A Model for Electric Vehicle Charging Load Forecasting based on Simulated Driving Path

H Y Ma, J H Wang, T Zheng, Z Li and H Y Wang
Xi’an Jiao Tong University, Xi’an 710049, China
E-mail address: 1025026963@qq.com

Abstract. With the replacement of power sources of traditional vehicles, the penetration of EVs in the world is increasing year by year. When large-scale EVs are connected to the power grid, it will affect the structure and power flow of the grid. This paper simulates the vehicle route in the planning area, proposes a method to predict the probability distribution method for the users to choose the specific route based on the Markov process theory and the traffic network database. Refer to the habits and charging preferences of EV users, taking private EVs as the research object, Monte Carlo simulation is used to predict the charging demand generated by EVs in the function area and important road nodes in the planned area. In view of the difference of peak price and valley price, considering the low valley-time price, the probability of load transfer is large. Changing the discharge strategy to realize the peak load shifting in V2V mode.

1. Introduction
Faced with the increasing global carbon dioxide emissions and the increasingly severe oil crisis, it is urgent to develop new energy to replace the power sources of traditional vehicles. Since the pilot implementation of the subsidy policy in 2009, Chinese new energy vehicle sales have increased rapidly from 7,577 in 2011 to 777,000 in 2017. By 2017, the number of charging piles in China has increased to 210,000. The uncertainty and difference of EV users’ behaviours determine that the load of EV has the characteristics of space-time (S-T) distribution, randomness, intermittence and volatility [1].

At present, researchers in China and abroad mostly predict the load of EVs from the perspective of users. The charging load of the EV is equivalent to the fuel consumption of the users [2]. The research [3] proposes that with the development of data acquisition technology, high-precision geographic information, traffic congestion, specific path, estimated travel time and other data can be obtained through Google and Baidu maps. At the same time, traffic management system can provide periodic vehicle flow data. The idea of import large data into load forecasting can broadens the sources of statistical data, and a large number of long-term periodic data ensure the comprehensiveness and reliability of forecasting, and improve the accuracy of forecasting.

Considering the actual trip path of private cars, this paper predicts the load of EVs in the planning area and important road nodes, based on the traffic network database. According to the analysis of user’s travel purpose, the probability distribution of user’s travel purpose in the planning area is formed. Monte Carlo sampling is used to obtain the travel time, travel path and battery status of a single private car. The running EV is transformed into a moving load in the road network.
formulation of charging strategy, the charging amount, charging mode and charging place of the EV in a day are predicted.

2. Functional area model
Through the analysis of the map of the planning area, the planning is divided into five functional areas, namely residential area (R), working area (W), commercial area (C), education area (E), social service area (S). Usually there are more than one functional area in the planning area. In this paper, according to the mobility and activity of the population, different weights are set for each functional area of the same kind, as a reference value for setting the starting point and target location of the travel chain. The number of X function area in the planning area is \( n \). The daily average flow rate of the X function area numbered \( i \) is \( V(X_i) \), and the comprehensive value coefficient is \( \varepsilon(X_i) \). Accordingly, the weight of \( X_i \) is expressed as:

\[
\omega(X_i) = \frac{V(X_i)\varepsilon(X_i)}{\sum_{i=1}^{n}V(X_i)\varepsilon(X_i)}
\]

3. Analysis of private vehicle users’ travel rules
In a trip chain, the transfer is a stochastic process with Markov property. Given the current knowledge or information, the previous historical state is irrelevant for predicting the future state. The residential area, work area, commercial area, education area and social service area of the planning area are expressed as \( R_j, W_k, C_b, E_m, S_g \) respectively, where \( j, k, b, m, g = 1, 2, 3, ..., n \) are the numbers of the corresponding functional areas.

3.1. The probability of trip chain selection
The probability of user starting from \( R_j \) is \( P(R_j) \), the probability of user transferring from \( R_j \) to \( E_m \) is \( P(E_m|R_j) \), and the probability of transferring from \( E_m \) to \( R_j \) is \( P(R_j|E_m) \). According to Markov theory, the probability of users choosing \( R_j \rightarrow E_m \rightarrow R_j \) trip chain can be given by

\[
P(R_j \rightarrow E_m \rightarrow R_j) = P(R_j)P(E_m|R_j)P(R_j|E_m)
\]

3.2. The probability of transition path selection
When determining the starting point and end point of the transfer, there are multiple paths to choose from the actual road network. Considering the different road conditions at different time points, it is assumed that the probability of choosing the same route remains unchanged for a certain period of time. Take \( R_j \rightarrow E_m \) as an example, the path that can be chosen is \( f_j \), and the probability of choosing \( f_j \) is

\[
P(L = f_j \mid R_j \rightarrow E_m)
\]

And have another relationship is

\[
\sum_{j=1}^{g} P(L = f_j \mid R_j \rightarrow E_m) = 1
\]

According to the above method, the probability distribution of all the routes of different travel chains in the planning area starting from residential areas can be obtained.

3.3. Calculation of residents’ trip chain probability
Studies have shown that the traveling patterns of private vehicles depend on the habits of drivers, and have a certain degree of inertia [4]. On the basis of researching the law of residents' travel purposes,
we can make reasonable assumptions about the trip purposes and the travel chains of private vehicle users.

Through the analysis of the composition chart of Beijing residents’ travel purpose in 2016, the proportion of five kinds of travel chains is obtained, as shown in table 1.

| Number | Trip chain     | Probability |
|--------|----------------|-------------|
| 1      | R→W→R         | 0.358       |
| 2      | R→E→R         | 0.066       |
| 3      | R→S→R         | 0.172       |
| 4      | R→C→R         | 0.112       |
| 5      | R→W→C→R       | 0.292       |

### 3.4. Trip parameters

The starting time, travel chain, actual path, parking duration and charging habit of a single trip determine the time and location of the load. On the premise of statistic a large number of historical data, the load forecasting model of a single EV is established with full consideration of the above factors. Table 2 shows the probability distribution function of each trip parameter.

| Trip parameter                      | Probability distribution or parameter expression | Parameter description                  |
|-------------------------------------|--------------------------------------------------|---------------------------------------|
| Travel start time                   | Gamma distribution $f(t_0) = \frac{\beta^\alpha}{\Gamma(\alpha)} t_0^{\alpha - 1} e^{-\beta t_0}$ | Shape parameter $\alpha = 9.881$ Scale parameter $\beta = 58.908$ |
| Parking duration of working areas & education areas | GEV distribution $f(t) = \frac{1}{\sigma} \left(1 + \frac{z}{\xi} \right)^{-1 - \frac{1}{\xi}} e^{\left(-\left(1 + \frac{z}{\xi}\right)\right)^{-1}}$ | Scale parameter $\sigma = 164.506$ Position parameter $\mu = 438.445$ |
| Other areas parking duration        | $z = \frac{t - \mu}{\sigma}$                     | Scale parameter $\sigma = 47.761$ Position parameter $\mu = 68.520$ |
| Initial SOC                         | Power law distribution $f(SOC_0) = cSOC_0'$     | $c = 4.3520$ $r = 3.3552$ |
| Habitual charging critical SOC      | Normal distribution $f(SOC_1) = \frac{1}{\sqrt{2\pi\sigma}} \exp \left[-\frac{(SOC_1 - \mu)^2}{2\sigma^2}\right]$ | Mean value $\mu = 0.466$ Standard deviation $\sigma = 0.179$ |

### 4. Monte Carlo simulation

#### 4.1. Path selection strategy

Considering the actual situation and users’ choice habits, users can determine the final path on the basis of the congestion coefficient and distance of each alternative path, form a set of travel paths finally. From function area $R_j$ to $E_m$, there are $r_t$ routes recommended in map software, in which the total length of the route $f_j$ is recorded as $l(f_j)$, and the congestion coefficient varies with time and is recorded as $\lambda(f_j, t)$. It can be obtained according to the statistical data of traffic network. Therefore, the principle of route selection is defined as:

$$\min \lambda(f_j, t)l(f_j), \ f_j \in (1, r_t), t \in (1, 24)$$

#### 4.2. The charging strategy

According to the user’s habit, before each trip EV user should be judged whether the electricity is enough or not, and if it can’t be maintained to the next destination, it will choose to charge. In order to
ensure the service life of EV batteries, the SOC of batteries should be controlled in the range of 0.2–0.8. Based on these two principles, the charging strategy is as follows:

- When traveling from home for the first time, judge whether the current electricity is enough for the next stage of the journey.
- In the process of driving on the road, the SOC of the battery is monitored. When the SOC is lower than the user's customary charging SOC value, EV user will searching for charging station. Select a charging station that can be driven before the battery’s SOC reaches 0.2 and is the closest to the current location. The charging mode in the road is only fast charging.
- EVs staying in the functional area will choose whether to charge or not on the basis of the SOC, the parking duration and the distance of the next distance.

5. Example analysis

5.1. Simulation description

As shown in figure 1, the planning area is 225km$^2$, which is divided into two residential areas, two working areas, one business area, one education area and one social service area. There are 14 alternative charging stations, which are located in the center of the functional area and near the streets with large traffic flow. The main streets have been drawn in the figure 1.

![Figure 1. The road map of planning area in the example.](image)

Suppose that there are 1000 private EVs in the planning area, of which 600 belong to residential area1 and 400 belong to residential area2. Suppose that the EV has only one trip chain every day, and the starting point and end point are home. Suppose the battery capacity of EV is 50kW·h, the speed is 50 km/h, the power consumption is 0.22 kW/h, the charging power of slow charging pile is 7 kW, and the charging power of fast charging pile is 50kW. Considering the actual situation of the planning area in the example, through statistical data and equation (5), the probability distribution of the specific travel path is formed as shown in table 3.

| Route   | Probability | Route   | Probability | Route   | Probability | Route   | Probability | Route   | Probability |
|---------|-------------|---------|-------------|---------|-------------|---------|-------------|---------|-------------|
| R11→W1→R11 | 0.04725    | R23→W2→R23 | 0.04257    | R22→E→R22 | 0.00858    | R11→S→R11 | 0.02575    |         |             |
| R12→W1→R12 | 0.04825    | R11→C→R11 | 0.01675    | R23→E→R23 | 0.00858    | R12→S→R12 | 0.02575    |         |             |
| R13→W1→R13 | 0.04825    | R12→C→R12 | 0.01675    | R14→S→R14 | 0.02575    | R13→S→R13 | 0.02575    |         |             |
| R14→W1→R14 | 0.04825    | R13→C→R13 | 0.01675    | R21→S→R21 | 0.02346    | R11→W2→C→R11 | 0.00450  |         |             |
| R21→W1→R21 | 0.00476    | R14→C→R14 | 0.01675    | R22→S→R22 | 0.02777    | R12→W2→C→R12 | 0.00450  |         |             |
| R22→W1→R22 | 0.00462    | R21→C→R21 | 0.01530    | R23→S→R23 | 0.02777    | R13→W2→C→R13 | 0.00450  |         |             |
Table 3. Probability distribution of path. (continued)

| Route          | Probability | Route          | Probability | Route          | Probability | Route          | Probability |
|----------------|-------------|----------------|-------------|----------------|-------------|----------------|-------------|
| R23→W1→R23    | 0.00462     | R22→C→R22     | 0.01485     | R11→W1→C→R11  | 0.03950     | R14→W2→C→R14  | 0.00450     |
| R11→W2→R11    | 0.00550     | R23→C→R23     | 0.01485     | R12→W1→C→R12  | 0.03950     | R21→W2→C→R21  | 0.03570     |
| R12→W2→R12    | 0.00550     | R11→E→R11     | 0.01000     | R13→W1→C→R13  | 0.03950     | R22→W2→C→R22  | 0.03465     |
| R13→W2→R13    | 0.00550     | R12→E→R12     | 0.01000     | R14→W1→C→R14  | 0.03950     | R23→W2→C→R23  | 0.03465     |
| R14→W2→R14    | 0.00550     | R13→E→R13     | 0.01000     | R21→W1→C→R21  | 0.00408     | R22→W2→C→R22  | 0.00396     |
| R21→W2→R21    | 0.04386     | R14→E→R14     | 0.01000     | R22→W1→C→R23  | 0.00396     | R21→W2→C→R21  | 0.00884     |
| R22→W2→R22    | 0.04257     | R21→E→R21     | 0.00884     | R23→W1→C→R23  | 0.00396     | R22→W2→C→R22  | 0.00396     |

5.2. Simulation results

According to the above process and example data, the load of 14 alternative locations in the planning area in one day is predicted, as shown in figure 2 and figure 3.

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Figure 2. The total load generated by EVs in 14 alternative locations.

Figure 3. The total load of EVs.

Figure 4. The total load of EVs in V2V mode.
Considering the difference between peak-time price and valley-time price, when the EV returns home, it makes full use of the flexible charging and discharging control of the EV to shift peak load in V2V mode. Discharge is carried out during peak hours, stopped before 22:00. According to the above charging and discharging strategy, assuming the discharge power of EV is 10 kW, load forecasting is carried out again. The results are shown in figure 4. Comparing with figure 3, we can see the effect of peak load shifting.

5.3. Explanation of results
When only considering the charging of EVs, this simulation only carries out single-chain travel, so the load of residential areas mainly concentrates on the period of 13:00-15:00 and 19:00-21:00, while the slow-charging load of the other four functional areas mainly concentrates on the period of 10:00-13:00. Because only fast charging is used when charging on the road, the seven alternative locations on the road around the business district generate large loads at noon (11:00-13:00) and evening (17:00-20:00). Because of the longest parking duration in residential and working areas, most of the slow charging is concentrated in these areas.

For V2V mode, this charging and discharging strategy can transfer the peak load of 12:00-16:00 electric vehicle to 22:00, which can reduce the peak load. If the discharging power is 10 kW, the cumulative discharges in a day can reach about 16,312 kW·h, and the daily profit is about CNY 5,032.50.

6. Conclusion
The simulation results show that the method based on simulated actual path can effectively predict the charging load of EVs in a planning area, avoid repeated calculation of the load and improve the prediction accuracy. Finally, considering V2V mode, through the formulation of reasonable charging and discharging strategy, users can be guided to load transfer, which can shift the peak load of EVs. It can alleviate the pressure of charging on the power grid of EV, and create profits for EV users.

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