

Research of Charging(Discharging) Orderly and Optimizing Load Curve for Electric Vehicles Based on Dynamic Electric Price and V2G

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Abstract. Firstly, using the Monte Carlo method and simulation analysis, this paper builds models for the behaviour of electric vehicles, the conventional charging model and the fast charging model. Secondly, this paper studies the impact that the number of electric vehicles which get access to power grid has on the daily load curve. Then, the paper put forwards a dynamic pricing mechanism of electricity, and studies how this dynamic pricing mechanism guides the electric vehicles to charge orderly. Last but not the least, the paper presents a V2G mechanism. Under this mechanism, electric vehicles can charge orderly and take part in the peak shaving. Research finds that massive electric vehicles' access to the power grid will increase the peak-valley difference of daily load curve. Dynamic pricing mechanism and V2G mechanism can effectively lead the electric vehicles to take part in peak-shaving, and optimize the daily load curve.

1 Introduction

Compared with traditional vehicle, electric vehicle has advantages of low pollution and abundant fuel supply. According to analysis, by 2020 the number of electric vehicle ownership in china will exceed 5 million[1]. Nowadays, many scholars are applying themselves to researching on the subject of large scale of electric vehicles connecting to the power grid[2-5].

This paper is organized as follows. In section II, we use Monte Carlo method to model the conventional charging behaviour of electric vehicles and use analogy simulation to model the fast charging behaviour of electric vehicles. In section III, we propose a kind of dynamic electricity price method which can guide electric vehicles to charge orderly. In section IV, we propose a kind of V2G method which can guide electric vehicles to charge(discharge) orderly. In the last section, we look back the full text and tally up textual point.

2 Model the Behaviour of Electric Vehicles

According to the forecast[1], by 2020 the number of electric vehicle ownership in china will exceed 5 million, of which the personal cars are more than 4.3 million, almost 86% of the total number. Electric vehicles mainly have two kinds of charging models, which are conventional charging model and fast

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charging model. Conventional charging facilities are generally located in residential, corporation, parking lot and so on. In general, charging power of this model is about 10kW, its charging time is longer and its charging speed is slow. Conventional charging is used to meet the needs of daily use, usually being conducted in the evening or at night. Fast charging facilities are generally located in a special charging station, mainly to meet the needs of temporary charging. Its charging speed is relatively fast and its charging power is about 40kW. When being charged half an hour in the fast charging station, electric vehicles can drive almost 100 kilometers.

We use the Monte Carlo method and analogy simulation to model the behaviors of electric vehicles.

2.1 Conventional Charging Modeling

We use *DENZA* charging facility in this paper which produces 10kW of power. According to related data, we can get the last trip ending and return time distribution probability density[6] and electric vehicle driving distance distribution probability density[7][8]. Continuous charging time is calculated as follow:

$$t_i = \frac{s_i}{100 \times (p_c \times \eta)} \times k \quad (1)$$

t_i is the charging time of the i_{th} datum, s_i is the driving distance of the i_{th} datum. The two share the same distribution probability density. p_c is the rated power of charging facility. $\eta=0.9$ is charging efficiency, k is power consumption per hundred kilometers. The $k=18.6kwh$ refers to Q_{in} of *BYD*. The result are shown in Figure 1 and Figure 2

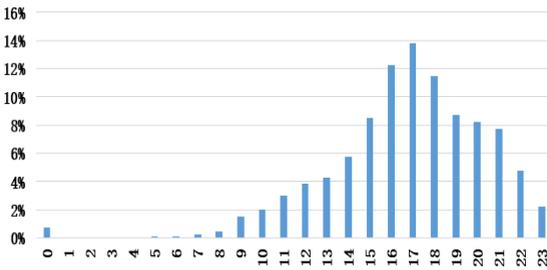


Figure 1. Last trip ending and return time distribution probability density

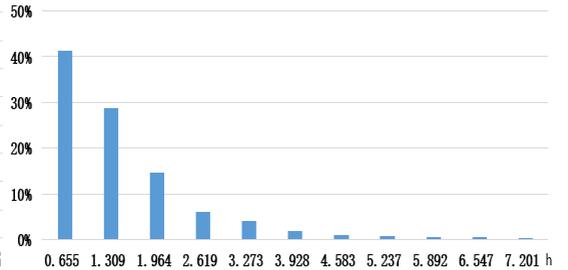


Figure 2. Continuous charging time distribution probability density

2.2 Monte Carlo simulation

Monte Carlo simulation is based on Probability and Mathematical Statistics. Under this method, the problem is solved with a certain probability model, and the approximate solution of the problem is obtained by using large scale simulation[9].

The mathematical and empirical evidence show that the random variables which are influenced by plenty independent homogeneous-small effects are subject to normal distribution. That is to say, if a variable is influenced by many small independent random factors, then it can be considered to be subject to normal distribution. Charging starting time and duration of charging are related to personal preference and mutual independence. Therefore, the charging time of electric vehicle and the duration of charging can be used for the curve fitting of normal distribution[5]. The results of curve fitting are as follows:

$$f_1(t) = a_1 \times \exp\left(-\left(\frac{t-b_1}{c_1}\right)^2\right), t \in [0, 24] \quad (2)$$

$$f_2(t) = a_2 \times \exp\left(-\left(\frac{t-b_2}{c_2}\right)^2\right), t \in [0, \infty) \quad (3)$$

$a_1=0.1195, b_1=17.32, c_1=4.721; a_2=0.5283, b_2=-0.3791, c_2=2.113$; 95% confidence interval. $f_1(t)$ is the probability distribution of charging start time, $f_2(t)$ is the probability distribution of charging duration. Then daily charging expectation of single electric vehicle can be gotten by Monte Carlo simulation. The calculation is shown in Figure 3 and the result is shown in Figure 4.

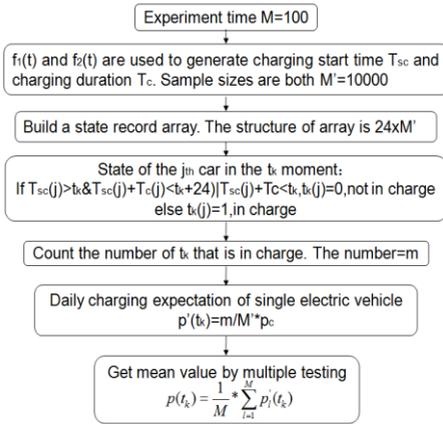


Figure 3. Calculation of Monte Carlo simulation

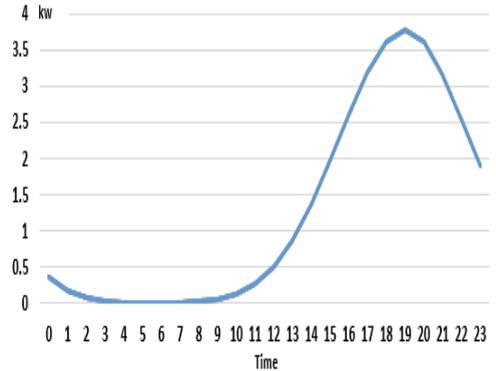


Figure 4. Daily load curve of single electric vehicle

2.3 Fast charging modeling

Because it is hard to estimate the fast charging behaviour, we get the load curve of fast charging through modeling the business of fast charging station. The vehicle flow of charging station is not the same in different time[10]. The power of charging facility is 40kW, which is referred to BYD’s charging facility. The modeling of fast charging behaviour is shown in Table 1.

Table 1. Model of fast charging behavior

Charging Station Status	Station Numbers	Charging Facility Number in Each Station	Charging Manners	Charging Time per Car	Business Hours
	220 sites	5 sites	1 facility 1 charging interface	30min	5:00-24:00
Arrival Interval	5:00-6:00	6:00-10:00	10:00-14:00	14:00-17:00	17:00-20:00
	15min	10min	8min	6min	4min
	20:00-21:00	21:00-22:00	22:00-24:00		
	6min	10min	15min		

According to calculation, the daily load curve of fast charging is obtained as Figure.5.

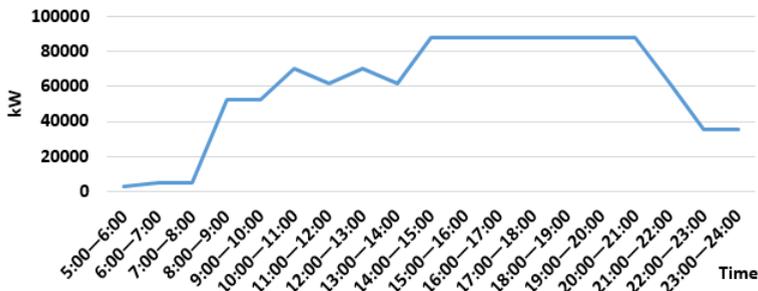


Figure 5. Daily load curve of fast charging

2.4 Fast charging modeling

We choose the daily load of a northern city in China as the basic load. When the number of electric vehicles is 100,000, 200,000 and 500,000 respectively, the daily load curves are shown in Figure 6.

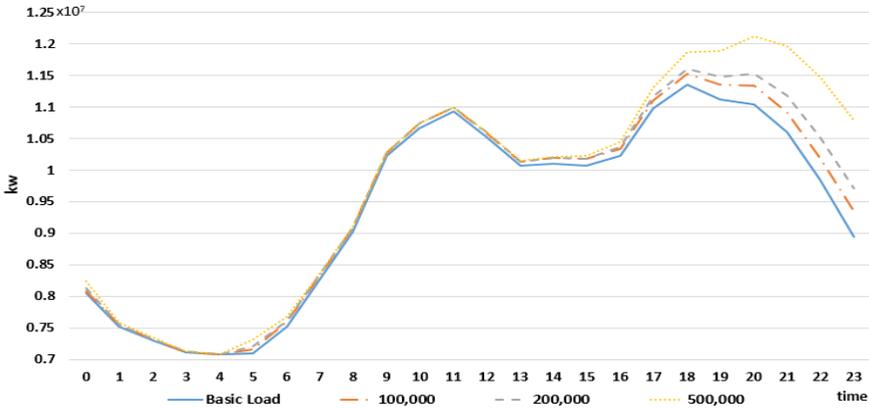


Figure 6. Daily load curve after electric vehicles connecting to the grid

Definite peak valley ratio:

$$\delta = \frac{(P_{max} - P_{min})}{P_{max}} \times 100\% \tag{4}$$

In the formulation above, δ is peak valley ratio, P_{max} is peak load, P_{min} is valley load.

Definite peak superposition and valley superposition:

$$\gamma_g = \frac{(p'_{min} - p_{min})}{P_{min}} \times 100\% \tag{5}$$

$$\gamma_f = \frac{(p'_{max} - p_{max})}{P_{max}} \times 100\% \tag{6}$$

In the formulations above, γ_g and γ_f are peak superposition and valley superposition respectively. p'_{min} is valley load which contains both basic load and electric vehicle load; p'_{max} is peak load which contains both basic load and electric vehicle load. p_{min} is basic valley load and p_{max} is basic peak load. The result of calculation about load curve that electric vehicles connect to the grid is shown in Table 2.

Table 2. The calculation about the electric vehicles connecting to the grid

	p'_{min} (MW)	γ_g	p'_{max} (MW)	γ_f	δ
Basic Load	7,075	0	11,350	0	37.67%
100,000	7,076.82	0.03%	11,525.23	1.544%	38.60%
200,000	7,078.72	0.05%	11,534.14	1.62%	38.63%
500,000	7,084.3	0.13%	13,056.35	15.03%	45.74%

According to Figure.6 and Table.2, the load characteristics of electric vehicles are similar to the city's electricity load characteristics. The reason is that most users tend to charge electric vehicles after stopping work and arriving at home in the evening in the meanwhile the charging period is also the peak period. This characteristic makes the difference between peak load and valley load bigger. In addition, it can be inferred from Figure.1 and Figure.2 that the electric vehicle is usually used as a tool replacing the foot, so the driving distance is not so long. This characteristic makes it unavailable to fill the valley by charging in the midnight. The characteristics discussed above may waste the power, increase the power loss and increase the burden of power grid. From what has been discussed above, we may safely arrive at the conclusion that due attention has to be paid to guide the charging behaviors of electric vehicles.

3 Dynamic Power Price

Different power prices in different time can guide charging behaviors of electric vehicles. When the price is high, users tend to charge at other times. Conversely, when the price is low, users tend to charge in this time. The price elasticity function can explain this phenomenon:

$$\varepsilon = \frac{\Delta D_t / D_t}{\Delta C_t / C_t} \tag{7}$$

In formulation(7), ε is price elasticity index; ΔD_t and ΔC_t are demand changes and price changes respectively in t_{th} moment; D_t and C_t are demand and price in t_{th} moment.

In this paper, one day is separated into 24 electric price ranges. Each range starts at the beginning of this hour and the price continues one hour. The electric price of each range is related to the total load of this range and the mean load of the whole day. The models are as follows:

$$D'_t = D_t + \Delta D_t \tag{8}$$

$$\Delta D_t = D_t \times \frac{\Delta C_t}{C_t} \times \varepsilon \tag{9}$$

$$\frac{\Delta C_t}{C_t} = \frac{D_t - \bar{D}}{D_t} \tag{10}$$

$$\bar{D} = \sum_{t=1}^T D_t \tag{11}$$

D'_t is the load adjusted by dynamic electric price, \bar{D} is the mean demand of the day, T is the time range, $\varepsilon = -0.3$ [11], the number of electric vehicles connecting to power grid is 500,000. Comparison of load curves before and after being adjusted by dynamic electric price are shown in Figure 7 and Table 3.

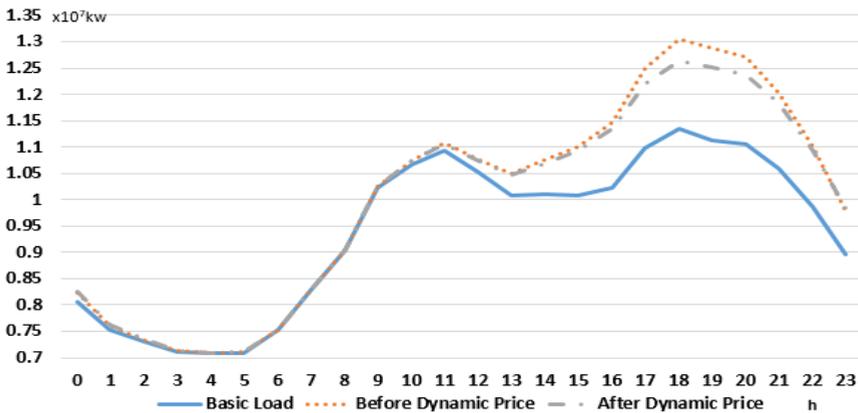


Figure 7. The effect of dynamic electric price 1

Table 3. The effect of dynamic electric price 2

	γ_g	γ_f	δ
Basic Load	0	0	37.67%
Before Dynamic Price	0.131%	15.030%	45.74%
After Dynamic Price	0.117%	11.381%	43.97%

It can be seen from Figure.7 and Table.3 that load curve condition is improved by dynamic electric price. Under this dynamic electric price, although γ_g has a little decrease, γ_f has a significant reduction. γ_f decreases from 15.030% to 11.381%, having 3.649% fall. In addition δ decreases from 45.74% to 43.97%, having 1.77% fall. So it can be concluded that it is useful for this dynamic electric price to guide the charging behaviors of electric vehicles and smooth the load curve.

4 V2G Regulation

Vehicle to Grid is called V2G for short[12]. V2G describes a system where plug-in electric vehicles communicate with the electric power grid to sell demand response[13]. Hence, V2G application is transformational and revolutionary in that it precipitates the confluence of transportation and electric power system, thereby introducing electricity as a meaningful automotive fuel[14]. Under V2G regulation, electric vehicles require charging and discharging batteries.

Its model is as followed:

- The electric vehicle can obtain power from power grid when it need to charge;
- The electric vehicle can release power energy to power grid when it need to discharge.

It can be inferred from Figure.1 and Figure.2 that most users drive their electric vehicles not so far. So their charging time is not so long. Charging time is less than 4 hours in a day for most users. It means that when the battery is full, there will be a long time without any activities for electric vehicles. The free time can be used to fill the valley of load curve in order to reduce the burden of power grid and conserve the energy. Under V2G regulation, electric vehicles are discharged in peak period and charged in valley period.

Based on Figure.1, Figure.7 and the experience, the users who get home from 16:00pm to 23:00pm can be regarded as main force to participate in V2G program. Referring to the step electric price mechanism of Beijing[15], we set the peak load period from 18:00pm to 23:00pm and the valley load period from 23:00pm to 7:00am. Under the prerequisite of fully charging in electric vehicles, the cars participating in V2G program discharge in peak load period and charge in valley load period. The main mission of V2G program set by us in this paper is to clip the peak load and fill the valley load. The car that begins to discharge in i o'clock. The model is as follows:

$$t_{fi} \rightarrow \max \tag{12}$$

$$T_i + 2t_{fi} + t_{ci} \leq (24 - 23 + 7) \tag{13}$$

$$0 \leq t_{fi} \leq (23 - 16) \tag{14}$$

t_{fi} is the maximum discharging time of electric vehicles that begin to discharge in i o'clock, t_{ci} is the charging time of electric vehicles which begin to discharge in i o'clock. After calculation, the maximum discharging time of electric vehicles that begin to discharge in i o'clock is shown in Table 5.

Table 4. Maximum discharging time

	0.655h	1.309h	1.964h	2.619h	3.273h	3.928h	4.583h	5.237h
16:00	7h	6.691h	6.036h	5.381h	4.727h	4.072h	3.417h	2.763h
17:00	6h	6h	6h	5.381h	4.727h	4.072h	3.417h	2.763h
18:00	5h	5h	5h	5h	4.727h	4.072h	3.417h	2.763h
19:00	4h	4h	4h	4h	4h	4h	3.417h	2.763h
20:00	3h	2.763h						
21:00	2h							
22:00	1h							

In Table 4, the first row represents duration and the first column represents starting time.

Definition: a_{ij} is the discharging element exiting in Table.5. i is the beginning time of discharging, j is the duration of charging. The total number of electric vehicle accessing the grid is $A=500,000$, p_i is the probability of charging in i o'clock, q_j is the probability of that electric vehicle charge for j hour(s), D_i is the power that is injected to the grid by electric vehicles in i o'clock. Search the a_{ij} above the Table.5 one by one and calculate the total contribution every a_{ij} makes to D_i . Sum of D_i is the power injection. The calculation and results are shown in Figure.8 and Table 5 respectively.

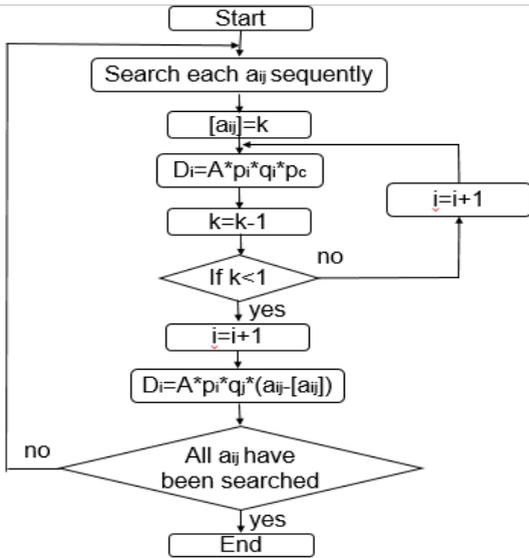


Figure 8. The calculation of discharging

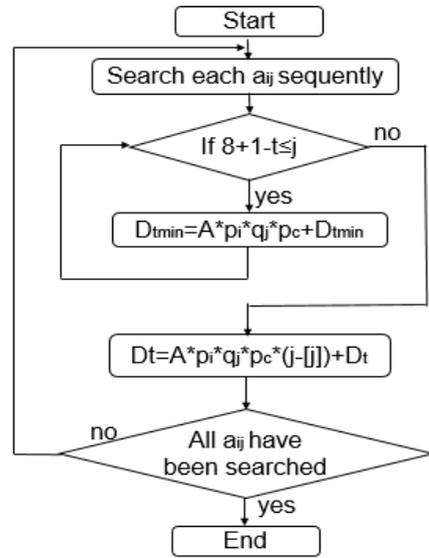


Figure 9. The calculation of charging

Table 5.Power of discharging

	16:00-17:00	17:00-18:00	18:00-19:00	19:00-20:00	20:00-21:00	21:00-22:00	22:00-23:00
16:00	611,750 kw	611,750 kw	610,552 kw	603,465 kw	584,159 kw	542,239 kw	377,856 kw
17:00		690,000 kw	690,000 kw	688,649 kw	680,656 kw	658,880 kw	601,186 kw
18:00			575,000 kw	575,000 kw	573,874 kw	567,213 kw	540,390 kw
19:00				437,500 kw	437,500 kw	436,643 kw	431,575 kw
20:00					412,500 kw	412,500 kw	387,500 kw
21:00						387,500 kw	387,500 kw
22:00							237,500 kw

In Table 5, the first row represents the time period of discharging and the first column represents the start time of discharging.

After getting t_{fi} and t_{ci} , we can calculate t'_{ci} , the value of charging time in valley load period.

$$t'_{ci} = t_{fi} + t_{ci} \tag{15}$$

We separate the valley load period into 8 time periods. Each a_{ij} select one period that has the minimum load. Generally speaking, from 23:00-7:00, the later time is, the lower the loads are. So the charging rule we propose is that charging in later time period is prior than charging in the early time period. If a_{ij} can charges only 1.3h, for example, it charges 1h in the time period of 6:00-7:00 and charges 0.3h in the time period of 5:00-6:00. In other words, it charges from 6:00 to 7:00 at rated power and charges from 5:00 to 6:00 at 30% rated power. The calculation of charging is shown in Figure.9 and Table 6.

Table 6. Power of charging

	23:00-0:00	0:00-1:00	1:00-2:00	2:00-3:00	3:00-4:00	4:00-5:00	5:00-6:00	6:00-7:00
16:00	524,536	611,750	611,750	611,750	611,750	611,750	611,750	611,750
17:00	263,811	591,630	690,000	690,000	690,000	690,000	690,000	690,000

18:00	54,871	219,842	493,025	575,000	575,000	575,000	575,000	575,000
19:00	19,731	49,711	160,669	375,128	437,500	437,500	437,500	437,500
20:00	5,586	18,604	46,870	151,488	353,692	412,500	412,500	412,500
21:00	758	5,247	17,476	44,029	142,307	332,256	387,500	387,500
22:00	0	464	3,216	10,711	26,985	87,220	203,640	237,500

Based on Figure 8, Figure 9, Table 5 and Table 6, we can get the daily load curve adjusted by dynamic electric price and V2G. The comparison between load curve and load curve adjusted by dynamic electric price and V2G is shown in Figure.10 and Table 7. The number of electric vehicles connecting the grid is 500,000.

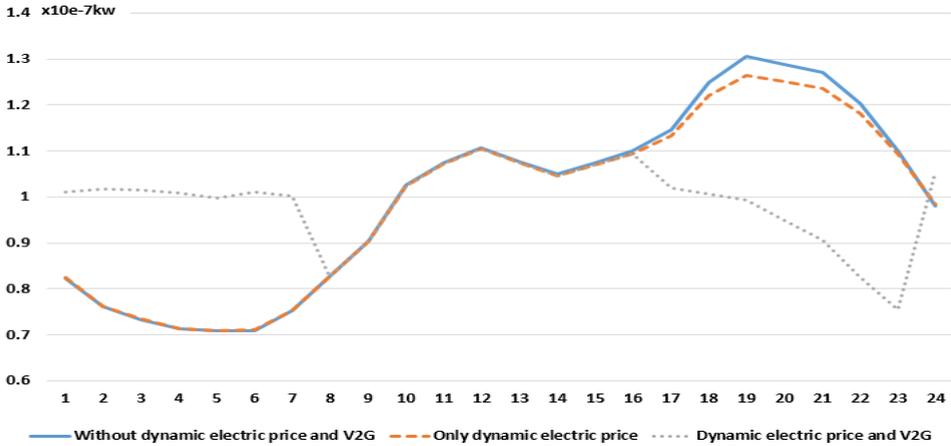


Figure 10. The effects of V2G and dynamic electric price 1

Table 7. The effects of V2G and dynamic electric price 2

	Valley Time	p'_{min}	Peak Time	p'_{max}	δ
No dynamic electric price	4:00-5:00	7081 MW	18:00-19:00	13056 MW	45.76%
Only dynamic electric price	4:00-5:00	7083 MW	18:00-19:00	12642 MW	43.97%
Dynamic electric price and V2G	22:00-23:00	7553 MW	11:00-12:00	11046 MW	31.62%

It can be known from Figure.10, and Table.7 that the method of V2G is valuable for improvement of power load characteristics. But it should be noticed that the valley time has been changed after V2G method adopted. If the number of electric vehicles remain elevated, V2G maybe be not enough. The problems will be more complicated. If we just make use of V2G simply when the number of electric vehicles is large enough, the new valley load period may appear.

5 Conclusion

When the number of electric vehicles connecting to power grid is small, the influence to the grid is limited. When the number of electric vehicles connecting power grid is big, the influence to the grid is tremendous. Dynamic electric price is available to optimize the daily load curve. It can guide electric vehicle users to charge their cars orderly. V2G is more useful to optimize the daily load curve. It allows users of electric vehicles to participate in peak/valley load regulating of power system. But it should be noticed that the valley time has been changed after V2G method being adopted. If the number of electric vehicles remain elevated, V2G will be not enough. If we just make use of V2G simply when the number of electric vehicles is large enough, the new valley load period may appear.

Many problems still need to be further studied, such as charging/discharging period segmentation, the subsidy rule to V2G users, coordination between renewable energy and electric vehicles and so on.

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