Research on Charge and Discharge Strategy of Electric Vehicles Based on New Distribution Network Planning

Min-an Lu¹, Tangzheng Ren¹, Kunhua Ji¹, Zimeng Wang¹, Dongxia Gu¹, Chen Peng²*, Zhijie Cao²

¹ State Grid Shanghai Municipal Electric Power Company Qingpu Power Supply Company, Shanghai, China
² Nanjing Haoqing Information Technology Limited Company, Nanjing, China
*Corresponding author’s e-mail: pchhu@qq.com

Abstract. Based on the planning and distribution of new distribution network, the charging and discharging strategies of existing electric vehicles are studied. According to the number and distribution of existing charging piles, as well as the charging quantity of electric vehicles in each region, the travel law of electric vehicles is analyzed by using the travel chain theory and Monte Carlo algorithm; then, according to the user travel rules and the charging pile capacity of each area, each area is rated, and a hierarchical V2G distribution network is designed. Then, the power supply behavior of electric vehicles in V2G distribution network is analyzed, and the main power supply time period of electric vehicles in the improved V2G distribution network is obtained by using Monte Carlo algorithm; finally, the effectiveness of the proposed scheme is verified by an example, and the power supply situation of electric vehicles is classified.

1. Introduction

Electric vehicle is driven by electric energy. Because of its green travel mode, it can not only alleviate the energy crisis, climate warming and other problems, but also connect to the power grid as reserve capacity to alleviate the problem of excessive load of the power grid[1-2]. 2020 new energy vehicles increased nearly 11%[3]. It shows that more and more consumers are willing to choose electric vehicles as travel tools, so it is of great practical significance to study the related problems of electric vehicles[4].

The large-scale development of electric vehicles requires the construction of more electric vehicle charging facilities, including charging piles and charging stations, but these factors have not been fully considered in the traditional distribution network planning [5]. Different from the gas stations of traditional fuel vehicles, the construction of electric vehicle charging infrastructure is mainly limited by the traffic network and the strong randomness of charging time and space, which brings great difficulties to the urban network planning and design [6]. The reasonable use of vehicle to grid(V2G) technology can greatly alleviate the above problems. V2G technology enables electric vehicles not only to absorb power from the grid, but also to transmit power to the grid. This two-way interaction technology greatly enlivens the power market [7-9].

In this paper, the travel chain theory and Monte Carlo algorithm are used to analyze the travel law of electric vehicles, and then according to the user travel law and the charging pile capacity of each area, a hierarchical V2G distribution network is designed. The area with larger capacity is set as the switch station in the V2G distribution network, as the central node of the distribution network, which can not only carry out V2G distribution Charging and discharging activities can also provide certain power
guarantee for the ring website; setting the area with smaller capacity as the ring website and connecting multiple ring websites has more economic benefits than the point-to-point mode. Then, based on the new V2G distribution network structure, the power supply behavior of electric vehicles is analyzed, and the main power supply period of electric vehicles is obtained according to the power supply. Therefore, the new distribution network structure is more stable in the V2G process than the point-to-point distribution network structure, and has less impact on the battery life of electric vehicles.

2. Analysis of electric vehicles in electric vehicles based on travel chains

The travel rules of electric vehicle users can be generally divided into simple travel chain and complex travel chain, and it is considered that the starting point and end point of the user's travel are home (H) [10]. The simple travel chain consists of two destinations, and the complex travel chain consists of three destinations. Destinations include home (H), workplace (W), social place (SO), shopping place (SH) and other places (O).

![Simple Travel Chain](image1)

![Complex Travel Chain](image2)

2.1. Electric vehicle user travel analysis

The probability density function \( f(x_{11}) \) of the travel start time and travel end time of electric vehicle users can be obtained by the formula (1):

\[
f(x_{11}) = \frac{1}{\sqrt{2\pi} \sigma_{11}} \exp \left( -\frac{(x_{11} - \mu_{11})^2}{2\sigma_{11}^2} \right)
\]

where \( x_{11} \) indicates the start time of the travel or the end time of travel, probability distribution is expressed as \( X_{11} \sim N(\mu_{11}, \sigma_{11}^2) \), \( \mu_{11} \) is the expectation of \( X_{11} \), \( \sigma_{11} \) is the standard deviation of \( X_{11} \).

The mileage probability density function \( f(x_{12}) \) of the electric car is obtained by the formula (2):

\[
f(x_{12}) = \frac{1}{x_{12}\sigma_{12}\sqrt{2\pi}} \exp \left( -\frac{(\ln(x_{12}) - \mu_{12})^2}{2\sigma_{12}^2} \right)
\]

where \( x_{12} \) is the mileage, the probability distribution \( \ln(X_{12}) \) of \( x_{12} \) is \( \ln(X_{12}) \sim N(\mu_{12}, \sigma_{12}^2) \), \( \mu_{12} \) is the average of \( \ln(X_{12}) \), \( \sigma_{12} \) is the standard deviation of \( \ln(X_{12}) \).

2.2. Electric vehicle V2G charge and discharge analysis

By studying the travel law of electric vehicle users, we can establish the charging and discharging model of electric vehicles using V2G technology, and use Monte Carlo algorithm to get the V2G distribution network capacity of each area[11].

When the random variable \( \xi_t \) is 1, the electric vehicle is connected to the grid, and the charge and discharge activity; when the random variable \( \xi_t \) is 0, indicating that the electric vehicle is not connected to the grid, and its probability satisfies the following formula[12]:

\[
P(\xi_t = 1) = 1 - F_{ST}(s > t_e, s + t_e \leq t_e + 24) - F_{ST}(s + t_e \leq t_e)
\]

(3)
In the formula (3) and the formula (4), $\xi_{t_0}$ is a random variable of a certain time $t_0$ in one day, $t_0$ represents a certain moment in one day, $s$ represents the start time of the charge and discharge, $t_c$ represents the charge and discharge time. $F_{STc}$ is the joint probability distribution function of the charge and discharge start time and the charge and discharge time. Assuming that these two random variables are independent of each other, then $F_{STc} = F_S F_{Tc}$, $F_S$, $F_{Tc}$ are the probability distribution function of the charge and discharge start time and the charge and discharge time, respectively. The charge and discharge power of the electric vehicle in the middle of the day $t_0$ is $P_{t_0} = \xi_{t_0} P_c$, the probability distribution of $P_{t_0}$ satisfies the following formula [12]:

$$P(P_{t_0} = 0) = P(\xi_{t_0} = 0)$$

(5)

$$P(0 < P_{t_0} \leq 0) = P(\xi_{t_0} = 1) \times P(0 < P_c < P_0)$$

(6)

In the formula (5) and the formula (6), $P_{t_0}$ is the power of the $t_0$ time, $\xi_{t_0}$ is a random variable of $t_0$, $P_c$ is charge and discharge power, $P_0$ is charge and discharge power.

3. V2G distribution network planning

The existing charging piles of electric vehicles in urban areas are mostly built in residential areas or large public places, and the parking places of electric vehicles in different periods of time are also random [13]. In order to make full use of the battery energy of electric vehicles and stabilize the V2G distribution network, it is necessary to make reasonable planning.

3.1. Distribution network structure

Based on the existing charging piles, the number of charging piles in each area can be counted, and the V2G distribution network capacity of each area can be estimated. Combined with the distance between each area and other factors, the V2G distribution network can be built by using the main network and secondary network cables. Because the importance of each transmission line is different in different time periods [14], the specifications of main network cable and secondary network cable should be the same. The advantage of this hierarchical V2G distribution network is that users can select the best area for charging and discharging according to the real-time rating.

V2G distribution network is mainly composed of substation, switch station and ring network. The switch station is the main node, and it is connected to 1-2 substations. Each ring network is used as the secondary node, and it operates in open-loop mode. It is connected to the main switch station nearby, and the main switch station is used as the power supply. The specific structure of the distribution network is shown in Figure 3, and the main features are as follows:

(a) The substation is 110kV substation, the switch station is 10KV switch station, the ring website is 10KV ring website, and the substation and switch station are connected to the 10kV background, and the switching station is connected to the ring website.

(b) There are switching stations connected between substations. In order to ensure the temporary power supply of one substation after failure, the other two substations can be used.

(c) Each substation is connected to four switch stations, and three switching stations are connected to the ring website, and the two are connected to the switching station.

(d) Each switch station is connected with four ring websites end-to-end, and the two ring websites in the middle are not directly connected with any switch station.

(e) When the V2G capacity of a certain switching station or ring site is insufficient, it can provide redundant power through other sites to ensure the stability of the power grid.
According to the previous analysis on the travel law of electric vehicles, the charging capacity of each area is predicted based on Monte Carlo simulation method, and the areas with large charging demand and large capacity of electric vehicle charging pile are set as switching stations, such as large parking lots and shopping malls; the areas with small charging demand and small capacity of electric vehicle charging pile are set as switching stations, such as residential areas.

4. Electric vehicle V2G power supply analysis
V2G technology can be used in the charging and power supply of electric vehicles. However, due to the small battery capacity of electric vehicles and the uncertainty of the number of simultaneous access to V2G distribution network, V2G power supply of electric vehicles has the characteristics of short power supply time and strong randomness compared with V2G charging[15].

Based on the above research, it shows that the power supply of electric vehicles is the largest at 20-22, followed by 3-5 and the smallest at 12-14. It can be concluded that after the electric vehicles are connected to the V2G distribution network, the power supply time is concentrated in 3-5:00, 12-14:00 and 20-22:00. According to the size of power supply, the power supply situation of electric vehicles can be divided into three categories: one supply per day, two supply per day and three supply per day. The time of one supply per day is mainly concentrated in 20-22 o'clock, the time of two supply per day is mainly concentrated in 3-5 o'clock and 20-22 o'clock, and the time of three supply per day is mainly concentrated in 3-5 o'clock, 12-14 o'clock and 20-22 o'clock.

5. Example analysis
Based on the statistical results of the 2017 national household travel survey, the starting time, ending time and mileage of private cars in a day are extracted to study the operation characteristics of electric vehicles. As shown in Figure 5, the electric vehicles in an electric vehicle parking lot participate in V2G
charging. The parameter information of electric vehicles is shown in Table 1. The total number of vehicles is 600, and the number of models accounts for one third of the total.

Table 1 Comparison of three electric vehicle battery parameters

| Vehicle Type  | Battery Type  | Battery Capacity/kWh | Mileage/km |
|---------------|---------------|----------------------|------------|
| BYD-E6        | Lithium battery | 63.3                 | 295        |
| Nissan-Altra  | Lithium battery | 29.07                | 130        |
| Wuling mini   | Lithium battery | 13.8                 | 170        |

After the electric vehicle is connected to V2G distribution network, 30% of the power supply is provided one day, 40% is supplied two times a day, and 30% is supplied three times a day. The random mileage of different electric vehicles is 10km, and the starting charging time is taken in 2 hours, and the initial charge is extracted in 0.1kwh.

By continuously stacking the power supply curves of 600 electric vehicles, the daily average V2G power supply curve of electric vehicles in the electric vehicle parking lot can be obtained, as shown in Figure 5.

The above steps are carried out for a residential area with 210 vehicles. The same number of vehicles accounts for one third of the total number, and the geographical location of the residential area is close to the above parking lot. The daily average V2G power supply curve of electric vehicles in the residential area is obtained, as shown in Figure 6.

6. Conclusions

To sum up, based on the new distribution network planning, this paper studies the charging and discharging strategy of electric vehicles. Through hierarchical classification, the areas with different capacities are divided into switching stations and ring sites, and users are guided to charge orderly by using the improved charging pile, so that V2G distribution network has good adaptability to power supply and user access. Furthermore, this paper analyzes the V2G power supply behavior of electric vehicles and draws the following conclusions:
(a) When the electric vehicle is powered at 20-22, there are many burrs in the power supply curve, which indicates that V2G power supply has strong randomness and is easy to impact the power grid.

(b) According to the size of power supply, the power supply situation of electric vehicles can be divided into three categories, namely one supply per day, two supply per day and three supply per day.

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