Research on power generation's declaration strategy of wind farm spot market considering forecasting error

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Abstract. With the acceleration of the construction of the power market, new energy sources such as wind power gradually begin to compete with traditional energy sources such as thermal power. In this paper, considering the deviation between the actual output of wind farms and the predicted power generation, and aiming at improving the overall income of wind farms in the spot market, the strategy of the wind farm's daily market power generation declaration is studied. The clearing models of the day-ahead market and the real-time market are derived, and the wind farm income function is integrated by combining the error penalty cost caused by the wind power prediction error. The bidding strategy for wind farm income maximization under different wind speed conditions is proposed. It is proved that this bidding strategy can increase the wind farm income by 6%.

Keywords: wind power prediction; wind farm; spot market; energy generation reporting strategy; bidding strategy coefficient.

1 Introduction

The main source of wind farm income is wind power grid-connected. In the competition with traditional energy sources, a suitable declaration plan can improve wind farm income. Literature [1] analyzed the impact of wind power uncertainty on the day-ahead market, proposed a day-ahead clearing model of the power pool market considering wind power, and introduced the concept of "after-sale price". However, since the "after-sale price" can only be obtained after the end of the system operation, it is not stable when used.

On the premise that offshore wind farms participate in the day-ahead market, literature [2] verifies that participating in the real-time market can improve returns. Literature [3] proposes to use bidding strategy parameters to adjust the declared power generation of wind farms, and makes a functional analysis of the overall income of wind farms in the pre-participation market and real-time market, and finds that the income of wind farms can be increased by adjusting bidding strategy. Literature [4] takes virtual power plants containing renewable new energy as research objects and constructs multi-stage bidding models in which they participate in the day-ahead energy market, intraday

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demand response trading market and real-time energy market. Based on the pilot spot market trading mechanism in China, literature [5] studies and analyzes several existing market participation modes of new energy, and puts forward market participation mechanisms suitable for the rapid development stage of new energy. It is worth pointing out that although the above literature takes into account the instability of wind power, it does not consider the penalty cost when balancing the difference between the actual output and the predicted output.

2 Spot Market Clearing Model

The day-ahead market and the real-time market together constitute the spot market. On the day-ahead market bidding day, the power generation enterprises participating in the market transaction need to submit the quotation and unit operation information to the power trading center before the power market closes. According to the load prediction and quotation information, the power trading center takes the "system marginal price" as the clearing price when the system is not blocked. And follow the principle of maximizing social welfare to develop the power generation plan of each power generation enterprise.

In order to highlight the role of wind power in the power market and facilitate the analysis of wind farm income, the supply side of the spot market clearing model only considers thermal power and wind power, and takes the maximization of social welfare as the clearing objective function:

$$\max\{M(P_{load})-\sum_{1}^{G}F(P_i)\} \tag{1}$$

Where $M(P_{load})$ is the production efficiency determined by the load, $\sum_{1}^{G}F(P_i)$ represents the quotation function of G thermal power unit.

When thermal power plants participate in market competition, the generation cost curve is submitted to the market as a quotation curve for quotation, which is in line with the purpose of maximizing the revenue of thermal power plants[6].The quotation function of thermal power unit can be expressed as:

$$F(P_i)=a_iP_i^2+b_iP_i+c_i \tag{2}$$

Where P_i is the output of the i thermal power unit in one hour, a_i, b_i, c_i are the quoted parameters of the i thermal power unit.

When a wind farm participates in the market bidding, its output shall be declared according to the predicted power generation P_f, and the declared amount αP_f shall participate in the market bidding. The specific declared power generation shall be changed by adjusting the coefficient α when deciding to declare the power generation.In order to meet the market equilibrium, the sum of power generation of thermal power units and the declared power of wind farms is equal to the market demand, and the constraints of the market supply and demand balance are as follows:

$$\sum_{i=1}^{G} P_i + \alpha P_f = P_{load} \tag{3}$$

Where P_{load} is an hour demand load for the market.

From equation (2) and equation (3), Lagrange function of the market clearing problem before departure can be constructed:

$$L_{DA} = \sum_{i=1}^{G} (a_i P_i^2 + b_i P_i + c_i) + \lambda_{DA} (P_{load} - \sum_{i=1}^{G} P_i - \alpha P_f) \tag{4}$$

According to the real-time electricity price theory[7], the dual multiplier corresponding to the constraint conditions reflects the production cost of the system's electric energy during the period and can be used as the clearing price of the system, where λ_{DA} is the unified clearing price in the day-ahead market.By taking the partial derivative of equation (4) with respect to P_i, we get:

$$\frac{\partial L_{DA}}{\partial P_i} = 2a_i P_i + b_i - \lambda_{DA} = 0 \tag{5}$$

Simultaneous with (3) Available day market clearing price:

$$\lambda_{DA} = \frac{2\sum_{i=1}^{G} a_i (P_{load} - \alpha P_f) + \sum_{i=1}^{G} b_i}{\sum_{i=1}^{G} 1} = \frac{2(P_{load} - \alpha P_f) + \sum_{i=1}^{G} \frac{b_i}{a_i}}{\sum_{i=1}^{G} \frac{1}{a_i}} \tag{6}$$

As the last gateway connecting market transactions with the physical execution of the system, the real-time market is usually organized by the system dispatching center one hour in advance, and its focus is not on power trading, but more importantly on ensuring that the actual operation of the system conforms to the power generation plan[8].The system dispatching center performs the clearance according to the actual output of the wind farm. At this time, the sum of power generation of the thermal power unit and the actual power generation of the wind farm is equal to the market demand, and the supply and demand balance constraint to be met is as follows:

$$\sum_{i=1}^{G} P_i + P_w = P_{load} \tag{7}$$

Where P_w is the actual output of the wind farm in one hour, Similarly, the real-time market clearing price can be listed:

$$\lambda_{\mathrm{RT}} = \frac{2(P_{load} - P_w) + \sum_{i=1}^{G} \frac{b_i}{a_i}}{\sum_{i=1}^{G} \frac{1}{a_i}} \tag{8}$$

where λ_{RT} is the unified clearing price in the real-time market.

In the process of market declaration before the day, the wind farm is based on the predicted power generation, and there is an error between the predicted power generation and the final actual power generation, and the resulting difference needs to be made up by the balancing unit or consumed[9]. Taking the actual output of wind farm and the declared power generation as the dividing line, the wind farm income function is divided into two situations: actual output is less than the declared power generation and actual output is more than the declared power generation. If the actual output of the wind farm is less than the declared power generation, in order to meet the load demand, the system needs to be controlled by the dispatching center to balance the forward output of the unit to compensate for the missing power of the wind farm. The increased cost should be borne by the wind farm, which is represented by the wind shortage penalty cost. If the actual output of the wind farm is greater than the declared power generation, the system dispatching center controls the negative output of the balancing unit, and the cost incurred also needs to be borne by the wind farm. The penalty cost for output deviation is represented by $M(\alpha)$:

$$M(\alpha) = \lambda_r(\alpha P_f - P_w) \tag{9}$$

$$M(\alpha) = \lambda_p(P_w - \alpha P_f) \tag{10}$$

λ_r and λ_p are overestimating and underestimating cost penalty coefficients respectively.

In summary, the overall income function of wind farm can be obtained $F(\alpha)$:

$$F(\alpha) = \lambda_{DA}\alpha P_f + \lambda_{RT}(P_w - \alpha P_f) - M(\alpha) =$$

$$\frac{2(P_{load} - \alpha P_f) + \sum_{i=1}^{G} \frac{b_i}{a_i}}{\sum_{i=1}^{G} \frac{1}{a_i}} \alpha P_f + \frac{2(P_{load} - P_w) + \sum_{i=1}^{G} \frac{b_i}{a_i}}{\sum_{i=1}^{G} \frac{1}{a_i}} (P_w - \alpha P_f) - \left\{ \begin{matrix} \lambda_r(\alpha P_f - P_w)(\alpha P_f \geq P_w) \\ \lambda_p(P_w - \alpha P_f)(P_w \geq \alpha P_f) \end{matrix} \right. \tag{11}$$

$F(\alpha)$ is a quadratic function of the declaration strategy coefficient α .The first is the income of the wind farm participating in the market before the day; The second item is the income of the wind farm participating in the real-time market. The participating transaction electricity is the difference between the actual output and the declared power generation. If the actual output is less than the declared power generation, the income is negative. The third item is the penalty cost of error compensation.

3 Analysis of Bidding Strategy for Wind Farm

Considering that there are two situations where the actual output is greater than the declared power generation and the actual output is less than the declared power generation, so that the actual output is equal to the declared power generation, it is easy to obtain the subsection point $\alpha_0 = \frac{P_w}{P_f}$.

Using the quadratic function property, the maximum value of wind farm income function can be obtained respectively in two cases. The maximum point is α^* when the actual output is greater than the declared power generation, and the maximum point is α_1^* when the actual output is less than the declared power generation.

$$\alpha^* = \frac{P_w + \frac{1}{2}\sum_{i=1}^{G}\frac{1}{a_i}\lambda_p}{2P_f} \tag{12}$$

$$\alpha_1^* = \frac{P_w - \frac{1}{2}\sum_{i=1}^{G}\frac{1}{a_i}\lambda_r}{2P_f} \tag{13}$$

As shown in Figure 1, the actual output less than the declared power generation corresponds to the function on the right side of the segment point. α_0 has the same denominator as α_1^*, and the numerator of α_0 is greater than α_1^*, so α_0 is always greater than α_1^*, so α_1^* is never found.

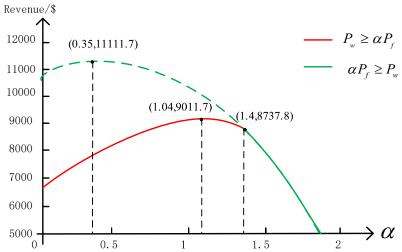

Fig. 1. Income function curve when the actual power generation is greater than the declared power generation

Therefore, the optimal bidding strategy coefficient appears when the actual output is greater than or equal to the declared power generation. Let $\alpha^* = \alpha_0$, can get:

$$P_w = \frac{1}{2}\lambda_p \sum_{i=1}^{G} \frac{1}{a_i} \tag{14}$$

In the day-ahead market power generation declaration, when the forecast output is greater than $\frac{1}{2}\lambda_p \sum_{i=1}^{G} \frac{1}{a_i}$, as shown in Figure 1, the bidding strategy coefficient is α^*; when the predicted power is less than or equal to $\frac{1}{2}\lambda_p \sum_{i=1}^{G} \frac{1}{a_i}$i, as shown in Figure 2, the bidding strategy coefficient is α_0.

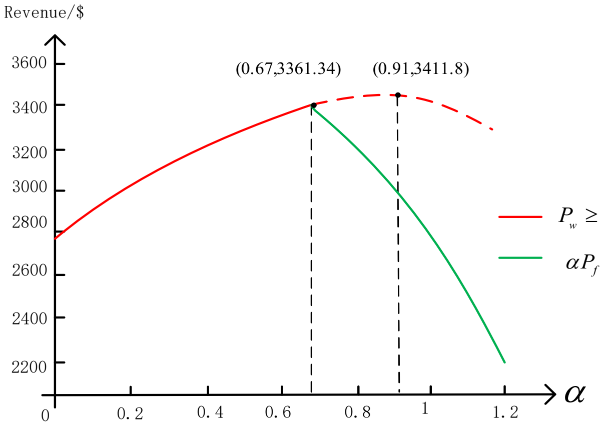

Fig. 2. Income function curve when the actual power generation is less than the declared power generation

4 Bidding Strategy Verification

Reference of thermal power unit data in the simulation example[10], $\lambda_p = 3$.The wind power data comes from a wind farm in Hebei Province. For a wind farm with an installed capacity of 1500 MW, the daily revenue curve is shown in Figure 3. The revenue of the wind farm fluctuates with the load demand, and the revenue of the wind farm increases in each period after the generation declaration strategy is adopted. The sum and comparison of the 24-hour revenue show that the generation declaration strategy increases the revenue of the wind farm by 6%.

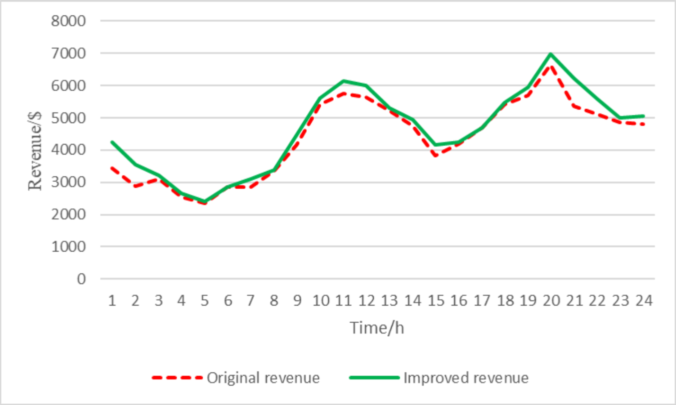

Fig. 3. Daily yield curve of wind farm

5 Conclusion

This paper proposes a generation declaration strategy for wind farm participating in the day-ahead market, fully considers the wind farm's income in the day-ahead market, real-time market and error penalty cost, deduces and analyzes the wind farm's income function by using the Lagrange multiplier method, and solves the income extremal point, and puts forward a declaration strategy for optimizing wind farm's income according to different wind speed conditions. This strategy has been shown to increase wind farm revenues by 6%.

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