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A multi-objective optimization problem for allocating parking lots in a distribution network

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ABSTRACT

This paper presents a multi-objective approach to determine optimal site and size of parking lots, which provide vehicle to grid (V2G) power in distribution system as new type of distributed generations (DGs). In this approach, the reliability of distribution system and power losses along with investment cost are considered in optimization problem. This optimization problem is solved using genetic algorithm (GA) method. Simulation study is carried out on a nine bus test system. The results of simulations show that the economic issue of parking lots installation depends on many factors such as availability of electric vehicles (EVs) as well as the electricity price. Also, it is shown that by taking enough incentive for EVs owners, optimal sitting and sizing of parking lots has economical benefit for distribution system companies. Also, optimal allocation of parking lots can improve the distribution system voltage profile.

1. Introduction

In recent years several problems including environmental issues, decrease in fuel quantity and volatility in its price and the need for decreasing dependency on fossil fuels caused the electric vehicles (EVs) get known as an effective resource in transportation and power system [1–5]. As addressed in [6], the backbone of smart grid emphasis on environmental protection, using variable generation (such as wind and solar), demand response, and distributed generation (DG) including EV technology, driving for better asset utilization, while maintaining reliable system operation, and the need for enhanced customer choice. Fig. 1 depicts these factors in relation to the new emerging smart grid paradigm, and illustrates the role of EV technology in the new era [7]. In [8,9], it is shown that vehicles are parked for about 93–96% time during a day. Therefore, they are available for other purposes such as serving as storage device to the grid. Based on this fact and the increasing need for economical storages in power system, EVs are suggested to be used as limited energy resources in power system [10]. Additionally, EVs can be utilized as controllable loads. In other words, they can be operated as a battery to save energy during off-peak period. Also, these can act as generation units during peak period or high electricity price intervals. Since EVs have limited power output, they can be used in distribution system as a DG resource. For using EV as a DG in distribution system, charging and discharging of batteries should be controlled. Some models for vehicle to grid (V2G) power output are presented in [11–14].

Distribution system planners try to supply economical and reliable electricity to their customers. These companies deploy different technologies such as DGs and capacitors. DG technologies have many economical and technical benefits [15,16]. These benefits cannot be maximized except when optimal sizes and sites of DG units are determined. Therefore, optimal allocation of DG is one of the most important issues, which have to be considered in distribution planning problem. An appropriate decision making can provide benefits to distribution network, suppliers, and customers. Reliability index and loss reduction are two major objectives that have to be considered in sitting and sizing of DGs [17,18]. Using a type of DGs such as renewable DGs has an important role in smart environment.

Optimum allocation of parking lots, as new type of DGs, should be accomplished as well as other type of DGs. High-penetrations of distribution-connected storage devices or plug-in vehicles have adverse impacts on the grid due to their charging loads, randomly-located or unmanaged additions. Contrary, optimal allocation of parking lots can reduce the network loss such as other DGs, enhance reliability, improve voltage profile, and consequently bring economical benefits for distribution system company (DISCO). Many studies have been accomplished regarding associated problems with EVs and their impacts on power system. In many of the studies it is shown that the impact of EVs depends on charging schedule and electricity tariffs [19–21]. Ref. [22] presents a simulator tool in order to evaluate EVs impacts on power system. The proposed simulator in [22] allows estimation of the impacts of charging on each bus of the system.

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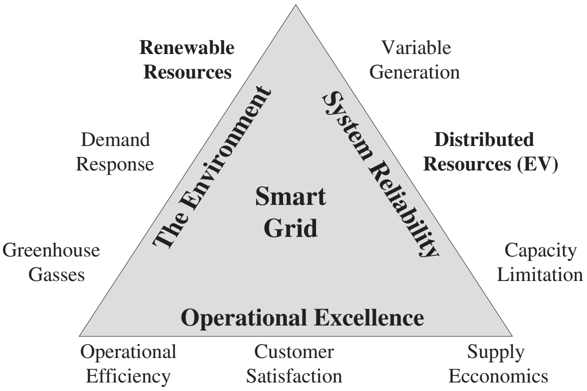

Fig. 1. The role of EV in smart grid [11].

Despite numerous studies about EVs, optimal allocation of parking lots has not been considered until now in the studies. Hence, this paper presents a multi-objective approach to determine optimal site and size of parking lots as DGs. Due to the multi-objective feature of allocation problem, Analytic Hierarchy Process (AHP) is employed in this paper to determine the optimal weighting coefficient for each objective. AHP was proposed in 1970 and since then, it has been progressively become an algorithm with extensive uses in multi-objective comprehensive evaluations [23].

One of the main differences between parking lot and other traditional DGs is that this resource does not have deterministic output. In this paper, a simplified model is used for power output of EV parking lots. In the modeling of parking lots, they act as storage devices and store electrical power in the batteries of vehicles at times with low electricity price and deliver power to distribution system at times with high electricity price. Also, parking lots act as charging stations of EVs for driving purposes. Because of stochastic nature of EV owners' behavior, the parking lots output is stochastic. One approach for decreasing the uncertainty of EV owners' behavior is implementing some incentive mechanisms. Enough incentive mechanism should be considered to promote EV drivers to participate in providing power to the network.

In this study, the allocation optimization problem is solved using genetic algorithm (GA) method. Due to the stochastic nature of the outputs of these resources, reliability is taken into consideration as an important issue. On the other hand, the power loss as well as the investment cost are other objectives have to be paid enough attention. For this reason, a trade-off shall be made between these objectives.

The rest of this paper is organized in the following order. Section 2 describes the proposed model of parking lots allocation framework. In Section 3, the parking lot power generation is discussed. Section 4 presents the problem formulation. In Section 5, the solving method is discussed. The case study and discussion on the results are driven in Section 6. Finally, the last section is devoted to conclusions.

2. Framework of allocation problem

The proposed framework of parking lots allocation is illustrated in Fig. 2, which is structured in 9 blocks. The data required for solving the optimization problem (e.g., data of load, EV data, and electricity price data) is indicated in block one. The output power of EVs depends on drivers' behavior. Thus, the incentive mechanism as illustrated in block 1 can be considered for management of EVs power output and promote the owners of these resources.

Generally, EVs do not have deterministic output therefore, in this paper the simplified model is used for power output of EVs parking lots (block 2). Due to the stochastic output of this resource, reliability is taken into consideration as an important issue. In this study, the energy not supplied (ENS) is proposed as a reliability index (block 3). On the other hand, the power loss as the other objective has to be paid attention (block 4). Another objective, which has important impacts on these resources allocation is the investment cost of parking lots, which is illustrated in block 5. Since optimal allocation of parking lots is a multi-objective optimization problem, a trade-off between these objectives is taken into account in this paper. GA is used for solving optimization problem as indicated in block 6.

Number of EVs in each candidate bus, reliability benefit, and loss benefit are outputs of the simulation, as presented in blocks 7, 8, and 9, respectively.

In order to allocate parking lots, some assumptions are taken into account as follows:

1. In this study it is assumed that, DISCO is responsible for supplying customers demand, parking lots installation, and controlling charging and discharging of EVs batteries. DISCO tries to carry all of these responsibilities based on cost reduction and improving the quality and reliability of customer service.
2. It should be noted that in calculating the profit, it is assumed that the DISCO does not receive compensation from EV owners for battery charging necessary for driving purposes. Also, degradation cost of vehicles due to V2G is paid to EV owners by DISCO. These assumptions are taken to encourage EV owners to park their vehicles in parking lot in the days with high price peak electricity.
3. All vehicles are charged and discharged with maximum charging rate. It should be noted that this assumption has been considered in several EV studies [20,21].
4. In the modeling of parking lots, it is assumed that the initial state of charge (SOC) of EVs has three levels. The proposed model can be used for other SOC levels too. The initial SOC of vehicles can be fitted with suitable distribution function and parking lots can be placed optimally, considering this function. Other assumption used in modeling of parking lots is that all batteries have the same size. Thus, the output power of parking lot is flat in discharging state. This assumption has been taken in many EV studies such as [20–22].

3. Parking lot power generation

The EV battery storage has a low capacity. Thus, in this paper, wide use of aggregated EVs in parking lots is suggested to overcome the small storage capacity of an EV. EV parking lots are considered as new players whose roles are collecting the EVs in order to reach high storage capacity from small battery capacity of EVs, affecting the grid beneficially.

In a restructured power system, DISCO buys electricity from wholesale market to supply the consumers. Purchasing electricity in off-peak hours from the market with low prices, storing it in batteries of vehicles in parking lots, and delivering electricity to consumers in peak time are three major steps that enable DISCOs to save costs through preventing purchasing fraction of required peak power with high price. Usually, peak power is generated by power plants that can be switched on for shorter periods, such as gas turbines at the hours of day when high levels of power consumption are expected (for example, in hot summer afternoons) [24]. The peak power is typically needed only a few 100 h/year. This power is usually provided by generators with low capital cost however high operational cost. Providing peak power by parking lots may be an economic alternative source. For optimal participation of parking lots in providing peak power, they should be allocated optimally.

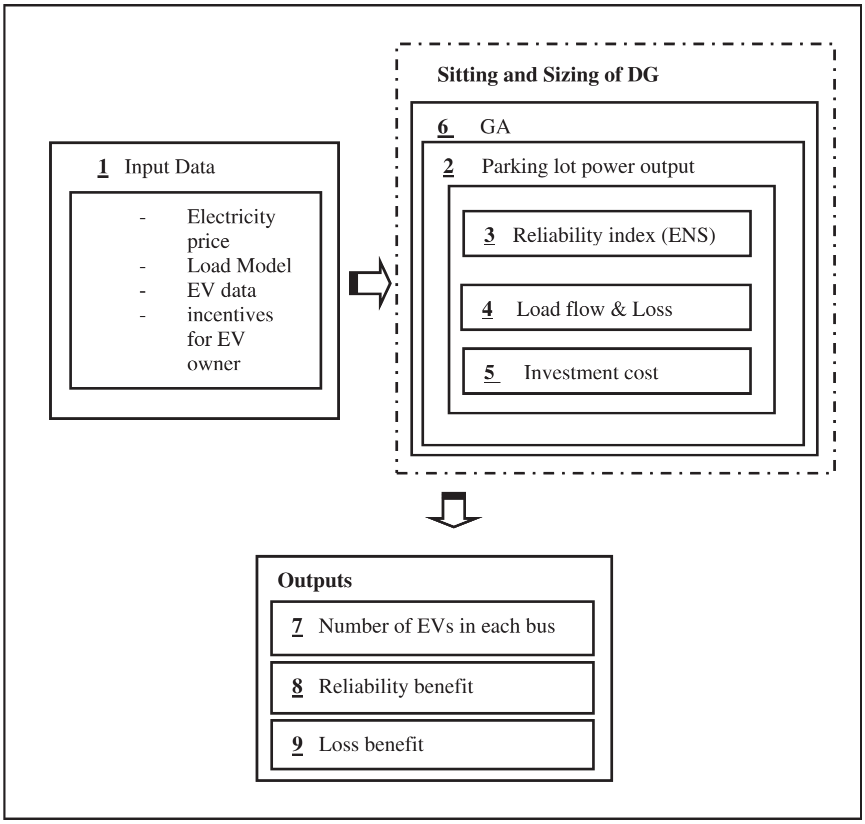

Fig. 2. Proposed framework of parking lots allocation.

Table 1
Initial SOC of vehicles.

Initial SOC	SOC_1	SOC_2	SOC_3
Number of vehicles	n_1	n_2	n_3

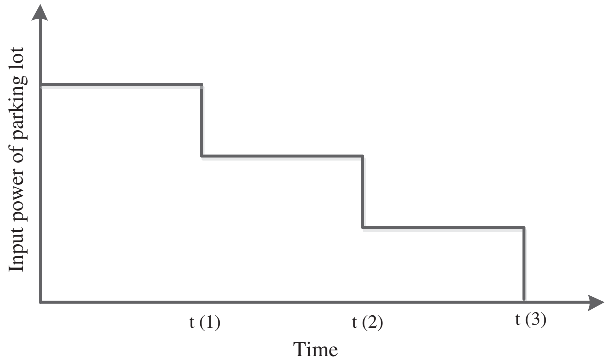

Fig. 3. Input power of parking lot for charging EVs.

The first step in parking lots allocation is modeling the output power of these lots. To charge EVs, the output power of parking lot depends on initial SOC of vehicles batteries, as well as the number of available vehicles, and output power of each vehicle. In this paper, a simple charging and discharging scheduling of batteries are considered as described in the following.

The required time for full charging of an EV as a function of initial SOC can be calculated as follows:

$$t(i) = \frac{(1 - SOC_i) * ES_i}{P_v} \tag{1}$$

where SOC_i is the initial SOC of vehicle i, ES_i is the battery capacity of EV i, and P_v is the power rate with which EV is charged.

The output power of the parking lot can be represented as:

$$P_{park} = P_v * n \tag{2}$$

where n is the number of available vehicles in the parking lot.

By assuming three levels of SOC for batteries, as shown in Table 1, the input power of parking lot will have 4 stages similar to Fig. 3.

4. Problem formulation

In this section, the revenue and the costs of parking lot application are modeled. Details of formulations expressed in the next subsections.

4.1. Revenue and cost of V2G

The revenue obtained from V2G power depends on the type of electricity market that the V2G power is sold to. For markets such as peak power market that pay only for energy, the revenue is the product of price and energy dispatched [25]. A portion of peak power can be supplied by V2G power and consequently less purchasing electric power from wholesale market by DISCO. Therefore, saving costs by supplying loads with V2G power instead of purchasing power from wholesale market can be formulated as follows:

$$r(i) = Pr_P * P_{park}(i) * t_{disp}(i) \tag{3}$$

where $r(i)$ is the total revenue gained from ith parking lot, $t_{disp}(i)$ is the total time that the V2G power is dispatched, and Pr_P is market price of electricity at peak times.

On a yearly basis, the net revenue is calculated by summing up the revenue for only those hours in which the cost of energy from V2G is lower than the market rate [25].

The cost of V2G power is made of three elements: purchased energy, wear, and capital costs [25]. The purchased energy and the wear cost for V2G are the additional costs needed for V2G however not for driving. Similarly, the capital cost is the cost of additional equipments needed for V2G however not for the main function of the vehicles, which is transportation. In addition to the cost of V2G power, the cost of purchased energy for driving purposes is also modeled in this section. Assuming a yearly basis, these costs can be formulated as follows:

$$CF_{cap}(i) = c_{ac} * PC(i) \tag{4}$$

$$CF_{Pu.driving}(i) = \sum_{k=1}^{t_n} \frac{Pr_{off}}{\mu_{conv}} * P_{parkch}(i,k) * t(k) \tag{5}$$

$$CF_{pu.V2G}(i) = Pr_{pe} * P_{park}(i) * t_{disp} \tag{6}$$

where $CF_{cap}(i)$ is the capital cost of parking lot i, c_{ac} is the annualized capital cost for each vehicle, $PC(i)$ is the capacity of parking lot i, $CF_{Pu.driving}(i)$ is the cost of purchased energy to charge vehicles for driving, Pr_{off} is the market price of electricity at off-peak times, $P_{parkch}(i,k)$ is the needed power at parking lot for charging vehicles from SOC 0 to SOC 1, $t(k)$ is the time duration at which the output power of parking lot in order to charge EVs is $P_{parkch}(i,k)$, $CF_{pu.V2G}(i)$ is the cost of purchased energy to charge vehicles for V2G power, and Pr_{pe} is the purchased energy cost.

$P_{parkch}(i,k)$ is calculated by Eq. (2) in which n at each time interval, equals to the number of vehicle with SOC less than 1. The equation for calculating Pr_{pe} includes a purchased energy term and an equipment degradation term:

$$Pr_{pe} = \frac{Pr_{off}}{\mu_{conv}} + c_d \tag{7}$$

where c_d is the cost of equipment degradation due to the extra use for V2G, and μ_{conv} is the efficiency of the inverter. More details about calculating c_d are given in [25].

4.2. Reliability improvement

As mentioned, in this paper a multi-objective optimization method is developed to determine the appropriate size and site of parking lots. One of the objectives is meeting the system reliability in an acceptable level. The energy not-supplied index (ENS), which is considered as the reliability index is calculated for this work. This index reflects the network total energy not supplied due to the faults during study period. Therefore, the system disruption cost can be evaluated as represented in following equation:

$$C_{NS}(j) = \left[\sum_{b=1}^{B} C_{inj} * \gamma_b * L_b * \left(\sum_{res=1}^{Nres} P_{res} * t_{res} + \sum_{rep=1}^{Nrep} P_{rep} * t_{rep}\right)\right] + C_{Equipj} \tag{8}$$

where B is the number of branches in network, C_{inj} is the price of energy not supplied in load level j, γ_b is the failure rate of line section b, L_b is the length of line section b, $Nres$ is the number of nodes isolated during fault location, $Nrep$ is the number of nodes isolated during fault repair, P_{res} is the loads not supplied during fault location, t_{res} is duration of the fault location and switching time, P_{rep} is the loads not supplied during fault repair, t_{rep} is duration of the fault repair, and C_{Equipj} is the cost of energy not supplied based on failure in equipment except for branches.

If the parking lot is sited in distribution system, it is used as alternative source to restore power for fraction of the loads that are failed and therefore the system reliability will be improved. The reliability enhancement benefit for each year that DISCO can reach is expressed by following equation:

$$DC_{NS}(j) = C_{NS}(j) - C_{NSV2G}(j) \tag{9}$$

where $C_{NS}(j)$ is the cost of energy not supplied without V2G in load level, and $C_{NSV2G}(j)$ is the cost of energy not supplied with V2G.

4.3. Loss reduction benefit

The output power of parking lots causes the power loss of distribution system to change. Therefore, the cost of system loss can be evaluated by:

$$DC_{loss}(j) = Price(j) * (loss(j) - loss_{V2G}(j)) \tag{10}$$

$$loss(j) = \sum_{b=1}^{B} R_b * I_b(j)^2 * t(k) \tag{11}$$

where $Price(j)$ is the electricity price in load level j, $loss(j)$ is the network loss in load level j without V2G, $loss_{V2G}(j)$ is the network loss in load level j with V2G, R_b is the resistance of branch b, and $I_b(j)$ is the current of branch b at time interval j.

4.4. Objective function

Considering the revenue and cost, which have been described in previous sections, the objective function can be stated as follows:

$$MAX\,F = \sum_{i=1}^{N_{V2G}} (w_1 * r(i) - (w_2 * CF_{cap}(i) + w_3 * CF_{Pu.driving}(i) + w_4 * CF_{pu.V2G}(i)) + \sum_{j=1}^{J} (w_5 * DC_{NS}(j) + w_6 * DC_{loss}(j)) \tag{12}$$

where N_{V2G} is the number of parking lots, J is the number of load levels, and $w_1, \ldots, w_6$ are weighting coefficients.

4.5. Calculating of weighting factors

In this study, AHP is used to calculate the optimal weighting coefficient for each index in Eq. (12) [23]. First, a matrix is formed with arrays, which are made by comparing the importance of each two indices. For example, the array in i_Nth row and j_Nth column is a number between 1 and 9 that indicates the importance of the i_Nth index compared to j_Nth index. This comparison matrix can be expressed as follows:

$$N = \begin{bmatrix} N_{11} \ldots N_{1m} \\ \cdots\cdots\cdots \\ N_{m1} \ldots N_{mm} \end{bmatrix} \tag{13}$$

where $N(i_N, i_N) = 1$ (importance of index i_N compared to itself is 1), $N(i_N, j_N) = 1/N(j_N, i_N)$ represent the importance of i_Nth index compared to j_Nth index.

The next step is computing of weighting coefficients. The weighting coefficients are calculated as follows:

$$w_{i_N} = \frac{\sqrt[m]{\prod_{j_N=1}^{m} N(i_N, j_N)}}{\sum_{i_N=1}^{m} \sqrt[m]{\prod_{j=1}^{m} N(i_N, j_N)}} \tag{14}$$

where m is number of objectives.

After calculating the weighting coefficients, the consistency index of matrix N is calculated as below:

$$I_{CR} = \frac{(\gamma_{max} - m)}{(m-1) * I_{RI}} \tag{15}$$

where γ_{max} is maximum eigenvalue of matrix N.

If $I_{CR} < 0.1$ the consistency of each weighting coefficient is acceptable. I_{RI} is a random index, and its values are given in [23] for a different index number m.

4.6. Constraints

The objective function should be maximized subject to different constraints.

4.6.1. Distribution line capacity limit

The power flow of lines should be less than maximum permitted power of lines because of line thermal capacity.

$$S_{(i',j')} \leqslant S_{(i',j')max} \tag{16}$$

where $S_{i,j}$ is the MVA in the line connecting bus i' to bus j', and $S_{(i,j)max}$ is the MVA capacity of the line between bus i' to bus j'.

4.6.2. Voltage drop limit

The voltage of each bus should be in the range of minimum and maximum voltages.

$$V_{min} \leqslant V \leqslant V_{max} \tag{17}$$

where V_{min}, V_{max} are minimum and maximum allowable voltages at buses, respectively.

4.6.3. Number of vehicles limit in each parking lot

Capacity of each parking lot in specific area is limited by the number of EVs in that area. This constraint can be expressed as follows:

$$CP \leqslant CP_{max} \tag{18}$$

where CP_{max} is the maximum capacity of parking lot, which can be installed.

4.7. Load flow

To solve the optimal parking lot placement problem for a typical radial distribution network a simple power flow method known as the backward–forward sweep power flow is used for computing the power loss. This method is described briefly as follows:

4.7.1. Current injection calculation for each node

$$i_n^{(k)} = \left(\frac{S_n^{(k)}}{V_n^{(k)}}\right) \tag{19}$$

where i_n is the current injection at node n corresponding to constant power load, S_n is scheduled power injection at node n, and V_n is the voltage at node n.

4.7.2. Backward sweep to sum up line section current

The current in line section l is computed as below:

$$J_l^{(k)} = -i_n^{(k)} + \sum_{mM} J_m^{(k)} \tag{20}$$

Line section l connects node s to node n, where n stands for receiving point of line section l, and s stands for sending point of line section l.

4.7.3. Forward sweep to update nodal voltage

The voltage at node j is computed as:

$$V_j^{(k)} = V_i^{(k)} - Z_l * J_l \tag{21}$$

In all of the equations, k is the loop counter.

Iteration of these steps is kept on until the convergence criteria are satisfied ($\Delta V_i^k \leqslant \varepsilon$).

$$\Delta V_i^k = |V_i^k| - |V_i^{k-1}| \tag{22}$$

5. Solving method

The main goal of the proposed modeling is to determine proper locations for parking lots and their optimal size by maximizing objective function. In the following, GA and placement algorithm, which is used to solve multi-objective optimization problem are described.

5.1. Problem optimization using GA

GA is able to reach an optimum solution by finite number of evolution steps performed on a finite set of possible solutions.

The objective function stated in Eq. (12), is maximized with GA. In this paper, the fitness function is equal to the objective function because the chromosome with maximum objective function is the fittest chromosome.

Before using the GA to solve the optimization problem, representation of a chromosome must be defined. In this paper, each chromosome is composed of several sub chromosomes. The number of sub chromosomes is equal to the number of candidate buses used for connecting the parking lot. Each sub chromosome represents a binary number that shows the capacity of parking lot. Therefore, the number of bits in the sub chromosomes depends on the maximum capacity, which parking lots can have. The major steps of the optimization algorithm are:

1. *Generation of initial population*: In the first iteration, chromosomes are initialized.
2. *Calculation fitness function*: For each chromosome the parking is modeled and the fitness function is calculated.
3. *Generation of new population*: Each chromosome is copied to the second generation for a number of times that is proportional to its fractional fitness function in the reproduction phase and genetic operators are applied on the set of chromosomes.
4. *Termination criteria*: Steps 2 and 3 are repeated and the algorithm stops when acceptable fitness level has been reached for the population.

Parameters of GA are as follows:

- Population size (Nc): 5.
- Mutation probability: 0.1.
- Crossover probability: 1.

6. Numerical study

The test system for the numerical study is a 9 bus distribution system as shown in Fig. 4. The data of this test system and loads are given in [17,26]. The distribution test system includes high voltage distribution substation 132–33 kV, which feeds eight load points.

For placement of parking lot in the study distribution system following criteria are taken into account:

1. Batteries of vehicles are charged with a constant power of 15 kW.
2. 2. Loads are time variant. In this paper, the load condition is considered in three levels (light, medium, and peak load) [17].
3. In the simulation, the parking lot is modeled as a bus ($Q = 0$). In charging state, Q is positive and during discharging, P is negative.

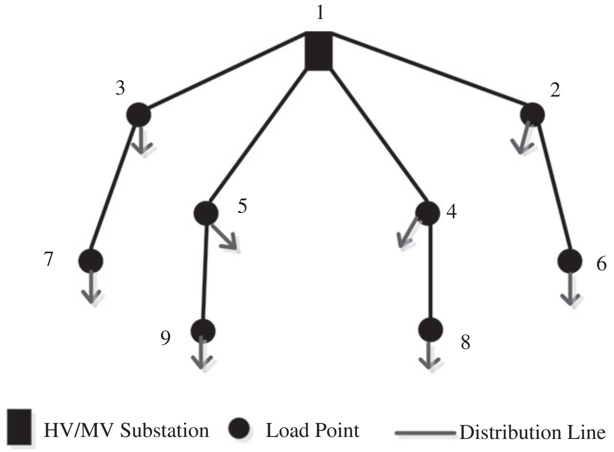

Fig. 4. Studied test system [8].

Table 2
Required information for parking lot placement.

Initial SOC Number of vehicles (%)	0.3 25%		0.45 25%	0.7 50%
C_d (USD$/kW h)	C_{ac} (USD$/year for each vehicle)	μ_{conv}	$Price_p$ (USD$/kW h)	*Price* (USD$/kW h)
0.225	304	0.85	0.05	0.5

Table 3
Simulation results of scenario 1 (availability = 100%).

Bus number Optimum number of EVs	2 375	3 375	6 225
Benefit of loss reduction (USD$)		38,705	
Benefit of reliability improvement (USD$)		31,356	
Benefit of providing peak power (USD$)		411,640	
Total benefit (USD$)		481,700	

Table 4
Simulation results of scenario 1 (availability = 80%).

Bus number Optimum number of EVs	2 375	3 375	6 225
Benefit of loss reduction (USD$)		33,113	
Benefit of reliability improvement (USD$)		31,828	
Benefit of providing peak power (USD$)		259,820	
Total benefit (USD$)		324,760	

4. Buses 2, 3, and 6 are candidates for connecting the parking lot.
5. Initial SOC of vehicles is based on data given in Table 2.
6. Under traditional approximations used by utilities, there might be 200 peak hours in a year during which an incremental kW h of electricity would be worth 50 USD$/kW h [25]. Therefore, the maximum hours that vehicles deliver power to the network is assumed to be 200 h in a year.

Degradation and annualized investment cost and efficiency of the inverter, which are used in this study are given in Table 2 [25]. The larger the batteries are, the more economical installation of parking lots will be and vice versa. Therefore, it is assumed that DISCO makes contracts with vehicles of high battery capacities. The battery's capacity is assumed to be 50 kW h.

Considering the value of the objective function and the problem constraints, the optimum location for parking lot is determined using GA. Two scenarios are considered in terms of analyzing simulation results. In the first scenario, all weighting coefficients are identical and in the second scenario, they are different from each other.

6.1. Scenario 1

In this scenario, all arrays of matrix *N* are 1. Thus, the vector of weighting coefficients is as follows:

$W = [0.1667\ 0.1667\ 0.1667\ 0.1667\ 0.1667\ 0.16670]$

The results of this scenario are shown in Table 3. As can be observed from the results, the total annual benefit is 481,700 USD$. It is assumed that the availability of vehicles is 100 percent. In other words, all EV owners respect the contract. If the availability of vehicles be 80%, the annual benefit decreases to 324,760 USD$. As it can be seen from Table 4, the benefit of providing peak power is decreased in comparison with Table 3. Reduction in the benefit from the loss and reliability view points is not as much as benefit of providing peak power. This was predictable because the investment cost is modeled in benefit of providing peak power and it is constant for various EVs' availability. On the other hand, the revenue from providing V2G power decreases with a decrease in the availability of EVs. The total benefit as a function of EVs' availability is shown in Fig. 5. As it is observed from Fig. 5, when the availability of vehicles is decreased to 0.35, the total benefit becomes negative. It is thus necessary to assume enough incentives for EV owners in order to encourage them to park their vehicles in parking lots.

The voltage profile of load points at peak times, which parking lots deliver power to the distribution system is shown in Fig. 6. As can be observed from Fig. 6, there are improvements in voltage profile of some buses in the presence of V2G power.

As mentioned, it is assumed that high price of electricity is synchronized with the peak power of the distribution system. If it is

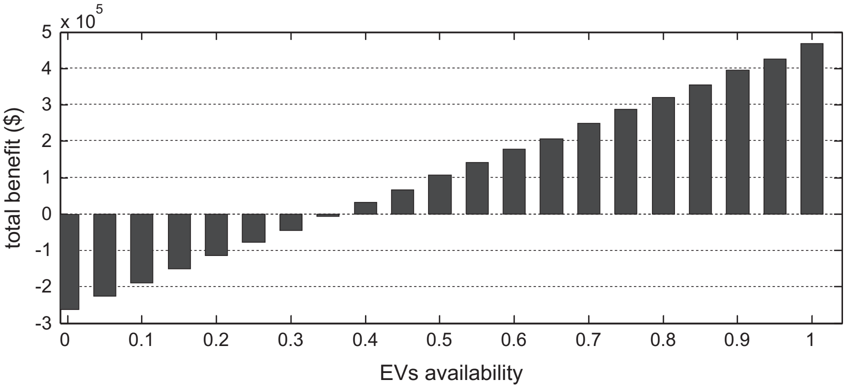

Fig. 5. Total benefit as a function of EVs availability.

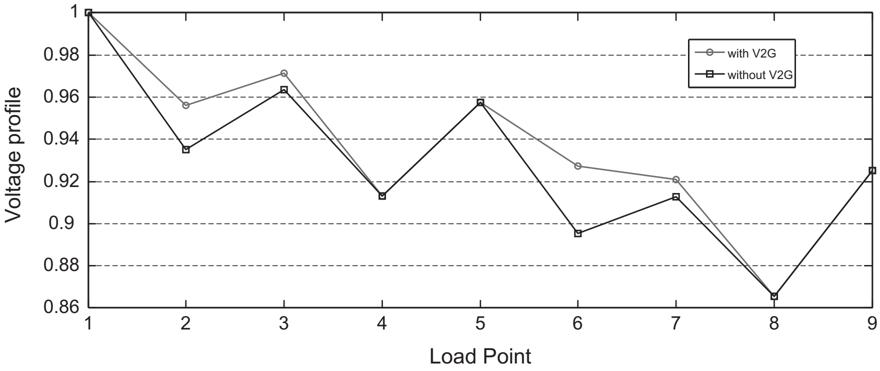

Fig. 6. Voltage profile in peak load (scenario 1).

Table 5
Results of simulation scenario 1 (change in electricity price).

Bus number	2	3	6
Optimum number of EVs	375	375	225
Benefit of loss reduction (USD$)		−565,930	
Benefit of reliability improvement (USD$)		−101,150	
Benefit of providing high price power (USD$)		395,080	
Total benefit (USD$)		−272,000	

assumed that the high price of electricity occurs in off- peak time, the results would differ as shown in Table 5. As it can be seen from the results of Table 5, the benefit becomes negative in this situation and accordingly the voltage profile is deteriorated as shown in Fig. 7. To prevent this situation, it is necessary to forecast the electricity price exactly for decision making on parking lot installation.

If it is assumed that the battery capacity of all EVs is 15 kW h, the optimum number of EVs in the entire candidate buses become zero. This result was predictable because the investment cost is the same for all type of vehicles.

6.2. Scenario 2

In this scenario, the matrix N in Eq. (12) is as follows:

$$N = \left|\begin{array}{c|cccccc} & r & CF_{cap} & CF_{Pu.driving} & CF_{pu.V2G} & DC_{NS} & DC_{loss} \\ \hline r & 1 & 0.33333 & 1 & 1 & 0.33333 & 0.14286 \\ CF_{cap} & 3 & 1 & 3 & 3 & 1 & 0.42857 \\ CF_{Pu.driving} & 1 & 0.33333 & 1 & 1 & 0.33333 & 0.14286 \\ CF_{pu.V2G} & 1 & 0.33333 & 1 & 1 & 0.33333 & 0.14286 \\ DC_{NS} & 3 & 1 & 3 & 3 & 1 & 0.42857 \\ DC_{loss} & 7 & 2.3333 & 7 & 7 & 2.3333 & 1 \end{array}\right|$$

The weighting coefficient vector related to matrix N is calculated using Eq. (13) with the result as below.

$$W = [0.0625\ 0.1875\ 0.0625\ 0.\ 0.1875\ 0.4375]$$

It is assumed that the availability of vehicles in this scenario is 100%. Also, high price of electricity is synchronized with the peak power of the distribution system.

As it can be seen from the weighting coefficient vector, the energy not supplied index and the capital cost index are more important indices in this scenario. The results of simulation indicates that with increasing the importance of the capital cost index, the parking lots capacities decrease and consequently the benefit of providing peak power and the total annual benefit decrease. With comparing Table 3 and Table 6 it can be seen that the benefit of reliability improvement increases in this scenario. Thus, parking lots allocation can be carried out for various purposes in different areas.

7. Conclusion

This paper addressed a multi-objective approach for allocation of parking lots as an attractive option in distribution system for supplying loads. An optimization model is successfully implemented to determine the optimal capacity and size of parking lot for serving demands in peak hours. The proposed optimization model aims to maximizing the total benefit.

Based on the data and the market prices used in the paper to examine the model, the results confirmed that parking lots installation can have economical profit for DISCO and improves the voltage profile as well. GA was used to optimally allocate the parking lot in the distribution system.

As simulation results demonstrate, any change in the battery capacity of vehicles in parking lots and weighting coefficients of

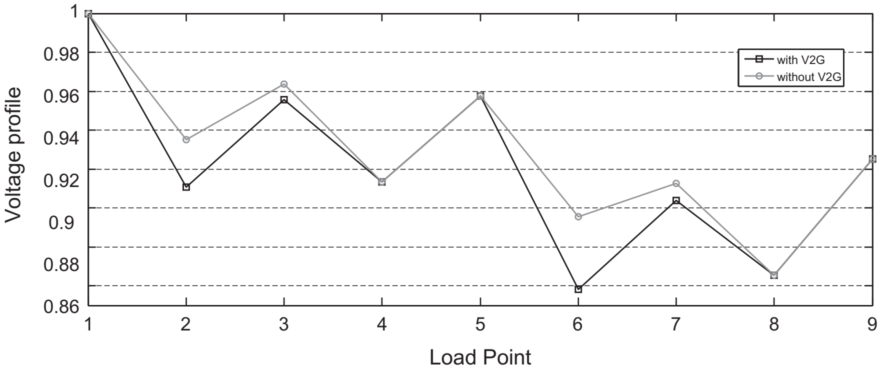

Fig. 7. Voltage profile in peak load scenario 1 (change in electricity price).

Table 6
Results of simulation scenario 2 (availability = 100%).

Bus number	2	3	6
Optimum number of EVs	25	50	150
Benefit of loss reduction (USD$)		9764.2	
Benefit of reliability improvement (USD$)		33,350	
Benefit of providing high price power (USD$)		61,564	
Total benefit (USD$)		104,680	

various indices lead to variation in the results. In order to reach more precious results, it is necessary to determine the size of batteries and efficiency of inverters, exactly.

A simple charging and discharging scheduling of batteries have been considered in this paper for placement of parking lots. The proposed method can be used for other V2G problems.

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