Effects of EV-parking lots on transmission lines congestion and price in the electricity market

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ABSTRACT

Nowadays, the use of distributed energy resources (DERs) is increase to supply loads in power system. EV-parking lots are one of these resources that presence of them in the system can have an influential impact on improvement of operation conditions and electricity price in the market. In this paper, an algorithm is proposed for participation of EV-parking lot in the market and selection of optimal parking. Results show that the presence of EV-parking lots in the electricity market can reduce the market total cost and the congestion costs.

INTRODUCTION

With the decrease of fossil fuel resources, researchers are seeking for new technologies of energy. Different types of distributed enrgy resources (DERs) have been introduced in recent decades one of which is electrical vehicles with the ability to connect to the grid, refered to as V2G (vehicle to grid). On the other hand, with the restructuring of the electricity industry and appearance of competitive electricity market, parking lots can participate in the market as a virtual power plant and inject power to the network if they win. The importance of distributed energy sources such as electrical viechle (EV) parking lots are more clarified when the congestion occurs in the transmission lines and system cannot provide a part of load. Therefore, other generation units should be operated based on constraints. Since these units do not win in the first step of market clearance, because of higher prices, the electricity price in the market may increase and even a big price jump happens in the market. In this situation, DERs which are close to the loads can be operated to prevent system blackouts and market price increase. In this paper, an algorithm is presented for selecting optimal parking lots from ISO's view point to participate in the market for mitigating congestions in the lines. Two step clearance methods are used to balance price and announce the winner in the market [1, 2].

EFFECT OF EV-PARKING LOTS ON LINE CONGESTION AND ELECTRICITY MARKET PRICE

Power system constraints should be considered in the operation to maintain the system stable. So, the system should have a safety margin. On the other hand, appearance of competitive electricity market and privatization of electricity industry, operators incline to operate system so close to their boundaries to achieve maximum benefit. In such circumstances, management has an important role in the use of existing facilities based on the conditions. The importance of management is determined when system experience a critical situation. One of these critical situations is system peak condition. If an efficient interaction is not performed between the system operators and market operators, a part of load will not be supplied. One of these constraints is transmission lines capacity limit. This limit can cause the congestion in the transmission lines when the lines load ability limit is violated. In congestion which actually means the operation of the system in the permissible boundaries the unsupplied load should be supplied by using the other lines and units. On the other hand, in the electricity market, after the ISO receives the bids from generators and consumers, market is run and the winner announced. Obviously, first the units with the lower price will win and operate. But if congestion occurs in the system, units with higher price should be operated, leading to the increase of electricity price in the market. Power system is an interconnected network all components of which affect each other's performance. When congestion occurs in a line, operator has to transfer its load to the other lines, so the probability of congestion increases in other lines. Another factor that can exacerbate the congestion is the level of system loading in the peak time. In this time period, all lines are loaded close to their boundaries. So, all these factors can cause congestion and successive interruptions result in market price growth [1, 3-4]. In this situation, congestion management should be done to control the congestion with the aim of providing system's all loads and preventing electricity price growth. Sometimes using distributed generation resources instead of conventional units can be more effective due to low capacity and lower operation cost. These resources have lower price in the market and because of proximity to the consumer, when congestion occurs in the transmission lines, these resources can easily supply the loads. One of these resources is EV-parking lots that can have an effective role in the system. The important matter is the selection of the EV-parking lots which can be more effective both in the congestion times and algorithm of entering the parking in the market equations. So the proposed algorithm illustrated in the next section.

PROPOSED ALGORITHM

There are different methods to manage market. Two-step market clearance is the one that is used in this paper. In this method, as shown in figure 1, first the generation units give their bids to ISO. Then, without considering the transmission network constraints, ISO clears the electricity market and results are informed to generators and consumers. Then, the load flow program is used to check if transmission constraints are established due to market outcomes or not. If any of system's constraints has been violated, generators give new bids to ISO for changing power generations of their units according to market results. Afterwards, the ISO minimizes the total cost of units' generation changes against market results, called congestion costs, with a re-optimization process to establish the transmission network constraints. EV-parking lots can be used in both phases of the process. In this paper, EV-parking lots are used during the market re-dispatch process which means that if transmission line's constraints are violated, market clearance is performed two more time, once with considering the transmission line's constraints and once with considering EV-parking lots. Finally, the total cost of market and congestion cost in the presence and absence of EV-parking lots are compared and the efficient case is determined. In the next section, relations of the market in both cases are presented.

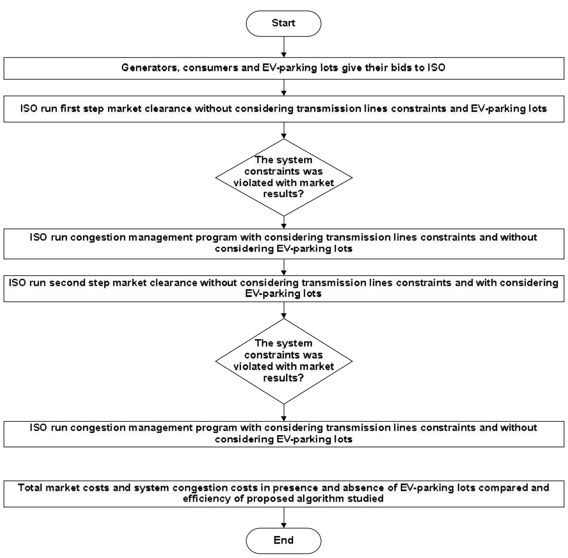

Fig .1. Proposed algorithm

Market functions without considering EV-parking lots

The objective of electricity market is maximization of social welfare that is total surplus benefit of generators and consumers. Following relations show market objective function and constraints without considering EV-parking lots [5]:

$$Max: \sum_{i=1}^{N_D} \sum_{k=1}^{N_{Di}} (\rho_{Di,k} . P_{Di,k}) - \sum_{j=1}^{N_G} \sum_{l=1}^{N_{Gj}} (\rho_{Gj,l} . P_{Gj,l}) \quad (1)$$

$$S.t:$$

$$0 \le P_{Di,k} \le P_{Di,k}^{\max}, \forall i = 1, ..., N_D, \forall k = 1, ..., N_{Di} \quad (2)$$

$$0 \le P_{Gj,l} \le P_{Gj,l}^{\max}, \forall j = 1, ..., N_G, \forall l = 1, ..., N_{Gj} \quad (3)$$

$$u_j \sum_{l=1}^{N_{Gj}} P_{Gj,l}^{\min} \le \sum_{l=1}^{N_{Gj}} P_{Gj,l} \le u_j \sum_{l=1}^{N_{Gj}} P_{Gj,l}^{\max}, \forall j \in G \quad (4)$$

$$\sum_{i=1}^{N_D} \sum_{k=1}^{N_{Di}} P_{Di,k} = \sum_{j=1}^{N_G} \sum_{l=1}^{N_{Gj}} P_{Gj,l} \quad (5)$$

By considering all the above constraints, ISO runs the market and determines the power each unit should be generated. Now, ISO checks the transmission lines constraints according to achieved results. If any constraint is violated and congestion has occurred, the re-dispatch program for power plants runs. Actually, another optimization program is required to minimize the cost of re-dispatch (congestion cost) that is imposed by transmission line constraints. Following equations show the re-dispatch objective function and constraints [5].

$$Min: \sum_{j \in G} (r_j^{up} \Delta P_{Gj}^{up} + r_j^{down} \Delta P_{Gj}^{down}) \quad (6)$$

$$S.t:$$

$$P_{Gn}^A + \Delta P_{Gn}^{up} - \Delta P_{Gn}^{down} - P_{Dn}^A - \sum_{m \in \Omega_n} B_{nm}(\delta_n - \delta_m) = 0, \forall n = 1, ..., N \quad (7)$$

$$-P_{nm}^{\max} \le B_{nm}(\delta_n - \delta_m) \le P_{nm}^{\max}, \quad \forall n = 1, ..., N, \forall m \in \Omega_n \quad (8)$$

$$u_j P_{Gj}^{\min} \le P_{Gj}^A + \Delta P_{Gj}^{up} - \Delta P_{Gj}^{down} \le u_j P_{Gj}^{\max}, \quad \forall j = 1, ..., N_G \quad (9)$$

$$\Delta P_{Gn}^{up} = \sum_{j \in G_n} \Delta P_{Gj}^{up}, \forall n = 1, ..., N \quad (10)$$

$$\Delta P_{Gn}^{down} = \sum_{j \in G_n} \Delta P_{Gj}^{down}, \quad \forall n = 1, ..., N \quad (11)$$

$$P_{Gn}^A = \sum_{j \in G_n} P_{Gj}^A, \forall n = 1, ..., N \quad (12)$$

$$P_{Dn}^A = \sum_{i \in D_n} P_{Di}^A, \forall n = 1, ..., N \quad (13)$$

Objective function has two parts in this case. The first part is that the total cost must be paid to the power plants which increase their generation because of line's congestion. The second part is the total cost must be paid to power plants which have decrease their generations from winning amount in the market.

Market functions with considering EV-parking lots

Market equations and the equations used in re-dispatch program with consideration of EV-parking lots are similar to pervious section equations and only differ in some details. The following equations illustrate market and its constraints in the presence of EV-parking lots.

$$Max: \sum_{i=1}^{N_D} \sum_{k=1}^{N_{Di}} (\rho_{Di,k} . P_{Di,k}) - \sum_{j=1}^{N_G} \sum_{l=1}^{N_{Gj}} (\rho_{Gj,l} . P_{Gj,l}) - \sum_{i=1}^{N_{plD}} \sum_{k=1}^{N_{Di}} (\rho_{plDi,k} . P_{plDi,k}) \quad (14)$$

The third part that is added to the above equation is related to ith parking lots' participation in the market with offered price, $\rho_{plDi,k}$ and the re-dispatch program objective function changes in the below pattern:

$$Min: \sum_{j\hat{I}G} (r_j^{up} \Delta P_{Gj}^{up} + r_j^{down} \Delta P_{Gj}^{down}) + \sum_{i\hat{I}plD} (r_i^{down} \Delta P_{plDi}^{down}) \quad (15)$$

Part one and two of this function are similar to the pervious section. The third part is the total costs paid to the EV-parking lots' which participating in the market and supplying the part of loads.

OPTIMAL PARKING LOT SELECTION WHEN CONGESTION OCCURS

Firstly EV-parking lots which want to participate in the market give their bids to ISO. Then, ISO should select the optimal parking to prevent price spikes in the market and improve social welfare. In this paper, three conditions are recommended for optimal EV-parking lot that can achieve the above mentioned goal. So the EV-parking lot can participate in the market that has: 1) the least distance from the buses that have the maximum impact on reducing the overload, 2) the minimum proposed price between the parking lots with the least distance from the buses which have the maximum impact on reducing overload and 3) has high reliability level (high reliability level means that is has reliable power supply according to the historical data).

As noted above, the buses with the maximum impact on congestion (overload) should be determined. Usually, the system operator uses sensitivity analysis to identify the buses that have the maximum impact on reducing overload in system. In this paper, *GSF* factor is used and defined as follows:

$$GSF_{l,i} = \frac{\Delta f_i}{\Delta p_i} \quad (16)$$

Δp_l, is the change in generation of bus i, Δf_l is change in power transmission of line l because of change Δp in generation of bus i. This paper assumes that changes in generation, Δp_i exactly compensated with the opposite changes in the slack bus and generation of other units remain constant. So, $GSF_{l,i}$ factor shows the sensitivity of transmission power from line l against change in generation of bus i. By using GSF factor the operator can identify that the interruptions of generation in bus i, in which lines can cause the overload. So, those buses with the maximum impact on system overload can be identified. Therefore, the optimal EV-parking lots for participating in the market is nearest parking to the buses have maximum impact on system's overload.

SIMULATION

In this paper, system and electricity market behavior are studied when the congestion in transmission lines occurs. During the peak time, the probability of congestion in lines increases. So, during the simulation process all of the loads are assumed at their peak level to achieve the critical conditions of the system. According to the proposed algorithm, market clearance runs in two different cases of presence and absence of EV-parking lots and the optimal case is determined.

To demonstrate the efficiency of the proposed algorithm, IEEE 57-bus system is implemented in *MATLAB* software. This test system, due to the proximity to the actual network and existence of several buses can show the impact of EV-parking lots in the network. EV-parking lots give their bids to ISO for the peak and off-peak time periods. We assume that there are10 EV-parking lots in the system and their proposed price for non-peak and peak hours are 14$ and 25$, respectively. Table 1 shows the properties of EV-parking lots.

Table 1. Properties of EV-parking lots

Parking number	Capacity	Bus number
1	500	1
2	500	6
3	1000	19
4	1000	30
5	1000	32
6	1000	33
7	1500	35
8	1500	43
9	1500	54
10	2000	55
11	3000	14
12	5000	13

At first in order to determine the buses with maximum impact on system overload, sensitivity analysis is performed. Now the operator receives bids only from EV-parking lots that are close to designated buses. By applying GSF factor to desired system buses 3, 8, 9, 12, 13, 14, 18, 27, 29 and 38 specified. After specifying the buses with maximum impact on the system overloads and receiving the parking price bids and load modeling, ISO runs the two-step market clearance program. In the first step, the market is cleared and congestion management is performed without considering EV-parking lots and in the next step, the EV-parking lots that are close to the specified buses are participated in the market clearance.

Case one: market clearance without considering EV-parking lots

In this case market clearance runs twice; once without considering transmission lines constraints and once with considering those constraints. Table 2 shows the generation of units in the market clearance in absence of EV-parking lots. In this case the system is in the normal operating mode.

Table 2. Outputs of generators in normal mode

Gen. number	Bus number	Generation(MWh)
1	1	139.46
2	2	81.93
3	3	43.28
4	6	81.93
5	8	486.87
6	9	83.93
7	12	335.4

Case two: market clearing with considering the EV-parking lots

In this case, market clearance runs twice, once without considering transmission lines constraints and EV-parking lots and once without considering these constraints and with considering EV-parking lots. Then, total market cost and congestion costs of two case studies are compared and the optimal case is determined. In this paper, the proposed prices of all EV-parking lots are same. Thus, the decisions are based on sensitivity factor and closeness to the bus with maximum impact on system overload. So, the parking near the buses 1, 6, 13, 14, 19, 54, 55 are victorious in the market. Output of the generators is depicted in this case in table 3. As shown below, part of the system loads is supplied with these EV-parking lots.

Table 3. Output of generators in the presence of EV-parking lots

Gen. number	Bus number	Generation (MWh)	EV-parking generation
1	1	137.69	1.77
2	2	78.18	3.75
3	3	43.73	0.55
4	6	78.18	3.75
5	8	484.68	3.19
6	9	78.18	3.75
7	12	331.14	4.26

The results attained in two case studies are compared in figure 2 and 3. The first diagram is shows the congestion cost and the second diagram show the total market cost in both cases. Participation of EV-parking lots at the peak hours, when transmission lines are congested, results in the 12.7 percent reduction of congestion cost and also results in the 3.14 percent reduction of total market cost. As noted above, simulation is performed based on load model in peak hours, so that the critical condition is studied.

Case three: reliability and spinning reserve test

In this section, reliability of system is investigated in the cases of presence and absence of EV-parking lots in loads supply. The energy not supplied (ENS) Factor is used to evaluate the system. The results show that the system ENS factor has improved 9.88 percent. This improvement is due to proximity of these resources to the consumer and there is not any contingency for lines in this situation. In addition, taking advantage of these resources as a spinning reserve of system has been investigated. The results show that if the capacity of EV-parking lots is 5 MW or more, these resources can be used as spinning reserves.

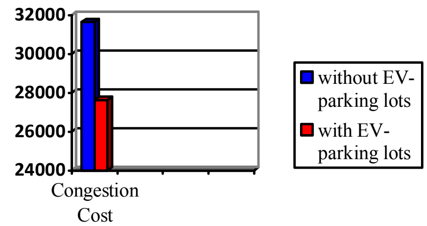

Fig 2. Systems' congestion cost ($/hour)

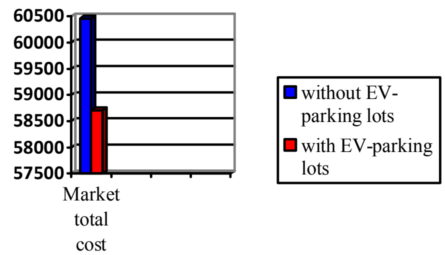

Fig 3. Market total cost ($/hour)

CONCLUSION

As the numerical results show, participation of EV-parking lots in the market during the peak times can reduce the market total cost. Thus, the price spikes can be prevented and congestion cost that is imposed on the system because of lines constraints can be controlled. Placement of EV-parking lots is another important issue in a city, that if the EV-parking is located in the right place, it can efficiently affect the electricity market and control the electricity price. It is essential to note that, this paper proposes an algorithm for placement and participating of EV-parking lots in the market from ISO's viewpoint. Usage of EV-parking lots in the system for supplying the loads can also improve the system's reliability.

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