Market Mechanism Framework Design and Prospect of Potential Business Mode Research of Virtual Power Plant for Promoting Clean Energy Development

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Abstract. With the high proportion and penetration access of clean energy to the power grid, the difficulty of clean power consumption is intensified. The emergence of virtual power plant (VPP) with significant regulatory potential provides a new path to solve the severe problem caused by the rapid development of clean energy. However, the design of VPP transaction varieties and the construction of market mode have not been maturely established at present, which is not conducive to the long-term development of VPP. First of all, this paper designed the transaction varieties that VPP can provide in the power market and ancillary service market. Secondly, the basic framework of VPP participating in market transactions under the promotion of spot market is designed. Finally, the prospects of potential business modes of VPP including providing smart energy services, providing big data value-added services, participating in carbon trading and peer-to-peer energy-trading market are explored, which can fully mobilize the enthusiasm of market participation, realize the sustainable development of VPPs and finally promote the consumption of clean energy.

1. Introduction
Under the goal of carbon peak and carbon neutral, renewable energy will embrace an explosive growth. The access of high proportion and high penetration of renewable energy on the distribution network side has exacerbated the difficulty of balancing the power of supply and demand. With the promotion of DR and VPP [1][2], numerous demand-side resources become substitute resources for available capacity, which can relieve the pressure of real-time grid dispatching by participating in frequency and peak regulation [3]. At present, the northern Hebei [4] and Shanghai [5], as pilot units of VPP market, clearly stipulate that VPPs can participate in the peak regulation market. However, the design of transaction varieties and the construction of market environment are far from mature.

At present, the research on the market mechanism and business mode design of VPP is relatively scarce. The literature [6] proposes a business mode and a typical transaction organization mode for the wholesale and retail markets of VPP, which contributes to the development of VPP in China in the context of the ubiquitous power Internet of Things. Literature [7][8] put forward suggestions related to the construction of market mechanism for the VPP participation in peak and frequency regulation services from four perspectives: market composition, market access, offer clearing, and settlement. Literature [9] presents studies on the participation ways, organizational framework, market bidding
strategy, and market game mode for demand response participation in VPPs. Based on the current level of China’s power distribution system and the relevant policies of the power system reform, literature [10] prospects the future application of VPP and provides suggestions on the critical issues.

From the existing study on VPP, it is found that the current VPP operation profit is derived from government and power company subsidies. It lacks a suitable market mechanism and a mature business mode to effectively mobilize users’ enthusiasm. The issues such as the way and process for VPPs to participate in market transactions have no practical application as a reference basis; the mechanism for VPPs to participate in supply-demand interaction in a market-oriented manner is yet to be improved.

Based on the above-mentioned problems, this paper designs the VPP market mechanism and business modes, constructs a framework of VPP participation in electric energy and ancillary service market transactions, and explores the potential business modes of VPP. Meanwhile, the market value and functions of VPP are further explored and its sustainable development by market-based means will be achieved.

2. VPP participating in electric energy market transaction

2.1. Substitute generation transaction

The transaction variety in the substitute generation transaction mode of VPP is the generation rights, in which the power plant transferring the generation right is the buyer and the VPP is the seller, and the subject matter in transaction is the trading electricity of VPP. VPP participates in generation rights trading mainly in the form of centralized bidding for generation rights trade. In the generation rights trading platform, both participants of generation rights trading declare information including pre-transaction time, transaction power and transaction price, and the power trading center will match the transaction according to a certain clearing mode. After the security check is confirmed by the power dispatching center, it will determine the final transaction of each declaration unit.

The contract energy deviation treatment is carried out by the power trading agency. The electricity that VPP cannot complete is subject to cost assessment, and the assessment cost of energy deviation in generation rights trading is calculated as formula (1).

\[ M = P_{\text{default}} \times C_{\text{price}} \times K \]  

where \( P_{\text{default}} \) is default electricity in generation rights trade, \( C_{\text{price}} \) is transaction price negotiated in generation rights trade and \( K \) is the assessment coefficient.

2.2. Direct transactions with users

Direct transaction between power users and VPPs which meet the access conditions is dominated by annual transactions and supplemented by monthly transactions, while power grid enterprises provide the prescribed transmission and distribution services. The direct transactions price is determined via the transaction mode. In bilateral transactions, it is determined by negotiation between power users and VPPs; and in other transaction modes, the transaction price is determined by the transaction results.

The contract energy deviation treatment is carried out by the power trading agency. The electricity that VPP cannot complete is subject to cost assessment, and the assessment cost of energy deviation in generation rights trading is calculated as formula (1).

3. VPP participating in ancillary services market transaction

3.1. Valley peak-regulation transaction

Due to the minimum output limit of thermal power units, its down-regulated output is insufficient during the valley load period, which leads to great difficulty in low valley peak regulation. VPP, as a special type of power plant that aggregates multiple distributed energy resources, is possible to achieve valley peak-regulation by reducing power output. Because of the low power price during the low load period, few
profits of VPP can be made during this period. Therefore, the VPPs can earn additional benefits by selling peak-regulation rights, while thermal units can avoid frequent start-stop conditions by purchasing peak-regulation rights to improve operational efficiency.

During the peak regulation period, the actual amount of peak regulation power of VPP is counted as the deep peak regulation of thermal power enterprises, while thermal power enterprises compensate VPP in accordance with the transaction result. The final compensation cost is settled as follows.

\[ M = P_{\text{actual}} \times T \times C_{\text{price}} \times K_1 \times K_2 \times K_3 \]  

(2)

where \( M \) is the final compensation cost; \( P_{\text{actual}} \) is the actual execution power; \( T \) is the duration of valley peak regulation; \( C_{\text{price}} \) is the negotiated transaction price; \( K_1 \) is the price correction coefficient considering the proportion of the actual participation amount to the contracted amount; \( K_2 \) is the price correction coefficient considering response speed; \( K_3 \) is the correction coefficient for actual participation duration.

### 3.2. Peak-regulation transaction

VPP can address power supply shortage by increasing the power output during the peak load, whereby the original users with orderly power utilization can voluntarily purchase power from VPP. In the case of power supply shortage, the allocation of peak regulation amount of VPP through administrative instructions exists the following two problems: first, it fails to ensure the optimal allocation of peak regulation amount; second, even if the efficiency of each unit can be accurately obtained, the differential allocation of power violates the fairness principle. Therefore, it is possible to establish a transaction market of peak regulation amount, in which all generating units, including VPPs, trade peak regulation amount according to certain rules.

After the deployment of VPP, it is compensated according to the actual peak regulation amount and the declared price, and the final compensation cost is settled as formula (2).

### 3.3. Frequency regulation transaction

The cost and quotations of high-quality and fast frequency regulation resources are quite high and they are not advantageous in frequency regulation service transaction. VPP can regulate frequency in various ways such as regulating air conditioning load, electric vehicle, and multi-resource integration. Therefore, VPP can be designed to participate in the mechanism of frequency regulation ancillary service transaction, which includes two transaction modes.

- **Direct purchase mode of dispatching agencies**

  Based on the determination of the frequency regulation capacity, VPP is given the status of frequency regulation generators, taking into account the capacity, rate, and precision, etc., and compensated according to the standard of the conventional generators, which is described as follows.

  \[ F = 300 \times \Delta Q_s Y \times Y \]  

  (3)

  Where \( F \) is the compensation cost, \( \Delta Q_s Y \) is actual integral power of generators, \( Y \) is the low-frequency regulation compensation standard.

- **Substitute frequency regulation ancillary service with conventional generators**

  The conventional generators purchase the frequency regulation ancillary services from VPP. The conventional generators are bundled with VPP which is assessed and compensated.

### 4. Overall framework for VPP participation in power market

The development and improvement of the power market mechanism are a long-term process, which are closely related to many factors including market maturity, resource structure, technology level, and enthusiasm of market players. The design of VPP participation in the power market mechanism is depending on the construction of the regional power market. This paper proposes that the future VPP participation in the power market mechanism can be considered in two stages, namely, the current power market and the long-term power market, as showed in Figure 1.
4.1. VPP participating in the spot market

There are two implementation scenarios of VPP participating in spot power market, respectively incentive-based and price-based scenario. And there are also two implementation scenarios of VPP participating in the spot ancillary service market, respectively in the auxiliary service market organization level and the VPP operator connected with end-user level.

4.2. VPP participation in the capacity market

In regions with more mature power markets, capacity market transactions are organized where its transactions are settled in credits. Capacity credits are fully available generating capacity, and each electricity supplier is required to fulfill capacity obligations corresponding to the sum of its end-user load. VPP participates in capacity market transactions by treating part of the adjustable load as capacity credits equivalent to generation resources.

5. VPP business mode exploration

5.1. Subordinate resources agent participation in market-based transactions

VPP can obtain benefits by providing electricity or ancillary service through subordinate resources agents and participate in power market bidding and trading as a whole. The agency modes include the in-full agency mode, the free access mode and the ancillary services agency mode. In the in-full agency mode, the distributed resource subject delivers all control to VPP, while VPP simply pays a certain fee to the distributed resource subject periodically. In the free access mode, distributed resource can freely choose whether to compete in the electricity market at a certain point in time, or whether to trade all control with
the VPP, thus approximately achieving risk aversion. In the ancillary service agent mode, VPP and distributed resources can form an ancillary service agency mode, which distributed resources automatically participate in the main energy market, but provide VPP with full control of reserve capacity.

5.2. Integrated energy services provided to subordinate resources

VPP can combine power generation and power sales, and the power generation resources under its jurisdiction can sell electricity directly to other resource entities through the way of offering cooperation, while the VPP can obtain certain revenue, to achieve a win-win situation for both supply and sales. Besides, VPP can provide a full range of intelligent energy housekeeping services, such as energy trusteeship, energy-saving diagnosis and energy consumption monitoring, to meet the needs of economic benefits and environmental protection of the resources under their jurisdiction. And through setting different service packages or centralized bidding and decentralized block-chain technology to determine user revenue distribution.

5.3. The prospect of VPP business mode

To further promote the development of VPP, new business modes should be developed, the key to which is to rely on artificial intelligence, “Internet plus” technology to provide relevant value-added services to users, and to explore and practice the business and operation modes of regional intelligence energy-using scenarios via VPP.

- Intelligent energy service mode

As Figure 3 showed, VPP operators utilize artificial intelligence algorithms to mine user data information. Hence, intelligent energy housekeeping services are provided to users. Meanwhile, VPP can fully tap the source-side characteristics of green power and the load characteristics of the user side, providing users with a channel to independently choose to use clean energy.

- Big data value-added services

As shown in Figure 4, Based on numerous power equipment measurement data, VPP can not only assess the online status of user equipment such as air conditioners, elevators, lighting and charging piles, and regulate user equipment, but also deliver suggestions on optimizing the product to provide energy-saving and efficiency for users.

- Participation in the carbon trading market

As an independent entity, VPP can participate in the carbon trading market where carbon credits will be traded in the market as a commodity. VPP can sell or buy carbon emission rights in the carbon trading market according to the relationship between their actual carbon emissions and the amount of allowances.

- Participation in the transactive energy market

The transactive mode is the basis of future distribution network operation and the main approach of new energy to be locally consumed in the future. With the introduction of transactive energy market, VPP can use market incentive rules to coordinate optimal dispatch and control the pronumers in power market through price signals to avoid centralized computing and information transaction security problems.

6. Conclusion

- On the basis of the characteristics of VPP, this paper designs the transaction varieties and corresponding trading rules that can be offered by VPP participating in power and ancillary service
market transactions, including substitute generation transactions, direct transactions with users, valley peak-regulation transactions, peak regulation transactions and frequency regulation transactions.

- Secondly, as the spot market construction process continues to advance, this paper designs a basic framework for VPPs to participate in market transactions at different stages.
- Finally, this paper explores and foresees potential business operation modes for VPPs, including the provision of intelligent energy services, value-added services equipment status big data, and participation in carbon market trading and transactive energy trading.

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