Charging and discharging strategies for electric vehicles based on V2G

Shihui Tian
School of Economics and Management organization
Beijing Jiaotong University
Beijing, China
14120599@bjtu.edu.cn

Guowei Hua*
School of Economics and Management organization
Beijing Jiaotong University
Beijing, China
gwhua@bjtu.edu.cn

***Abstract*—The extensive application of electric vehicles will make a series influence on power gird. Based on V2G technology this paper discusses the charging and discharging strategies, combining the peak-valley price and the travel habit. We propose a non-cooperation master-slave game model, in which the power company decides discharging price, and the owner of electric vehicles decides the amount of charging and discharging. In this game, we incorporate the loss of power grid into the total cost, and the amount of discharging is limited by the surplus power. At the game equilibrium point, both of the participants will achieve the maximum benefits.**

Keywords—V2G; discharging price; game theory

I. Introduction

As people become increasingly concerned about environmental issues, renewable energy sources caught public eye. As new energy vehicles, electric vehicles have great advantages in terms of energy, which will take the dominant place of diesel vehicles. "Beijing air pollution emergency plan" is issued on March 30th, pointed out that Beijing is to ban vehicles with even and odd-numbered license plates when starting air pollution red alert, except for pure electric vehicles. This measure will further promote the sale of electric vehicles. Based on the forecast of electric vehicle development strategy research report, the quantity of will reach 60 million until 2030.

The charging of electric vehicles will bring certain impact on power grid. On the other hand, each electric vehicle has large battery capacity, while the idle time of most vehicles is about 22 hours a day. If this part of energy can be used, the power grid will be eased considerably.V2G (vehicle-to-gird) provides a new solution to grid balance.

V2G combines power electronics technology, and information control technology, regarding the storage of battery as grid buffer. A series of experiments prove that V2G". Technology is feasible, and the economic benefits are significant. At the peak of grid load, electric vehicles discharges and provide power to grid, while at the valley of grid load, electric vehicles charges and store energy. In the situation of peak-valley price, buying power at a lower price and selling power at a higher price will bring revenue for the owner of electric vehicles. The charging and discharging strategies will make a big difference for the grid load. We must meet the electricity needs of daily travel, as well as balance the grid load. V2G is aim to coordination between electric vehicles and the power grid. This paper utilizes non-cooperation master-slave game model, in which power company, as the leader, decides the discharging price, the owner of the electric vehicle, as the follower, decides the amount of charging and discharging.

At present, the research about V2G is focused on theoretical level, namely the potential impact on economy's technology and environment. Based on this technology, there are two kind of Commercial operation plans. One is that the owner of electric vehicle is eager to participate in V2G plan and accept the real time control. Professor Kempton form university of Delaware underlined that this optimal strategy coming from theory can hardly be accepted by owner in practice. The other way is to lead owner's behavior by price, discharge at peak, charge at the valley, reducing constraints to the owners, as well as achieving the purpose of peak shaving and valley filling for power grid.

Reference analyzes the pricing elements and principles of charging, and brings out a new pricing model [1].Presents an optimized model for power price time-period considering how to use ordered charging of electric vehicles to cut the peak and fill the valley [2]. Analyze the feasibility of V2G technology and implementation method [3]. By comparing the differences and similarities between V2G reserve and generation side reserve, analyzed the interactive relationships of the relevant reserve need established an optimal formulation proposed to minimize load fluctuations [4-5]. Compared the respond speed of owner in different prices when participate in V2G [6].

II. THE IMPACT OF CHARGING AND DISCHARING ON POWER GRID

With the popularity of electric vehicles, the number of charge and discharge station has also increased. Electric vehicles will become an important new load for grid. The impact of charging and discharging on power grid is increasingly clear, mainly reflected in: the impact of

This research was supported in part by the National Natural Science Foundation of China (NSFC) under grant numbers 71390334 and 71071015, and the Beijing philosophy and Social Science Foundation under grant number 13JGB042.

978-1-4799-1891-1/15/$31.00 ©2015 IEEE

charging randomness on grid; the impact on power quality; the impact on grid planning.

A. The impact of charging randomness on grid

When numerous electric vehicles charges at the same time in the period of time, it will bring a tremendous impact on local power grid, and cause local overload phenomenon. It has a very negative impact on grid, so we should guide the owner to decide the suitable charging time during the process of popularity of electric vehicles.

B. The impact of charging and discharging on power quality

It's easy to produce harmonics when charging and discharging, leading to harmonic pollution and affecting power quality. In-situ treatment would be useful ,which means completing the treatment in charging station.

C. The impact of charging and discharging on grid planning

In the daily peak period, the electric vehicle's battery can provides power to grid. And because of dispersion and mobility, the charging and discharging station will influenced the distribution lines and capacity setting in grid plan. In other words, the randomness of charging will lead to bias of prediction, so that the grid planning face greater uncertainty.

In the future, through the improvement of the charge-discharge facilities, electric vehicles will be closely connected to the grid. In the case of intelligent charging and discharging, stabilizing the grid load 、 frequency fluctuations, reducing grid FM, balancing the peaks and valleys, and improving the operation of grid will come true.

III. ANALYSIS OF PEAK AND VALLEY IN POWER AND TRAVEL

Driven by the rapid economic and industry, the load of grid is also growing. Since electricity time is concentrated, result in the power grid fluctuations. At valley, a large number of equipment is idle, while at peak, operate a switch and ration the power supply. In this way, it doesn't only reduce the overall economic benefits, but also results in a waste of resources.

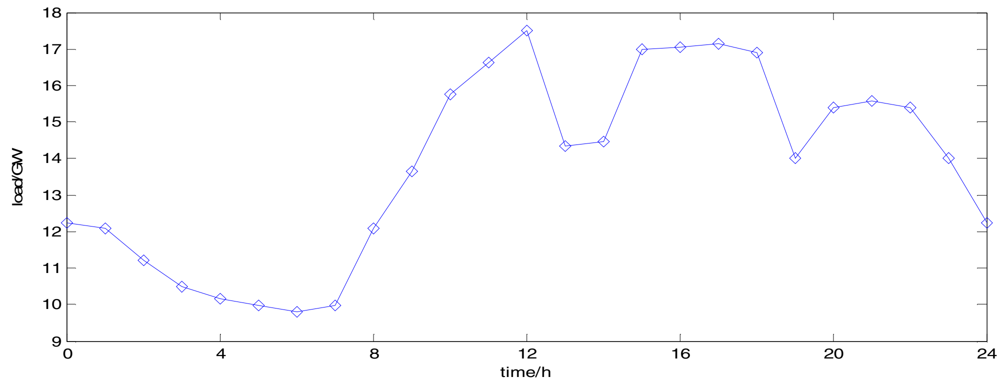

Fig. 1. Load of power grid in different time

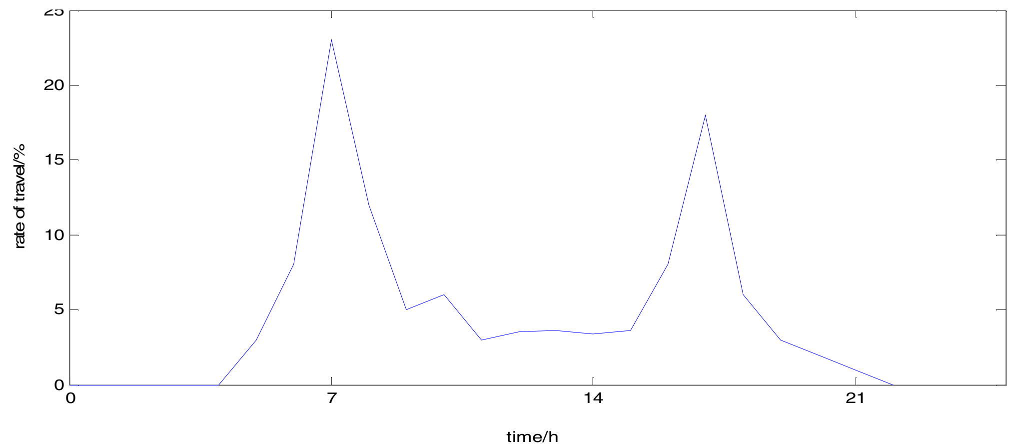

Fig. 2. Time of travel habit

In summer, there are three grid peaks in general: 11:00 to 12:00、16:00 to 17:00、20:00 to 21:00 and valley time starts from 23:00 until 7:00， we can see trend in Fig. 1. The implementation of peak-valley price has different division in the provinces, on the whole, peak price time includes 8:00 to 11:00 and 18:00 to 23:00, and valley price time is 23:00 to 7:00.

In the case of certain power supply, the loss of power grid is minimum when the grid runs at continuous average load. Different load curves have different influence on grid, the loss is larger when the margin in peak and valley is big [7]. Reducing load fluctuations is the main measure to decrease the loss of power grid. Regardless of the season or off-season for electricity, power company should adjust actively to make grid load remain balance.

Reference has counted the travel time of private car in Beijing. Fig. 2 displays the result of the research [8]. It's clear that the rush hour is concentrated in 7:00 to 9:00, the evening peak period focused on 17:00 to 19:00.

The owner of electric vehicles often decides to charge after work and before go to work in the second day. When take V2G into consideration, owner will discharge in peak price, and charge in valley price. The price of electricity directly affect the amount of charging and discharging [9]. Owners should make objective decisions to ensure normal travel and receive benefit, and power company dominates the behavior of owners by price of electricity, to remain the stability of grid and achieve the purpose of peak shaving and valley filling for power grid.

IV. HYPOTHESIS AND MODEL

A. Hypothesis

On normal situation, the owner of electric vehicle will charge and discharge after work and before go to work next day. People arrive home between 17 o'clock and 19 o'clock, which is also the period of peak price. Assume that the owner is rational, and can't charge in this period, in opposite, he will discharge to power grid, and he won't charge until the valley price starts. For peak-valley price, namely TOU(time of use), relevant standards exist in various regions. As V2G is emerging technology, relevant provisions of discharging are still blank. Now assume that the price of charging at peak load is P_1, the price of charging at valley load is P_2, the price of discharging at peak load is P_3. Among them, P_1 , P_2 are known, and $P_1 > P_2$， $P_3 > P_2$.

The amount of electric vehicle discharging at peak load is F, and the amount of electric vehicle charging at valley load is D.

$$D = q + P_1 * a - P_2 * b + P_3 * c \tag{1}$$

Within it, q presents the Maximum electric demand when there is no price impact; a is the response parameter of owner to P_1, $a>0$; b is the response parameter of owner to P_2, $b>0$; c is the response parameter of owner to discharging price P_3, $c>0$.

In this paper, we don't consider the cost of battery resulted from the discharging behavior. For the power company, the cost of providing power at valley is C_1.

In order to show the impact of V2G in peak shaving and valley filling for power grid, we compare the demand of owner when there is no discharging behavior, D' present the demand in this situation:

$$D' = q + P_1 * a - P_2 * b \tag{2}$$

Compared this two situation, the margin of demand is $P_3 * c$. *Fig. 3* reveals the effect of V2G on grid load. At the peak load of grid, discharging lead to the drop of the peak, for each electric vehicle, the quantity is F; at the valley load of grid, the owner will charge more, the quantity is $P_3 * c$. the margin load of the peak and valley will result in loss of grid, and the parameter is λ. For the power company, V2G can bring revenue on some degree: $\lambda(F + P_3 * c)$.

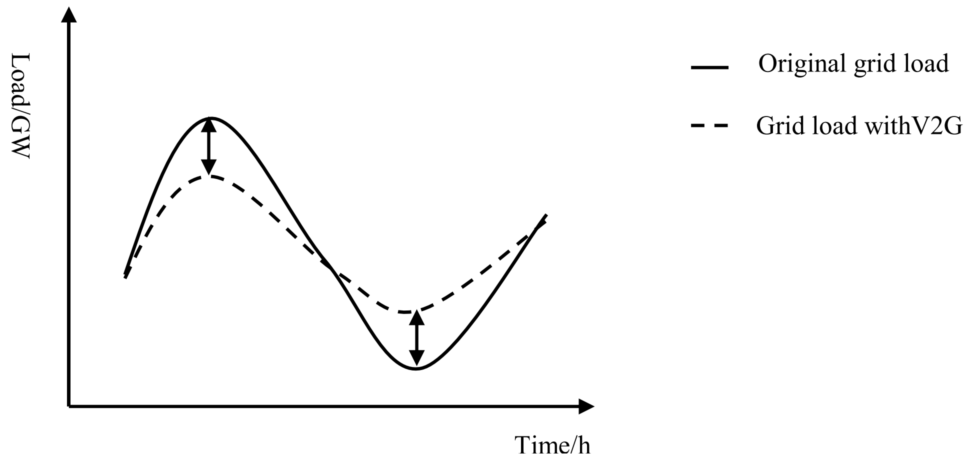

Fig. 4. The impact of V2G on grid

For the owner of electric vehicle, even though V2G can bring revenue, he must ensure the daily travel in the next day. The lowest demand of daily travel is W. The amount of charging and discharging must satisfy the constraints:

$$D >= W \tag{3}$$

$$F <= D - W \tag{4}$$

Assume that both the travel habit and the amount of charging stay the same, and after arriving home, the owner at most supply the whole surplus power to the grid, this maximum equal the amount of charging yesterday minus the amount of used for travel today.

B. Model establishment

In V2G market, there is a game model, in which the power company is the leader, and the owner of the electric vehicle is the follower. At beginning, the power company decides the discharging price based on the market information, and then the owner decides the amount of charging and discharging after knowing the price.

The revenue of power company is:

$$\pi_1 = D(P_2 - C_1) - F * P_3 + \lambda(F + P_3 * c) \tag{5}$$

Namely:

$$\pi_1 = (q + P_1 * a - P_2 * b + P_3 * c) * (P_2 - C_1) - F * P_3 + \lambda(F + P_3 * c) \tag{6}$$

The revenue of owner is π_2 :

$$\pi_2 = F * P_3 - D * P_2 \tag{7}$$

$$\pi_2 = F * P_3 - (q + P_1 * a - P_2 * b + P_3 * c) * P_2 \tag{8}$$

s.t.

$$D >= W \tag{9}$$

$$F <= D - W \tag{10}$$

To find the game equilibrium point, firstly we solve the game equilibrium in second stage. When P_3 is certain , the owner of electric vehicle maximizes the revenue by deciding F. From (8) we can see, π_2 is a monotonically increasing function about F . π_2 obtains maximum when F is maximum.

$$F^* = q + P_1 * a - P_2 * b + P_3 * c \tag{11}$$

$$\max\pi_2 = (q + P_1 * a - P_2 * b + P_3 * c - W) * P_3 - (q + P_1 * a - P_2 * b + P_3 * c) * P_2 \tag{12}$$

Combined (6) and (11):

$$\max\pi_1 = (q + P_1 * a - P_2 * b + P_3 * c) * (P_2 - C_1 - \lambda - P_3) + (\lambda - W) * P_3 + W * \lambda$$

$$P_3^* = \frac{(P_2 - C_1) * c - (q + P_1 * a - P_2 * b - W) + 2\lambda c}{2c}$$

F^* and P_3^* is the equilibrium point, where power company and the owner of electric vehicle get maximum revenue.

C. Case analysis

Generally, the battery capacityelectric vehicles is approximately 15kw • h, and the loss of grid λ is 8%. Based on previous literature, we can know that: a=3kw/yuan ,b=5kw/yuan ,c=6kw/yuan. In a city of China, which implemented TOU, the price of charging in peak time is 0.5583yuan/kw • h, the price of charging in valley time is 0.3583yuan/kw • h, the cost of providing power in valley time is 0.15yuan/kw • h. where, W is 13 kw • h .

Based on the above data, we can calculate the price of discharging in peak time is 0.43yuan/kw • h.

TABLE I. ELECTRICITY PRICE AND TIME

	Price(yuan/kw • h)	Time
Charging in peak time	0.5583	21:00-8:00（next day）
Charging in valley time	0.3583	8:00-21:00
Discharging in peak time	0.43	21:00-8:00（next day）

Because V2G technology has not been popular, and how to set the discharging price lack of experience. Take the game model and related data into consideration, we can provide a reference for setting of discharging.

V. CONCLUSION

This paper is based on V2G technology, consider the game between electric vehicle and power company. The impact of large-scale charging of electric vehicle on grid should not be underestimated, and V2G technology makes it possible to reverse discharge from electric vehicles, which plays a very significant role to remain the stability of grid. When the travel habit and Peak - valley price are known, discharging price influences charging and discharging decision. We apply the non-cooperation master-slave game model, in which the power company is leader who develops discharging price, the owner, as the follower, determines the amount of charging and discharging, the result of the game aims to gain maximum revenue. This paper belongs to theoretical research, and is meaningful to promote V2G technology, at the same time, provides reference for the setting of discharging price.

REFERENCE

[1] Yan B (2014) Discussion of electric vehicle charging service pricing model. Power dsm 16(3):41-44.

[2] Ge SY, Huang L, Liu H (2012) Optimization of peak-valley TOU power price time-period in ordered charging mode of electric vehicle. Power system protection and control 40(10):1-5.

[3] Liu XF, Zhang QF, Cui SM(2012) Review of Electric Vehicle V2G Technology.Transactions of china electrotechnical society 27(2):121-126.

[4] Zhang Q, Shi LF, Ren YL, Zhou LW, Luo QM(2012) The Reserve Trading Model Considering Vehicle-to-grid Reserve. Proceedings of the CSEE 32(31):59-67.

[5] Xiang D, Song YH, Hu ZC, Xu ZW(2013) Research on Optimal Time of Use Price for Electric Vehicle Participating V2G.. Proceedings of the CSEE 33(31):15-25.

[6] Shi LF, Ren YL, Yu JH, Shen W(2012) Strategy research of price on V2G reverse supply market. Journal of industrial engineering 26(2):113-118.

[7] Liu MJ, Guo JF, Gao LP(2009) Analysis and modeling of private car usage through travel behavior. Engineering and technology 39(2):25-30.

[8] Zhang HY, Li JW(2013) Effect analysis on the electric vehicle charging and discharging to power grid. Electric drive automation 35(2):11-14.

[9] Bei YQ(2010) Analysis of power line loss factors. Innerm ongolia science technology& econany 209(7):91-94.