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# Charging Load Forecasting of Electric Vehicle Based on Charging Frequency

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**Abstract.** The rapid development of electric vehicles (EVs) will gradually increase the operating pressure of the power grid. The charging load of EVs need to be predicted to release this pressure. In this paper, the influence factors of EV charging load are analyzed and the load curve of different charging modes is obtained. According to the 2009 American families travel survey, EVs are divided into three types: private cars, buses and taxis. Then, different EVs' charging frequency, together with the starting point for state of charge (SOC) and daily mileage can be calculated. Correspondingly, the probability density function model can be established. Finally, the daily charging load is calculated by Monte Carlo algorithm, which provides the basis for the research of orderly EV charging.

## 1. Introduction

Recently, with the development of electric vehicles (EVs) and the support of government policies [1], large-scale EVs access to the load grid has become a trend, which is bound to have a certain impact on the operation and scheduling of the load grid [2-3]. As is known to all that the charging load of EVs is highly uncertain in both time and space [4]. In order to rationalize the operation and scheduling mode, it is of great significance to predict the charging load of large-scale EVs.

Many literatures have been involved in the calculation of EVs charging load, and most of them adopt some algorithm to calculate charging load. In [5], EVs are divided into four types, private cars, buses, taxis and official cars. However, the distribution of state of charge (SOC) and initial charging time (ICT) are selected subjectively, in addition, the power during charging is actually a variable rather than a constant. In [6], statistical methods are applied to establish the probability distribution model of the end time and daily mileage of the journey. It is believed that the end time is equal to the ICT, but it is not reasonable for EVs whose charging frequency is more than 1 time/day. In [7], the uncertainty of EV owners' charging habits are analyzed, and a charging load calculation model with uncertainty factors is established. In [8], The driving and parking characteristics of EVs are considered and the charging load is modelled from the perspective of spatial and temporal distribution. In [9], trip destinations are divided into five class, and trip chains are constructed accordingly. Then, spatial and temporal distribution model of travel time and distance is established.

In this paper, the change process of charging power in two charging modes of EV are analysed. The user's composition is considered from two aspects of daily charging frequency and type of EVs.



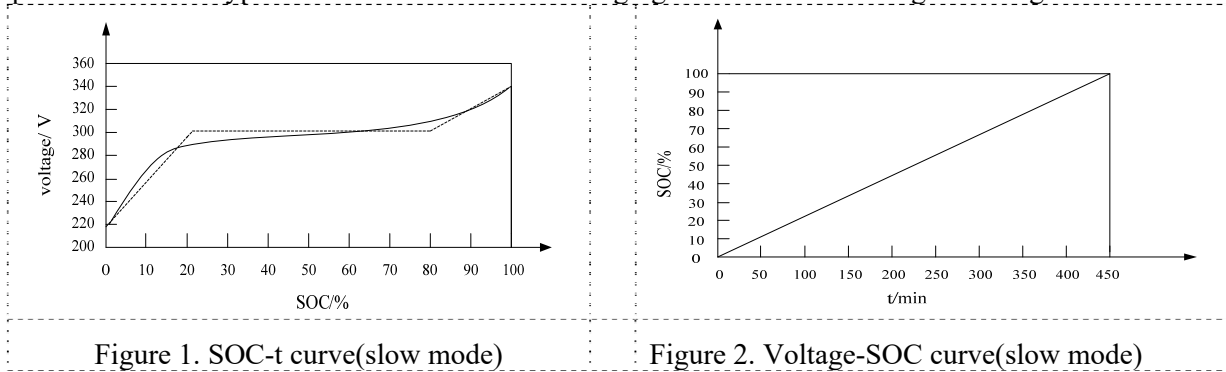
Then, the probability density function are built correspondingly. The distribution of SOC is determined by the distribution of daily mileage, and the charging load of EVs is simulated by Monte Carlo algorithm, which provides a certain reference for the scheduling and operation of the electric power system.

## 2. Analysis of charging mode of EVs

According to the characteristics and charging speed of EV batteries, charging methods can be divided into slow mode, quick mode and replace-battery mode. In 2012, the state council issued the development plan for the energy saving and new energy automobile industry (2012-2020) in China, which established the development direction of EVs mainly based on plug-in charging, so this paper doesn't consider the replace-battery mode.

### 2.1. Slow mode

The charging current of slow mode is small, generally about 16~32A, and the charging power is generally around 3.5~7kw. In addition, the charging time is very long, about 5~8 hours. And the installation cost is relatively low, which is conducive to extending the service life of the battery. The power curve of a typical slow constant current charging mode is shown in Fig.1 and Fig.2.



The voltage-SOC curve can be regarded as three linear functions, which the middle section can be approximately regarded as constant power charging, and the SOC-t curve can be linearized approximately. The fitting formula is as follows:

$$V = \begin{cases} 400 \cdot SOC + 220 & 0\% \leq SOC \leq 20\% \\ 300 & 20\% \leq SOC \leq 80\% \\ 200 \cdot (SOC - 0.8) + 300 & 80\% \leq SOC \leq 100\% \end{cases} \quad (1)$$

$$SOC = 2.22t \cdot 10^{-3} \quad (2)$$

In the slow constant current charging mode, the power is approximately proportional to the voltage, while the SOC in the charged state is approximately proportional to the charging time. Hence, the functional relationship between the power and the charging time can be obtained. Suppose the charging current is 16A, then

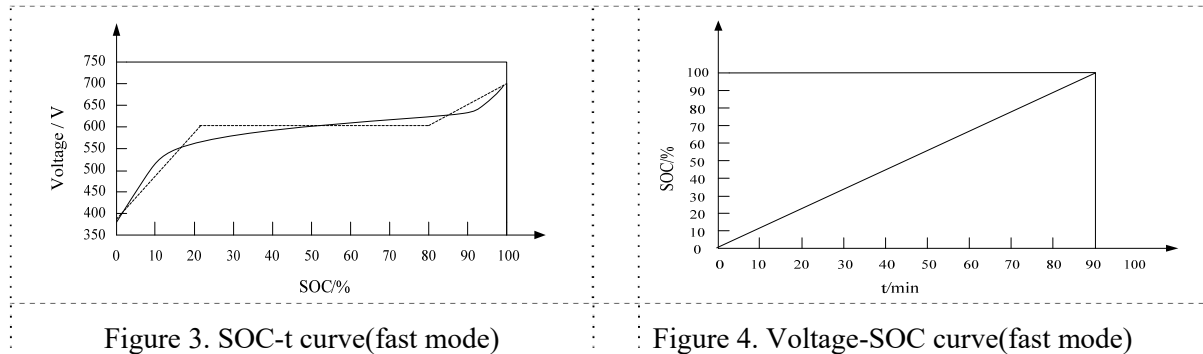
$$P_{cl} = \begin{cases} 14.24 \cdot 10^{-3}t + 3.52 & 0 \leq t \leq 90 \\ 4.8 & 90 \leq t \leq 360 \\ 7.09 \cdot 10^{-3}t + 2.24 & 360 \leq t \leq 450 \end{cases} \quad (3)$$

### 2.2. Fast mode

Fast mode is also called emergency charging. The charging current is generally 150~400A and charging power is about 150kw. Generally, it takes 0.16 to 2 hours for an EV to be fully charged. In addition, the installation cost is relatively higher, and the battery's service life is shorter. The typical fast constant current charging power curve is shown in Fig.3 and Fig.4.

Similarly, as the curves shown in Fig.3 and Fig.4, assuming that the charging current is constantly 250A, the relationship between power and charging time is as follows:

$$P_{c2} = \begin{cases} 3.055t + 95 & 0 \leq t \leq 18 \\ 150 & 18 \leq t \leq 72 \\ 1.39t + 50 & 72 \leq t \leq 90 \end{cases} \quad (4)$$



### 3. Factors influencing Evs charging load

#### 3.1. Types and Development Trends of EVs

The research of the national "13th Five-Year Plan" and "Thousand Cars In Ten Cities" plan are analyzed[10], then the future types of electric cars can be roughly divided into private cars, taxis and buses. With the development of the EV industry, the number of EVs in China has reached 1.2 million in 2014 and 5 million in 2020.

Fujian province in China is taken as an example to carry on the analysis in this paper. According to "the new energy vehicles industry development planning of Fujian province (2017-2020)", in 2017, the number of EVs in Fujian Province has reached 150,000. By 2020, that in Fujian Province will reach 300,000. The number of passenger vehicles including private cars and taxis will reach 185,000, and the number of electric buses will reach 47,000. This paper assumes that the ratio of private cars to taxis is 5:1, then the number of private cars reaches 154,000 and the number of taxis reaches 31,000.

#### 3.2. Charging Frequency

Private cars are mainly driven in homes, companies, shopping malls, entertainment and other areas. Parking in residential parking lots and company parking lots takes a long time, therefore, more slow charging mode is adopted. According to the investigation, the daily load consumption and charging times of the user are shown in Tab.1.

Table 1. Private car user charging frequency

| Daily Electricity Consumption/% | Charging Frequency/time |
|---------------------------------|-------------------------|
| 0~10%                           | 1/7                     |
| 10~20%                          | 1/3                     |
| 20~30%                          | 1/2                     |
| 30~70%                          | 1                       |
| 70~100%                         | 2                       |
| >=100%                          | 3                       |

In the following analysis, Toyota RAV4 EV is taken as an example. The maximum mileage of this vehicle is 160km. According to the statistical results of the national household travel survey[12] (NHTS) in 2009, the proportion of load consumption of users can be obtained as shown in Fig.5.

Buses and taxis are commercial vehicles, and the running speed of buses is generally around 15km/h. They start at about 5:30 am and finish at around 22:30 pm. However, the bus will not leave immediately after it arrives at the terminal. It usually waits about 3 hours. The actual running time is

about 14 hours, and the daily mileage is about 220km. According to the investigation on the operation of pure-EVs in various cities, the ideal maximum driving distance of electric buses is generally 200km to 250km, but the endurance is poor in actual operation, and the battery life is seriously weakened.

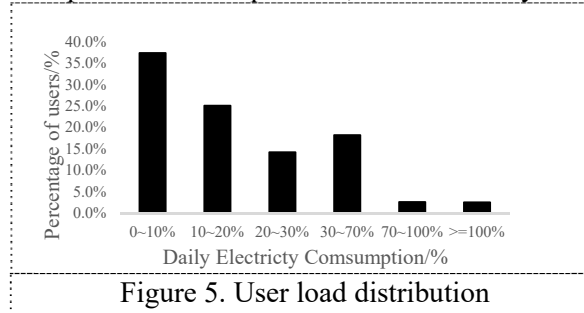


Figure 5. User load distribution

Generally, electric buses can run about 150km after fully charged, and they can't complete its daily tasks without the second charge. In this paper, it is assumed that 100% of the buses adopt fast charging mode and charge twice a day.

Electric taxis are divided into single-shift and double-shift operations. Single-shift operation charge 2 times a day by using slow charging modes and double-shift operation charge 4 times by using quick charging modes. The taxi driving range is 180-220km and the actual daily operating mileage is generally around 450km. When the residual load SOC drops to 20%, it needs to be recharged. This paper assumes that the ratio of single class and double class is 2:5.

### 3.3. Daily Mileage and Initial Load Status

According to the statistical results of NHTS, the driving distance of an EV is logarithmic normal distribution approximately. Its probability density function is as follows:

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{(\ln x - \mu)^2}{2\sigma^2}\right] \quad (5)$$

Where  $\mu$  is the expectation of the distance traveled,  $\sigma$  is the standard deviation. After fitting,  $\mu = 3.68$ ,  $\sigma = 0.88$ . The distribution of SOC is determined by the distribution of daily mileage.

$$SOC = 1 - \frac{D}{L} \quad (6)$$

Where  $D$  represents the actual driving distance and  $L$  represents the maximum driving distance of an EV, the charging time can be calculated according to Fig.1 and Fig.2.

### 3.4. Initial Charging Time

1) For most private car users whose charging frequency is less than 1 time/day, the ICT can be considered as the end time of the journey. According to the survey results of NHTS, the probability of the end time of a user's trip is shown in Fig.6. The ICT of this part of private car users satisfies the normal distribution, and its probability density function is:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x - \mu)^2}{2\sigma^2}\right] \quad (7)$$

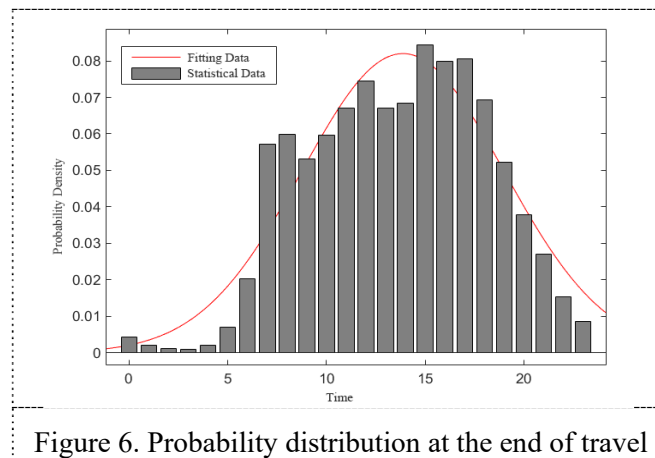


Figure 6. Probability distribution at the end of travel

2) For vehicles with 2-4 times of daily charging, the probability distribution of the ICT is shown in Fig.7.

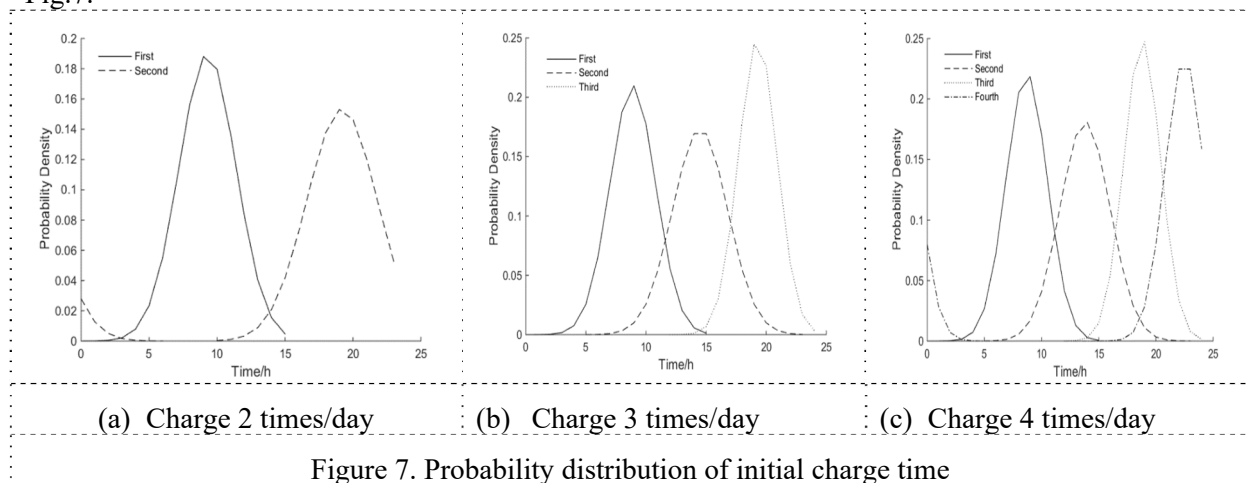


Figure 7. Probability distribution of initial charge time

The ICT distribution parameters corresponding to the charging frequency are shown in Tab.2.

Table 2. ICT normal distribution parameter

| Charging Frequency | First     | Second    | Third     | Fourth    |
|--------------------|-----------|-----------|-----------|-----------|
| $\leq 1$           | 17.3, 3.4 |           |           |           |
| 2                  | 9.3, 1.9  | 19.2, 2.8 |           |           |
| 3                  | 8.9, 1.9  | 14.5, 2.3 | 19.3, 1.6 |           |
| 4                  | 8.7, 1.8  | 13.8, 2.2 | 18.8, 1.6 | 22.5, 1.7 |

#### 4. Calculation of charging load of EVs

Monte Carlo algorithm is a statistical simulation method that uses random numbers to solve mathematical problems. When simulating a certain process, it needs to generate a random object with a certain probability distribution, then statistical methods are applied to estimate the numerical characteristics of the model, so as to obtain the numerical solution of the actual problem. In this paper, the Monte Carlo algorithm is applied to simulate and calculate the charging load of EVs. The daily mileage and ICT are randomly selected according to the probability distribution function. The range of charging time is calculated, and the total charging load curve is obtained by accumulative stacking.

This paper assumes that the starting time, daily mileage and charging load of charging are independent random variables. The calculation steps of charging load are as follows:

1) The total number of EVs  $N$  is setted. According to the above analysis, the total number of private cars in 2020 is 154,000, the total number of taxis is 31,000 and the total number of public buses is 47,000.

2) The simulation times of Monte Carlo algorithm are setted as  $M$ , and  $M$  is at least 5000 times in this paper.

3) According to the ratio of charging frequencies set above, when the charging frequency is less than 1, the probability of the vehicle charging on the same day is considered to be equal to its charging frequency.

4) Set the ratio of charging modes of all types of vehicles according to the above analysis.

5) According to formula (5), the random number of daily mileage  $D$  is generated. And the initial SOC and charging time of the SOC are calculated according to equation (6).

6) According to formula (7) and Tab.2, initial charging time  $T$  is generated randomly, and the range of charging time is calculated.

7) Superimposed charging load curve. The whole day is divided into 1440 minutes, and the load of the  $n$  car in the  $i$  minute is set as  $P_{n,i}$ , then the total charge load of the  $i$  minute is set as:

$$P_i = \sum_{n=1}^N P_{n,i} \quad (8)$$

8) Define the charging load variance coefficient  $\beta_i$

$$\beta_i = \frac{\theta_i(\bar{p})}{\sqrt{M P_i}} \quad (9)$$

In the above equation,  $\theta_i(\bar{p})$  represents the standard deviation of the charging load at time  $i$ ,  $P_i$  represents the expected value of the charging load at time  $i$ , and  $M$  represents the calculation times. When  $\max(\beta_i) \leq 0.05\%$ , the simulation converges; otherwise, it does not converge and restarts the calculation.

## 5. Case studies

Taking Fujian province as an example, daily charging load curves of all types of EVs in Fujian province in 2020 are obtained according to the steps as shown in Fig.8.

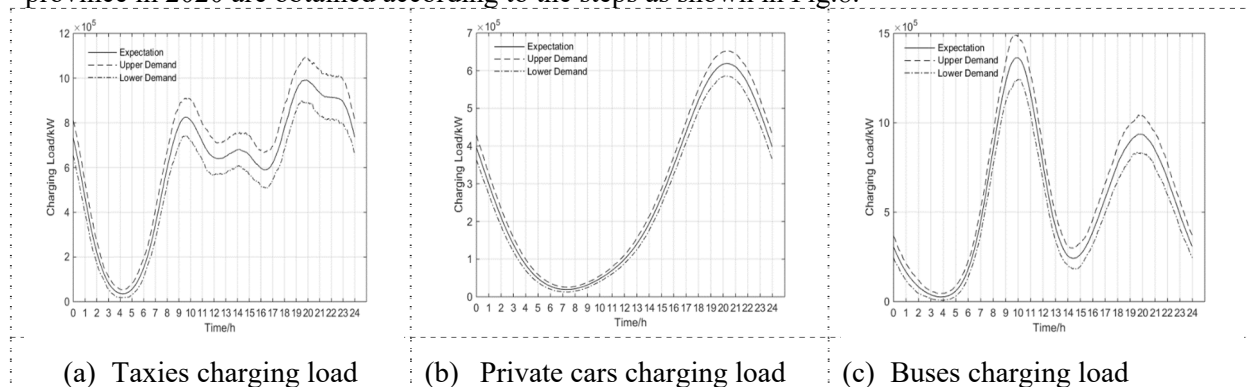


Figure 8. Various types of EV charging load curves

As can be seen from Fig.8, the daily charging load of taxis reaches the low point around 4 am, and there are two peaks from 9 am to 19 pm, reaching 900MW and 1100MW respectively, which is caused by different charging modes for single and double shifts of taxis. The daily charging load of private cars reaches the minimum around 7 o'clock and reaches the peak of 620MW at 19 o'clock in the afternoon. Due to the fact that some private car users charge less than one time per day, the peak charging period is delayed by about two hours. The daily charging load of buses has two peak periods, ranging from 9 to 11 o'clock and 19 to 21 o'clock respectively, both of which adopt rapid charging

mode, with the load reaching 1360MW and 935MW. The daily charging load of the three types of EVs is superimposed to obtain the daily total charging load curve as shown in Fig.9.

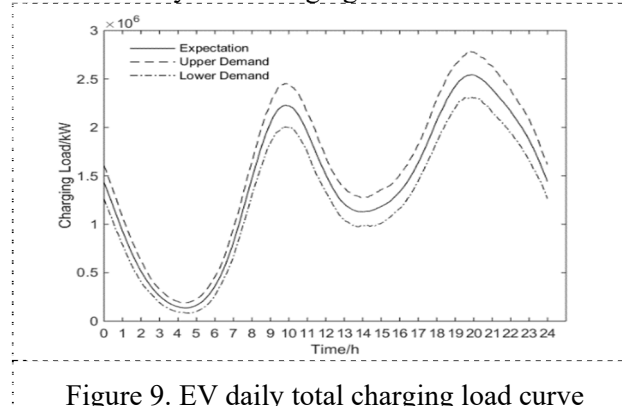


Figure 9. EV daily total charging load curve

As can be seen from Fig.9, the daily total charging load curve of EVs peaked at about 9 am and 19 pm respectively, about 2200MW and 2530MW. These two points basically coincide with the peak period of electricity consumption of residents, which increases the burden on the grid and causes adverse effects on the safe operation of the load grid. Therefore, it is necessary to regulate the charging load of EVs and cut off the peak and fill the valley, so as to reduce the operating pressure of the load grid.

## 6. Conclusion

In this paper, the change process of charging power in slow mode and fast mode is analyzed. Firstly, The EV types can be divided into private cars, buses and taxis. Secondly, three kinds of EVs' charging frequency and ICT are analyzed, and corresponding probability density functions are established. Then Monte Carlo simulation algorithm is applied to calculate the daily EV charging load, and the results showed that the charging load peaked at 9 am and 19 pm. Charging load of EVs in daily life is indirectly affected by climate conditions, in future studies, the influence of climate factors can be further considered to make the predicted results more realistic.

## Acknowledgments

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## References

- [1] Gomez J C and Moros M M. Impact of EV battery chargers on the power quality of distribution systems. *IEEE Power Engineering Review*, 2002, 22:63-63.
- [2] Gao C W and Zhang L. A survey of influence of electric vehicle charging on power grid. *Power System Technology*, 2011, 35:127-131.
- [3] Wang X F, Shao C C, Wang X L and Du C. Survey of electric vehicle charging load and dispatch control strategies. *Proceedings of the CSEE*, 2013, 33:1-10.
- [4] Wu D, Aliprantis D C and K. Gkritza. Electric energy and power consumption by light-duty plug-in electric vehicles. *IEEE Transactions on Power Systems*, 2011, 26:738-746.
- [5] Luo Z W, Hu Z C, Song Y H, Yang X, Zhan K Q and Wu J Y. Study on plug-in electric vehicles charging load calculating. *Automation of Electric Power Systems*, 2011, 35:36-42.
- [6] Tian L T, Shi S L and Jia Z. A statistical model for charging power demand of electric vehicles. *Power System Technology*, 2010, 34:126-130.
- [7] Yang B, Wang L F, Liao C L, Ji L and Dong F Y. Effects of Uncertainty Charging Habits on Electric Vehicles' Charging Load Demand and the Charging Load Regulation. *Transactions of China Electrotechnical Society*, 2015, 30:226-232.

- [8] Zhang H C, Hu Z C, Song Y H, Xu Z W and Jia L. Prediction method of electric vehicle charging load considering space-time distribution. *Automation of Electric Power Systems*, 2014, 38:13-20.
- [9] Chen L D, Nie Y Q and Zhong Q. A Model for Electric Vehicle Charging Load Forecasting Based on Trip Chains. *Transactions of China Electrotechnical Society*, 2015, 30:216-225.
- [10] Wu Q T. Progresses in “Ten Cities & Thousand Units” plan. *Automobile and Parts*, 2009, 1:15-19.
- [11] Tan Q L. Modeling and simulation of charging and discharging characteristics of MH-Ni batteries. Beijing, *North China University of Technology*, 2007.
- [12] U.S. Department of transportation, federal highway administration, 2009 national household travel survey. URL: <http://nhts.ornl.gov>.
- [13] Yang S B, Wu M L and Jiang J C. An Approach for Load Modeling of Electric Vehicle Charging Station. *Power System Technology*, 2013, 37:1190-1195.