Community electric vehicle load forecasting based on time series distribution

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Abstract: Electric vehicle charging load forecasting helps power system planning management and optimization. This paper proposes a residential private electric vehicle load forecasting model based on positive-reverse valley time charging, which predicts the load while satisfying the orderly charging of large-scale private electric vehicles in residential areas. Firstly, it analyzes the historical travel rules of private electric vehicles in the community and the charging and discharging characteristics of electric vehicles. Secondly, based on the peak-to-valley time-of-use (TOU) electricity price, the owner of the vehicle is fully utilized to make the electric vehicle orderly charging, so as to obtain the total charging load of the electric vehicle in the community; Finally, the actual data is used to predict the change of the load curve of private electric vehicles in the future after large-scale access to the grid. It is found that under the scenario of disorderly charging of private electric vehicles, the larger volume of the grid has the greater difference between the peaks and valleys of the grid. Through further calculations, it is found that the use of valley time charging can alleviate the impact of the electric vehicle charging load on the power grid to a certain extent. That also can effectively reduce the peak-to-valley difference of the grid load and residential area distribution network overload rate.

1. Introduction

Electric vehicles (EVs) have developed rapidly in recent years due to their high energy efficiency and no exhaust emissions. However, the disordered charging behavior of EVs will adversely affect the safety and economy of urban power grid operation. Therefore, by establishing a reasonable EV orderly charging model, it can reduce the adverse effects caused by a large number of EVs connected to the power grid and at the same time provide a strong guarantee for the safe operation of the power grid. According to the travel rules and charging load of the private EVs in the community, the daily load is divided into the peak load period and the valley load period. It is assumed that the private EVs in the residential area are charged in the grid load valley period without emergency and combined with the positive sequence of the trough period. The reverse charging mode is used to charge the EV. The EV charging load of the entire community is predicted by analyzing the historical charging load data,
driving and parking characteristics of the working day and the holiday. Reference [1], an optimal filling strategy for decentralized charging of EVs is proposed, which effectively suppresses the peak-to-valley difference when considering user competition. In [2] pointed out that EV load can be controlled by means of electricity price and other means to avoid its impact on grid load. Literature [3], the EV is regarded as a group, the optimization method is proposed with the goal of optimal peak clipping and valley filling. Literature [4] shows that using the TOU price to guide can concentrate the charging load in the valley period. Literature [5] used the model simulation method to construct the space-time distribution model of EV charging load. Literature [6] established a space-time model for mobile EV loads. In terms of load forecasting considering spatiotemporal changes. The literature [7] analyzes the travel rules of electric buses, electric taxis, electric official cars and electric private cars, according to the travel rules solve the vehicle load. Literature [8] proposed a space-time prediction method for charging load based on the driving characteristics of EVs. Literature [9] obtained the spatiotemporal distribution of EV charging load through historical statistics. The literature [10] shows that the dynamic time-sharing electricity price can stimulate the user's self-response, which can effectively realize the “shaving peak filling” benefit compared with the disordered charging. The above research content lays a theoretical foundation for the study of EV in urban residential districts using the charging and control of the reversed-phase valley period and load forecasting. This paper mainly studies the slow charging method of private EVs and the prediction of the charging load of the residential area in a residential area of Lanzhou City. By analyzing the regular living electricity consumption rules of the residential residents and the historical travel rules of the vehicle owners, combined with the peak-to-valley TOU electricity price of the grid, a new private EV load forecasting model based on the positive reverse valley time charging is proposed. Considering the charging load of EVs and the residential electricity load of residential quarters all have similar time characteristics, the EV charging characteristics of a residential area in Lanzhou City are simulated and verified by examples. The results show that the method satisfies the user's vehicle. Under the condition of demand, the owner of the vehicle can be reasonably arranged to charge and accurately predict the charging load of the residential area.

2. Community EVs orderly charging mode
From 2021 to 2030, EVs will embark on the track of rapid development in China, and the proportion of users will continue to rise. However, the disordered charging of a large number of EVs will increase the load of the regional distribution network and the peak-to-valley difference of the load will further change large. By using peak and valley TOU electricity prices to guide users to use the low load period to charge, not only can reduce the charging cost of the owner's users, but also reduce the peak-to-valley difference of the load. Since the residential area is mainly for parking private cars, this paper does not consider the charging load of buses, official vehicles and taxis in the community. Private EVs are mainly used car owners for daily work and leisure. Since most private EVs do not need to be recharged in the morning, this paper mainly models and analyzes the afternoon and evening charging load forecast of private EVs in the community. In addition, EVs have not been popularized in China. The research on the daily travel rules of EVs and the reliable historical charging data are relatively lacking. This paper analyzes the EVs by simulating the travel rules and characteristics of fuel vehicles in the community and it meets the charging needs of the owners. The charging load of the EV in the community is predicted without affecting the habit of using the vehicle.

3. Community EVs load forecasting model under time series distribution
3.1. Private EV travel return time and mileage distribution probability distribution
If there is no special emergency, the EV users in the community will adopt the TOU electricity price. At the same time, according to the difference between the peak and valley TOU electricity price, the user is guided to charge, thereby reducing the peak-to-valley difference of the grid load and reducing the user charging cost. Under the condition that the peak-to-valley TOU electricity price is not
implemented, the user generally randomly selects the charging time according to the daily travel habits and living rules.

According to the historical travel data combined with the travel habits of EV users, the probability density distribution function of the last return time of the private EV travel can be as follows:

\[
f(x_i) = \begin{cases} 
\frac{1}{\sigma_s \sqrt{2\pi}} \exp\left[-\frac{(x_i - \mu_s)^2}{2\sigma_s^2}\right] & (\mu_s - 12) < x_i \leq 24 \\
\frac{1}{\sigma_s \sqrt{2\pi}} \exp\left[-\frac{(x_i + 24 - \mu_s)^2}{2\sigma_s^2}\right] & 0 < x_i \leq (\mu_s - 12)
\end{cases}
\]

where \(x_i\) is the return time of EV users; \(\mu_s = 17.8\) is an average return time of EV users and \(\sigma_s = 3.2\) is its standard deviation.

The EV daily mileage probability density function is as follows:

\[
f_D(S) = \frac{1}{S \sigma_D \sqrt{2\pi}} \exp\left[-\frac{(\ln S - \mu_D)^2}{2\sigma_D^2}\right]
\]

where \(S\) is the daily mileage of EVs; \(\mu_D = 3.4\) is an average of EVs daily mileage logarithm and \(\sigma_D = 0.9\) is its standard deviation.

### 3.2. Community EV charging power and time

The power battery capacity of ordinary private EVs in residential areas is generally 25~35 kW·h. Most EVs still use lithium batteries and these are generally used in residential areas as three-stage slow charging mode, namely pre-charging stage, constant current charging stage and constant voltage charging stage. Since the constant current charging phase accounts for the largest proportion of the entire charging process, it is assumed in the study of this paper that the entire battery charging process is constant current charging and the charging power of each EV is distributed in the range of 3 to 4 kW.

The formula for charging time for private EVs is as follows:

\[
T_e = \frac{S \omega}{P_e \eta}
\]

where \(T_e\) is the charging time for EVs, its unit is hour; \(S\) is the daily mileage of residential EVs, its unit is kilometer; \(\omega\) is the electricity consumption per kilometer of EVs, its unit is kW·h/km; \(P_e\) is the charging power of residential EVs, its unit is kW; \(\eta\) is the charging efficiency of EVs.

### 3.3. Optimal valley time charging method and steps combining positive and reverse sequence

The charging mode of the EV in the community has disordered charging, positive sequence valley charging, reverse valley charging and positive reverse valley charging. The positive reverse valley time charging is used to divide the load valley time into two segments, so that the EV can fully utilize the valley time period for orderly charging, which not only reduces the charging cost of the vehicle owner, but also reduces the peak-to-valley difference of the grid load. Therefore, it has strong applicability compared to other charging methods. The peak-to-valley period of the residential electricity load can be obtained by analyzing the historical electricity consumption data of the residential area in China, as shown in Table 1. \(T_{vb}\) is the peak period start time, \(T_{ve}\) is the peak period end time, \(T_{gb}\) is the valley period start time and \(T_{ge}\) is the end period of the valley period.

| type       | Period               |
|------------|----------------------|
| peak       | 06:00—22:00          |
|            | \(T_{vb}—T_{ve}\)    |
| valley     | 22:00—06:00          |
|            | \(T_{gb}—T_{ge}\)    |

Electric vehicles can make full use of the valley period for orderly charging and load forecasting. The specific implementation process is as follows:
Step 1. The charging time is calculated by analyzing the historical travel data and reading the initial state of charge of the EV and the minimum required battery charge determined according to the travel mileage requirement when the user leaves.

Step 2. The users are charged according to the daily demand of the EVs. If the user does not have a special demand for the vehicle, then the valley period with the combination of the reverse and the reverse is used to maximize the orderly charging method for charging; For users with special vehicle needs, if the user is in the reverse order valley when the charging method of the time period cannot meet the charging requirement, the charging is performed by the disorderly charging method.

Step 3. Combining the typical daily load data of the typical daily history of the community with the number of EVs and analyzing the historical charging mode of the owner of the community, the ratio of the number of vehicles in the positive sequence valley period and the number of charged vehicles in the reverse valley period is 1:1, which is the optimal valley combined with the positive sequence order. The charging mode of the period is analyzed and compared with the conventional disordered charging mode.

4. analysis of examples

This paper takes a residential area in Lanzhou as an example to simulate and verify the applicability of the method. During the working day, the normal charging load peak period of ordinary residential quarters generally occurs at noon and night, the peak period of holiday charging load lasts from late afternoon to late night and it has strong regularity. Assume that there are 1000 households in the community, each housing area is 100 square meters, and the coverage rate of EVs is 70%. The electricity consumption of the residential area is calculated by counting the historical travel rules of the owner of the community and the historical regular power load. The analysis method combines the disorderly charging and reverse charging methods of holidays and working days to compare the two charging modes of the valley period so as to predict and optimize the grid dispatching. In the valley time charging mode in which the reverse sequence is combined, the ratio of the number of positive sequence charging and reverse charging vehicles in the valley period is 1:1 and the daily load curve of the charging area of the EV is as shown in Figure 1.

Figure 1. EV charging community daily load curve
Comparing the disordered charging mode and the positive reversal valley charging mode in the working day and holiday in Fig.1, it can be seen that the working day and the holiday load are obviously different, the working day is mostly charged at noon and night and the holiday charging peak appears from the afternoon time. It lasts until late at night and it may be due to the parade of holiday users. Electric vehicles have a relatively long charging time. The positive-reverse valley time charging mode can significantly reduce the peak-to-valley difference. According to the travel rules of the owner of the vehicle and the load law of the residential community's electricity consumption, the charging load is predicted. The method maximizes the use of the valley period for charging without increasing the existing allocated capacity of the residential area and reducing the charging cost of the vehicle owner, thereby increasing the community's ability to accept the electric vehicle.

5. Conclusion
This paper proposes an optimal positive-reverse valley period charging method. This charging method can reduce the charging cost of the vehicle owner's users at the same time and accurately predict the charging load. The disordered charging of EVs will increase the peak load of the grid and its peak-to-valley difference. The peak-to-valley TOU electricity price combined with the optimal positive-reverse valley time charging can be used to adjust the charging time of the owner's users, cut the peaks and fill the valley. The simulation of EV charging in a residential area of Lanzhou City is carried out by an example. The results show that the charging method not only reduces the overload rate and load fluctuation of the distribution network, but also can increase the existing power distribution capacity of the residential area. In order to meet the requirements of more electric vehicle owners, the charging load of electric vehicles should be accurately predicted.

Data Availability
The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest
The authors declare that there are no conflicts of interest regarding the publication of this paper.

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