# AN ECONOMIC MODEL FOR POWER EXCHANGE OF V2GS IN PARKING LOTS

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## ABSTRACT

*Each battery vehicle (V2G) can be charged from the power grid or return its stored energy back to the grid. The effect of a single V2G on the power grid is approximately an ignorable noise. Parking lots can cumulate hundreds of V2Gs in a way that their load/generation impact can influence the grid. This paper proposes a technical and economic model for managing the charging and discharging time of battery vehicles in a parking lot. This model is employed maximizes the parking lot profit, while satisfying vehicle owners. The Genetic Algorithm (GA) is used to set the charging & discharging time table of vehicles. Finally, profit fluctuations due to varying the V2G parameters are investigated.*

## INTRODUCTION

During the recent years, increasing of the price of the oil beside environmental concerns arisen by its usage, convince the authorities of the developed countries to consider green technologies as the good alternatives[1].
According to the report of international energy agency, during 2004, share of transportation systems out of global energy consumption was around 30%, which makes the green technologies of this field, unavoidable to develop.
Electrical vehicle (EV) is becoming one of the most popular technologies of our life. The most wide spread technologies of electrical vehicles are: battery electric vehicles (BEVs), hybrid electric vehicles (HEVs) and fuel cell electric vehicles (FCV) [2].The EV receives the power from the electricity grid and stores it in its battery through charging. If manufacturers modify the power electronic circuits of these vehicles, they will be able to transfer stored electricity in their battery back to the grid [3]. Consequently this type of vehicles, known as vehicle-to-grid (V2G), can store electricity in their batteries to use for either transportation or feeding the power grid.
Because of the storage ability of Vehicles, one can gain profit due to the difference between daily peak and off-peak costs by buying of electricity during the off-peak hours and selling it back to the grid during the peak hours.
V2G benefits in many fields like environmental, economic and technical aspects, for example V2Gs can reduce $CO_2$ emission of transportation system by 2.4%[4]. Also its implementation to the wind generation can increase the reliability and efficiency of the plant[5]. Some studies [6-7], have investigated benefits of using V2G in ancillary service market such as peak power shaving, spinning reserve and regulation.
The storage capacity of each V2G is mostly between 1 and 30kWh, and because of such a small capacity, the effect of a single V2G on the power grid is nothing but approximately an ignorable noise. As the result, it is necessary to aggregate V2Gs together to have an effective flexible load/generation proportionate to the power system scale [8]. Aggregators and parking lots can cumulate hundreds of V2Gs in the way that their impact can influence the grid.

The object of this study is to find the optimal charging/ discharging time table of the parked V2Gs, which maximizes the parking lot profit while satisfying the vehicle owners. It is assumed that the capacity and the vehicle presence curve (VPC) of the PL during a day are available. The genetic algorithm (GA) is used to set this table. GA is a search technique which is conceptually based on the mechanism of natural genetics and evolution [9]. GA uses genetic-like operators for searching the global optimum.

## MATHEMATICAL MODEL

In order to have an optimal charging/ discharging time table of the parked V2Gs, it is necessary to have arrival and leaving time of the V2Gs based on the VPC during 24 hours, Fig. 1. In this paper, it is assumed that each V2G declares its initial and desired leaving state of charge (SoC) at the arrival time.

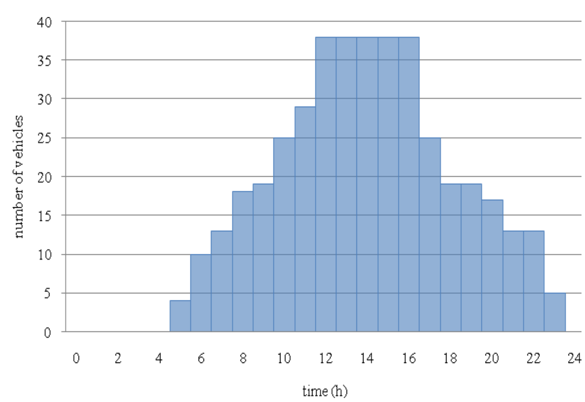


Fig. 1. The number of the parked vehicle in PL during 24 hours

The parking lot has bi-directional power transaction with V2Gs and power grid. Knowing the selling and buying price curves of electricity, one part of the profit of the parking lot is due to discrepancy of these price curves and the other part may be gained as the discrepancy of the electricity price of the off and peak hours.
The block diagram of power transaction between the

power grid, parking lot and V2Gs is shown in Fig. 2. In this figure:

$P_{BG}(h)$: the power that the parking lot buys from the grid at the hour $h$ of the day.

$P_{SG}(h)$: the power that the parking lot sells to the grid at the hour $h$ of the day.

$P_{BV}(h)$: the power that the parking lot buys from the $i$th V2G at the hour $h$ of the day.

$P_{SV}(h)$: the power that the parking lot sells to the $i$th V2G at the hour $h$ of the day.

$P_{Bat}(i)$: the power that the battery of the $i$th V2G can exchange through the converter.

The charging efficiency of converter is $\eta_c$ and its discharging efficiency is $\eta_d$. The power transaction between V2G and parking lot can be defined by (1),(2).

$$P_{SV}(i,h) = Sgn(s(i,h)) \times (P_{Bat}(i)/\eta_c(i)) \quad (1)$$

$$P_{BV}(i,h) = Sgn(-s(i,h)) \times P_{Bat}(i) \times \eta_d(i) \quad (2)$$

Where $Sgn(x)$ is the sign function, and $S(i,h)$ shows the status of charging or discharging of the V2G:

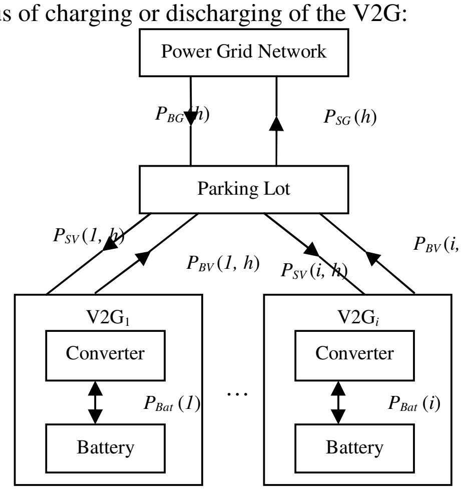


Fig. 2. Block diagram of power transaction between the power grid, PL & V2Gs.

$$s(i,h) = \begin{cases} +1 & \text{If V2G is Chargin} \\ -1 & \text{If V2G is Discharging} \\ 0 & \text{If V2G is not connected to the Parking Lot} \end{cases} \quad (3)$$

Total received power from all vehicles, $P_G(h)$, and total transferred power to them, $P_L(h)$, at time h, is calculated by:

$$P_G(h) = \sum_{i=1}^{n} P_{BV}(i,h) \quad (4)$$

$$P_L(h) = \sum_{i=1}^{n} P_{SV}(i,h) \quad (5)$$

The exchanged power between parking lot and V2Gs can be obtained from (6).

$$P_{net}(h) = P_G(h) - P_L(h) \quad (6)$$

Parking lot will act as a load and should buy electricity from grid If $P_{net}<0$, otherwise it will act as a generation source and can sell electricity to the grid. Hence:

$$P_{BG}(h) = Sgn(-P_{net}(h)) \times (P_L(h) - P_G(h)) \quad (7)$$

$$P_{SG}(h) = Sgn(P_{net}(h)) \times (P_G(h) - P_L(h)) \quad (8)$$

## Objective Function

To calculate the profit of parking lot, costs and incomes of PL should be calculated which requires the price curves of selling and buying of the electricity.

$Pr_{BG}$: the price curve of buying electricity from the grid

$Pr_{SG}$: the price curve of selling electricity to the grid

$Pr_{BV}$: the price curve of buying electricity from vehicles

$Pr_{SV}$: the price curve of selling electricity to vehicles

The total cost paid for buying electricity from the power grid, $C_{BG}$, and the total income gained from selling electricity to it, $C_{SG}$, obtain from (9),(10).

$$C_{BG} = \sum_{h=1}^{24} P_{BG}(h) \times P_{rBG}(h) \quad (9)$$

$$C_{SG} = \sum_{h=1}^{24} P_{SG}(h) \times P_{rSG}(h) \quad (10)$$

The next step is to calculate $C_{BV}$ and $C_{SV}$, which are the total cost paid for buying electricity from $i$thV2G and the total income gained from selling electricity to it, respectively. Any parked V2G, should be charged/discharged in some hours between $h_i$, the time of arrival and $h_O$, the time of leaving. So the duration of charging/discharging, $h_c$, will be calculated from:

$$h_c(i) = \frac{|SOC_o(i) - SoC_i(i)|}{P_{Bat}(i)/E_t(i)} \quad (11)$$

Where:

$SoC_i(i)$: the SoC of $i$th V2G at its time of arrival

$SoC_O(i)$: the desired SoC of $i$th V2G at its leaving time

$E_t(i)$: the total battery capacity of $i$th V2G

To satisfy V2G owners, PL should charge and discharge V2Gs when parking electricity prices are the lowest and the highest, respectively. For that, the parking electricity prices should be sorted ascending and descending, (12), (13). So, the electricity cost and income can be calculated from (14), (15)

$$Pr_{SV}^{as}(i,h) = sort(Pr_{SV}(h))_{h=h_i(i)}^{h=h_O(i)} \quad (12)$$

$$Pr_{BV}^{ds}(i,h) = sort(Pr_{BV}(h))_{h=h_i(i)}^{h=h_O(i)} \quad (13)$$

$$C_{SV}(i) = Sgn(SoC_o(i) - SoC_i(i)) \times \frac{P_{Bat}(i)}{\eta_c(i)} \times \sum_{h=1}^{h_c(i)} Pr_{SV}^{as}(i,h) \quad (14)$$

$$C_{BV}(i) = Sgn(SoC_i(i) - SoC_o(i)) \times P_{Bat}(i) \times \eta_d(i) \times \sum_{h=1}^{h_c(i)} Pr_{BV}^{ds}(i,h) \quad (15)$$

Now, the objective function, the profit of the parking lot, can be obtained using (16)

$$profit = [C_{SG} - C_{BG}] + \sum_{i=1}^{n} [C_{SV}(i) - C_{BV}(i)] \quad (16)$$

## Contraints

State of charge of a battery at any hour of the day is equal to the summation of initial SoC ($SoC_i$) and the proportion of net received energy to the battery (17):

$$SoC(i,h) = SoC_i(i) + \sum_{i=1}^{t} [P_{SV}(i,h) \times \eta_c - P_{BV}(i,h) / \eta_d] / E_t(i) \quad (17)$$

The first constraint ensures that SoC of each vehicle battery will not exceed its boundaries:

$$SoC_{\min}(i) < SoC(i,h) < 100\% \quad (18)$$

Where, $SoC_{min}$ depends on the technology of the V2Gs. The second constraint ensures that the leaving time SoC will be as the request of V2G's owner (19):

$$SoC(i, h_o(i)) = SoC_o(i) \quad (19)$$

## OPTIMIZATION PROBLEM

The objective function of this study, as shown in (20), is a profit function which should be maximized.

$$\begin{aligned} & Max\, profit = [C_{SG} - C_{BG}] + \sum_{i=1}^{n} [C_{SV}(i) - C_{BV}(i)] \\ & st. \quad SoC_{\min}(i) < SoC(i,h) < 100\% \\ & st. \quad SoC(i, h_o(i)) = SoC_o(i) \end{aligned} \quad (20)$$

## CASE STUDY

In this section, the proposed method is used to maximize a parking lot with 40 parking spaces. Its VPC is shown in Fig. 1. The arrival and leaving times of V2Gs are set according to this curve. The parameters of batteries are randomly considered based on their restricts expressed by table I. The parking price data are given in table II.

TABLE I: VEHICLE PARAMETERS

| *Parameter* | *Minimum Value* | *Maximum Value* |
|---|---|---|
| Battery Capacity (KWh) | 15 | 30 |
| $SoC_o$ (%) | 40 | 100 |
| $SoC_i$ (%) | 0 | 100 |
| Battery Discharge Eff(%) | 80 | 95 |
| Battery charge Eff (%) | 80 | 95 |

The parking lot profit is expressed in per-unit and its base value, $Profit_{base}$, is defined as the cost of charging a 25kWh battery of a vehicle from the power grid. The mean value of buying electricity price during a day, $Pr_{BG}^{Av}$, can be obtained using table II. Hence, $Profit_{Base}$ is calculated by:

$$Profit_{Base} = Pr_{BG}^{Av}(\$/kWh) \times 25(kWh) = 1.725(\$) \quad (21)$$

TABLE II: THE PARKING ELECTRICITY PRICES

| *Time (h)* | *$Pr_{BG}$* ($/MWh) | *$Pr_{BV}$* ($/MWh) | *$Pr_{SG}$* ($/MWh) | *$Pr_{SG}$* ($/MWh) |
|---|---|---|---|---|
| 1 | 67,054 | 60,3486 | 67,054 | 67,054 |
| 2 | 64,285 | 57,8565 | 64,285 | 64,285 |
| 3 | 63,544 | 57,1896 | 63,544 | 63,544 |
| 4 | 63,401 | 57,0609 | 63,401 | 63,401 |
| 5 | 63,479 | 57,1311 | 63,479 | 63,479 |
| 6 | 66,885 | 60,1965 | 66,885 | 66,885 |
| 7 | 70,564 | 63,5076 | 70,564 | 70,564 |
| 8 | 72,345 | 65,1105 | 72,345 | 72,345 |
| 9 | 72,878 | 65,5902 | 72,878 | 72,878 |
| 10 | 73,19 | 65,871 | 73,19 | 73,19 |
| 11 | 72,878 | 65,5902 | 72,878 | 72,878 |
| 12 | 72,54 | 65,286 | 72,54 | 72,54 |
| 13 | 72,488 | 65,2392 | 72,488 | 72,488 |
| 14 | 72,189 | 64,9701 | 72,189 | 72,189 |
| 15 | 71,695 | 64,5255 | 71,695 | 71,695 |
| 16 | 71,24 | 64,116 | 71,24 | 71,24 |
| 17 | 70,798 | 63,7182 | 70,798 | 70,798 |
| 18 | 69,16 | 62,244 | 69,16 | 69,16 |
| 19 | 67,86 | 61,074 | 67,86 | 67,86 |
| 20 | 67,73 | 60,957 | 67,73 | 67,73 |
| 21 | 67,73 | 60,957 | 67,73 | 67,73 |
| 22 | 67,6 | 60,84 | 67,6 | 67,6 |
| 23 | 67,34 | 60,606 | 67,34 | 67,34 |
| 24 | 67,21 | 60,489 | 67,21 | 67,21 |

## NUMERICAL RESULTS

In this section, the effects of batteries parameter variation on the parking profit are numerically investigated.

### Presence duration of vehicles in the parking lot

For a fixed charging/discharging time the presence duration of vehicles in the parking lot are increased and the corresponding parking profit are calculated. It is expected that the parking profit increases directly by the increment of presence duration of vehicles. But, as the results, Fig. 3, show this would not happen. As the presence duration of vehicles expands, the V2Gs have more chance to receive the cheaper energy. Hence, it causes a decrement in parking lot profit in order to satisfy the V2G owners.

### Battery discharge efficiency

The simulation results show that increasing the battery discharge efficiency could increase the parking lot profit, Fig. 4, because the parking lot can receive more power from V2Gs and sell it to the grid at expensive hours.

### Battery charge efficiency

As it can be seen in Fig. 5, the simulation results show that increasing the battery charge efficiency could increase or decrease the parking lot profit. In the low efficiencies, the parking lot profit is a result of selling the electricity to vehicles so increment of the battery charge efficiency will decrease it. But in the high efficiencies, the profit is a result of storage ability of V2Gs and increment of the efficiency will increase it.

### Battery capacity of vehicles

Since a part of parking lot profit is a result of storage ability of vehicles, increasing their battery capacities can increase the power transaction ability of PL and so its profit. These results are driven from the simulations too, Fig. 6.

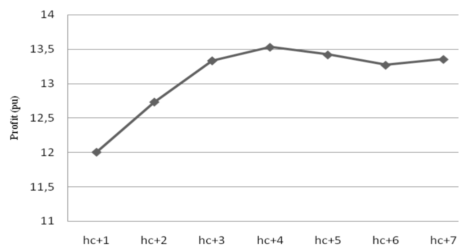


Fig. 3. Variation of profit versus increasing duration of presence of vehicles in the parking lot

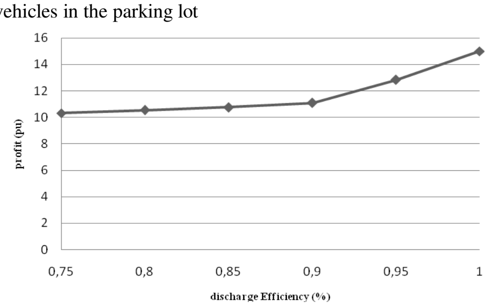


Fig. 4. Variation of profit versus increasing battery discharge efficiency

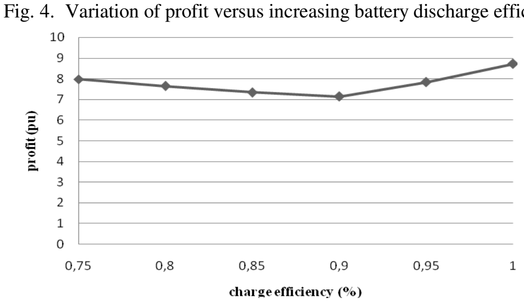


Fig. 3. Variation of profit versus increasing battery charge efficiency

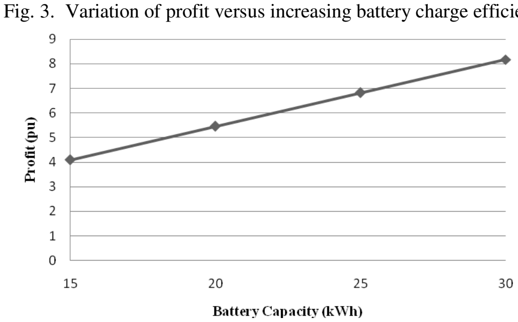


Fig. 4. Variation of profit versus increasing battery capacity

## CONCLUSION

In this paper the method of managing the power transaction in the parking lot has been proposed as an optimization problem and solved using genetic algorithm. The object of this problem was maximization of the parking lot profit, while satisfying the V2G owners. As the case study, a parking lot with 40 parking spaces were considered and the sensitivity of parking lot profit to variation of some parameters of vehicles like the battery capacity and charge and discharge efficiencies were analyzed. The results showed that increasing battery capacity or discharge efficiency will increase the parking profit. But increasing the battery charge efficiency causes different behaviors in the parking lot profit. Also such a behavior can be observed while the presence duration of vehicles in the parking lot was increased.

## REFERENCES

[1] M. Hajian, *et al.*, "Environmental benefits of plug-in hybrid electric vehicles: The case of Alberta," 2009, pp. 1-6.

[2] W. Kempton and S. E. Letendre, "Electric vehicles as a new power source for electric utilities," *Transportation Research Part D: Transport and Environment,* vol. 2, pp. 157-175, 1997.

[3] C. Hutson, *et al.*, "Intelligent scheduling of hybrid and electric vehicle storage capacity in a parking lot for profit maximization in grid power transactions," 2008, pp. 1-8.

[4] C. Zhou, *et al.*, "Modeling of the Cost of EV Battery Wear Due to V2G Application in Power Systems," *Energy Conversion, IEEE Transactions on,* vol. 26, pp. 1041-1050, 2011.

[5] W. Kempton and J. Tomic, "Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy," *Journal of Power Sources,* vol. 144, pp. 280-294, 2005.

[6] W. Kempton and J. Tomic, "Vehicle-to-grid power fundamentals: Calculating capacity and net revenue," *Journal of Power Sources,* vol. 144, pp. 268-279, 2005.

[7] K. Clement-Nyns, *et al.*, "The impact of vehicle-to-grid on the distribution grid," *Electric Power Systems Research,* vol. 81, pp. 185-192, 2011.

[8] C. Guille and G. Gross, "A conceptual framework for the vehicle-to-grid implementation," *Energy Policy,* vol. 37, pp. 4379-4390, 2009.

[9] H. John, "Holland, Adaptation in natural and artificial systems," ed: MIT Press, Cambridge, MA, 1992.