Energy and Power Engineering, **2013, 5, 1347-1351**
doi:10.4236/epe.2013.54B255 Published Online July 2013 (http://www.scirp.org/journal/epe)

Impact of Electric Vehicle Charging on Power Load Based on TOU Price*

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Received February, 2013

ABSTRACT

Large-scale electric vehicle charging has a significant impact on power grid load, disorderly charging will increase power grid peak load. This article proposes an orderly charging mechanism based on TOU price. To build an orderly charging model by researching TOU price and user price reaction model. This article research the impact of electric vehicle charging on grid load by orderly charging model. With this model the grid's peak and valley characteristics, the utilization of charging equipment, the economics of grid operation can all be improved.

Keywords: Electric Vehicles; DSM; TOU Price; Orderly Charge; Power Load

1. Introduction

TOU price refers to a kind of tariff system. In that system, a day will be divided into multiple time periods, and will change different prices for different time periods of electricity consumption. TOU price is an important means of Demand Side Management (DSM), it can also direct users to utilize electricity in reasonable way[1-6].

With economic development and social progress, power has increasingly became a necessity of people's production and life, electricity demand continues to increase which will further intensification of the contradicttion between electricity supply and demand. Generally, the electricity change is very obvious in both corporate users and residential customers every day, and most users have low power consumption at night than during the day[7-9].

We call a time period Peak Time when power load is greater than a certain value, on the contrary, when power load is below a certain value, we call that time period Valley Time, except this two kinds time periods, all other times is called flat section. Valley time and flat section are also called non-peak time. If electric energy can be stored massively in a long time like ordinary goods, there will be tiny differences in power supply cost between peak time and other time period. However, as a special commodity, massive storage is difficulty and costly for power, its production and consumption needs it synchronously.

Every day, in order to meet power demand in peak time, power plants according to peak time power demand to organize electric power production. Meantime, according to the requirements of power load, power grid coordinates power supply and installs plenty power transmission and distribution equipment. Among them, there must be part of equipment in idle or low load condition when in non-peak period. In load peak period, since all equipment is in operation condition, the cost is higher. In other time, only a small amount of generating set, power transmission and distribution equipment can make a balance between power supply and demand, so the cost is lower. Therefore, according to economic principles, it is reasonable and feasible to charge different power price in different consumption period.

From the implementation effect, we can see that TOU price plays an effective role in power price leverage. It can inhibit irrational electricity growth in peak time and improve power consumption in valley period, which will enhance economic benefits of the whole power system and ensure power supply and demand balance.

TOU price system will stimulate electric vehicle users reduce peak time urgency electricity demand, and transfer it to flat section or valley period. For electricity companies, TOU price will adjust users' consumption ways, so as to reduce power production cost and balance power demand and supply. For electric vehicle users, TOU price will make charging process happen in electricity price lower time, which will greatly reduce the

*This work is supported by: National High Technology R&D Program of China (863Program) (2012AA050804), Key Project of the National Research Program of China (2011BAG02B14), National High Technology R&D Program of China (863 Program) (2011AA05A109).

cost of using electric vehicles.

2. Effects of Disordered Charge to Power Load

2.1. Forecasting of EV Charging Load

The most important factor of electric vehicles charging behavior is the beginning moment, the more concentrated the charging begin time is, the more bigger power margin is needed from the grid, and the equipment investment cost is also greater[10-13].

To study the distributed electric vehicle charging start time, we can assume the return time of traditional fuel vehicle for the start time of distributed electric vehicle charging in the future.

At present, there is no collection statistics about return time of traditional fuel automobile, we can use statistics of America transportation department as our reference. According to National Household Travel Survey (NHTS) in 2001, the probability statistical results of household vehicles' return moment shows in column **Figure 1**.

According to electric vehicle users' tradition[14-15], we assume that the owner start charging his car immediately after he back home, the above probability distribution namely for electric vehicles normal charging start time. After analysis the column figure, we can see that without any limit or guide, there must be kind of charging concentration of electric vehicles (as shown in figure in rush hour of 16:00-18:00).

At present, the rated battery capacity of mainly used electric vehicle is 20 kW·h--30 kW·h, we assume it as 25 kw-h, meanwhile, the car charger power is about 2-3 kw, we assume it as 2.5 kw. In this way if the efficiency of charging machine is 1, the electricity charge of battery from 0% to 100% needs ten hours. Therefore, we can assume the charging time T_L as standard normal distribution, whose probability function expression is

$$f_{T_L}(t) = \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-5)^2}{2}} \quad (1)$$

We assume that NHTS finding is applicable to Chinese household automobile users, so based on the probability distribution of individual household vehicle and electric vehicle car charger power, we can get ordinary charging power expectation of single electric vehicle within a day, which is shown in **Figure 2**.

Single electric vehicle charging expectation only express the charging possibilities in certain time, it has no actual meaning with charging power. However, when large-scale(set to N) electric vehicles connected to the grid simultaneously, the product of single charge expectation and number N can be considered as electric vehicle's charging load at this moment. When N equals to 500,000, the electric vehicle charging load carve is shown in **Figure 3**.

2.2. The Impact of EV Disordered Charging

As a modern city, Beijing has a large number of cars, highly developed traffic and well-equipped infrastructure; all these show the potential of electric vehicle promotion. We consider Beijing grid load as the original value to study the impacts of large-scale electric vehicle access on the load curve. When the access scale of electric vehicle N equals to 500,000, the grid load is shown as in **Figure 4**. When the access scale N equals to 1000,000, the grid load shows in **Figure 5**.

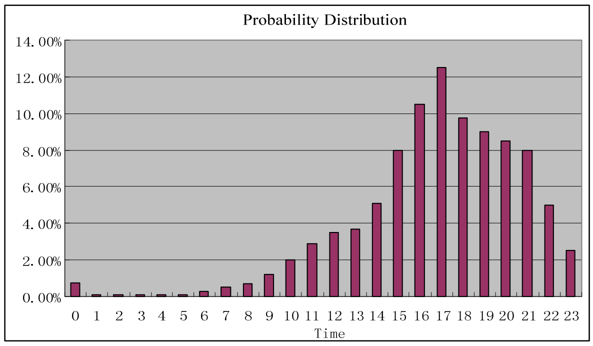

Figure 1. Probability distribution of household automobile return time.

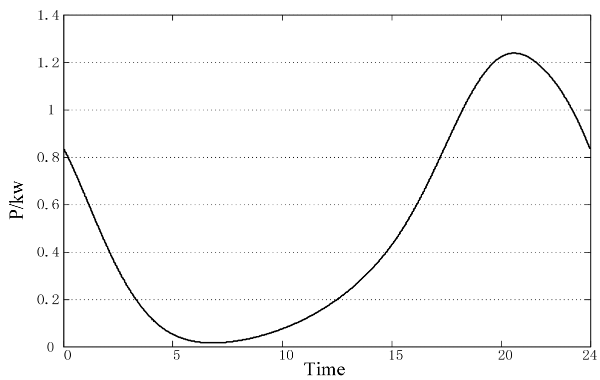

Figure 2. Charging expectations of single electric vehicle.

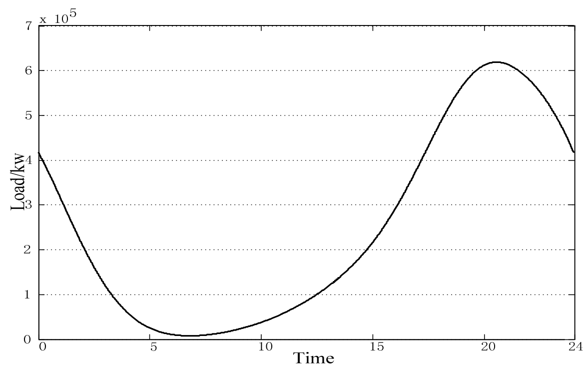

Figure 3. Charging expectations of 500,000 electric vehicles.

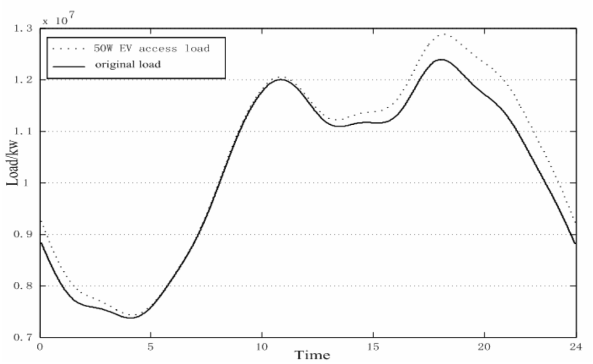

Figure 4. Grid load after 500,000 electric vehicles connected to grid.

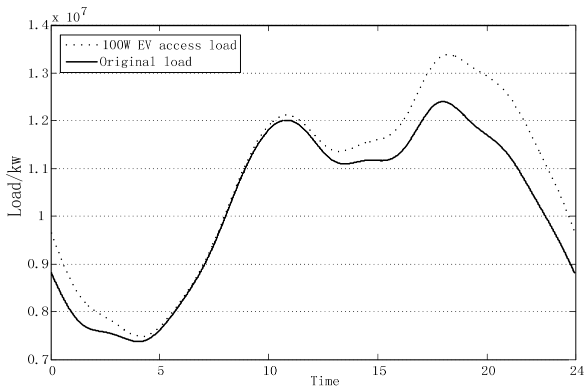

Figure 5. Grid load after 1,000,000 electric vehicles assess.

From **Figure 4**, **Figure 5**, we can see that without TOU price, there will be an obvious elevation on grid load when large-scale electric vehicle charging load connected to the grid. When electric vehicle charging load not connected to the grid, the highest peak of original grid load appears in around 18:00, which is a concentrated period of the residential electricity consumption. According to our statistics of car owners return time, electric vehicle charging start time also centered in this period. In this case, there must be a grid load problem. However, the original grid load valley is also the electric vehicle charging load valley, which increases the difference between grid load peaks and valleys. With the increase grid load from electric vehicle, this phenomenon will be more and more obvious.

From the Table 1, we can see that there are peak load increases of 3.95% and 7.94%, and valley load increase of 0.81% and 1.51% when 500,000, 1,000,000, electric vehicle connected to grid.

When electric vehicle connected to grid, the peak load increase is much higher than valley load increase, the gap between peak load and valley load become deeper.

We defined the ratio of the grid peak and valley as peak-to-valley rate. Peak-to-valley rate is an important parameter of power equipment, it is a reflection of power equipment utilization status.

The installed capacity of the generator is designed according to grid load expectation, therefore, when the peak and valley difference is big, there will be a lot of generator sets and other equipment stay in low-loaded or stop condition, which will greatly reduce the utilization of electrical equipment and cause unnecessary waste.

Take Beijing power grid as an example, when 1,000,000 electric vehicles connected to grid, the peak load is 985MW higher than the original one. If the capacity of distribution is the only factor we consider, we assume capacity-load ratio as 2.0, power factor as 0.9, then the increase distribution transformer capacity is 2188.89 MVA, and however, the valley load is only increase 111 MW at the same time. In this case, the utilization rate of distribution transformer is only 5.07% at the lowest moment.

3. The Impact of EV Ordered Charging Based on TOU Price

3.1. Ordered Charging Model Based on TOU Price

From the above analysis, we can see that there will be a significant impact of grid peak load when large-scale electric vehicle connected to grid. Therefore, there must be an effective and direct method or economic lever guide to change people's charging habit. In this paper, our main object is household electric vehicle, with its disperse and slow charging characters, it will be more difficult to charge them in a central way. Therefore, TOU price will guide users charging their vehicle in valley period, and this is a convenient charging way.

Suppose the charge capacity of electric vehicles in the peak period before the implementation of TOU pricing for W1, the charge capacity of the flat period for W2, the charge capacity of Valley period for W3.

After implementation of TOU price, due to the guiding role of the value, the charge level of the peak period transferred $\eta_{12}W_1$ to non-peak period, $\eta_{13}W_1$ to Valley period. Non-peak charging amount transferred $\eta_{23}W_2$ to

Table 1. Grid load changes after electric vehicle connected to the grid.

	peak load	Valley load	Peak and valley difference	Peak-to-valley rate
Original load	12400MW	7370 MW	5030MW	40.56%
After 500,000 electric vehicles connected to grid	12890MW	7430 MW	5460MW	42.36%
After 1,000,000 electric vehicles connected to grid	13385MW	7481 MW	5904MW	44.11%

the Valley period, here is the transfer matrix.

$$\begin{bmatrix} W_1' \\ W_2' \\ W_3' \end{bmatrix} = \begin{bmatrix} 1 & -\eta_{12} & -\eta_{13} \\ 1 & -\eta_{23} & \eta_{12} \\ 1 & \eta_{13} & \eta_{23} \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ W_3 \end{bmatrix} \quad (1)$$

W_1', W_2', W_3' are respectively for the implementation of TOU price after the charge level of the peak, non-peak, valley period.

Electric vehicle users' reaction to charging tariff is shown in **Figure 6**. Point is corresponding to the user's reaction blind the spot that the difference of electricity price is less than another, user does not adjust the original charging habits. Point b is corresponding to the maximum of user's reaction, which is the maximum percentage of changing the charging habits.

Assuming users can achieve the maximum degree of reaction after the implementation the peak and valley price as the price difference between peak and valley not smell .Set the user reaction b of the peak to level segment value of 0.6, the peak to valley segment value of 0.8, the level to valley segment value of 0.6. We can see that the price does not impact the 20% users' charging habits of charging on peak period.

$$\begin{cases} \eta_{12} + \eta_{13} = 0.8 \\ \dfrac{\eta_{12}}{\eta_{13}} = \dfrac{0.8}{0.6} \\ \eta_{23} = 0.6 \end{cases} \quad (2)$$

From the formula we can know: η_{12} = 0.342, η_{13} = 0.457, η_{23} = 0.6，charging expectation of Single Electric Vehicle show as **Figure 7**.

3.2. The Impact of EV Ordered Charging

When electric vehicle access scale N equals to 500,000, the grid load status as follows in **Figure 8**. When electric vehicle access scale N equals to 1,000,000, the grid load status as follows in **Figure 9**.

Figures 8, **9** tell us that after the effect of TOU price, sensitive tariff users transfer their charging time to valley period, thus they can enjoy cheaper tariff. But there are a few people who are not sensitive to tariff or care more about charging time, their charging time are not changed. The above grid peak load is still higher than original load, because most users are more sensitive for electricity tariff, so they will be guided by TOU price and then the valley load will be improved greatly. We can see this clearly in **Table 2**.

From the **Table 2**, we can see that with TOU price system there are peak load increases of 1.97% and 4.02%, and valley load increase of 6.23% and 11.68% when 500,000, and 1,000,000, electric vehicle connected to grid, this shows that TOU price system plays a guiding way in electric vehicles charging time. Meanwhile, with TOU price, the peak-to-valley rate is smaller than the original one that is to way, after electric vehicle connected to grid, the equipment utilization is higher, which makes an economic grid operation.

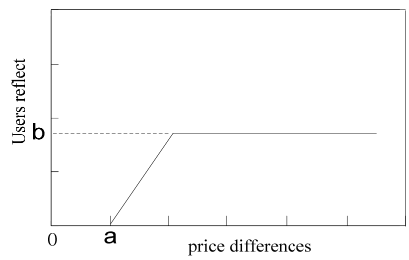

Figure 6. Users reflect model.

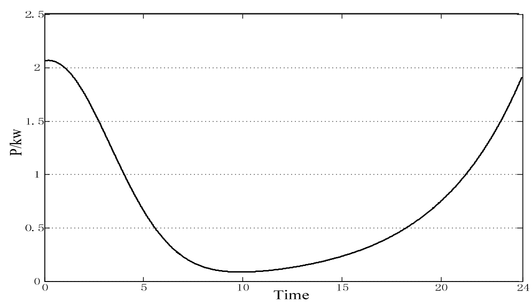

Figure 7. Charging expectation of single electric vehicle

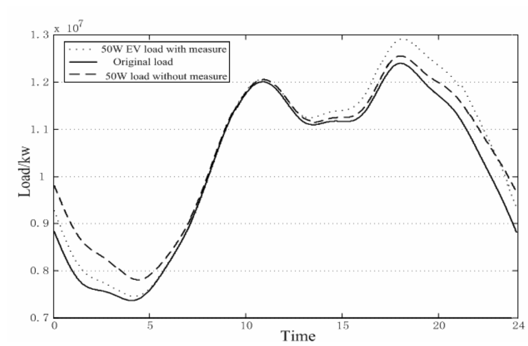

Figure 8. Grid load after 500,000 electric vehicles connected to Grid.

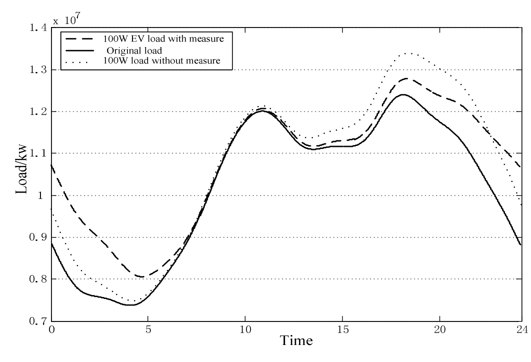

Figure 9. Grid load after 1,000,000 electric vehicles connected to grid.

Table 2. Grid load changes after electric vehicle connected to grid.

		Peak Load	Peak Valley	Peak and Valley Difference	Peak-to-Valley rate
Original Load		12400 MW	7370 MW	5030 MW	40.56%
After 500,000 Electric Vehicle connected to grid	Traditional Power Triff	12890 MW	7430 MW	5460 MW	42.36%
	TOU Price	12644 MW	7829 MW	4815 MW	38.08%
after 1,000,000 electric vehicle connected to grid	Traditional Power Triff	13385 MW	7481 MW	5904 MW	44.11%
	TOU PRICE	12789 MW	8131 MW	4658 MW	36.42%

4. Conclusions

From the above analysis, we can see that TOU price plays a guiding role in adjusting large-scale electric vehicle charging time. However, due to users' autonomy transfer charging time from peak time to valley time is unrealistic. TOU price system plays a positive way in guiding disordered charging way, and there is no need to build complex orderly charging control system, which will improve the utilization of power equipment, reduce investment and enhance charging reliability.

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