The Research on System of Charging Load Aggregator Participating in Market Transaction based on Internet of Vehicles

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Abstract. The electric vehicle market has gained rapid growth in various countries. Electric vehicles will be one of the largest loads in the future power grid. This paper sorts out the typical models of charging load aggregators' participation in ancillary services, demand response, and valley drop electricity curve tracing, and formulates the trading strategies of charging load aggregators in the electricity direct trading market, ancillary service market and electricity derivatives market. And then the strategy of aggregators participating in multi market coordination is proposed. Based on the contribution of aggregators to participate in market transactions, considering the willingness of different entities to participate in charging load aggregated transactions, a reasonable game model as well as a fair and reasonable value sharing mechanism is established to achieve the transmission of market trading dividends and promote the charging load aggregators to participate in the electricity market transactions.

1. Introduction
In recent years, the electric vehicle market has gained more rapid growth in all countries. Electric vehicles will be one of the largest loads in the future power grid. Its random and simultaneous load characteristics will inject new demand growth points into the power grid operation. With the growth of the parc, the greater the impact on the peak valley balance of the power grid \cite{1}. At the same time, electric vehicle is an important energy storage resource and technology application object of smart grid, which has a long stop time and loose demand, and is an important distributed energy storage resource of power grid. Electric vehicle energy storage has the advantages of fast response, small market impact, flexibility and no increase in transmission congestion. Through orderly charging and discharging, it can achieve the dual effect of peak shaving and valley filling \cite{2}. Therefore, the power balance pressure of power grid is significantly increased, and the traditional power grid balance regulation method based on thermal power deep peak shaving has been difficult to meet the needs of the rapid development of new energy...
in power grid. Therefore, there is an urgent need to tap the potential of flexible charging loads such as electric vehicles to participate in regulation and control, and mobilize them to actively participate in grid regulation and control operation [3-4].

The research on charging load aggregator business abroad is relatively mature. Many countries and regions have application examples of charging load aggregator. The charging load aggregator has developed from the original power purchasing agent to the demand response resource integrator providing a variety of technologies and services. In the face of the demand of load regulation capacity and demand response technology development, it is of great significance to study the charging load aggregator polymerizing the electric vehicles to participate in the market-oriented transaction and the aggregator participating in a variety of market transaction operation mechanisms as the main body of the market [5].

2. The typical models of charging load aggregators' participation in Market transaction

Typical modes of EV aggregated resources that can participate in market transactions include ancillary services, demand response, and valley drop electricity curve tracing, deviation substitution between new energy and users, etc., as shown in the table below:

| Tab. 1 Typical models of electric vehicle aggregating resources to participate in market transaction |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Model                                        | Characteristics                                | Source of Benefit                             | Applicable Conditions                          |
| Ancillary Services                           | The compensation price is high and the income is considerable | Government subsidies                           | The region with insufficient peak regulation capacity and large peak valley difference |
| Demand Response                              | Easy to start because of the market base       | Power plant allocation                        |                                                |
| Valley Drop Electricity Curve Tracing        | Change user's habit and adapt to new energy output characteristics | Price reduction of abandoned power and time-of-day tariff | The areas with a lot of new energy resources, and in which users have higher flexibility and can absorb Affluent renewable energy |
| Deviation Substitution between New Energy and Users | Restrain volatility and reduce deviation        | New energy subsidies                          |                                                |

2.1. Participation in Ancillary Services

The working mechanism of aggregators participating in the ancillary service market is as follows. First they calculate the capacity, adjustable range as well as time of the aggregated electric vehicle resources, and get the callable capacity of the aggregated resources; then quote prices in the market, sign ancillary service contracts of different time periods, adjustment capacity and price; after getting dispatching instructions, adjust the resources in real time through intelligent device control or information transmission-user response Charge and discharge to realize the control of electric vehicles to participate in ancillary services.

2.2. Participation in Demand Response

Based on the platform of Internet of vehicles, a large number of electric vehicle resources are aggregated, and the response capacity is greatly improved. Its equipment has strong control ability, high prediction technology, sufficient equipment conditions, and the response ability is also significantly improved. Therefore, the aggregation of electric vehicles in response transaction has obvious advantages. Charging load aggregators first count the load curve and predict the trend of load baseline; then determine the adjustable range of electric vehicle aggregating resources by considering the response ability of electric vehicle resources owned by aggregators; and the next one is to report the capacity and price in the market; finally, electric vehicles participate in the response through the means of intelligent operation control platform or information transmission-user response.
2.3. Valley Drop Electricity Curve Tracing
Flexible interaction between supply and demand can promote the consumption of renewable energy. The charge load aggregators aggregate the adjustable resources of electric vehicles, on the one hand, because there is the demand of electric power and on the other hand they hope to obtain more economic power supply. Tracking the low-level power abandonment can realize the electricity transaction at a relatively low price. First, the clean energy station issues the information of low-level waste power consumption demand; then the aggregators timely transfer the charging time or power of electric vehicles to complete the consumption of the power in question; finally, it will settle accounts according to different power transaction methods.

2.4. Deviation Substitution between New Energy and Users
Charging load aggregators have a large number of adjustable electric vehicle resources, which can flexibly interact with new energy stations to solve their grid connected assessment problems. On the alternative method, when the new energy station finds that the new energy output of the next node cannot reach the predicted power generation within the deviation, it will send the grid connection assessment demand to the load aggregators in time. After the aggregator receives the processing curve information of the new energy station, it will dispatch the charging and discharging of the electric vehicle resources in time, reduce the assessment deviation of the new energy station, and finally make the new energy station avoid the grid connection assessment.

3. The strategy of charging load aggregators participating in multi market transaction

3.1. Electric energy market
There are two levels of electricity purchasing market for load aggregators. In the first level market, load aggregators enter the wholesale market as agents to purchase electricity, while in the second level market, load aggregators perform agency contracts with internal entities. There is a demand for high-quality and low-cost power among the internal entities of load aggregators. However, due to the low power demand of a single internal entity, it is unable to participate in the power wholesale market, so it has no bargaining power and competitive conditions. Through the collection of a large number of internal users' demands, load aggregators form the analogous cooperation mode of power sales companies acting as large users to enter the wholesale market to participate in the quotation, so as to make professional quotation based on the familiarity with the electricity market transactions and the quite volume, strive for the price difference for the internal main body, and increase the income of load aggregators as a whole and the internal main body through a reasonable agency mode.

3.2. Electricity ancillary services market
Load aggregators aggregate electric vehicles to meet the peak shaving demand of power grid. After acting for all kinds of entities, load aggregators participate in market quotation as auxiliary service providers. After clearing by the trading center, load aggregators aggregate internal resources to follow market orders and finally participate in wholesale market settlement. Through coordinated control optimization, the impact of the grid connection of distributed resources on large power grid is reduced, the dispatching difficulty caused by the growth of distributed resources is reduced, and the stability of system operation is improved. Load aggregators earn auxiliary service income from external power grid by participating in auxiliary service, and distribute the income according to the contribution degree of internal main body.

3.3. Electricity Derivatives Market
The green certificate transaction within the charging load aggregators occurs among charging load users. The renewable energy quota will assess the power utilization of the above power users, so as to encourage users to participate in the green certificate transaction. For charging load aggregators, on the one hand, they need to establish contact with the trading center and power grid companies to measure
and calculate the total amount of renewable energy consumed by charging load users, so as to provide the basis for green certificate assessment; on the other hand, they need to innovate the operation mode and provide diversified channels to realize renewable energy distribution for users by providing diversified renewable energy consumption products.

3.4. Multi market coordination strategy
In the day ahead market, load aggregators determine the electricity declaration of the main energy market and the reserve capacity declaration of the spinning reserve market according to the forecast data. After the day ahead market is cleared, the trading electricity of the main energy market and the reserve capacity of the spinning reserve market are determined. Aggregators will get certain reduction compensation according to the contract to fulfill the reduction plan, and will pay penalty if they breach the contract. In the real-time market, load aggregators trade according to the declared capacity in the main energy market, the declared reserve capacity in the spinning reserve market, and the difference between the planned reduced capacity and the actual delivered capacity in the load reduction contract, and bear the corresponding imbalance penalty cost.

4. Multi agent value sharing mechanism under charging load aggregation based on Internet of vehicles

4.1. Multi agent benefit calculation
(1) Power grid company
\[ R_{dr} = C_c + C_e \]  
(1)
Among them, \( C_c \) and \( C_e \) represents avoidable capacity cost and avoidable electricity cost respectively; \( \Delta R_c \) is the benefit of reducing reserve capacity. The specific calculation can be seen in the following formula:
\[ C_c = P_t \times \theta \]  
(2)
\[ C_e = \Delta E \times \omega \]  
(3)
In the formula: \( \theta \) is the conversion factor of avoidable capacity cost; \( \omega \) is the conversion factor of avoidable electricity cost.

(2) Charging station / aggregators
The subsidy for charging station is calculated as follows:
\[ R_{p-v} = \begin{cases} k (L_{p-v}^0 - L_{p-v}^1), & L_{p-v}^0 \leq L_{p-v}^1 \\ 0, & L_{p-v}^0 > L_{p-v}^1 \end{cases} \]  
(4)
In the formula: \( L_{p-v}^0 \) is the peak valley difference before optimization; \( L_{p-v}^1 \) is the peak valley difference after optimization; \( k \) is the incentive coefficient and it can be set as 1.5 yuan / (kW · h).

Since the subsidy is less than the benefit of the grid due to demand response, there are the following limitations:
\[ R_{p-v} \leq R_{dr} \]  
(5)

(3) Electric vehicles
Assuming that the total daily revenue of the charging station before and after optimization is \( Y, Y^* \), the maximum value of the rebate revenue for electric vehicle users is \( R_{EV} \).
\[ R_{EV} = Y + R_{p-v} - Y^* \]  
(6)

4.2. Multi subject value sharing mechanism
In the charging service chain, the electricity used for charging electric vehicles is no different from that used by other electrical equipment. Users can charge electric vehicles according to their own wishes, which is not limited by the power generation end. When and how long users charge will have a
significant impact on the operation of power generation companies and power grid. To sum up, in the whole charging service chain, the upstream of the service chain no longer plays a leading role, while the charging behavior of users plays a greater role.

In the whole charging service chain, power flow, benefit flow and utility flow play an important role respectively. Power flow is the basis of chain connection and the link connecting the whole charging service chain; interest flow is the transaction mode between the two neighboring parties, utility flow is the influence and function formed between the participants, utility flow is the way of bargaining between the demand side and the power supply side, and interest flow is the key to coordinate the whole service chain. From this, we can get the whole binding framework of charging service stakeholders, as shown in Fig.1.

Under the direct charging mode, the generator first quotes, the grid side sets the time-of-day tariff to guide the users to charge orderly, the operators charge reasonable charging service fees, and the users change their behavior according to the time-of-day tariff and implement the orderly charging strategy. The optimized charging load helps to balance the load fluctuation and improve the construction delay benefit of the power generation end, so as to reduce the on-grid electricity price. The linked electricity price affects the user behavior again, and finally realizes the balance of the whole price chain through many layers of game and multiple linkage.

In the charging service chain, the generation side puts forward the on-grid price based on the comprehensive generation cost. On this basis, the grid side formulates the sales price considering the reasonable benefits. The time-of-day tariff transmits the price downward. Finally, the demand side adjusts the behavior according to the time-of-day tariff. The newly generated charging behavior will transfer the utility flow to the upstream of the service chain. The power generation side will reverify the generation on-grid price according to the utility impact, and then transfer it to the power grid side to revise the sales price. The charging behavior based on the new price will act on the power generation side again, and the whole service chain will cycle, forming a dynamic repeated game, and finally reaching the balance of interests. The process is shown in Fig. 2.
Initial state

The generation side puts forward the grid price

Put forward the sales price on the grid side

Charging operators propose service price

Users change charging behavior according to electricity price

Total power load after optimization

Can the generation side be optimized on grid tariff

Yes

No

Achieve the balance of interest chain

Fig. 2 Interest chain coordination optimization route

The economic compensation of the power grid will first act on the charging operators, and then the operators will transfer the incentive to form the price transmission.

5. Conclusion
Based on the operation mode of charging load aggregators, this paper formulates the trading strategies for charging load aggregators to participate in the power direct trading market, auxiliary service market, green certificate trading market, carbon emission rights and other markets. Then, based on the contribution of each subject of charging load aggregator participating in market transaction, considering the willingness of different subjects to participate in charging load aggregation transaction, a reasonable game model as well as a fair and reasonable value sharing mechanism is established, and it will realize the transmission of market transaction dividend.

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References
[1] Peng, J., Huang, H., Liu, F.C., Zheng, J.J., Li, Z.X. (2020) Research on orderly charging and discharging strategy of electric vehicle based on V2G technology, Electrical automation, 42: 12-15.
[2] Tao, L., L.J., Z, J.Y., Zhang, L. (2020) Load Aggregator Purchase Optimization Strategy Considering Renewable Energy Quota. E3S Web of Conferences.
[3] Liu, D.N., Wang, M.B., Li, G.Z., Zhang, T., Lu, Y.P., Chen, Y.Y. (2019) The research on the business operation mode of electric vehicle participating in the power market. Global energy Internet, 2: 516-524.

[4] Chen, Q.G., Wang, B.C., Ding, W.J. (2019) Participation mechanism and value analysis of aggregators in power market. In: Power market professional committee of China Society of Electrical Engineering, Shanghai.

[5] Lv, J.B., Song, H., Liu, Y., Li, G.D., Liu, C.H., Xu, Y.M. (2018) Research on influence of electric vehicle charging on voltage quality of distribution network. Electrical measurement and instrument, 55: 33-40.