TECHNO-ECONOMICAL EVALUATION OF EVS PARKING LOT CONSTRUCTION BY DISTRIBUTION COMPANIES

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ABSTRACT

In this paper techno-economical evaluation of constructing an electric vehicles parking lot by a distribution company is discussed. Electric Vehicles (EVs) have been the centre of attention in recent years because they can be used to form a bidirectional connection to the power grid. In this scheme an aggregation of electric vehicles can be used to provide ancillary services for a power grid which is known as Vehicle to Grid (V2G) concept. Aggregation of EVs in a parking lot can be considered as a distributed generation (DG) unit. During off-peak hours, power grid provides electrical energy for charging the EVs in a parking lot while during peak hours some part of their stored energy should be given back to the grid. In this paper, it is considered that the parking lot belongs to a distribution company. Such parking lots is considered as a distributed generation (DG) unit which may offer some advantages like emission reduction, power quality improvement, reliability enhancement and deferral in distribution upgrades.

INTRODUCTION

Vehicle to Grid (V2G) connection 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 [1]. Some studies have been done on cost-benefit analysis of EVs [2-3], while constructing an electric vehicle parking lot from a distribution company point of view has not been investigated yet. In this paper, a parking lot as an aggregation of electric vehicles is assumed to provide electrical energy for electric vehicles during off-peak hours and in return the stored energy in the vehicles batteries is given back to the grid during peak hours to smooth the load profile.

A distribution company can be the investor of the parking lot aiming to gain potential benefits. Such benefits includes: emission reduction, power quality improvement, reliability enhancement and deferral in distribution upgrades [4-5]. The schematic of connecting such parking lot to a distribution substation is illustrated in Fig. 1. In order to implement the proposed scheme, a contract is made between each vehicle's owner and the distribution company, which states each vehicle's battery is charged during off-peak hours up to 25KWh and discharged down to 15KWh. A part of the battery replacement cost can also be paid to the electric vehicle's owner by the distribution company.

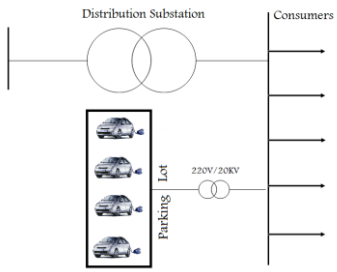

Fig .1. Connection of a parking lot to a distribution substation.

MATHEMATICAL MODELLING OF REVENUES AND COSTS

A. Revenues

1. Substation capacity expansion deferral

The annual growth of electricity consumption leads to distribution network expansion. As shown in Fig. 2, while the electricity consumption increases in a year, the initial substation peak load ($S_{D,\max}$) reaches the maximum loadability of the substation ($S_{S,\max}$). Then in order to supply the load, the capacity of the substation should be developed. By constructing a parking lot with the capacity $S_{V2G,\max}$, according to the rate of load growth, the transformer peak power decreases. Under such conditions, after N years the substation transformer loading reaches the maximum loadability. Therefore, the time of substation capacity expansion will be postponed ($\Delta T = T_2 - T_1$).

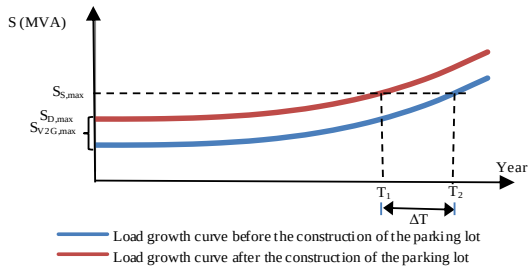

Fig. 2. Load profile of a substation before/ after parking lot construction.

Before constructing a parking lot, maximum loadability of substation is calculated by (1):

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

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

$$S_{V2G,\max} = N_2 \times P_1 \times \eta_{discharge} \quad (2)$$

$$\gamma = \frac{S_{V2G,\max}}{S_{D,\max}} \quad (3)$$

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

From (1) and (4), the deferral time of the substation capacity expansion can be derived from (5):

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

The revenue of substation capacity expansion that is obtained at year T_1 is R_1, which can be calculated using (6) and the net present worth (NPW) of the revenue is derived from (7) [6].

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

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

2. Decreasing the cost of active power at peak hours

In a competitive environment, distribution companies can buy electrical energy from power market. Real power delivered to a distribution network will cover the total demand as well as active power losses shown by (8).

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

The annual cost of active power in a distribution network before parking lot construction is:

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

Constructing a parking lot makes it possible that distribution company procuring some part of required active power from the parking lot and thus less power is purchased from market. The produced power through the parking lot is calculated by (10).

$$P_{V2G,i} = N_i \times P_1 \times \eta_{discharge} \quad (10)$$

A saving in purchased power can be calculated using (11).

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

So the annual cost of active power for the distribution company will be decreased using (12).

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

The annual revenue and its NPW offered by the proposed method is then calculated by (13), (14).

$$R_2 = C_{Pb,before} - C_{Pb,after} \quad (13)$$

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

3. System reliability improvement at peak hours

In order to calculate the reliability of a power system the number of hours of expected energy not served (EENS) at peak hours (t_{EENS}) is used. Before parking lot construction the corresponding cost of EENS is calculated using (15).

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

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

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

The annual revenue and its NPW due to the new scheme is obtained from (17), (18).

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

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

B. Costs

1. Increasing the cost of active power at off-peak hours

As mentioned before electric vehicles receive power from the parking lot at off-peak hours, so they are considered as loads during off-peak hours that impose the cost required energy charging to the distribution company. The substation load before parking lot construction is obtained from (19) and its annual cost is obtained from (20).

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

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

Parking lot construction imposes an additional load to the substation, while the required power to supply this new load is obtained from (21). The sum of the parking lot required power and the system initial load required power is calculated using (22) and its annual cost is derived from (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 to distribution company at off-peak hours due to the parking lot construction and its NPW is obtained from (24), (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 parking lot construction, land and accessories

The cost of parking lot construction including land is proportional to the parking capacity. The room required for each EV is $6m^2$. The cost of accessories like converter, plug, and etc. are

proportional to the maximum power drawn from the grid. By using (26), NPW of such cost is obtained using (27).

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

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

3. Annual costs

The annual costs are composed of two parts which is calculated by (28). The first part is the parking lot maintenance cost which is proportional to the maximum power drawn from the grid. The second part is the batteries degradation and replacement costs [7-8]. The distribution company provides a part of the latter cost for EVs as a motivation for EV owners. As it is assumed each EV charges and discharges once a day, the lifetime of the batteries is 8 years (3000 cycle). So the EV batteries should be replaced every 8 years. The NPW of the annual cost is then calculated by (29).

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

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

C. Objective Function

The objective function is maximizing the distribution company profit, which is the difference between the costs and the revenues.

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

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

D. Constraints

1. Number of EVs constraints

The total number of EVs entering the parking lot at peak hours as well as off-peak hours should be equal to the number of agreed EVs to participate in the proposed scheme.

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

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

2. Maximum parking capacity constraint

The parking capacity has a maximum because of economic issues.

$$N_2 = Max(N_K) \quad , k = 1, ..., 24$$
$$N_2 \le N_{2,\max} \tag{33}$$

SIMULATION RESULTS

The economic evaluation of a constructing parking lot as DG along with a substation with a nominal capacity of 33MVA of a distribution company is performed. The related sample data is given in Table 1 for city of Kerman, Iran. The prices of real power at peak hours as well as off-peak hours are gathered from [9]. Using the data in Table 1 the optimization is performed via GA where the optimum number of available EVs in the parking lot is presented in Table 2. The obtained load profile is shown in Fig. 3 that shows that day and night peaks are managed in which it is smoother in the presence of parking lot. The maximum possible profit resulted through implementing the proposed method is $10338646.

CONCLUSION

In this paper a techno-economical evaluation of EVs parking lot construction by distribution companies is presented. The optimization procedure in order to find the maximum profit of the distribution company is performed using genetic algorithm. The profit can be an incentive for distribution companies to invest in the construction of parking lots of EVs to smooth the load profile and shave peak load in order to improve load management. It is also shown that the bilateral contract between EV owners and the distribution company as the owner of the parking lot can be profitable for EV owners as well as the distribution company. The optimum number of the EVs available in the parking lot to satisfy the contract may guarantee such bilateral agreement.

Table 1. 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_{EENS}	30	P_1	15
T	35	P_2	25
K	3%	$P_{Loss,N}$	0.151
C_{EENS}	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_{land}	1000		

Table 2. Optimum number of available EVs in parking lot.

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**

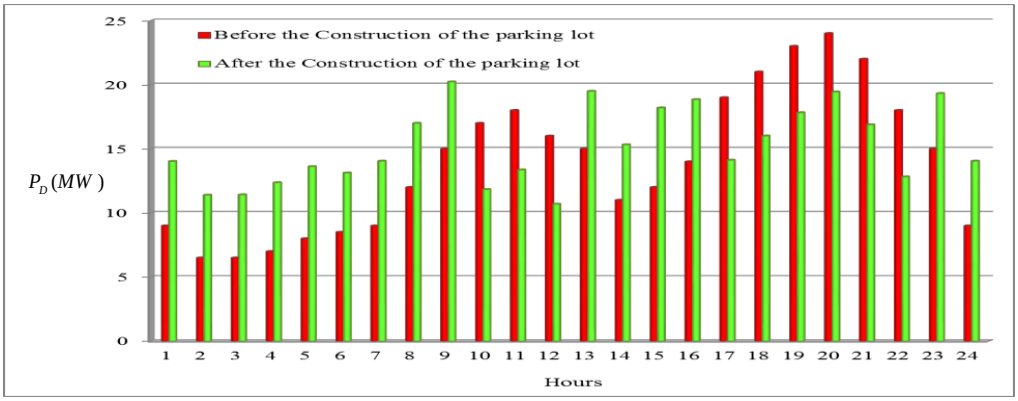

Fig. 3. The obtained load profile.

REFERENCES

[1] W. Kempton, and J. Tomic, Jun. 2005, "Vehicle-to-grid power fundamentals: Calculating capacity and net revenue", J. Power Sources, vol. 144, 268–279.

[2] A. Simpson, "Cost-Benefit Analysis of Plug-in Hybrid Electric Vehicle Technology", 2006, 22nd International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exhibition (EVS-22), Yokohama, Japan.

[3] K. Morrow, D. Karner, and J. Francfort, 2008, "Plug-in hybrid electric vehicle charging infrastructure review", The Idaho National Laboratory, Tech. Rep.

[4] C.Guille, G.Gross, 2009, "A conceptual framework for the vehicle-to-grid (V2G) implementation", J. Energy Policy, vol. 37, 4379-4390.

[5] H. Falaghi, M.R. Haghifam, M. Parsa, 2006, "Economic evaluation of construction of distributed generation units in transmission substation", Iranian Journal of Electrical and Electronic Engineering, vol. 40, 347-360.

[6] D. Kirschen, G. Strbac, 2004, *Fundamentals of power system economics*, Hoboken, NJ: John Wiley & Sons.

[7] J. Tomic, "Vehicle-to-Grid Power Economics from a Fleet Perspective", University of Delaware.

[8] S. Petersona, J. Whitacreb, J. Aptc, 2010, "The Economics of Using PHEV Battery Packs for Grid Storage", CEIC09-03, [Online]. Available: http:// www.cmu.edu/electricity

[9] (2011) Tavanir website, [Online]. Available: http:// www.tavanir.org.ir/

NOMENCLATURE

N_1 : number of EVs having bilateral contract with parking lot,

N_2 : parking capacity,

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

N_i : number of available EVs in the parking lot at hour i for discharge ($i = 10,11,12,17,18,...,22$),

N_j : number of available electric vehicles in parking lot at hour j for charge ($j = 1:24 \neq 10,11,12,17,18,...,22$),

η_{charge} : charging efficiency,

$\eta_{discharge}$: discharging efficiency,

P_1 : power given back to grid by each EV (KW),

P_2 : power obtained from parking by each EV (KW),

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

$P_{G2V,j}$: power provided for the parking lot by 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 grid by parking lot (MVA),

$S_{V2G,\max}$: maximum power drawn from aggregation of EVs by parking lot (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 peak load (MVA),

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

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

C_{land} : cost of land for parking lot construction ($/m^2),

$C_{parking}$: cost of parking lot construction for an EV ($/m^2),

$C_{accessories}$: cost of parking lot accessories like converter and plug ($/MVA),

C_{EENS} : cost of expected energy not served ($/MVA-year),

C_{pa} : annual cost of active power at off-peak hours ($),

C_{pb} : annual cost of active power at peak hours ($),

C_m : annual cost of maintenance ($/MVA-year),

$C_{R,b}$: replacement cost of batteries ($),

$C_{T,1}$: purchasing power price at peak hours ($/MW),

$C_{T,2}$: purchasing power price at off-peak hours ($/MW),

C_R : unreliability cost ($),

α : annual substation load growth rate,

f : annual inflation rate,

i : Annual interest rate,

T : parking lot lifetime (year),

T_1 : substation capacity expansion year before parking lot construction,

T_2 : substation capacity expansion year after parking lot construction,

ΔT : substation capacity expansion deferral time,

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

K : a constant regarding degradation and replacement cost provided by distribution company.