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Smart Orderly Charging of Electric Vehicles Based on Demand-side Management

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ABSTRACT

In the context of the expansion of the scale of electric vehicles and the increase in renewable energy generation, smart orderly charging of electric vehicles is an effective means to improve economic and environmental benefits. Smart orderly charging of electric vehicles can not only reduce the impact of electric vehicle charging on the grid but also provide new dispatching resources for power system regulation, thereby avoiding the waste of large amounts of renewable resources, and reducing users' charging costs and related investments in the power sector. Therefore, this paper focuses on the analysis of the basic elements of the implementation of smart orderly charging of electric vehicles, the research composition of smart orderly charging, and the smart orderly charging incentive measures based on demand-side management. The result that first identifies the user groups and characteristics of smart orderly charging of electric vehicles, and divides its business model into two stages. Secondly, the important components of the research on smart orderly charging are highlighted, such as the determination of influencing factors and the selection of charging load forecasting methods. Thirdly, smart orderly charging incentive measures based on demand-side management is proposed in terms of technology and economy, etc. And the last section summarizes the paper and looks forward to future research directions.

Keywords: electric vehicles, smart orderly charging, demand-side management

1. INTRODUCTION

In recent years, electric vehicles quickly enter people's lives, but new challenges also follow. In a global environment where fossil energy is increasingly depleted and environmental problems are becoming increasingly prominent, electric vehicles develop rapidly around the world due to their high efficiency, cleanliness, and pollution-free characteristics. The scale of electric vehicles continues to grow globally, especially in important automotive markets such as China, the United States, and Europe. But with the large-scale development of electric vehicles, the impact of electric vehicles on the grid cannot be ignored when a large number of electric vehicles are connected to the grid. And under the pressure of energy and the environment, the use of renewable clean energy becomes a definite trend in the development of future power grids. However, due to the characteristics of strong volatility and poor controllability, the large-scale integration of renewable energy power generation into the grid also has a direct impact on the security and stability of the grid. Therefore, smart orderly charging came into being—that is, under the premise of meeting the charging demand of electric vehicles and grid constraints, the charging sequence and power of electric vehicles are optimized and adjusted by using economic measures such as peak and valley electricity prices, and government subsidies.

Smart orderly charging can be implemented to assist the grid in peak shaving and valley filling. The current charging of electric vehicles is in a disorderly charging stage, that is, users charge anywhere, anytime, and randomly. The charging load of electric vehicles affects the stability of the power grid, leading to the peak superposition of centralized charging during peak hours,

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thereby threatening the safe and stable operation of the power grid. Therefore, it is necessary to carry out sufficient information interaction and hierarchical control between the distribution network, users, charging piles, and electric vehicles, fully perceive the changing trend of the distribution load, dynamically adjust the charging time and power, and optimize the distribution load operation curve to achieve peak shaving and valley filling. It not only meets the charging needs of users, but also improves the utilization rate of distribution network equipment and power generation equipment, and reduces the investment in the power grid and power generation equipment.

Smart orderly charging can be implemented to promote the consumption of renewable energy. Under the scenario of increasing power generation from renewable energy, effective use of electric energy and maintaining the stable operation of the grid are new challenges for utilities and grid operators. Smart orderly charging of electric vehicles is one of the technical solutions for grid connection and consumption of renewable energy. It has a series of advantages such as low cost, dispatchability, and rapid response. Smart orderly charging can reduce the load peak-to-valley difference caused by disordered charging control, improve the utilization rate of distribution network equipment and power generation equipment, reduce the investment in power grid and power generation equipment, and increase the consumption capacity of renewable energy. Therefore, how to achieve smart orderly charging to improve economic and environmental benefits becomes an urgent issue to be solved.

Smart orderly charging is a key element in the smart electric vehicle ecosystem. The project of car network collaboration is spreading with the popularization of electric vehicles. China, the United States, France, Germany, Switzerland, Sweden, Denmark, and other countries have begun to launch pilot programs. Among them, there are three existing charging standards in Europe, namely Tesla's supercharging station standard, Japan's CHAdeMO standard, and the United States and most European countries' CCS standards. And automakers (such as Renault Group and Fiat Chrysler Group) are cooperating with energy companies, software companies, and grid operators. After more than years of development, the car-network collaboration pilot project has completed the transition from technical feasibility verification to business model verification. In terms of specific content, these pilot projects have covered almost all application scenarios, and the scale of testing has gradually expanded. The specific car network collaboration project is shown in Table 1.

Talbe 1 car network collaboration project

Pilot Project	Mode	Initiator
Germany-REDISPATCHING	Smart orderly charging / V2G	TenneT, Mobility House, Nissan, etc.
France-Grid Motion	Smart orderly charging / V2G	PSA, Enel, NUVVE, DTU
Denmark-Parker	V2G	Technical University of Denmark, NUVVE, Nissan, Mitsubishi, ENEL, etc.
Hawaii-Jumpsmart Maui	V2G	Government of Hawaii, Maui electricity company, Hitachi, University of Hawaii, etc.

Smart orderly charging of electric vehicles can not only reduce the impact of electric vehicle charging on the grid but also provide new dispatching resources for power system regulation, thereby avoiding the waste of large amounts of renewable resources, and reducing users' charging costs and related investments in the power sector. This paper focuses on the basic elements of the implementation of smart orderly charging of electric vehicles, the research composition of smart orderly charging, and the smart orderly charging incentive measures based on demand-side management. Specifically, the second section includes the types and characteristics of users participating in smart orderly charging, and business models of smart orderly charging. The third section includes the influencing factors of electric vehicle charging load, electric vehicle charging load forecasting method, smart orderly charging control strategy, and solutions to the problem of smart orderly charging of electric vehicles. The fourth section includes the incentive measures for smart orderly charging in terms of technology and economy and so on. The last section summarizes the paper and looks forward to future research directions.

2. THE BASIC ELEMENTS OF THE IMPLEMENTATION OF SMART ORDERLY CHARGING OF ELECTRIC VEHICLES

Before implementing the smart orderly charging of electric vehicles, it is necessary to have an in-depth understanding of the objects, methods, and promotion of implementation. Therefore, the following delineates the user group for smart and orderly charging and analyzes the characteristics of smart and orderly charging users. And the business models of smart orderly charging are discussed

Considering feasibility and dispatchability, the users participating in smart orderly charging are private electric vehicles, bus passenger electric vehicles, and special-purpose electric vehicles (such as electric logistics vehicles). And users who participate in smart orderly charging are characterized by private charging piles, high frequency of using cars, and strong running regularity.

Electric vehicle loads are highly flexible and dispatchable. One way of smart orderly charging is to use the charging pile to control the start, pause, and continue charging according to the user's time requirements. Besides, another way of smart orderly charging is to control the charging power of the vehicle through the charging pile according to the time the user picks up the car. The concrete business model of smart orderly charging is shown in Figure 1.

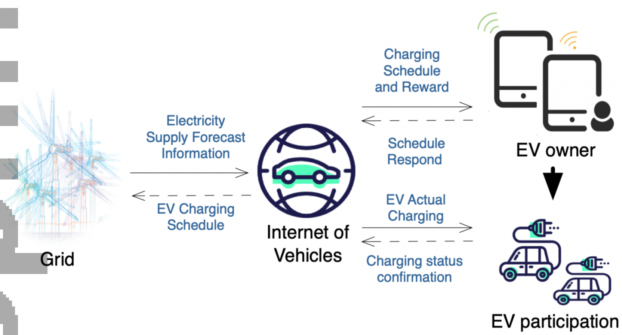

Fig 1 Smart orderly charging business model

Electric vehicles can also be used as energy storage facilities for "discharge". Smart orderly charging business model 2.0, that is, the two-way charging and discharging of electric vehicles (V2G). V2G gathers the adjustable load of electric vehicles in a certain area. And according to the demand of the grid, the electric vehicle energy in the area is uniformly deployed. Besides, according to the different needs of each user, the optimal charging and discharging strategy for each vehicle is calculated, and specific management strategies are generated. V2G realizes real-time interaction between the platform and vehicle users, as well as intelligent analysis and control. The concrete business model of V2G is shown in Figure 2.

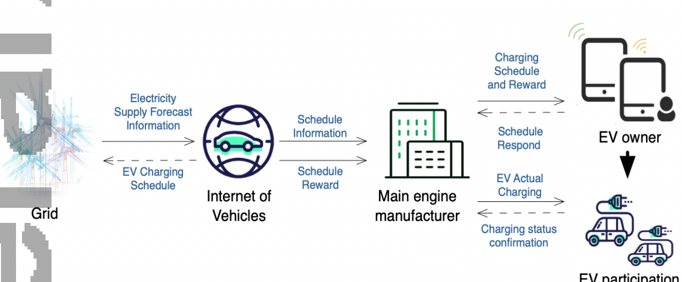

Fig 2 V2G business model

3. RESEARCH COMPOSITION OF SMART ORDERLY CHARGING OF ELECTRIC VEHICLES

The rapid implementation of smart orderly charging of electric vehicles requires decision-making and optimization in multiple links. Among them, it is very important to fully consider the temporal and spatial distribution characteristics of the electric vehicle charging load. And the determination of the electric vehicle load forecasting method considering the time and space distribution is the premise. Besides, the choice of smart and orderly charging control strategy also has a significant impact on practical applications. The above problems and the solutions to the existing electric vehicle smart orderly charging problems are respectively analyzed below.

3.1 Influencing factors of electric vehicle charging load

(1) User behavior

The randomness of EV charging mainly comes from the randomness of users' charging choices. Users' charging behavior is a key influencing factor of the charging load. The difference in charging behavior between different users mainly depends on two aspects [1][2]. One is users' charging time, which is determined by the user's travel habits. The other is the mileage, which can directly reflect the amount of electricity consumed by the EV and directly determine the needed charging time and required charging load.

(2) Charging mode

The charging mode of electric vehicles causes changes in the charging load characteristics. The difference in charging modes is an important factor that affects the charging and discharging load characteristics of electric vehicles. Generally, the charging modes can be classified into three categories: distributed charging, centralized charging, and smart charging. The specific charging mode is shown in Table 2.

(3) Battery characteristic

The characteristics of rechargeable batteries of electric vehicles significantly affect the charging efficiency of electric vehicles. At present, the most widely used electric vehicle battery is a lithium battery, which is affected by factors such as charging current, SOC, and ambient temperature during charging.

(4) Demographics and social attribute

Talbe 2 Classification of Charging Modes of EV

Charging Mode	Definition	Character
Distributed charging	Charge at plug-in charging point, mainly refer to parking lot of residential area, working area, etc.	Charge anytime, anywhere and slow charging speed
Centralized charging	Charge at specific time period and specific area，mainly refer to quick charging stations and batter swapping stations	Fast charging speed
Smart charging	Divided into Orderly Charging mode and V2G mode, according to the collaboration mode between EV and power grid.	Consider the impact of EV charging on power grid and charging economy of users simultaneously

Users with different characteristics have different work and life patterns, which leads to different travel modes and energy consumption [3][4][5]. For example, occupation greatly affects the daily travel time and parking time, and the peak load of the daily load curve [6][7].

3.2 Forecasting methods of electric vehicle charging load

According to the period, the forecasting methods of electric vehicle charging load can be roughly divided into super short-term, short-term, and medium-long-term. Among them, short-term charging load forecasting mainly predicts the charging load in the future 6h-48h period, which is a key research area for the orderly charging of electric vehicles. Commonly used methods for short-term charging load forecasting can be divided into two categories: forecasting methods based on statistical models and forecasting methods based on machine learning.

Among them, the electric vehicle charging load based on statistical models mainly include Markov transition models, linear regression analysis methods, autoregressive integrated moving average methods, and so on [8][9]. With the maturity and popularization of machine learning methods, more machine learning methods are applied to short-term charging load forecasting of electric vehicles, mainly including artificial neural networks (ANN), support vector machines (SVM), and deep learning methods [10][11].

3.3 The smart orderly charging control strategy

According to different control methods, the orderly charging strategy of EVs can be divided into three types: centralized control, distributed control, and hierarchical control.

(1) Centralized control: After the general control center collects and analyzes all-electric vehicle information, the unified charging plan is formulated for all-electric vehicles [12]. This control mode has simple control ideas and high control concentration. However, as the scale of electric vehicles continues to expand, the data processing and solving capabilities of the control center are significantly reduced.

(2) Distributed control: Each electric vehicle is an independent control decision-maker. After the electric vehicle obtains the price, voltage, frequency, and other signals from the power grid, it formulates a charging and discharging plan according to its situation [13]. The electric vehicle is fed back to the control center for correction. This control mode can avoid a lot of calculations and quickly formulate a car charging control plan, but the iterative calculation may not converge.

(3) Hierarchical control: Integrating the characteristics of centralized and distributed control, dividing electric vehicles into several clusters. Each cluster is managed by an aggregator centrally, and the grid control center only needs to coordinate and control the aggregator [14]. This control mode retains the advantages of centralized control while reducing the scale of data to be solved, reducing the computational difficulty of the grid control center.

3.4 Solutions to the problem of smart orderly charging of electric vehicles

At present, domestic and foreign scholars have begun to pay attention to the issue of smart orderly charging of electric vehicles. And most of the optimization goals are to minimize user charging costs and minimize grid load fluctuations. Solving algorithms mostly focus on genetic algorithms and so on. This paper

Talbe 3 Optimization solution of smart orderly charging for EV

Reference	Objective	Restraint	Solution
Tong et al.(2016)	Minimize users' charging cost and difference of charge load	Maximum charging power of charger	NSGA-II
Zhou(2019)	Minimize users' charging cost and difference of charge load	Charging demand and time	Multi-objective genetic algorithm, fuzzy theory
Tao, Y et al.(2019)	Minimize difference of charge load, Maximize charging capacity	Battery SOC, charging demand and time	Genetic Algorithm
Li(2020)	Minimize users' charge cost and difference of charge load	Charging time, transformer capacity, EV charging power, battery SOC	Genetic Algorithm
Han, X et al.(2020)	Minimize users' charge cost, difference of charge load and renewable energy consumption	Lower and upper limits of charger power、battery SOC	Genetic Algorithm

briefly summarizes recent related research [15-19], as shown in Table 3.

4. INCENTIVE MEASURES FOR SMART ORDERLY CHARGING OF ELECTRIC VEHICLES BASED ON DEMAND-SIDE MANAGEMENT

To make the business promotion measures of smart orderly charging of electric vehicles more efficient, it can start from the economic, technical, and other aspects. Among them, economic incentives can be implemented for participants. Users who participate in smart orderly charging can be subsidized according to the degree of overlap between the user's participation in the scheduling period and the planned scheduling period, the proportion of users' participation in scheduling in the planned electricity consumption, and the proportion of users' participation in the load schedule. And the application of new technologies in the field of smart orderly charging also promotes the effect of implementation. According to the grid charging plan and renewable energy consumption, the number of rewards for smart orderly charging is calculated. It is also possible to record the charging location, charging duration, and charging capacity of users participating in smart orderly charging on the blockchain. And smart contract technology can be applied to automatically match transactions, and allocate rewards based on the user's contribution value. Besides， to further increase the attraction of smart orderly charging, user value-added services can be provided. For example, electric vehicle charging management services can be provided for users participating in smart and orderly charging. Because electric vehicle health and safety charging management technology can effectively reduce the occurrence of charging accidents and extend the service life of the battery. Of course, there are still many value-added services that need to be further explored. And it can expand the smart orderly charging business of electric vehicles from public transportation, as well as special purpose vehicles such as rental, sanitation, and logistics. Through the demonstration effect formed, private electric vehicle users are aware of the benefits of smart orderly charging.

5. CONCLUSION

Smart orderly charging of electric vehicles is an effective means to improve economic and environmental benefits. Therefore, this paper analyzes the concept of smart orderly charging of electric vehicles, the background, and the significance of its development. The increase in the number of electric vehicles and renewable energy generation makes smart orderly charging more urgent. Compared with the current disorderly charging of electric vehicles, smart orderly charging has the advantages of reducing charging costs, helping the grid to cut peaks and fill valleys, and promote the consumption of renewable energy, etc. Besides, the experience of various countries and various companies in the field of smart orderly charging of electric vehicles is discussed. After years of attempts, charging standards, technical tests, and business models are constantly evolving. The car network collaboration covers all application scenarios, and the test scale is gradually expanding. This is an important attempt for demand-side management of electric vehicle charging.

According to feasibility and dispatchability, the types of users participating in the smart orderly charging of electric vehicles include private electric vehicles, bus passenger electric vehicles, and various types of electric vehicles for special purposes. And they are characterized by private charging piles, charging piles, high-intensity operation, and strong operation regularity. Besides， according to the situation of technological development, concept change, and participants, the smart orderly charging model is divided into two stages: namely, the charging of electric vehicles is completed in an orderly manner by adjusting the charging power or time; As a distributed energy storage facility, electric vehicles can not only charge from the grid but also discharge the grid. The V2G model realizes the two-way interaction between the power grid and electric vehicle users. In addition to reducing the electricity cost of users, the V2G model is more conducive to keeping the load on the grid stable and promoting the consumption of renewable energy.

Electric vehicle charging load forecasting is a critical link in the design of power supply schemes. And judging the factors that affect the charging of electric vehicles is the basis for accurately predicting the charging load of electric vehicles. The factors that affect electric vehicle charging are divided into user behavior, charging mode, battery characteristics, demographics, and social attributes, etc. With the diversification of modern power grid systems and the large-scale promotion and application of electric vehicles, the accuracy and effectiveness of load forecasting need to be improved. However, charging load forecasting methods based on traditional statistical models cannot provide a forecasting model with sufficient forecasting accuracy. Therefore, prediction methods based on machine learning came into being. Besides, the analysis shows that the hierarchical control mode of electric vehicles retains the advantages of centralized control while reducing the scale of data to be solved, and reducing the computational difficulty of the grid control center. And the optimization goal of the intelligent orderly charging problem is mainly to minimize the user's charging cost and minimize the fluctuation of the grid load. Solving algorithms mostly focus on genetic algorithms and so on.

Smart orderly charging incentive measures for electric vehicles based on demand-side management can start with the application of new technologies, economic rewards, and user value-added services. Demand-side management is a brand-new perspective of electric vehicle charging research. Because more scholars study the charging problem of electric vehicles from the supply side. Therefore, this paper hopes to cause scholars to pay more attention to the problem of smart orderly charging based on demand-side management. And we can also explore the way to achieve smart orderly charging by breaking through the routine. In addition to the basic scheduling model, we can study the recommendation model. That is, the charging plan is actively broadcast to the electric vehicle users to match the charging demand. This is also a promising research direction.

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