Bidding Strategy of Virtual Power Plant Participating in Electric Market based on Big Data Technology

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Abstract: In the process of information development, digitization, networking and intelligence are three parallel main lines. Digitalization lays the foundation, networking builds the platform and intelligence shows the ability, which can help human beings better understand complex things and solve difficult problems. Globally, it is becoming a trend to research and develop big data technology, use big data to promote economic development, improve social governance and improve government service. Generally speaking, people's decision-making process usually includes three basic steps: recognizing the current situation, predicting the future and choosing strategies. According to the load big data analysis of the demand side users, the deep-seated application of predicting the future and guiding practice will become the focus of development. Firstly, we introduce the existing demand response models in detail, and then a two-stage bidding strategy is proposed to predict the future and optimize the system operation in this paper. On the basis of massive data, this paper describes the demand response behavior of a large number of users, and then analyzes their bidding strategies. In the future, with the expansion of application fields, the improvement of technology and the improvement of the open mechanism of data sharing, predictive and guiding applications with greater potential value will be the focus of development.

1 INTRODUCTION

With the increasing diversification of load power consumption, the distributed resources such as virtual power plant (VPP), electric vehicles, energy storage develop rapidly. The characteristics of power demand side management resources are different and highly decentralized, which puts forward higher requirements for the comprehensive coordination and optimization technology. Nowadays with the development of big data acquisition, big data pre-processing, and big data analysis technologies, it provides more technical means for improving the collaborative optimization level of demand side resources and the implementation of collaborative optimization strategy.

In addition, the diversity of users in the characteristics of power consumption behaviour is highlighted as a large number of new loads with flexible regulation capacity connected to the system, such as electric vehicles, industrial process loads, and cloud computing loads. Highly dispersed users have different response characteristics, so it is urgent to adopt a more accurate response aggregation strategy for multi-cluster users, which aims to fully integrate all kinds of resources, give full play to the complementarity among multi cluster users, so as to better promote the resources allocation. Among them, the VPP can integrate energy storage devices in distributed energy, improve the flexibility of demand side response, and maximize revenue. Besides, flexible load can change the users' energy consumption habits through electricity price measures as an effective means to promote the consumption of new energy (Zhang, et al, 2008). It can also realize the peak shaving and valley filling of load, improve the power utilization rate and improve the whole society profit.

Demand response behaviour analysis is a key technical problem in the design of demand response mechanism and the bidding strategy of demand response system. Foreign scholars have carried out a large number of researches on demand response pricing mechanism and its optimization decision-

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making model based on the characteristics of demand response behaviour, such as demand price elasticity. The user side demand response mechanism, power consumption characteristic behaviour analysis and power big data application research in the United States are in a leading position in the world. The famous power big data application is "Los Angeles power map", which gathers the information of each block, users' personal information, power consumption information, geographic information, meteorological information and local economic information to obtain the law of user's power consumption behaviour, and the analysis aims to assist energy decision-making and investment. In 2012, the U.S. government announced the launch of the "big data research and development plan". In 2013, the Electric Power Research Institute (EPRI) launched two big data research projects: transmission and distribution network modernization demonstration projects (Catterson, 2016, Mcarthur, 2016). In the E-Energy plan of the German Federal Economic Department, two demonstration projects have applied power big data analysis to provide preliminary solutions for energy Internet technology (Wang, 2011, Wang, 2011).

For the participation of VPP in market bidding, plenty of studies have established demand response scheduling models based on price incentive information (Nguyen, 2018, Le, 2018, Wang, 2018). On the basis of considering the uncertainty of new energy output and market electricity price, literature (Chen, et al, 2018) establishes three-stage market transactions including day-ahead, day-in and real-time demand response. Literature (Xu, et al, 2019) and (Niu, 2014, Li, 2014, Wang, 2014) only consider the transactions in the power market when participating in electric market. Literature (Song, et al, 2017) and (Anvarimoghaddam, et al, 2017) established the bidding strategy of multiple VPP based on game theory. In the market bidding strategy, the VPP can not only act as the seller of energy, but also act as the buyer of energy, which fully explores the flexibility of its market traders and is conducive to the stable economic operation of the energy market. The coordinated operation of demand response in VPP can bid in different types of markets to maximize benefits. The participation of VPP in energy market bidding can give full play to the commercial value of VPP and greatly enhance the value of renewable energy resources.

To sum up, the existing research on VPP bidding strategy mainly focuses on considering the uncertainty of power demand response and renewable energy output. In terms of market bidding strategy, the impact of comprehensive demand response on market bidding is relatively small. Therefore, it is of great theoretical value and practical significance to carry out the analysis of multi-user energy and power consumption behaviour and bidding strategy modelling and analysis considering the demand response ability of users and demand response resources including VPP. Based on the above research background, it can be seen that there is an urgent need to carry out research on multi-user power consumption behaviour analysis and modelling technology, extract user power consumption behaviour characteristics based on big data technology, and formulate demand response bidding strategy model considering VPP.

Based on the above-mentioned literatures and current situation analyses, the bidding strategy of VPP has become an important problem we need to consider in electric power market. However, the theoretical model mentioned above has not been established. Therefore, it is of great significance to consider the impact of VPP and other demand side power response in the determined power grid, and then put forward the corresponding bidding strategies. The specific research contents of this paper are as follows:

1) Combined with the comprehensive demand response and VPP technology, this paper puts forward a two-stage bidding strategy to optimize the system operation. The proposed model can reduce the limitations of scattered individual load user demand response potential based on big data technology.

2) The proposed model can condense the load demand response resources of multiple users in power system, and provide important technical support for creating a flexible multi cluster user demand response system.

3) This paper considers the demand response resources including VPP to participate in the power market bidding model, which can give full play to the energy utilization potential and complementary advantages of multiple end users, and then improve the coupling degree between various user loads.

The rest part of this paper is structed as follows: Section II describes the VPP modeling. We then discuss the energy market structure in Section III. The numerical results were shown in Section IV. Section V draws the conclusion of paper.

2 VIRTUAL POWER PLANT MODELLING

2.1 Demand Response Pattern Classification

According to the Research Report of the U.S. Department of energy, the demand response in the power market can be divided into the following two types: price-based demand response and incentive-based demand response. According to the existing demand response projects and research results, the demand response types are summarized, as shown in Figure 1.

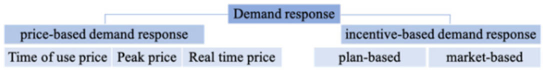

Figure 1: Different demand response types.

The first type is the price-based demand response, which mostly refers to guiding users to actively change their power consumption habits by using the price signal reflecting the situation of the electric power market, adjusting their power consumption amount, power consumption period and power consumption mode, and adjusting the power demand in the high price period to the low-price period in order to reduce the power consumption cost or exchange for economic compensation. Although Germany, the Netherlands and other regions have introduced a negative electricity price mechanism on the power sales side, generally, there is no reward and punishment mechanism for this type of demand response, and it is entirely up to users to decide whether to participate and the degree of participation. Even if they do not participate or the load reduction capacity is small, they will not be fined. At present, generally recognized electricity price mechanisms mainly include time of use electricity price, peak electricity price and real-time electricity price. The details are as follows:

2.1.1 Time of Use (TOU) Pricing Mechanism

TOU pricing mechanism is the pricing mechanism that sets different electricity prices in different time periods, dates and seasons to accurately reflect the power supply cost. Specifically, TOU includes peak/valley electricity price, high/low electricity price and seasonal electricity price according to the time period division. Generally speaking, TOU price aims to guide demand side users to reasonably arrange the working hours of electric equipment through the electricity price difference in different periods, so as to minimize the power consumption in peak load period and increase the power consumption in valley period, so as to achieve the purpose of balancing the seasonal load. TOU price first appeared in the U. S. in the 1960s, while China began to implement the peak valley TOU price mechanism since the 1980s. At present, twenty-nine provinces in China have implemented the TOU mechanism for large industrial and commercial users.

2.1.2 Peak Price Mechanism

Peak price mechanism is a dynamic pricing mechanism derived from TOU price mechanism. The key factor of the mechanism is to superimpose the peak rate which can be flexibly arranged on the TOU price and can reflect the change law of power supply cost. Generally speaking, it mainly includes two types: typical daily peak price and typical time peak price. In the United States, the promotion of peak price is far less than TOU price and real-time price. In China, only a few provinces and cities have the pilot work of peak electricity price for large industrial users, such as Beijing and Jiangsu Province.

2.1.3 Real Time Price Mechanism

Real time price mechanism is a dynamic pricing mechanism based on relatively mature power market conditions, considering operation investment, and taking the long-term marginal cost of power combined with the short-term marginal cost as the pricing basis. Specifically, the mechanism includes day-ahead and day-in real-time electricity price mechanism. The renewal cycle of real-time electricity price in the U. S., Australia and other places can reach 15 min, and some companies can even provide users with electricity price every 5 min.

To sum up, TOU and real-time price are formulated in advance, and real-time price is a linkage pricing mechanism. In addition, compared with TOU price, real-time price can not only reflect the change of long-term seasonal power supply cost of power grid, but also reflect the problem of short-term capacity shortage of power grid caused by large load fluctuation, and give the incentive signal of load reduction to users in time.

The second is incentive-based demand response. This demand response is that the regulation department or system operator adopts the price discount or direct incentive policy to guide the power demand side users to adjust the working state of power equipment in time to reduce the peak load when maintaining the normal operation of the power system. Once the user responds to such projects, it means the initiative of load control is handed over to the regulation department or system operator. This kind of demand response mainly includes two types: plan-based and market-based incentive price mechanism. Due to space constraints, detailed description and introduction will not be carried out here.

Generally, VPP includes wind power plant, energy storage equipment, electrical and thermal load. With the goal of maximizing their own interests, VPP and traditional units submit the transaction volume to the trading center. The market trading center integrates the information of all parties, determines the energy price of the next day with the goal of minimizing the energy operation and dispatching cost in the day ahead and in the day, and publishes the price information. All participants adjust their bidding volume according to the published information and report it to the market trading center again. After that, both parties adjust the bidding volume and price based on the energy balance until the transaction is completed.

2.2 Multi User Price Demand Response Potential

In this section, under the background of price-based and incentive-based demand response participating in power grid interaction, the user's response is included in power generation dispatching, and the optimal dispatching model of day-ahead price demand response and incentive demand response participating in power system optimal dispatching is explored and established. When carrying out the optimal dispatching of unit combination considering demand response, it is necessary to consider a variety of demand response implementation objectives and multiple stakeholders. Therefore, a power system optimal dispatching model based on user power consumption characteristics and social characteristics is established, and its cost-benefit is analyzed.

2.2.1 Objective Function

In the model built in this paper, the total system cost can be divided into generation side cost and demand side cost. Among them, the generation side cost includes unit operation cost and unit startup and shutdown cost, while the demand side cost includes incentive demand response cost and price demand response cost, with the minimum total cost as the objective function:

$$\min F=\min\sum_{t=1}^{T}\sum_{i=1}^{N_G}[u_{it}(a_i P_{G,it}^2+b_i P_{G,it}+ci)+SC_i u_{it}(1-u_{i,t-1})] + \sum_{t=1}^{T}\sum_{i=1}^{N_G} C_{P,t} P_{p,kt} \quad (1)$$

Where T is the time period, N_G, N_P are the number of generators and different users, u_{it} is binary variable, $P_{G,it}$, $P_{P,kt}$ are the output of generators and different users. a_i, b_i, c_i, SC_i are the cost coefficients.

2.2.2 Constraints

The system power balance constraint is as follows:

$$\sum\nolimits_{i=1}^{N_G} u_{i,t} P_{G,it} + P_{W,t} = P_{L,t} \quad (2)$$

Where $P_{L,t}$, $P_{W,t}$ are the load and wind power output in time period t. Alternate constraint is as follows:

$$\sum\nolimits_{i=1}^{N_G} u_{i,t} P_{Gmax,i} + P_{W,t} \geq P_{L,t} + R_{L,t} + R_{W,t} \quad (3)$$

Where $P_{Gmax,i}$, $P_{ILmax,j}$ are the maximum output of generator and maximum interruption of interruptible load j. The thermal power unit, wind power unit and interruptible load constraints are shown as follow.

$$u_{i,t} P_{Gmin,i} \leq P_{G,it} \leq u_{i,t} P_{Gmax,i} \quad (4)$$

$$0 \leq P_{W,t} \leq P_{Wmax,t} \quad (5)$$

Where $P_{Wmax,i,}$ is the maximum output of wind power unit. The power consumption after implementation of price-based demand response is as follows:

$$\begin{bmatrix} P_{P,k1} \\ \vdots \\ P_{P,kt} \end{bmatrix} = \begin{bmatrix} P_{0P,k1} \\ \vdots \\ P_{0P,kt} \end{bmatrix} + \begin{bmatrix} P_{0P,k1} \\ \vdots \\ P_{0P,kt} \end{bmatrix} \begin{bmatrix} \varepsilon_{11} & \cdots & \varepsilon_{1n} \\ \vdots & \ddots & \vdots \\ \varepsilon_{n1} & \cdots & \varepsilon_{nn} \end{bmatrix} \begin{bmatrix} \square C_{P,1}/C_{P,1} \\ \vdots \\ \square C_{P,t}/C_{P,t} \end{bmatrix} \quad (6)$$

Where $P_{0P,kt}$ is the electricity consumption in time period t before participating in price demand response.

3 ENERGY MARKET STRUCTURE

There are conventional units in the whole area in addition to VPP. In order to achieve the bidding goal, it is necessary to minimize the cost of the whole region. Therefore, in the regional market structure, the goal of VPP is optimized as the lower function and the minimum regional cost is optimized as the upper function. The two-stage bidding strategy flow chart of the system is shown in the Figure 2.

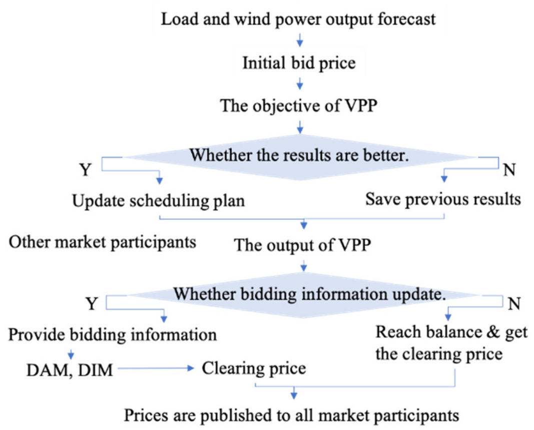

Figure 2: The two-stage bidding strategy flow chart.

In the lower-stage optimization, the VPP and conventional units are first optimized and dispatched according to the previous bidding price, and the preliminary results are obtained by maximizing the benefits of the VPP. Then the participants adjust the investment amount according to the price information and submit the results to the upper-stage dispatching. The upper-stage dispatching optimizes the market clearing price with the minimum total operation cost of the system and publishes it, Finally, the participants in the whole region are balanced.

4 CASE STUDY

The system includes one VPP, four thermal power units, six CHP units and one load aggregator. The coal price set as 600 $/t based on historical data. The installed capacity of wind turbine and energy storage equipment are 400MW and 30MWh, and the maximum charge and discharge power is 3MW according to historical numerical experience. The heat load accounts for 5% of the total heat load. The daily predicted load aggregator and heat load inside the VPP are 900MW and 40MW, respectively. Here we assume three different scenarios and the corresponding test result is shown in the following figure.

There is only one wind farm in the VPP, and the wind power output is first absorbed by the internal load. When there is still wind power that cannot be absorbed, it is sold to the market operator to meet the load demand of the external market. Because the VPP price sold to the operator is lower than that of the conventional thermal power plant, it can promote the consumption of wind power. As can be seen from Figure 3, The wind power consumed in scenario 2 is larger than that in scenario 1. The energy price in scenario 1 is the unified selling price. The wind power price is higher than that in scenario 2, and there are no bidding measures, resulting in lower wind power consumption. Due to the comprehensive demand response and energy storage, the load curve is cut peak and filled valley. The conversion of heat load to electric load also promotes the further consumption of wind power.

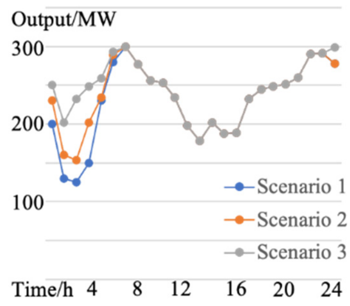

Figure 3: Wind power consumption under various scenarios.

5 CONCLUSION

Combined with the comprehensive demand response and VPP technology, this paper puts forward a two-stage bidding strategy to optimize the system operation. The upper and lower stages reach a balance through the adjustment of price and bidding amount. All participants can participate in the bidding, so as to promote the stable development of the energy market. In the model and case study section, we introduce different scenarios of demand side users participating in power grid demand response which are carried out based on historical data. Finally, this paper comprehensively evaluates the demand response to participate in the transaction bidding in the power market.

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