Economic-Driven Measure in Constructing a V2G Parking Lot from DisCo. Perspective

H.R. Esmaeilian[#1], M.M. Hosseini Bioki[#2], M. Rashidinejad[*3], A. Abdollahi[*4]

[#]Electrical and Computer Engineering Department, Kerman Graduate University of Technology, Kerman, Iran

[*]Electrical Engineering Department, Shahid Bahonar University of Kerman, Kerman, Iran

Department of Electrical Engineering, 22 Bahman Blvd, SBUK, Kerman, Iran

[1]hamidreza_89esm@yahoo.com; [2]mmhb1365@yahoo.com; [3]mrashidi@uk.ac.ir; [4]aabdollahi64@yahoo.com

Abstract- **Electric vehicles have been the center of attention in recent years because they can be used to set up a bidirectional connection to the power grid. In such a scheme an aggregation of Plug-in Hybrid Electric Vehicles (PHEVs) can be used to provide ancillary services for the power grid which is known as Vehicle to Grid (V2G) concept. Aggregation of these PHEVS can be parked in a parking lot which can be considered as a distributed generation unit. During off-peak hours, power grid provides electrical energy for charging the PHEVs in the parking lot and during peak hours the aggregation of PHEVs in the parking lot can give back some amount of their stored energy to the grid. In this paper, it is considered that the parking lot belongs to the Distribution Company (DisCo).The economic revenues and costs of constructing such a parking lot for a Distribution Company are modeled mathematically. Genetic algorithm is used to find the optimal number of the electric vehicles in the parking lot at each hour which can provide maximum benefit for the Distribution Company.**

Keywords- Vehicle to Grid (V2G); Gridable Vehicles; Parking Lot; Distribution Company; Distributed Generation; Economic Analysis

I. INTRODUCTION

Environmental pollution and emission of CO_2 caused by utilization of fossil fuels are imposing new challenges to the nation's energy infrastructure. In order to diminish these problems, renewable energies can be used which can reduce the amount of CO_2 emitted and thus help to the reduction of global warming [1]. The drawback of these modern technologies is that they are intermittent and can cause fluctuations in the power quality of the power grid. Vehicle to Grid (V2G) Concept has emerged as a modern technology that can provide ancillary services like peak shaving, power quality improvement, and voltage and frequency regulation in power systems [2], [3]. Cost-benefit analysis of penetration of renewable energies like solar and wind energy has been widely done in recent studies [4], [5], and [6]. Some studies have also been done on the cost-benefit analysis and impact of PHEVs[7], [8], and [9], but a practical model for cost-benefit analysis of constructing an electric vehicle parking lot for a Distribution Company has never been done. In this paper, a parking lot which accommodates an aggregation of plug-in hybrid electric vehicles (PHEVs) is assumed to provide electrical energy for these electric vehicles during off-peak hours and in return the stored energy in the batteries of these electric vehicles is given back to the grid during peak hours to smooth the load profile. In the approach proposed the Distribution Company is the owner of the parking lot which can gain more benefit if the number of available electric vehicles in its parking lot increases. It should be taken into consideration that this parking lot is a group of parking lots distributed in different places of a city.

As an example, if it is considered that the battery cost is 300 $/KWh, each electric vehicle needs 5 battery of 5 KWh Batteries which costs 7500$ [10], [11].The lead–acid batteries corrode due to charging and discharging up to3000, so their life time is 8 years. Therefore, each set of these batteries costs about937.5$ each year. If each vehicle uses 10KWh of its whole 25KWh capacity for transportation which is enough for transporting 60 Km, the remaining 15KWh can be sold to the grid. Considering that the electricity price at peak hours is 80cent/KWh, the revenue of selling electricity to the power grid for an electric vehicle is: 15 KWh× 80cent/KWh× 365= 4380$/year. So the benefit is: 4380 – 937.5=3442.5$/year. If an aggregation of these energy seller electric vehicles is gathered in a parking lot, its profit for the owner of the parking lot, which in this paper is the Distribution Company, can be remarkable.

This parking lot is considered as a distributed generation (DG) unit which has advantages like reduced emissions, utilization of waste heat, improved power quality, increased reliability and deferral of transmission or distribution upgrades [12-16]. The schematic of the connection of the mentioned parking lot as a DG along with the distribution substation to the consumers' loads is illustrated in Fig. 1.

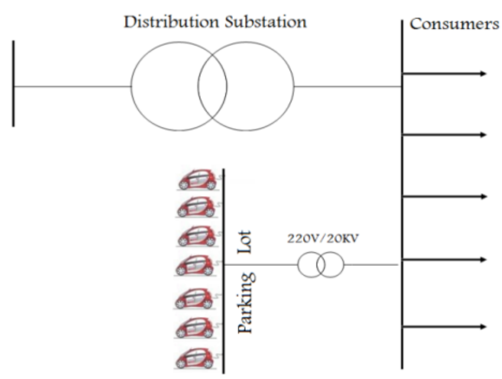

Fig. 1 Connecting a parking lot to a distribution feeder

In order to implement this scheme, a contract is made between each vehicle's owner and the Distribution Company as the owner of the parking lot. This contract clearly states that each vehicle's batteries are charged during off-peak hours up to 25KWh and are discharged down to 15KWh of the stored energy at peak hours to provide energy for the grid. A percentage of the battery replacement cost is also paid to the electric vehicle's owner by the Distribution Company. In the next section the mathematical modeling of cost-benefit analysis of the Distribution Company as the owner of the parking lot is proposed.

II. MATHEMATICAL MODELLING OF REVENUES AND COSTS

In this section the mathematical modeling of revenues and costs of the parking lot for the Distribution Company is proposed. It is assumed that the Distribution Company is in charge of providing the requested energy for charging the electric vehicles.

A. Nomenclature

The following notations are used in this paper.

N_1 : Number of electric vehicles in system that have contract with the parking lot of the Distribution Company

N_2 : Parking capacity

$N_{2,\max}$: Maximum parking capacity

N_i : Number of available electric vehicles in the parking lot at hour i for discharge

($i = 10, 11, 12, 17, 18, ..., 22$)

N_j : Number of available electric vehicles in the parking lot at hour j for charge

($j = 1:24 \neq 10, 11, 12, 17, 18, ..., 22$)

η_{charge} : Charging efficiency (Rectifying efficiency)

$\eta_{discharge}$: Discharging efficiency (Inverting efficiency)

P_1 : Power giving back to the grid by each vehicle (KW)

P_2 : Power each vehicle gets from parking (KW)

$P_{V2G,i}$: Power provided for the grid by the parking lot at peak hours

$P_{G2V,j}$: Power provided for the parking lot by the grid at off-peak hours

$P_{D,i}$: Active power demand at hour i (peak hours) (MW)

$P_{D,j}$: Active power demand at hour j (off-peak hours) (MW)

$P_{Loss,N}$: Substation transformer nominal loss (MW)

$P_{T,i}$: Power purchased at hour i (peak hours)

$P_{T,j}$: Power purchased at hour j (off-peak hours)

$S_{G2V,\max}$: Maximum power drawn from the grid by the parking lot providing electric vehicles energy (MVA)

$S_{V2G,\max}$: Maximum power drawn from the aggregation of electric vehicles by the parking lot providing energy for the grid (MVA)

$S_{D,i}$: Apparent power demand at hour i (peak hours) (MVA)

$S_{D,j}$: Apparent power demand at hour j (peak hours) (MVA)

S_T : Nominal capacity of substation transformer (MVA)

$S_{D,\max}$: Initial substation load peak (MVA)

$S_{S,\max}$: Maximum loadability of substation (MVA)

C_{invest} : Investment cost of expanding substation capacity ($)

C_{ground} : Cost of ground for the construction of the parking lot ($/m^2)

$C_{parking}$: Cost of constructing the parking lot for an electric vehicle ($/m^2)

$C_{accessories}$: Cost of accessories of the parking like converter and plug ($/MVA)

C_{EENS} : Cost of expected energy not served

($/MVA-year)

C_{pa} : Annual cost for providing active power of system at off-peak hours ($)

C_{pb} : Annual cost for providing active power of system at peak hours ($)

C_m : Annual costs of maintenance ($/MVA-year)

$C_{R,b}$: Replacement cost for batteries ($)

$C_{T,1}$: Price of buying power from transmission system at peak hours ($/MW)

$C_{T,2}$: Price of buying power from transmission system at off-peak hours ($/MW)

C_R : Cost of unreliability ($)

α : Annual growth rate of substation load

f : Annual inflation rate

i : Annual interest rate

T : Lifetime of the parking lot (year)

T_1 : Year of expanding substation capacity before the parking lot construction (year)

T_2 : Year of expanding substation capacity after the parking lot construction (year)

ΔT : Deferral time of expanding substation capacity due to the parking lot construction (year)

t_{EENS} : Number of hours of EENS at peak hours (h/year)

NPW: Net Present Worth of costs and revenues

B. Revenues

1) Deferral of Expanding Substation Capacity:

The annual growth of using electricity makes it essential to develop the distribution network. Development in distribution substation is about increasing the capacity of the substation transformer. As shown in Fig. 2, as the utilization of electricity increases in a year, the initial substation load peak

($S_{D,\max}$) reaches the maximum loadability of the substation ($S_{S,\max}$), so in order to supply the load, the capacity of the substation should develop. After constructing the parking lot with the capacity of $S_{V2G,\max}$, with the same rate of load growth, the peak power passing through the transformer decreases and after N years the loading reaches the maximum loadability of the substation. Therefore, the time of expanding the substation capacity postpones $\Delta T = T_2 - T_1$.

Before the construction of the parking lot, the maximum loadability of the substation is:

$$S_{S,\max} = S_{D,\max}(1+\alpha)^{T_1} \tag{1}$$

After the construction of the parking lot with the maximum capacity of $S_{V2G,\max}$, the maximum loadability of the substation is:

$$S_{V2G,\max} = N_2 \times P_1 \times \eta_{discharge} \tag{2}$$

$$\gamma = \frac{S_{V2G,\max}}{S_{D,\max}} \tag{3}$$

$$S_{S,\max} = S_{D,\max} \times (1-\gamma) \times (1+\alpha)^{T_2} \tag{4}$$

From Equations (1) and (4), the deferral time of the substation capacity expansion is obtained as (5):

$$\Delta T = T_2 - T_1 = \frac{\log \frac{1}{1-\gamma}}{\log(1+\alpha)} \tag{5}$$

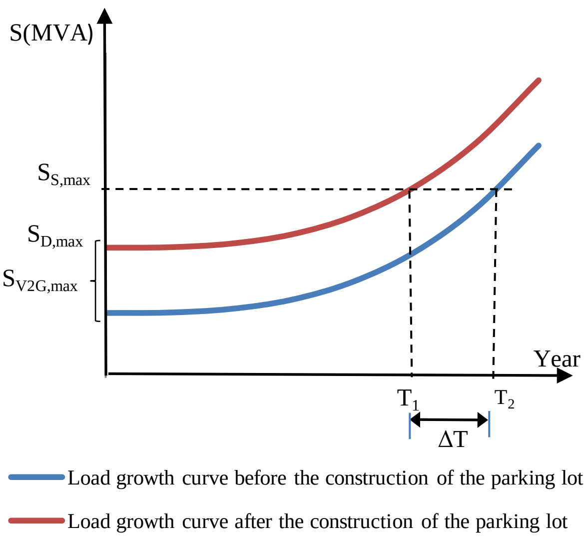

Fig. 2 Substation load growth before and after the construction a parking

The revenue from the substation capacity expansion that is gained at year T_1 is R_1, which is obtained from Equation (6) and the net present worth of this revenue is obtained from Equation (7) [17].

$$R_1 = C_{invest}\left(1-\left(\frac{1+f}{1+i}\right)^{\Delta T}\right) \tag{6}$$

$$NPW(R_1) = R_1\left(\frac{1+f}{1+i}\right)^{T_1} \tag{7}$$

2) Decreasing Cost of Providing Active Power at Peak Hours:

In a competitive power market, distribution companies buy the necessary electrical energy for the distribution network from the transmission system. The receiving active power from transmission system is consisted of two parts: first part is the load of the distribution network which is measured at secondary side of the distribution substation transformer. The second part is related to transformer resistive loss. This receiving active power can be calculated as follows.

$$P_{T,i,before} = P_{D,i} + \frac{S_{D,i}^2}{S_T^2} \times P_{Loss,N} \tag{8}$$

So the annual cost of providing active power of the distribution network before the construction of the parking lot which is bought from the transmission system is:

$$C_{Pb,before} = 365\sum_i \left[P_{T,i,before} \times C_{T,1}\left(P_{T,i,before}\right)\right] \tag{9}$$

Construction of the parking lot makes it possible for the Distribution Company to provide an amount of its required active power from the parking lot and thus less power is bought from the transmission system. The produced power by the parking lot is calculated based on Equation (10).

$$P_{V2G,i} = N_i \times P_1 \times \eta_{discharge} \tag{10}$$

So the bought power from the transmission system decreases as follow.

$$P_{T,i,after} = \left(P_{D,i} - P_{V2G,i}\right) + \left(\frac{S_{D,i} - P_{V2G,i}}{S_T}\right)^2 \times P_{Loss,N} \tag{11}$$

So the annual cost of providing active power for the distribution network from the transmission system after the construction of the parking lot is obtained from Equation (12).

$$C_{Pb,aftee} = 365\sum_i \left[P_{T,i,after} \times C_{T,1}\left(P_{T,i,after}\right)\right] \tag{12}$$

The annual revenue from constructing the parking lot is obtained from subtracting the cost of providing energy from the transmission system before the construction of the parking lot and after the construction of the parking lot.

$$R_2 = C_{Pb,before} - C_{Pb,after} \tag{13}$$

The net present worth of this revenue is calculated as Equation (14).

$$NPW(R_2) = R_2 \sum_{t=1}^{T}\left(\frac{1+f}{1+i}\right)^t \tag{14}$$

3) System Reliability Improvement at Peak Hours:

In order to calculate the reliability of a power system, some indexes that show the number and continuity of off hours is introduced. Number of hours of expected energy not served (EENS) at peak hours (t_{EENS}) is one of these indexes that is used in this article. Before the construction of the parking lot the cost of unreliability is calculated using Equation (15).

$$C_{R,before} = t_{EENS} \times S_{D,\max} \times C_{EENS} \tag{15}$$

The parking lot can act as a backup source during outage of the upstream network at peak hours. This source can provide the system load up to its capacity and thus increasing the grid reliability. So after the construction of the parking lot the cost of unreliability is calculated using Equation (16).

$$C_{R,after} = t_{EENS} \times \left(S_{D,\max} - S_{V2G,\max}\right) \times C_{EENS} \quad (16)$$

The annual revenue due to the reliability resulted from the construction of the parking lot is obtained from Equation (17).

$$R_3 = C_{R,before} - C_{R,after} = t_{EENS} \times S_{V2G,\max} \times C_{EENS} \quad (17)$$

The net present worth of this revenue is calculated as Equation (18).

$$NPW(R_3) = R_3 \sum_{t=1}^{T} \left(\frac{1+f}{1+i}\right)^t \quad (18)$$

C. Costs

1) Increasing Cost of Active Power at Off-peak Hours:

As mentioned before electric vehicles get power from the parking lot at off-peak hours, so they are considered as loads during off-peak hours that impose the cost of providing their required energy to the Distribution Company as the owner of the parking lot. The substation load before the construction of the parking lot is obtained from Equation (19) and the cost of providing energy for the load is obtained from Equation (20).

$$P_{T,j,before} = P_{D,j} + \frac{S_{D,j}^2}{S_T^2} \times P_{Loss,N} \quad (19)$$

$$C_{Pa,before} = 365 \sum_j \left[P_{T,j,before} \times C_{T,2}\left(P_{T,j,before}\right)\right] \quad (20)$$

Construction of the parking lot imposes an additional load to the substation to supply. The power required to supply this new load is obtained from Equation (21). The sum of the parking lot required power and the system initial load required power is calculated using Equation (22) and the cost of providing this amount of power for the Distribution Company is obtained from Equation (23).

$$P_{G2V,j} = N_j \times \frac{P_2}{\eta_{charge}} \quad (21)$$

$$P_{T,j,after} = \left(P_{D,j} + P_{G2V,j}\right) + \left(\frac{S_{D,j} + P_{G2V,j}}{S_T}\right)^2 \times P_{Loss,N} \quad (22)$$

$$C_{Pa,after} = 365 \sum_j \left[P_{T,j,after} \times C_{T,2}\left(P_{T,j,after}\right)\right] \quad (23)$$

The cost imposed on the Distribution Company at off-peak hours due to the construction of the parking lot of the electric vehicles is obtained from Equation (24) and the net present worth of this cost is presented in Equation (25).

$$C_1 = C_{pa,after} - C_{pa,before} \quad (24)$$

$$NPW(C_1) = C_1 \sum_{t=1}^{T} \left(\frac{1+f}{1+i}\right)^t \quad (25)$$

2) Cost of the Parking Lot Construction and Its Ground and Accessories:

The cost of constructing the parking lot and its ground is proportional to the parking capacity. The space considered for each of the electric vehicle is $6m^2$.The cost of the parking lot accessories like converter, plug, etc. are proportional to the maximum power drawn from the grid by the parking lot providing electric vehicles energy. These costs are calculated using Equation (26). The net present worth of this cost is obtained using Equation (27).

$$S_{G2V,\max} = N_2 \times \frac{P_2}{\eta_{charge}} \quad (26)$$

$$C_2 = NPW(C_2) = \left(S_{G2V,\max} \times C_{accessories}\right) + \left(\left(N_2 \times 6m^2\right) \times \left(C_{parking} + C_{ground}\right)\right) \quad (27)$$

3) Annual Costs:

The annual costs are composed of two parts which is shown in Equation (28). The first part is the parking lot maintenance cost which is proportional to the maximum power drawn from the grid by the parking lot. The second part is the batteries degradation and replacement cost. The battery degradation depends on factors like number of charging and discharging times and the depth of discharging of the batteries [18], [19]. The Distribution Company provides an amount of this latter cost for the electric vehicles which can be a motivation for the owners of the electric vehicles. The factor K in Equation (28) refers to this cost. As each vehicle charges once a day and also discharges once a day, the lifetime of the batteries used is 8 years (3000 cycle). So the vehicle's batteries should be replaced every eight years and the reason of using coefficient $1/8$ in Equation (28) is this matter. The net present worth of the annual costs is calculated from Equation (29).

$$C_3 = C_m \times S_{G2V,\max} + K \times N_1 \times \frac{C_{R,b}}{8} \quad (28)$$

$$NPW(C_3) = C_3 \sum_{t=1}^{T} \left(\frac{1+f}{1+i}\right)^t \quad (29)$$

D. Objective Function

The objective function is maximizing the profit gained by the Distribution Company. The profit of the Distribution Company is obtained from subtracting the costs mentioned in the previous subsections from the revenues gained by the Distribution Company.

$$O.F. = Max\ Profit = Max\left(\sum_{m=1}^{3} NPW(R_m) - \sum_{n=1}^{3} NPW(C_n)\right) \quad (30)$$

This objective function along with the following constraints constitutes the optimization problem that is solved using genetic algorithm.

E. Constraints

1) Equality Constraints:

The total number of electric vehicles entering the parking lot at peak hours and also the total number of electric vehicles entering the parking lot at off-peak hours should be equal to the number of electric vehicles in system that have contract with the parking lot of the Distribution Company.

$$\sum_i N_i = N_1 \tag{31}$$

$$\sum_j N_j = N_1 \tag{32}$$

2) Inequality Constraint:

The number of vehicles entering parking at every hour should be less than the maximum parking lot capacity.

$$N_k \le N_2 \quad ,k = 1,...,24 \tag{33}$$

3) Parking Capacity Constraint:

The parking capacity has a maximum because of economic issues.

$$N_2 = Max(N_K) \quad ,k = 1,...,24$$
$$N_2 \le N_{2,\max} \tag{34}$$

III. GENETIC ALGORITHM

Genetic algorithms are search algorithms based on the process of biological evolution. In this algorithm, the problem variables are defined as binary strings that are known as genes. A set of genes constitute a chromosome that is one of the possible solutions of the problem. The basic structure of GA is as follows. First, a randomly constructed initial population of chromosomes is generated. Then the fitness of each chromosome is defined by the objective function. The selection operator chooses the chromosomes with better fitness among the population. Using crossover and mutation operators, a new population is produced. The iterative loop is executed until the termination condition is satisfied [20]. In this paper, each gene represents the number of electric vehicles. The genetic algorithm used in this paper is shown in Fig. 3 and the genetic algorithm parameters are given in Table 1.

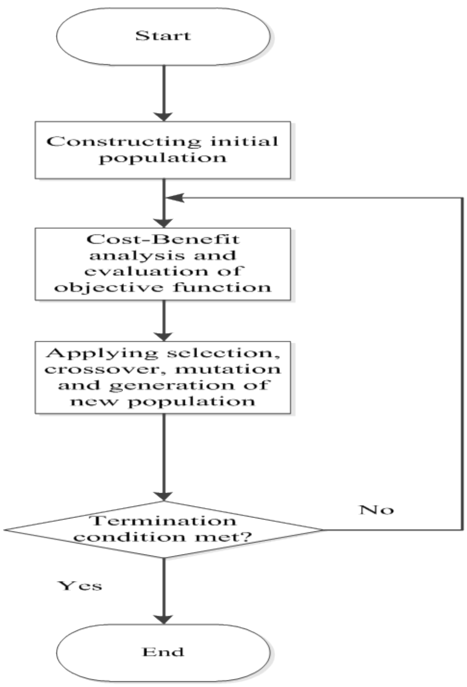

Fig. 3 GA procedure of the proposed problem

TABLE I GENETIC ALGORITHM PARAMETERS

Population Size	100
Selection Function	Roulette wheel
Number Of Variables	24
Crossover	Single point
Crossover Rate	0.9
Mutation Rate	0.05

IV. SIMULATION RESULTS

The economic evaluation of constructing the parking lot as DG along with a substation with a nominal capacity of 33MVA that both belong to the Distribution Company is done. The data used for the simulation of the problem is given in Table 2 which is the sample data of implementing the proposed model in city of Tehran, Iran. The price of buying power from transmission system at peak hours and the price of buying power from transmission system at off-peak hours are shown respectively in Fig. 4 and Fig. 5 [21].

The load profile is considered constant during a year and the power factor of the load is assumed to be 0.9. It is supposed that the aggregation of the electric vehicle in the parking lot is used to shave day and night peaks.

Using the data in Table 2 the optimization is done using GA in order to maximize the profit of the Distribution Company. The optimum number of electric vehicles that should be available in the parking lot to maximize the profit of the Distribution Company is presented in Table 3. Using this optimum number of electric vehicles, the load profile is shown in Fig. 6 that shows that day and night peaks are shaved and the load profile is smoother without the presence of the parking lot. The maximum possible profit of the Distribution Company and net present worth of optimization results are shown in Table 4.Smoother load profile can be gained by reducing from the profit of the Distribution Company. For this case, the number of electric vehicles that should be available in the parking lot to maximize the profit of the Distribution Company is presented in Table 5. Using this number of electric vehicles, the load profile is shown in Fig. 7 that is much smoother than the previous case. The maximum profit of the Distribution Company and net present worth of optimization results for this case are shown in Table 6.

TABLE II DATA USED FOR SIMULATION

Variable	Value	Variable	Value
α	5%	S_T	33
f	0.08	$S_{D,\max}$	26.67
i	0.14	$S_{S,\max}$	29.04
t_{RRNS}	30	P_1	15
T	35	P_2	25
K	3%	$P_{Loss,N}$	0.151
C_{RRNS}	1000	η_{charge}	0.9
$C_{parking}$	300	$\eta_{discharge}$	0.93
C_m	4380	N_1	3000
C_{invest}	1200000	$N_{2,\max}$	600
$C_{R,b}$	7500(300$/KWh)	$C_{accessories}$	40000
C_{ground}	1000		

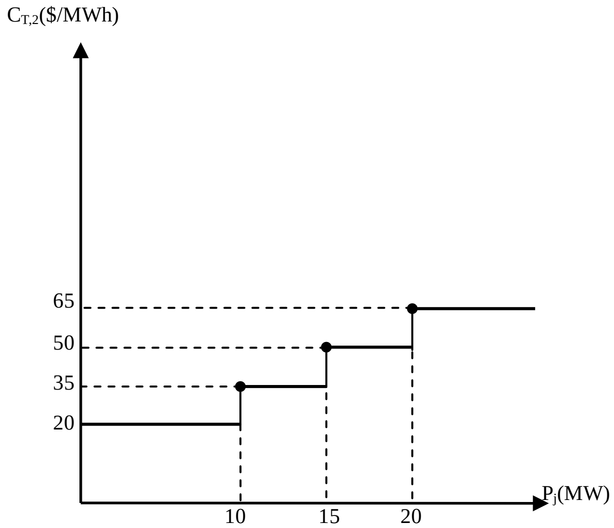

Fig. 4 Buying price of electric power at off-peak hours

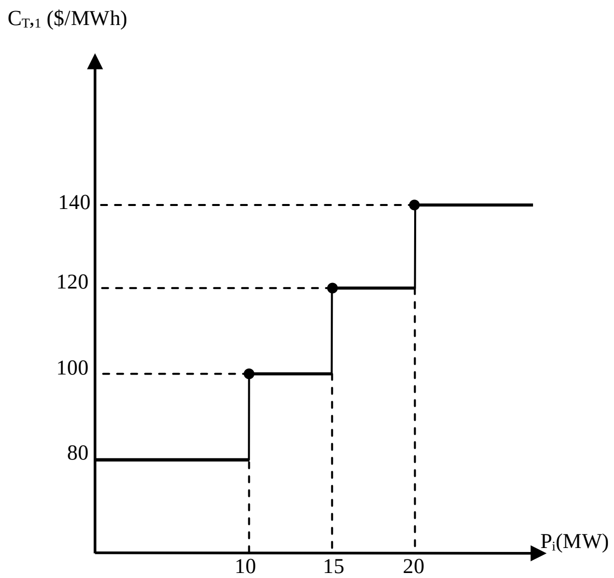

Fig. 5 Buying price of electric system at peak hours

V. CONCLUSION

In this paper cost-benefit analysis of constructing an electric vehicles parking lot for a Distribution Company is presented. The optimization procedure in order to find the maximum profit of the Distribution Company was done using genetic algorithm. The profit gained can be an incentive for the distribution companies to invest in the construction of parking lots of electric vehicles to smooth the load profile and shave the load peak in order to improve the reliability of the power systems. It was also shown that the contract between the electric vehicles and the Distribution Company as the owner of the parking lot can be profitable for the electric vehicles as well as the Distribution Company. The optimum number of the vehicles that should be available in the parking lot to satisfy the contract was also obtained.

TABLE III THE OPTIMUM NUMBER OF ELECTRIC VEHICLES AT EACH HOUR FOR GAINING MAXIMUM POSSIBLE PROFIT

Hour	1AM	2AM	3AM	4AM	5AM	6AM
Number	201	196	197	215	225	185
Hour	7AM	8AM	9AM	10AM	11AM	12PM
Number	202	200	209	344	309	354
Hour	1PM	2PM	3PM	4PM	5PM	6PM
Number	180	173	248	194	325	333
Hour	7PM	8PM	9PM	10PM	11PM	12AM
Number	345	304	341	345	173	202

TABLE IV OPTIMIZATION RESULTS FOR GAINING MAXIMUM POSSIBLE PROFIT

NPW of deferral of expanding substation capacity revenue	221681$
NPW of decreasing cost of providing active power at peak hours revenue	453469940$
NPW of System reliability improvement at peak hours revenue	2264768$
NPW of Increasing cost of active power at off-peak hours cost	32414946$
NPW of Cost of the parking lot construction and its accessories cost	3154533$
NPW of Annual costs	1948264$
Maximum profit of the Distribution Company	10338646$

TABLE V THE NUMBER OF ELECTRIC VEHICLES AT EACH HOUR FOR SMOOTHER LOAD PROFILE

Hour	1AM	2AM	3AM	4AM	5AM	6AM
Number	**252**	**353**	**351**	**334**	**293**	**274**
Hour	7AM	8AM	9AM	10AM	11AM	12PM
Number	**255**	**133**	**51**	**161**	**229**	**85**
Hour	1PM	2PM	3PM	4PM	5PM	6PM
Number	**48**	**173**	**132**	**51**	**294**	**431**
Hour	7PM	8PM	9PM	10PM	11PM	12AM
Number	**561**	**597**	**422**	**220**	**49**	**251**

TABLE VI OPTIMIZATION RESULTS FOR SMOOTHER LOAD PROFILE

NPW of deferral of expanding substation capacity revenue	370784 $
NPW of decreasing cost of providing active power at peak hours revenue	46452696 $
NPW of System reliability improvement at peak hours revenue	3819397 $
NPW of Increasing cost of active power at off-peak hours cost	38089724 $
NPW of Cost of the parking lot construction and its accessories cost	5319933 $
NPW of Annual costs	2400227 $
Maximum profit of the Distribution Company	4832992 $

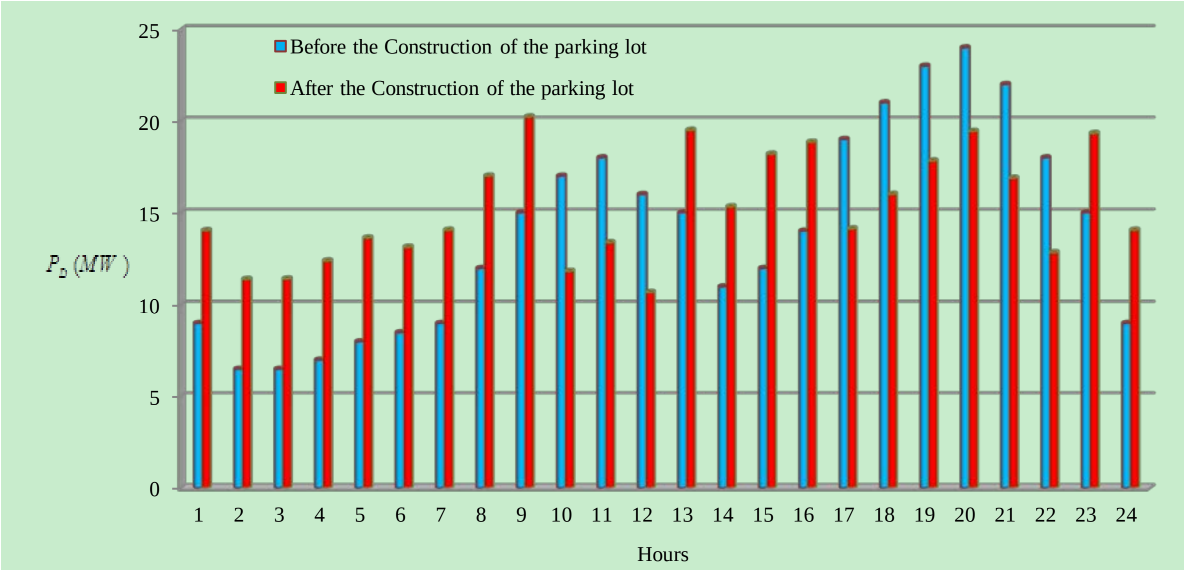

Fig. 6 The load profile before and after the construction of the parkingfor gaining maximum possible profit

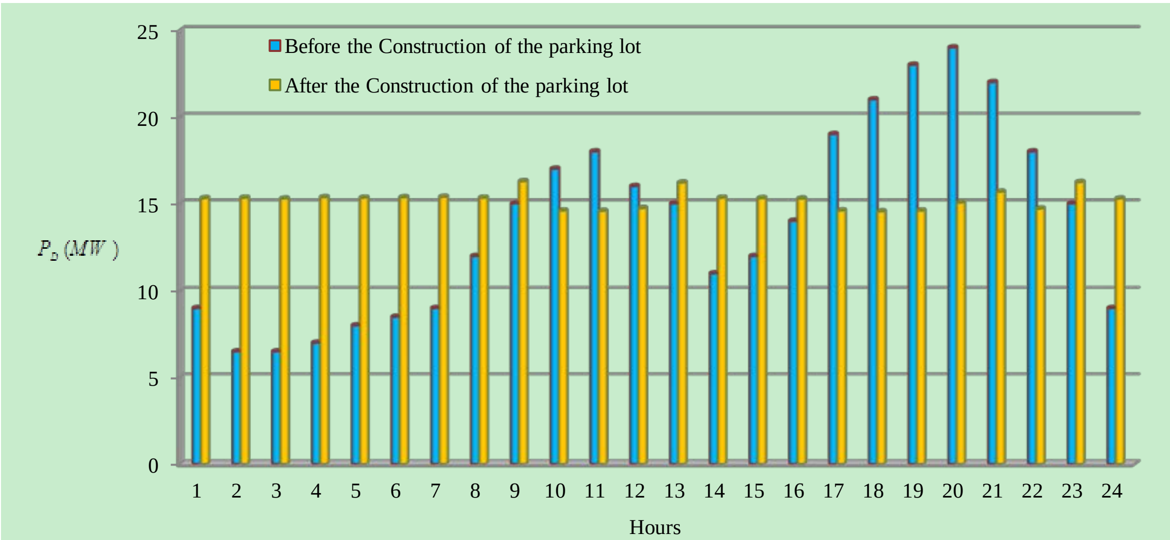

Fig. 7 The load profile before and after the construction of the parking for gaining smoother load profile

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Hamid Reza Esmaeilian received his B.Sc. degree in electrical engineering from Shahid Bahonar University of Kerman, Kerman, Iran, in 2009. He is currently pursuing the M.Sc. degree in electrical engineering at Kerman Graduate University of Technology (KGUT), Kerman, Iran. His research interests include distribution systems operation, power system optimization, power electronics and renewable energy systems.

Mohammad Mehdi Hosseini Bioki received his B.Sc. degree in electrical engineering from Shahid Bahonar University of Kerman, Kerman, Iran, in 2009. He is currently pursuing the M.Sc. degree in electrical engineering at Kerman Graduate University of Technology (KGUT), Kerman, Iran. His research interests include power system optimization, power system planning and economics, distribution systems operation, electricity restructuring and energy management, and smart grids.

Masoud Rashidinejad received his B.Sc. degree in electrical engineering and M.Sc. degree in systems engineering from Isfahan University of Technology, Iran. He received his PhD in electrical engineering from Brunel University, London, UK, 2000. He is currently an associate professor in the Department of the Electrical Engineering, Shahid Bahonar University of Kerman, Kerman, Iran. His area of interests is power system optimization, power system planning, electricity restructuring and energy management.

Amir Abdollahi received his B.Sc. degree in electrical engineering from Shahid Bahonar University, Kerman, Iran, in 2007 and M.Sc. degree in electrical engineering from Sharif University of Technology, Tehran, Iran, in 2009. He received his PhD in electrical engineering from Tarbiat Modarres University (TMU), Tehran, Iran, in 2012. He is also with the Iran Power System Engineering Research Center (IPSERC). He is currently an assistant professor in the Department of the Electrical Engineering, Shahid Bahonar University of Kerman, Iran. His research interests include demand side management, optimization, planning and economics in smart electricity grids.