Research on Virtual Power Plant’s Participation in Power Market under the Background of Energy Internet in China

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Abstract: Under the background of energy internet, a large influx of market entities participates in the interaction of "source network and load storage" and becomes an important resource for system regulation through the electricity marketization. Among them, the virtual power plant involves several market participators such as the distributed generation, demand side adjustable resources, distributed energy storage. The research of the operation mechanism and market-oriented trading organization for the virtual power plant becomes a popular topic in recent years. This paper proposes a novel mechanism for virtual power plants to participate in the electricity trading market, including the trading categories and auxiliary service which can be provided by the virtual power plant.

1. Introduction

With the increasing penetration of the distributed renewable energy and energy storage, the demand-side management and virtual power plant (VPP) have become key factors for energy internet construction.

Relying on the development of modern information communication and advanced intelligent technology, the VPP can integrate the distributed power, energy storage, controllable load, etc as an entire portfolio to participate in the power market and grid dispatch operations. Meanwhile, the VPP also provides the peak curtailment service, frequency modulation, emergency control and other auxiliary services to the system[1-3].

In addition, with the continually deeper reformation of the Chinese energy market, a significant progress can be seen in the present market, where the medium- and long-term transactions are the mainstay, spot transactions has already established, and the auxiliary services and capacity cost recovery mechanisms are gradually being impeccable. VPPs can provide effective ways for users and distributed energy market entities to participate in the power market [4-7], thereby promoting the diversified development of the power market.
2. Analysis of virtual power plants participating in various market transactions

2.1. Virtual power plants can participate in electricity market and regulatory market.

2.1.1. The electricity markets
The main objective for virtual power plant participating in the electricity market is to fulfill the basic power generation obligation to meet the electricity demand. In other words, the virtual power plant, equivalently, undertakes the responsibilities of both a power generator and an aggregator who organizes the transactions among various energy resources in the electricity market.

The objective of VPP is to relieve the grid pressure during the peak time by smartly distributing the individual decentralized generation units. A virtual power plant aggregates the power from decentralized mid-scale power generation units, such as wind turbines, solar energy, the Combined Heat and Power (CHP), storage systems as well as the flexible consumers. All the decentralized generation units are interconnected and dispatched through the central control of the virtual power plant, meanwhile, remain independent in their own operation. However, please note that the virtual power plant does not have to trades as an agent for the aggregated resources mandatorily in the market. Those distribution resources can organize their own transactions by themselves or through other energy aggregators.

Virtual power plants can participate in medium and long-term bilateral transactions, medium- and long-term concentrated markets, power generation rights markets, day-ahead and intra-day spot markets.

2.1.2. The regulatory market
Participating in the regulatory market is a necessary way for the virtual power plant to aggregate various energy resources and to provide balancing services or offer their flexibility for the power exchanges. The regulation market which virtual power plants can participate in includes auxiliary services, capacity markets, and real-time balance markets. Besides the revenues from the generation part, the resources aggregated by the virtual power plant can be rewarded according to their adjustment speed for demand response, capacity scales and other technical support services in the market.

2.1.3. Market participation conditions
There are three crucial factors deciding whether the VPP can participate into the power market transactions or not.

The first factor is the progress of market construction. For example, due to the absent of the spot market or auxiliary services market in some provinces, the development of the virtual power plant would be limited in the market naturally. The second factor is related to whether the relevant market rules allowing the virtual power plants to participate as market players or not. For example, according to the latest ancillary service regulations launched by the Jibei Energy Regulator, independent ancillary service providers (including virtual power plants) can join the market as market participants. The third one is related to whether the characteristics of a VPP can meet the market accessing requirements (such as the capacity scale requirement and regulation performance and so on) or not. Using Zhejiang province as an example, the capacity market in Zhejiang requires the market players can respond and adjust in 10 to 30 minutes to meet the system requirements.

2.2. The designs for virtual power plants to participate in the electricity market by stages
It is recommended that virtual power plants mainly participate in power regulation market transactions. In the near future, VPPs can gradually participate in medium and long-term markets, spot markets and other power markets and auxiliary service markets with higher technical requirements, as shown in the following table 1:

| Market trading categories | Advantages introduced by Virtual power plant participation |
|---------------------------|----------------------------------------------------------|

Table 1: Suggestions of each development stage for the virtual power plants participation in the electricity market
In the near future, VPPs in China are allowed to participate in the regulated power market. It mainly joins in the real-time balance market and deep peak shaving market. However, due to the higher technical requirements for participants in other auxiliary services, such as frequency modulation and voltage regulation, VPPs do not have these capabilities in China energy market at present stage. Among them, the deep peak shaving means that the system needs to reduce the output from other generation units (such as heating units) to ensure the market share of the renewable energy generation. For the conventional thermal power plants, reducing output means uneconomical operation and growth of operating costs. Therefore, the certain incentives are needed to encourage generators to participate in deep peak shaving. Peak shaving auxiliary service is a kind of a market-based mechanism which rewards generators participating in deep peak shaving.

In the peak shaving ancillary service market, the VPPs with flexible load can reduce the demand, which is equivalent to adding power into the system. The VPPs with energy storage can be charged and discharged on demand, which is equivalent to adding load or generation into the system.

### 3.1. Ways of VPPs to participate in the regulated power market

There are two ways to participate in peak-shaving auxiliary services for VPPs. The first way is to conduct a centralized bidding on a trading platform which contains the peak-shaving auxiliary service provided by thermal power plants. The biddings will be sorted in a descending order, and the
compensation will be given according to the final market clearing price. The second method is to sign a long-term peak-shaving auxiliary service contract with dispatching agencies. The VPPs will compete with the conventional thermal power plants in the peak-shaving auxiliary service market. It is actually a competition between the actual operation cost of VPPs and the extra fuel-cost of thermal power plants for peak-shaving service.

3.2. Ancillary service market price mechanism

3.2.1. Bidding models
To analysis the competitive relationship between virtual power plants and traditional thermal power plants in ancillary services, the marginal competitive advantages for VPPs depends on the comparison between the increased fuel-cost of thermal power plants (peak-shaving service may needs thermal power plants to reduce generation output which increasing their marginal cost) and the subsidies the VPPs need to pay for the participating energy resources.

There are two recommended bidding models between virtual power plants and traditional thermal power plants:

- **The equal competition model**: VPPs and traditional thermal power plants participate and bid in the ancillary service market equally. The VPP’s declaration may be completed, or it may not be completed because of the lack of price advantage.

- **The virtual power plant priority model**: VPPs would have a relatively high priority in this kind of auxiliary service market model. For example, VPP can apply for the peak-shaving service without declaring a price. All volume of electricity provided by the VPPs would be cleared with the final clearing price.

3.2.2. Source of funds
Currently, the ancillary service market is a unilateral market, where the market entities (such as the generators, independent ancillary service providers) can declare in the market but the transaction and dispatching are done by the system. Moreover, there are two types of cost allocation methods for ancillary services, which are:

- **Type I**: Allocating costs to the generators who are not providing the ancillary services (including the thermal power plant and the renewable energy generators) based on the ancillary service rules.

- **Type II**: Setting up balancing accounts for every generator and the profit and cost will be allocated by the provincial grid companies or power exchange center.

In the future stage, the inventive mechanisms and cost-allocation mechanisms will cover more market entities in the ancillary service market. Especially after the establishment of a complete price transmission mechanism and cost-sharing mechanism, more and more customers would participate in the ancillary service market to bear the entire service costs.

4. Medium and long term
In the future, the market transactions which VPPs can participate in will include medium- and long-term power contracts, power generation rights (contract transfer) transactions, spot market and more complex ancillary service markets.

4.1. Medium- and long-term electricity market
The way of VPPs participate in the medium- and long-term electricity market is similar to that of generators, large energy customers, and suppliers. The electricity trading contracts are formed through centralized or bilateral way to meet the electricity demand in medium- and long-term markets. As a market entity, VPPs participate in the medium and long-term electricity market with the following characteristics:

In terms of medium and long-term transactions, by comparing with other market entities, VPPs have four main advantages in the medium and long-term market. Firstly, VPPs can form partial transactions
among themselves before participating in the medium and long-term market; Secondly, after the resource aggregation by the VPP, the uncertainty can be reduced to a certain extent, which thereby further reducing the conservativeness of the VPP in the market; Thirdly, the adjustment capability of VPPs can make execution deviations smaller. Fourthly, compared with other market entities, VPPs have more flexibility in arranging the units start and stop and output, and VPPs are easier for the spot market trading and settlement.

4.2. generation rights transactions,
In terms of power generation rights transactions: the power generation rights transactions, the power generation right transferor purchases electricity from the power generation right transferee. The coal-fired power plant that transfers the power generation right is the seller, and the virtual power plant that is the transferee is the purchaser. The transaction between the seller and the seller is the transaction power of the virtual power plant. If the thermal power plant sells power generation rights at price A, the transfer price of power generation rights is B, the purchase price for the VPP is C and the power generation cost for VPP is D, then, the conditions for transaction and power execution are: A>B+C and C>D. Compared with centralized renewable generator, VPPs have lower uncertainty and adjustment capabilities, so they have the advantage of transaction time.

4.3. spot electricity market
VPPs participate in the spot market as same way as other market entities. They can adjust their declared electricity and acceptable prices based on price expectations when applying. However, compared with traditional market entities, VPPs have stronger adjustment capabilities.

The role of VPPs in the spot market is either as a purchaser or as a seller (similar to power generation companies). Since VPPs have the ability to control various constraints and can adjust the performance of their aggregated resources, VPPs have more reasonable and optimized bidding strategies. Additionally, VPPs also have the ability to control generation and the fine-tuning of consumption which make it more flexible than other traditional market players in risks avoidance and benefits gaining in the spot market.

If the VPP predicts that the spot market price will be higher in a certain time period, the VPP will provide good internal adjustment compensation prices to attract its aggregated resources to increase power generation (power-based virtual power plants). Thereby, the volume of declared power generation will be increase and the electricity demand (virtual power plant dominated by electricity users) will be reduced, finally reducing the declared electricity consumption.

On the contrary, if the price forecasting shows that the spot market price will be lower than average level in a near certain time period, the VPP will adjust the compensation price internally to attract its aggregated resources to reduce power generation, thereby reducing the declared power generation or increasing the electricity demand. Finally, the VPP can increase their declared electricity consumption.

In other words, the VPP can guide its aggregated resources to transfer to a more appropriate power generation period by utilizing the price forecasting and the market signals. Assuming that the transferred power volume is $Q$, the price for generation increasing or consumption reduction period is represented by $P_1$, and $P_2$ indicates the price for generation reduction or consumption increasing period. Then, the revenue $R$ earned by the VPP from the spot market can be calculated by equation (1).

$$R = Q \times (P_1 - P_2) - Q \times P_C$$

where $P_C$ is the kilowatt-hour compensation volume which needs to be paid to the participated resources by the VPPs according to the market price or the contract.

5. Conclusion
The VPPs can participate in the market by stages gradually. In the near future, VPPs in China can mainly participate in the regulated power market which mainly includes the real-time balance market and the deep peak shaving market.
After the power market construction becomes mature which contains more varieties of market transaction and higher VPPs technical conditions, VPPs can further participate in the medium- and long-term power transactions, power generation rights (contract transfer) transactions, spot market and more complex ancillary service markets.

In regulatory market, the competition exists between the VPPs and the traditional thermal power plants. Both VPPs and thermal power plants have strong adjustment capability. Therefore, the competition is directly related to the adjustment cost which is reflected from the biddings. Hence, after VPPs occupied a certain share of the regulatory market, it will affect the peak shaving revenue of conventional thermal power plants.

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