Evaluation and analysis of electric vehicle's ability to participate in power grid interaction

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Abstract. As an important part of energy Internet carrier, electric vehicles can participate in many interactions with power grid. Firstly, this paper defines the positioning of electric vehicles in the power market. Based on the natural characteristics of electric vehicles, the constraints of disordered charging mode, orderly charging and discharging modes of vehicle network interaction are formulated. According to the evaluation requirements of electric vehicles participating in power grid regulation, the key parameters required are analyzed, and the ideal of power grid application interaction ability is analyzed with examples of different interaction modes effect. The example shows that the implementation of interactive management of large-scale electric vehicles can effectively suppress the power grid load fluctuations, and the benefits of using electric vehicles are also very considerable.

1. Introduction

Electric vehicle has typical dual attributes of load and power supply, which plays an important role in the construction of safe, economic and environmental protection intelligent power system, and is one of the important means to solve the traffic, energy and environmental problems. As an important part of the energy Internet carrier, electric vehicles will be of great value in peak shaving and valley filling and system backup under the support of the interactive technology between electric vehicles and power grid represented by V2G [1-2].

Scholars from all over the world have conducted extensive research on the participation of electric vehicles in the electricity market. In reference [3], based on the transaction of electric auxiliary services, a method of providing reserve transaction for electric vehicles is proposed. Reference [4] analyzes the impact of electric vehicle bidding on electricity price, and constructs a two-tier bidding strategy model from the aspects of electric vehicle participating in day ahead and real-time power market. In reference [5], a charging right trading mechanism and model based on blockchain was proposed by using blockchain technology. In reference [6], a new reserve transaction model with V2G reserve service is proposed, which takes the reliability comprehensive price as the measurement index. Based on the charging characteristics of electric vehicles, reference [7] proposed a real-time unified transaction model of electric vehicles combined with day ahead. In reference [8-9], considering the V2G characteristics of electric vehicles, a multi-objective power grid transaction under the scenario of electric vehicle connection is proposed. Reference [10] proposed the concept of electric vehicle networking and electric energy two-way transmission, on which the United States built a demonstration project. Based on the current situation of power supply and demand in Pais, Australia, reference [11] studied the impact of large-scale electric vehicle connection on transmission lines.
Firstly, this paper defines the positioning of electric vehicles in the power market. Based on the natural characteristics of electric vehicles, the constraints of disordered charging mode, orderly charging and discharging modes of vehicle network interaction are formulated. According to the evaluation requirements of electric vehicles participating in power grid regulation, the key parameters required are analyzed, and the ideal of power grid application interaction ability is analyzed with examples of different interaction modes effect. The example shows that the implementation of interactive management of large-scale electric vehicles can effectively suppress the power grid load fluctuations, and the benefits of using electric vehicles are also very considerable.

2. Positioning of electric vehicles in power market
The main modes of electric vehicles participating in the electricity market include direct access and indirect access. Direct access mode refers to that electric vehicles are directly connected to the large power grid in public parking lots in the form of clusters, and are directly regulated by the power grid; indirect access mode refers to the way that electric vehicles are connected through families, buildings or by the third-party integrated operators (the intermediary between vehicles and power grid, responsible for vehicle scheduling and operation management).

When electric vehicles participate in the electricity market-oriented transaction, they can give full play to the excellent characteristics of two-way power transmission: on the one hand, when the power grid is in the low load or the wind and light are about to be abandoned, low-cost electricity is adopted to encourage electric vehicles to give priority to the use of renewable energy for charging, so as to reduce the start-up and shutdown costs of conventional units in the system, and improve the level of renewable energy consumption; On the other hand, when the power grid is in the peak load, high electricity price is adopted to encourage electric vehicles to use less electricity and discharge more, so as to effectively reduce the installed capacity of the system and reduce the investment and operation cost of the power grid.

In order to promote the coordinated development of electric vehicles and renewable energy, it is necessary to make a reasonable charging and discharging sequence according to the peak valley distribution of local power grid load, the characteristics of wind and solar power generation and the travel conditions of electric vehicles, so as to promote the coordinated development of electric vehicles and renewable energy, and form a good complementary with the demand of safe and economic operation of power grid in time distribution. This can not only provide a reasonable and feasible business model for the integration of electric vehicles into the power market, improve the level of renewable energy integration, and greatly reduce carbon emissions, but also effectively improve the level of benign interaction between power grid and transportation network.

3. Interaction modes and constraints between electric vehicles and power grid
The interaction form of electric vehicle energy storage and power grid includes information and energy interaction, and the interaction mode includes three modes: orderly charging and orderly charging and discharging.

3.1. Disorder charging mode constraint set
Disordered charging mode is a plug and play charging mode. After connecting the interconnection facilities, the electric vehicle is charged according to the maximum allowable charging power $P_{v_i}^{\text{ch}, \text{max}}$, and stops after charging until the expected power is $E_{v_i}^{\text{exp}}$, and there is no discharge function. The interaction constraint set of disordered charging mode is expressed as follows: $\forall t \in [t_{v_i}^{\text{arr}}, t_{v_i}^{\text{dep}}]$.

$$0 \leq P_{v_i}^{\text{ch}} \leq \min \left\{ P_{v_i}^{\text{ch}, \text{max}}, \frac{E_{v_i}^{\text{exp}} - E_{v_i}}{\Delta t} \right\}$$

$$P_{v_i}^{\text{ch}} = 0$$
In the above formula, \( E_{vt} \) is the electric quantity of electric vehicle \( V \) at time \( t \), \( \Delta t \) is the sampling interval, and all variables in the same \( \Delta t \) remain unchanged. Equation (1) constrains the charging power when the charge is close to the upper limit of capacity, which can approximately simulate the decrease of charging power when the battery is close to the full charge stage.

### 3.2. Interactive constraint set of orderly charging mode

In the orderly charging mode, the charging time and power can be adjusted during the interconnection period, that is, the charging period and power are controllable, and only the expected power can be guaranteed when leaving without discharge function. The interactive constraint set of ordered charging mode is expressed as follows,

\[
\begin{align*}
\max \left\{ 0, \frac{E_{vt}^{\exp} - E_{vt} - P_{v_i}^{\text{max}} (t_{\text{dep}}^v - t - 1)}{\Delta t} \right\} \leq P_{v_i}^{\text{ch}} \leq \min \left\{ P_{v_i}^{\text{ch} \text{ max}}, \frac{E_{vt}^{\exp} - E_{vt}}{\Delta t} \right\} \\
P_{v_i}^{\text{dch}} = 0 \\
\left| P_{v_i}^{\text{ch}} - P_{v_i}^{\text{ch} (t-1)} \right| \leq \Delta P_{v_i}^{\text{max}} \\
E_{vt} = E_{vt (t-1)} + P_{v_i}^{\text{ch}} \Delta t
\end{align*}
\]

In the formula (5), there is a constraint that the charging power at time \( t \) should not lead to the failure to reach the expected electric quantity when charging at the maximum power from time \( (T + 1) \) to \( t_{\text{dep}}^v \) when driving away.

### 3.3. Interactive constraint set of ordered charge discharge modes

Under the orderly charging and discharging mode, the electric vehicle can not only adjust the charging power, but also discharge to the higher level power grid through interconnection facilities according to the needs, which only needs to ensure that the expected electricity quantity can be met during the departure period. After the introduction of the discharge mode, the electric vehicle parking process is equivalent to the energy storage with dynamic constraints. The ordered charge discharge interaction constraint set is expressed as follows: \( \forall t \in [t_{\text{arr}}^v, t_{\text{dep}}^v] \)

\[
\begin{align*}
\max \left\{ 0, \frac{E_{vt}^{\exp} - E_{vt} - P_{v_i}^{\text{ch} \text{ max}} (t_{\text{dep}}^v - t - 1)}{\Delta t} \right\} \leq P_{v_i}^{\text{ch}} \leq \min \left\{ P_{v_i}^{\text{ch} \text{ max}}, \frac{E_{vt}^{\exp} - E_{vt}}{\Delta t} \right\} \\
0 \leq P_{v_i}^{\text{dch}} \leq \min[P_{v_i}^{\text{dch} \text{ max}}, \max(0, \frac{E_{vt}^{\exp} - E_{vt}^{\sup}}{\Delta t})] \\
\frac{E_{vt}^{\exp} - E_{vt} - P_{v_i}^{\text{ch} \text{ max}} (t_{\text{dep}}^v - t - 1)}{\Delta t} \leq P_{v_i}^{\text{ch}} - P_{v_i}^{\text{dch}} \leq \frac{E_{vt}^{\exp} - E_{vt} + P_{v_i}^{\text{dch} \text{ max}} (t_{\text{dep}}^v - t - 1)}{\Delta t} \\
P_{v_i}^{\text{ch}} P_{v_i}^{\text{dch}} = 0
\end{align*}
\]
According to the estimation of China Electric Power Enterprises Federation, the total installed capacity is expected to be 3 billion kwh by 2030. It is expected that the total electricity consumption of the whole society in 2030 will reach 10 trillion kwh without considering electric vehicles. The average value in a single day is 27.40twh, The approximate estimation of the maximum power consumption load of regional power grids in 2030 is shown in the table below.

Table 1. Estimation of maximum power load and electric vehicle spatial distribution in different regional power grids in 2030

| Region       | North China | East China | Central China | Northeast | Northwest | South | Sum  |
|--------------|-------------|------------|---------------|-----------|-----------|-------|------|
| EV           | 1811        | 1722       | 2033          | 525       | 433       | 1476  | 8000 |
| Maximum load | 288         | 305        | 172           | 55        | 115       | 265   | 1200 |

Taking the above-mentioned load estimation of electric vehicles and power grid in 2030 as an example, the performance of energy storage of electric vehicles as peak shaving resources is quantitatively analyzed to reduce the load peak valley difference. Under the disordered charging mode, affected by the travel characteristics of vehicle owners, the disordered charging load will obviously gather after the morning and evening travel peak hours, and will have a superposition effect with the grid load in the corresponding period. It can be observed in Figure 1 that the peak load will shift from 1200gw at 10:30h in the conventional load curve to 21:1 in the load with disordered charging -1345gw for 5h, the peak value increased by 12%. Considering that the load valley value only increased from 1061 GW to 1096 GW, the peak valley difference further increased from 139gw to 249gw.

Figure 1. Load curve and energy storage call power of electric vehicle under orderly charging mode

The orderly charge discharge mode has stronger peak regulation ability, and with more significant load peak valley transfer phenomenon, it can bring more smooth load curve. According to Fig. 2, the peak load of the grid with sequential charging and discharging load further decreased by 1210 GW, which was significantly lower than that of disordered charging and orderly charging mode, and only increased by 0.8% compared with the peak value of conventional load. From 10:30h to 11:00h, it can be observed that the total load under the orderly charging and discharging mode is lower than the original conventional load, which indicates that the total discharge power may be greater than the total...
charging power after the introduction of the discharge regulation of electric vehicles. At the same time, the load valley value further increased to 1169gw, and the peak valley difference further decreased to 41gw. Even in the conventional load curve without considering the electric vehicle, the peak valley difference is 12% compared with the peak load, and the ratio drops to only about 3%. Therefore, the vehicle network interaction under the orderly charging and discharging mode can not only offset the impact of disorderly charging on the power grid, but also effectively suppress the fluctuation of the existing conventional load.

Figure 2. Load curve and energy storage call power of electric vehicle under orderly charging and discharging mode

The main factor causing the difference of the above fluctuation suppression effect lies in the upper and lower limits of the adjustable energy storage capacity of electric vehicles. Because the orderly charging and discharging behavior of electric vehicles will not affect the power demand brought by electric vehicles, the large-scale electric vehicles under the above three modes will at least cause an increase of about 2.05 TWH and 26.75 TWH in a single day, which means that electric vehicles will account for about 7.7% of the total electricity consumption of the whole society. Among them, the ordered charge discharge mode will increase about 0.016twh loss due to the influence of discharge efficiency. However, considering that the electric vehicle energy storage itself is a distributed local equipment, the power regulation provided locally will also effectively reduce the network loss. Considering that the current power grid line loss rate is generally 5% - 6%, the loss in the charge discharge conversion process can partially offset the loss caused by the power grid transmission in different places. In addition, compared with this loss, the use of electric vehicle energy storage for peak shaving and valley filling can improve unit efficiency and delay power grid investment.

5. Conclusion

As an important part of the energy Internet carrier, electric vehicles will be of great value in peak shaving and valley filling and system backup under the support of the interactive technology between electric vehicles and power grid represented by V2G. Firstly, this paper defines the positioning of electric vehicles in the power market. Based on the natural characteristics of electric vehicles, the constraints of disordered charging mode, orderly charging and discharging modes of vehicle network interaction are formulated. According to the evaluation requirements of electric vehicles participating in power grid regulation, the key parameters required are analyzed, and the ideal of power grid application interaction ability is analyzed with examples of different interaction modes effect. The example shows that the implementation of interactive management of large-scale electric vehicles can effectively suppress the power grid load fluctuations, and the benefits of using electric vehicles are also very considerable.
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