A Summary of Research on Wide-area Distributed Electric Vehicle and Grid Interaction Technology

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Abstract: Electric vehicle charging behavior and grid interaction technology, including the impact assessment of electric vehicles for distribution networks and the planning and operation optimization of electric vehicles connected to the grid. Specifically, the main contents include: researching the agglomeration characteristics of large-scale electric vehicle charging behavior based on statistical data and charging history data, and evaluating the regulatory potential of large-scale electric vehicles; wide-area coordination strategy and station-level and regional-level orderly charging. The interaction mode and architecture, the hierarchical control strategy of large-scale electric vehicle charging behavior and grid interaction.

1. INTRODUCTION
With the promotion and popularization of electric vehicles, electric vehicles are moving towards the interactive development of charging and replacing services. In the case of increasing peak-to-valley difference of electric load, the large-scale commercial charging of electric vehicles will increase the power supply voltage to the power system. In the case of disorderly charging, a large number of electric vehicle charging will increase the local power grid. There are problems such as voltage drop and branch capacity mismatch. The development and application of electric vehicle and grid interaction technology to achieve the orderly charging of large-scale electric vehicles are important means to solve the above problems. In addition, the energy storage function of the electric vehicle battery allows it to participate in the operation of the power system as a distributed power source. Especially with the development and maturity of electric vehicle access technology, electric vehicles can completely feed their residual energy back into the power system when conditions permit, and provide auxiliary services such as peak clipping, frequency modulation, and rotation backup to the power system. And through the optimal scheduling of the power system, the benign energy interaction with the power grid is realized, thereby exerting its role in cutting peaks and valleys, reducing network losses, optimizing power flow, and stabilizing renewable energy fluctuations. In summary, the wide access problem of electric vehicles to the power grid is a major challenge to promote the development of China’s electric vehicle industry and smart grid in a rational, scientific and orderly manner, and systematically develop basic theories and core technologies for the wide random access problem of electric vehicles. It is conducive to providing basic environmental support for the wide random access of electric vehicles, promoting the large-scale development of electric vehicles in China and the flexible consumption of a large number of distributed renewable energy.
2. AGGLOMERATION CHARACTERISTICS OF ELECTRIC VEHICLE CHARGING BEHAVIO

The spatio-temporal distribution characteristics of electric vehicle charging load are closely related to the driving and parking behavior of electric vehicle users. At present, the research on the space-time distribution of charging load is mainly based on the investigation of the driving behavior of electric vehicles and the statistical results of the traditional fuel vehicle operating rules. For example, in the literature [1], the driving, parking and charging behaviors of electric vehicle users are studied through tracking investigations of multiple electric vehicle users. The literature [2] uses the GPS installed on 76 users to record the parameters such as the user's departure time, home time and driving distance, and proposes a charging load calculation method based on conditional probability.

Domestic and foreign research includes the impact of charging and replacing facilities on the power grid, orderly charging, and the interaction of electric vehicles and power grids (V2G) [3-7]. The impact of charging and replacing facilities on the power grid mainly studies the distribution characteristics of charging load, the harmonic characteristics of charging equipment and the charging behavior of electric vehicles on grid load balancing, power supply capacity, power quality and environment [8-11]. Ordered charging mainly studies the optimization strategy of electric vehicle charging, reduces the impact of large-scale random disordered charging on the power grid, and improves the load characteristics of the regional power grid. The interaction between electric vehicles and the power grid mainly studies the two-way interaction and exchange between the energy of electric vehicles and the power grid under controlled conditions, and uses the charging and discharging of batteries to cut peaks and fill valleys, improve the power supply capacity of the power grid, and maximize the existing power grid. The role of equipment and power resources.

In the research field related to electric vehicles accessing the power grid, it is a hot spot in foreign academic research and industry in recent years. Some researcher has been carried out on the load characteristics of large-scale electric vehicles connected to the power grid and their impact on the power grid, and some research results have been achieved. It is worth noting that foreign electric vehicles have not yet developed on a large scale, and most of the research is also forward-looking. In addition, the foreign power system, power grid structure, living environment, and driving behavior are very different from those in China. Many research methods and conclusions cannot be directly used for reference.

3. AGGLOMERATION CHARACTERISTICS OF ELECTRIC VEHICLE CHARGING BEHAVIOR

Electric cars can be seen as a moving load. In order to obtain the spatial distribution of electric vehicle demand, on the one hand, it is necessary to know the location of the electric vehicle, and on the other hand, it is necessary to know the charging load at each position. The current research analyzes the travel characteristics of household electric passenger cars and electric taxis, and proposes a suitable method to establish a traffic travel prediction model to obtain the spatial distribution of electric vehicle electricity demand; combined with charging mode and charging load (or Analysis of charging characteristics such as electricity), and a model for the demand for electricity in electric vehicles. Finally, the above two models are integrated to form a spatial distribution prediction method for the electricity demand of electric vehicles. The overall idea is shown in Figure 1.
Figure 1. The general idea of the spatial distribution prediction method for electric vehicle electricity demand

The main application scenarios of current electric vehicles are family passenger cars and taxis, and family passenger cars are generally used for commuting, shopping, and short trips. Although the daily driving is random, it has a certain regularity. The taxi’s travel characteristics are quite different from those of the family passenger car, and it has greater randomness. Considering the large differences in the travel characteristics of family passenger cars and taxis, they are considered separately when constructing the travel distribution prediction model and the electricity demand model. The differences in household travel and rental electric vehicle travel characteristics, travel destinations, travel distances, etc. can be considered separately, and the electric vehicle travel distribution prediction model can be comprehensively constructed. At the same time, combined with the charging load of single vehicle, the charging load of multiple vehicles, the charging time, the charging duration and other factors, the household passenger car and taxi electricity demand model can be obtained, and the electric vehicle can be obtained through further calculation. The spatial distribution of the demand for electricity is used to predict the results.

4. BUSINESS MODEL FOR INTERACTION BETWEEN ELECTRIC VEHICLES AND THE GRID

Electric vehicles accept operators’ regulation and participation in vehicle-to-grid (V2G) to better cope with intermittent new energy generation, thus creating huge economic and social benefits. This V2G model needs corresponding Business model as a support.

The partners include electric vehicle users, electric vehicle operators, power grid companies, and abandoned wind farms. Electric vehicle users are free to choose to participate or not participate in this mode. When the owner chooses to participate in the V2G service, he will get a more favorable electricity price and reach the amount of charge the user needs before the user sets the termination time. If the user does not choose to participate in the V2G service, the charge and discharge charges
will be charged according to the normal electricity price. In the process of managing the electric vehicle, the operator will obtain the profit of the controllable vehicle V2G selling electricity.

Under the premise of meeting the basic agreement of electric vehicle users to accept operator regulation and the basic agreement of V2G cooperation between electric vehicle operators, grid companies and abandoned wind farms, V2G business cooperation model can benefit the four parties: for electric vehicle users Under the premise of meeting the demand of its vehicles, reduce the user's electricity consumption costs; for operators, maximize their expected benefits; for grid companies, increase the revenue from their electricity sales; for wind farms, reduce wind abandonment, increase power generation revenue [ 12].

The basic cooperative operation process is as follows:
1) The operator reports to the grid “the vehicle load in the uncontrolled situation the next day”, and the grid company formulates a daily dispatch plan to determine the output and abandonment curve of each wind farm.
2) According to the abandonment curve and electric vehicle charging demand, the operator will formulate a new charging and discharging plan with the goal of minimizing abandonment of wind and report it;
3) The next day, the grid company calculates the amount of abandoned wind power that is reduced due to the regulation of charging and discharging of electric vehicles. The parties share the proceeds according to the agreement.

5. ORDERED CHARGING STRATEGY FOR ELECTRIC BUS CHARGING STATION

In general, the charging structure of an electric vehicle charging station is such that a conventional load and an electric vehicle charging load are connected under the distribution transformer, so the charging station can predict the proportion of the normal load at all times of the day based on historical data, thereby determining the maximum allowable electric power. The time curve of the car's charging load. In practical situations, for electric vehicle charging stations equipped with distribution transformers, the conventional load is usually small and can be neglected.

At home and abroad, we have conducted in-depth research on the orderly charging of electric vehicles and published a lot of results. Limited by many aspects such as policies, standards and market mechanisms, most of the theoretical research results of orderly charging are difficult to be practical. There are many studies on the orderly charging of private cars in foreign countries, but they are quite different from the actual situation in China. China has invested a large number of electric vehicles in public transportation, and its operation in the form of a fleet is conducive to the implementation of orderly charging. Studying the orderly charging strategy of electric bus fast charging station has certain theoretical significance and relatively good practical value.

The electric bus fast charging station has a certain flexibility because the stopping time is longer than the actual charging time required and the nighttime is long. With the goal of minimizing the charging cost of the electric bus fast charging station, to meet the charging requirements of the electric bus and the non-overload of the distribution transformer, a mathematical model for the orderly charging of the electric bus in the fast charging station is established to ensure the normal operation of the vehicle. Under the premise, by autonomously responding to the grid time-of-use electricity price, that is, the orderly charging control method that fully utilizes the evening valley electricity charging period can significantly reduce the charging cost of the charging station operation and reduce the operating cost of the entire bus system, thereby bringing economic benefits.

6. ORDERED CHARGING HIERARCHICAL CONTROL STRATEGY FOR ELECTRIC VEHICLES

In the actual application, the ordered charging control in a single station still has certain defects. From the control effect, the orderly charging control method in the charging station may only consider the charging demand of the users in the station, which may cause the electricity price to be low (such as at night). A charging peak; from the control method, some studies use a mixed integer programming
In the model, the solution depends on a more complex algorithm package, in actual operation, the scene may not have the environment to call the algorithm package. Aiming at the above problems, a large-scale electric vehicle charging station can be realized by an orderly charging control method based on a hierarchical control strategy, optimizing the total charging power of the charging station in the upper layer, and then performing a hierarchical coordination strategy for distribution in the lower layer.

To solve these issues, a large-scale charging station can be realized through an orderly charging control method based on a hierarchical control strategy. The control strategy involves coordinating charging in the upper layer and performing a hierarchical coordination strategy for distribution in the lower layer.

The concept of hierarchical control is to divide control objects into different levels, and each level conducts control activities relatively independently on the basis of obeying the overall goal. Literature [13] proposes an orderly charging hierarchical control strategy for electric vehicles with good scalability. The model framework is divided into three levels: the main control center, the local control center, and the electric vehicle. The main control center obtains the relevant constraints of electric vehicles and new energy power generation, establishes a two-stage optimization model with the goal of cutting peaks and valleys, calculates the electric vehicle charging load guidance curve of each local control center and delivers them; each local control center according to the actual situation selects a centralized or distributed control method to achieve the electric vehicle charging load following guidance curve. The layered control algorithm has good scalability, and can adapt a variety of different electric vehicle load following strategies according to local conditions, achieving the load following target of the local control center and the peaking and filling target of the main control center.

7. CONCLUSION

With the popularity and development of electric vehicles, the interaction between electric vehicles and the power grid has been increasing. By studying the agglomeration characteristics of the charging and discharging behavior of electric vehicles in wide-area distribution, this paper analyzes the impact of a large number of electric vehicles on the safe and stable operation of power systems, and forms an optimal scheduling scheme for charging and discharging electric vehicles. At the same time, it applies new information communication technologies and interactive technologies. The fast and effective calculation method realizes the coordinated and orderly control of electric vehicle charging and discharging of electric vehicles, which is of great significance for the development and application of electric vehicle and grid interaction technology.

Figure 2. Layered control model three-tier architecture
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