Orderly Charging of Peak and Valley Electricity Price Demand Response

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Abstract. Based on the analysis of the factors affecting the charging load of electric vehicles, the Monte Carlo method is used to predict the charging load of electric vehicles. According to the charge load response and demand price elasticity, the orderly charging strategy of electric vehicles based on peak-to-valley demand response is proposed. The effectiveness and feasibility of the strategy are verified by an example. The example shows that the strategy can effectively guide the charging time and charging power of the electric vehicle, effectively alleviating and optimizing the grid operation.

1. Introduction

With the expansion of the scale of electric vehicles, the information exchange between electric vehicles and electric vehicles, electric vehicles and road networks, electric vehicles and power grids has become more frequent and diverse, which puts higher demands on information processing speed. Therefore, hierarchical Control will be an important method for future orderly charging research. With the market-oriented development of power trading, the charging behavior of electric vehicle users has complete autonomy. It is of great practical significance to study the charging incentives of electric vehicles and guide the orderly charging of users. It is a future study to guide the orderly charging of electric vehicles through the electricity price mechanism. Main direction [14].The traditional research is based on the demand side response theory to describe the response mechanism of electric vehicle charging behavior. The electric vehicle user layer and the grid layer economic benefit are the optimization objectives, and the optimal time-of-use electricity price and real-time electricity price are measured. The research results show that the real-time electricity price is for electric vehicles. Ordered charging has better optimization results;In recent years, using game theory to describe the economic interests of various subjects in the electric vehicle charging network, so as to obtain more accurate electric vehicle charging demand response behavior, and develop an optimized electricity price strategy, has become a hot spot to study electric vehicle charging price. Literature studies show that the grid considers the economic income including network loss, peak-to-valley difference and charging revenue when formulating the electricity price strategy, while electric vehicle users want to obtain the most including charging time, short queue time and low charging cost. Good charging experience [15].In fact, the potential that can be scheduled when an electric car is in a driving state, an idle state, and a charging occupancy state is not the same. Due to its non-movable or non-long-distance movement characteristics, an idle electric vehicle can schedule its charging time and cannot change its charging position. The electric vehicle in the driving state is characterized by the randomness and urgency of its charging demand. The charging position of the electric vehicle can only be guided by the electricity price, and the charging time cannot be scheduled. Therefore, it is of great practical significance to study the charging control strategy for electric vehicles of different states.

2. The Factors Affecting the Charging Load of Electric Vehicles

When the number of electric cars is small, the charging load has little impact on the grid. However, when the number of electric vehicles increases, a large number of electric vehicles will be charged at the same time, which may cause problems such as "peak on peak" and threaten the safe and

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stable operation of the power grid.

With the rapid development of electric vehicle technology and the great support of national policies, electric vehicles have become more and more popular. According to China's energy saving and new energy vehicle statistics, we can know the national electric vehicle ownership data. It is estimated that by 2030 there will be close to 200 million electric vehicles, so their charging capacity will increase dramatically.

Electric vehicles can be charged in three ways: conventional charging, quick charging and battery replacement. Among them, conventional charging, also known as slow charging, has a small charging current, which does not damage the battery life, but requires a long charging time, which is suitable for private cars with short daily driving distance. Rapid charging generally USES a special dc machine for charging, which greatly reduces the time required, but high current will reduce the battery life, and also have a certain impact on the power grid. Generally, it only takes a few minutes to change the battery, which is convenient and fast. Moreover, the centralized processing of the replaced battery is conducive to the maintenance of the battery, and the centralized charging during valley time can also reduce the cost.

At present, electric vehicle power batteries mainly include lead-acid batteries, nickel-hydrogen batteries and lithium-ion batteries. Studies have shown that different types of battery charging characteristics are roughly the same, both constant current and constant voltage. That is, the battery is first charged with a constant current, raised to a set voltage value, and then the battery is fully charged at a constant voltage. In the conventional charging mode, the charging start phase and the end phase are shorter than the entire charging process and can be ignored. This paper uses a constant power model to describe the charging characteristics of electric vehicles.

The user's usage habits, including charging start time, daily driving mileage, charging frequency, etc., are the key factors affecting the charging load of electric vehicles, and have certain randomness.

In order to ensure the user's use needs without damaging the battery life, it can be considered that the charging frequency of the private car is once a day.

According to people's daily habits, assuming that a pure electric private car user in a city performs charging behavior immediately after the last trip is returned every day, the return time of the last trip can be used instead of the charging start time. By fitting with MATLAB, the distribution of the charging start time of the electric vehicle during the disordered charging can be obtained to satisfy the normal distribution law. The probability density function of the charging start time of an electric vehicle is:

$$f_{T-start}=\begin{cases}\frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{(x+24-\mu)^2}{2\sigma^2}\right], 0\le x<(\mu-12)\\ \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right], (\mu-12)\le x<24\end{cases} \tag{1}$$

Where $\mu = 17.5$ and $\sigma = 3.47$. μ is the expected starting time of an electric vehicle, while σ is the standard deviation of an electric vehicle.

The probability density function of daily driving distance of electric vehicle is:

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

Where $\mu = 3.38$ and $\sigma = 0.81$.

3. Orderly Charging Strategy Based on Demand Response of Peak and Valley Electricity Prices

Demand Response (DR) means that when the price of the wholesale electricity market increases or the system reliability is threatened, the power user changes after receiving the direct compensation notice or the power price increase signal from the inductive reduction load sent by the power supplier. Its inherent customary electricity mode achieves a short-term behavior that reduces or shifts the power load for a certain period of time in response to the power supply, thereby ensuring grid stability and suppressing the rise in electricity prices. It is one of the solutions for Demand Side Management (DSM).Demand response can be divided into price-based demand response and incentive-based demand response. The demand response based on the peak-to-valley time-of-use electricity price refers to the grid determining the peak-to-valley period according to the historical load situation, appropriately increasing the electricity price during the peak hours of electricity consumption, appropriately lowering the electricity price during the electricity low valley period, and making the user partially variable through price incentives. The load shifts from the peak hours of power consumption to the low valley period, reducing the system peak-to-valley difference.

3.1 Demand Response Model of Electric Vehicle Users to Peak and Valley Electricity Prices. As an effective and orderly charging strategy, peak-to-valley electricity price is also a demand-side management measure. Combined with economic principles, after the peak-to-valley time-of-use electricity price, the amount of change in electric vehicle charging power depends on the amount of electricity price change and electric vehicles. The user's power demand elasticity. The price elasticity ε of demand is defined as the ratio between the relative change in demand and the relative change in price.

$$\varepsilon = \frac{\Delta Q/Q}{\Delta P/P} = \frac{P}{Q} * \frac{\Delta Q}{\Delta P} \tag{3}$$

Where Q represents the demand and P represents the price. Since the demand quantity is inversely proportional to the price, mathematical analysis shows that the demand function Q=φ(P) is a monotonically decreasing function, so its first derivative is necessarily less than zero, that is $\frac{dQ}{dP} < 0$, so ε is a negative value.

The user's demand response model for peak and valley electricity prices can be described as:

$$\begin{bmatrix} \frac{\Delta Q_f}{Q_f} \\ \frac{\Delta Q_g}{Q_g} \end{bmatrix} = \begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} \\ \varepsilon_{21} & \varepsilon_{22} \end{bmatrix} \begin{bmatrix} \frac{\Delta P_f}{P_f} \\ \frac{\Delta P_g}{P_g} \end{bmatrix} \tag{4}$$

Among them, Q_f represents electricity consumption inthe peak, Q_g represents the electricity consumption in the valley, P_f indicates the peak electricity price, and P_g indicates the valley electricity price, $\begin{bmatrix} \varepsilon_{11} & \varepsilon_{12} \\ \varepsilon_{21} & \varepsilon_{22} \end{bmatrix}$ is the price elasticity matrix. Through the user's charge, peak and valley electricity price change rate and demand elasticity, the corresponding charge demand change can be predicted.

3.2 Example Analysis. In order to verify the effectiveness of the implementation of the peak-valley electricity price strategy, the user's charge change is predicted based on the peak-to-valley electricity price currently implemented in a city. Peak and valley electricity prices are shown in the table below:

Table 1 Peak and valley electricity price of residents in Xuzhou

Time	Electricity price(less than 1kV)
Peak hours （8：00—21：00）	0.5583
Valley hours （0：00—8：00，21：00—24：00）	0.3583

From Eq.4:

$$\Delta Q_f = \Delta Q_g = \left(\varepsilon_{11} \cdot \frac{\Delta P_f}{P_f} + \varepsilon_{12} \cdot \frac{\Delta P_g}{P_g}\right) \cdot Q_f \qquad (5)$$

China's electricity price elasticity coefficient is about -0.5 ~ -0.1, and ε_{12} is about -0.2. Substituting (5) is calculated:

$$\Delta Q_f = \Delta Q_g = 0.114 Q_f \qquad (6)$$

It can be seen from the load forecast that the peak load of the electric vehicle is 11770 kW·h, and the variation of the demand for electricity calculated by the substitution type (4) is 1341.78 kW·h.

It can be seen that under the peak-to-valley electricity price strategy, the user's charging demand changes, and the charging load of about 1341.78 kW·h will be transferred from the peak period to the low valley period, thereby alleviating the grid pressure during peak hours to a certain extent. If the gap between the peak and valley electricity prices is widened and the price of electricity is increased, more charging loads will be transferred, and the effect will be more obvious.

3.3 Realization of Orderly Charging System.

In the smart grid environment, APP (Application) can be used to perform real-time two-way interaction with users, and the peak and valley electricity prices can be sent to the user in real time to guide the user to actively adjust the charging operation, thereby ensuring the orderly charging of the electric vehicle.

The ordered charging system is mainly composed of three modules: electric vehicle user, intelligent charging and discharging dispatching system and charging station. The electric vehicle users can know the electricity price and charging strategy related information in real time through the APP, and upload the battery charging demand; the electric power company establishes the electric vehicle intelligent charging and discharging dispatching system to monitor the real-time running state of the power grid, according to the load forecasting data, the peak-to-valley time-of-use electricity price, electric The vehicle battery status, user requirements, etc. solve the optimal charging arrangement and send it to each charging station; each charging station intelligently dispatches and manages the connected vehicles according to the power grid scheduling command, and feeds back the current latest charging situation to the system. According to the actual situation, the grid will set the peak-to-valley time-of-use electricity price, which will be sent to the user via APP, guiding the user to choose the low-temperature charge and respond to the orderly charging mechanism.

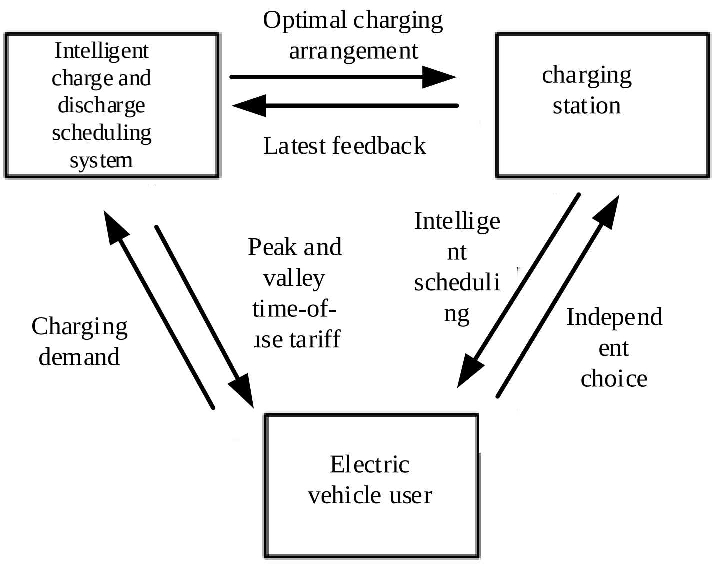

Figure1. Schematic diagram of orderly charging system

4. Conclusion

According to the characteristics of demand response of electric vehicle charging, the demand response of electric vehicle charging based on peak-to-valley time-of-use electricity price is analyzed. From the perspective of economics, according to the price elasticity of demand, the demand response model of electric vehicle users to peak and valley electricity prices is established. According to the current peak-to-valley electricity price in a city, the demand for electric vehicle users under the peak-to-valley electricity price strategy is predicted to be effective. The ground causes part of the charging load to shift from the peak period to the low valley period, alleviating the grid operating pressure. Finally, an orderly charging system is established, which uses the peak-to-valley electricity price to be sent to the user in real time to guide the user to orderly charge according to the grid condition to realize the vehicle network interconnection.

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