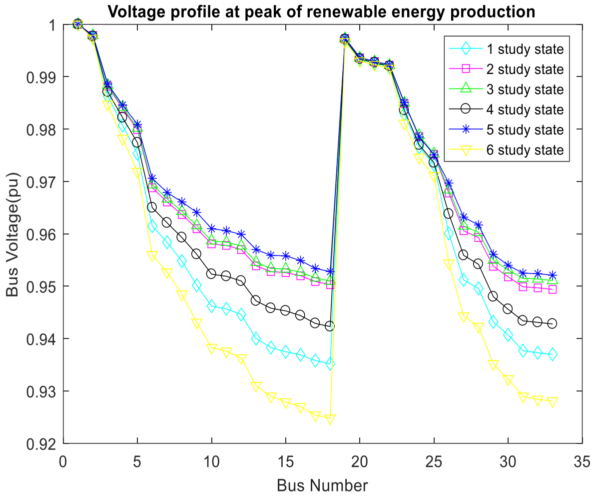

Fig.5. Network voltage level at the peak of renewable power generation

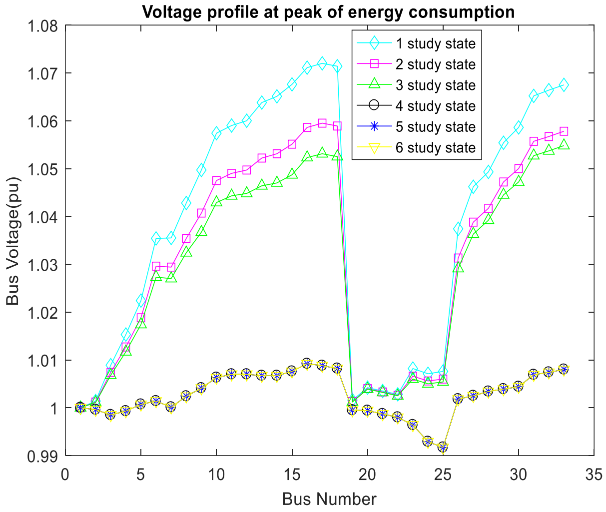

Fig.6. Network voltage level at peak power consumption

By reflecting to Fig. 5, in State 3, while penetration coefficient of EVs and renewable energy sources is simultaneously at its highest value, the voltage level is in the best way within the permissible range. From Fig.6, it can be seen that with increase of penetration of EVs (from state 1 to 3), the voltage profile of the buses is in a better range. This shows that the increasing penetration of EVs will help to improve the voltage profile in all buses.

As presented in Fig.7 an imbalance between local production and energy consumption exists. When the wind and photovoltaic power generation are at their highest level (10:00-15:00), the power generation is more than of consumption, on the other hand, during the peak consumption hours (18:00-23:00), the amount of consumption is more than production, and this imbalance must be compensated at a later stage.

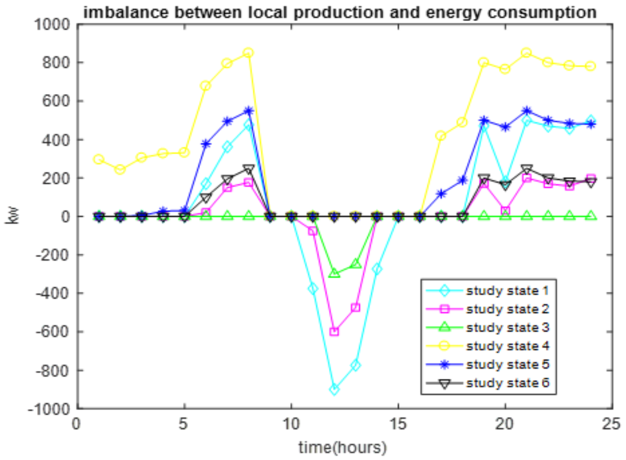

Fig.7. Imbalance between local generations

The results of optimal power flow manage the level of power exchange (capacity) of the parking lots. This is presented in Fig.8. As it is clear from this figure, the level of energy exchange of parking lots decreases during peak consumption hours (18:00-24:00) or when renewable energy generation decreases (5:00-8:00). Instead, in the peak state of production of renewable energy resources (10:00-15:00) the energy exchange level of the parking lots has increased and reached 650 KW in the highest state.

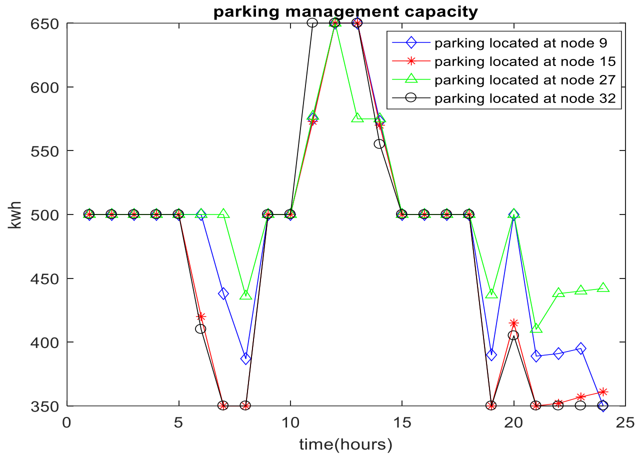

Fig.8. Parking lots managed capacity

At some times steps, parking design capacity is unchanged. In these intervals, local generation and energy consumption are at a level. In other words, energy consumptions are provided locally, or the supply of energy from the upstream network will not violate the network conditions.

The proposed model could also capitalize on the positive potential of connecting electric vehicles to the grid to increase the use of renewable energy.

C. Results of optimization of parking operator behavior

The power exchange level between parking and network for the three study states in Fig.9 is investigated. State 3, which shows the level of power needs of vehicle, expresses that the needs of the EVs aren't matched to the parking capacity.

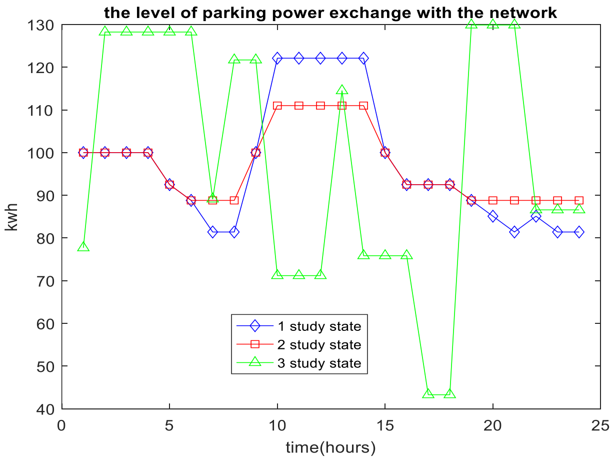

Fig.9. Power exchange level of parking with the network

The cumulative profit of the parking operator for the two study states 1 and 2 is compared in Fig.10. This is the result of the difference of parking cost in two states than the parking cost for state 3 (Elimination of the power needs of EVs). As it is known, parking is in the first state more profitable.

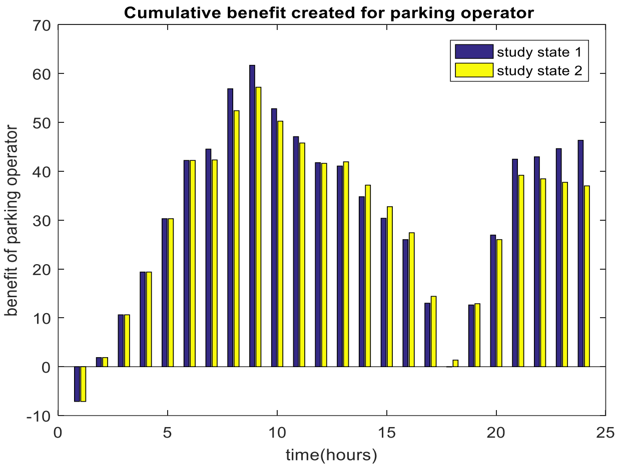

Fig.10. Cumulative profit created for parking operator

The results of the management program of charging/discharging EVs based on linear optimization are shown in Table IV. The fleet of EVs that were present in the parking lot before the peak of renewable generations, with the release of available battery capacity at expensive intervals, provided their energy at the peak of renewable generations.

For example, during 2:00-4:00, when renewable energy generation is low due to the lack of solar energy, in fleet 2, EVs benefit by discharging their batteries and selling power to the grid. Then during 6:00-9:00, when renewable energy generation increases, EVs receive energy from the grid and charge their batteries. The fleets of EVs that were in parking lots after peak renewable energy generation increased their financial benefits by transferring power from peak hours of renewable energy generation to peak consumption hours. In the meantime, the fleet of EVs that provided energy at the peak of renewable generations made the balance between power consumption and production.

TABLE IV
Results for Scheduling of Evs State Of Charge

hour	SOC of vehicle1 (%)	SOC of vehicle2 (%)	SOC of vehicle3 (%)	SOC of vehicle4 (%)	SOC of vehicle5 (%)	SOC of vehicle6 (%)
1	40.71					
2	54.6	42.07				
3	68.49	39.14				
4	82.38	36.21				
5	81.73	45.97				
6	80.68	55.73				
7		67.63	39.75			
8		79.53	30	35.07		
9		85	42	30		
10			54	37.33		
11			66	44.67		
12			78	52		
13			90	52	35.28	
14				63	42.36	
15				74	47.94	
16				85	53.02	
17					65.52	
18					78.02	
19					78.02	48.01
20					78.02	55.71
21					80	62.13
22						69.82
23						77.51
24						85.21

In order to better understand the performance of electric vehicle battery charging process in the presence of renewable energy sources, Fig.11 is presented.

In Fig.11, the SOC of EVs batteries for fleet 3 and fleet 4 are shown during the hours of high penetration of renewable energy sources. These two fleets enter the parking lot before the extensive renewable energy generation and leave the parking lot after its reduction. As seen in the performances of these two fleets, with the increase in wind and photovoltaic energy generation, EV owners charge their batteries more and increase their SOC. In fact, these EVs have supported the increase in renewable energy generation by managing their SOC.

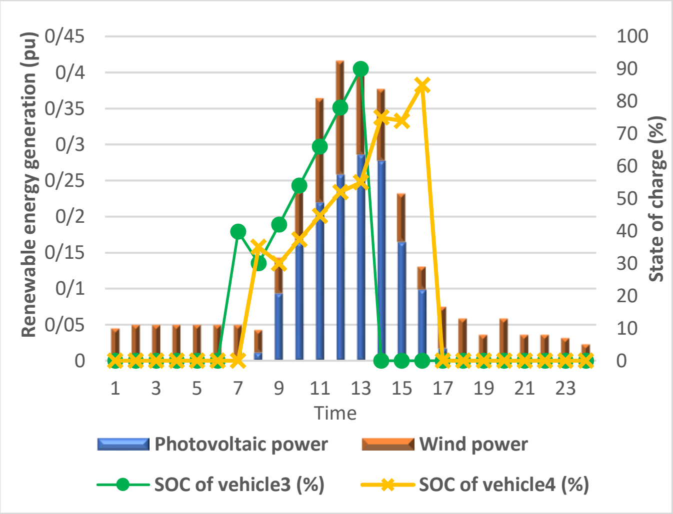

Fig.11. SOC of vehicle fleet 3 and vehicle fleet 4

V. CONCLUSION

This study sought to assess the impact of using energy prices as a basis for establishing coordination among EVs and the output of renewable energy sources in two stages. In addition, the freedom of EVs has been used to offset the imbalance between energy consumption and production. As seen from the simulation results, the profit of electric vehicles has increased and the grid voltage profile has also improved. It was observed that by using the presented method, the capacities of EVs parking lots are well managed. The proposed model could also capitalize on the positive potential of connecting EVs to the electricity distribution network to increase the use of renewable energy.

NOMENCLATURE

Indexes

A	Index of time steps that considered for earning revenue of EV
β	Variability coefficient of design capacity of parking lots
e	Index of EVs
i, j	Index of Buses
n	Index related to number of EVs available in the parking lot
N	Total number of buses in network
t	Index of Time
t_{ex}	Index related to the time which the EV exits from the parking lot
x	Percentage of daily consumptions that local productions are considered to meet them
γ	Impact of tariff price from diversion between renewable production and energy consumption

Parameters

a, b	Coefficient of cost function of non-renewable productions
δ_i	Voltage angle at bus i
δ_{ij}	The angle difference between the voltages of buses i and j
E_{batt}^{e}	Battery capacity of EV
$M_c^{e,t}$	The charge motive function of the vehicle e based on the energy price at time t
MDT	Minimum downtime
MUT	Minimum uptime
π^t	Price of energy market
π_l^t	Contractual energy price between DSO and uncontrollable consumptions
π_{LDG}^t	Energy price of non-renewable productions
$P_{charger}^{e}$	Charger power of EV e
$P_{EV,max}^{e,t}$	Maximum level of vehicle power exchange with the network
$P_{EV,min}^{e,t}$	Minimum level of vehicle power exchange with the network
$P_{lDG,max}$	Maximum output of non-renewable energy production
$P_{lDG,min}$	Minimum output of non-renewable energy production

$P_l^{t,j}$	Power consumption of uncontrollable loads at time t and bus j
$\mathrm{Q}_{\mathrm{ch}}^{e,t}$	Capacity available for charging EV at time t
$\mathrm{Q}_{\mathrm{dis}}^{e,t}$	Capacity available for discharging EV at time t
RD	Power downward rate for non-renewable productions
RU	Power upward rate for non-renewable productions
$S_{ij,max}$	Maximum power of the line between buss i and j
$S_{DG,max}$	Maximum of distributed generation output
soc_{fin}^{e}	Final state of charge of EV e
soc_{max}^{e}	Maximum of state of charge of EV e
soc_{min}^{e}	Minimum of state of charge of EV e
$T_m^{e,t}$	The time it takes to prepare the vehicle e for the first zero at time t
θ_{ij}	Angle of Y_{ij}
U	Start-up cost of non-renewable productions
V_m	Voltage of bus m
V_{max}	Maximum network voltage level
V_{min}	Minimum network voltage level
Y_{ij}	Admittance of line between buses i and j

Variables

$C_{avg}^{e,t}$	Average energy price in time steps related to index A
$D_{plag}^{e,t}$	A binary variable indicating that vehicle e be in the parking lot at a time step t
π_{avg}	The average 24-hour cost of providing energy of EVs
π_P^t	Tariff energy price for parking lots
$P_{ch}^{e,t}$	Transferred power from network to EV at time t
$P_{dis}^{e,t}$	Transferred power from EV e to the network at time t
$P_{DG}^{t,j}$	Output of distributed renewable energy generations at time t and bus j
$P_{EV}^{e,t}$	Power exchange level of vehicle e with the network at time t
p_i	Injected active power to bus i
p_{ij}	Active power of the line between buss i and j
$P_{LDG}^{t,j}$	Output of non-renewable energy generation at time t and bus j
$P_p^{t,j}$	Level of power exchanges based on the tariff price between the network and parking lot at time t and bus j
P_{pv}^t	Photovoltaic power generation output
P_{wt}^t	Wind power generation output
q_i	Injected reactive power to bus i
q_{ij}	Reactive power of the line between buss i and j
$soc^{e,t}$	State of charge of EV at time t

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