Research on market bidding mechanism of generation rights trade for promoting new energy consumption

Bi-Ke Xue¹, Tian-Xing Qi², Wei Zhang², Yan Li², Xiu-Li Wang²

¹China Electric Power Research Institute, Nanjing 21003, People’s Republic of China
²School of Electrical Engineering, Xi’an Jiaotong University, Xi’an 710049, People’s Republic of China
E-mail: z.wai@163.com

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Abstract: With large-scale wind power access to the power system, the volatility and random of wind power bring difficulties to the renewable energy accommodation. The generation rights trade between thermal power unit and wind power is an effective way for accommodating wind power. This study proposed a market bidding mechanism of generation rights trade for regional grid. The division of paid peak load regulation and the range of bidding price of thermal power unit are also analysed here. A case study of northwest power grid is conducted to verify the reasonability and effectiveness of proposed mechanisms. The results show that the market bidding mechanism cannot only effectively promote the renewable energy accommodation, but also make wind unit and thermal power unit to gain higher benefits.

1 Introduction

With the development of renewable energy technology, wind energy, as a non-polluting and renewable energy, has become an important strategy to develop clean energy. In recent years, China had a rapid development in wind power. By the end of 2015, the cumulative installed capacity of wind power has been up to 145,000 MW, with an increase of 26.8%. The new installed capacity and cumulative installed capacity are ranked first in the world [1]. Among them, the northwest region is the one in the six regions in China with the most new installed capacity and cumulative installed capacity. The rapid expansion of wind power production in the power grid brings conserved energy and reduced power generation costs. However, at the same time, it also causes a series of problems like wind power fluctuations, anti-peak characteristics of the peak load, scheduling, and so on. The phenomenon of abandoning wind power becomes serious. In year 2015, the national wind power utilisation hours was 1728 h, 172 h reduced. The abandoned wind rates of Gansu, Xinjiang, and Jilin Provinces were >30%. It can be seen that the problem of wind power consumption has become an important bottleneck of the development of wind power.

When the increasing wind power cannot be consumed, the use of hydropower or thermal power units for peak shaving is a more effective way. Many scholars at home and abroad have studied this aspect. In the literature [2, 3], the influence of large-scale wind power base access on the system equivalent load peak-valley variation and peaking capacity was studied. In the literature [4, 5], from the view of system peak load capacity evaluation, a number of indexes such as peak load shedding rate are proposed, which can help to determine the appropriate wind power access scale. In the literature [6], considering the intermittent characteristics of large-scale wind power, the correlation model between wind power prediction error and reserve demand change is established, and the renewable energy reserve capacity is calculated after wind power access. In the literature [7], a stochastic programming model for the daily clearing of the market is established, and the required rotating and non-rotating reserve capacity as well as the reverse economy are evaluated when the wind power permeability is high. In addition, many scholars did some researches on bringing in the power generation right and the peak shaving right to enhance the power grid peaking capacity. The literature [8] proposed the concept of peak shaving right, and developed a peak shaving volume trading model. In the literature [9], the load under demand management was revised to restore the peak and valley difference of real load, and based on which the peak-to-peak transaction was carried out. The literature [10] studied the way of generation right transactions of self-owned power plants, in which self-owned power plants can participate in peak shaving. The literature [11, 12] studied the method of implementing the auxiliary peak shaving to integrate wind power by establishing the outgoing channel.

The above literatures are on the method to improve the peak shaving capacity of the system after the access of the large-scale wind power and the transaction mechanism of the peak shaving plants, but between the research results and the actual operation of China’s power grid, there are some differences, what is more, the operability is poor. As to the generation right transactions based on the China’s current peak shaving situation, there are still few scholars to study. For renewable energy consumption in the peak load, China uses the ancillary services. The existing auxiliary service mechanism is in accordance with the ‘management and the implementation details of paralleled-in power plant operation’ and ‘management and implementation details of grid-connected power plant auxiliary service’ (hereinafter referred to as ‘two rules’). Power plant units pitch the peak load according to the dispatch instructions. ‘Two rules’ adjust the peak in the form of administrative instructions, resulting in passive adjusting process, without mobilising the enthusiasm. According to this, in order to improve the enthusiasm of thermal power units and effectively promote the consumption of renewable energy sources, this paper studies the market mechanism of regional generation right transactions involving trans-provincial power transactions. The bidding mechanism of power generation right bidding is put forward, and the key problems are analysed. On the basis of the actual calculation of the northwest power grid case, the feasibility and effectiveness of the bidding mechanism are verified.
2 Principle mechanism of generation right transaction market

The current power peak shaving auxiliary service is divided into the basic peak load shaving service and the paid peak load shaving service: the basic peak load shaving service is provided for power plants freely and the paid peak load shaving service should be provided with a certain compensation cost. For paid shaving service, the ‘two rules’ with the mark system cannot accurately measure the contribution of power plants. It is difficult to mobilise power plant enthusiasm.

This paper focuses on the deep peak shaving. With the use of market-oriented generation right bidding trading mechanism, the power plant is initiative to offer the price to reach power generation replacement. Through the level of the price, the power plants to provide power generation right transactions are determined in order. In the peak shaving day, the principles of ‘basic peak shaving is prior over power generation right transactions’ and ‘low price power generation right transaction is prior over high price power generation transaction’ are considered.

In the power generation right trading market mechanism, the thermal power generation units and biomass generation units participate in the transaction as the generation right provider; wind farms, photovoltaic power plants, and other intermittent power participate in market as the purchase of power generation right transactions; energy storage units and gas units considered to provide 100% of the basic peak shaving capacity do not participate in power generation right market.

3 Bidding mode of generation right transaction

China’s regional grid structure includes regional grid companies and provincial (district) power companies in each regional grid. The regional grid company is responsible for the regulation of the power plants in the region and the control of the provincial (regional) tie-line. The provincial (district) power company is responsible for the regulation of the remaining non-regional network companies in the province (area) and the provincial power lines. With the current operation and management of power grid, we can establish the ‘network province cooperation’ power generation bid trading model.

The bidding mechanism of power generation rights is divided into ‘intra-province transactions’ and ‘trans-provincial transactions’ according to the different objects of participation. The intra-province transaction refers to the generation right transaction between the two parties in a province (region), and the trans-provincial transaction refers to the trans-provincial generation right transaction via adjusting the provincial (regional) tie-line. In the ‘network province collaboration’ mode, the provinces power companies are responsible for the provincial generation right transactions, and the regional network companies are responsible for trans-province generation right transactions. The regional network company builds a public platform for auction transactions and it is responsible for daily platform management. Each province (district) power company is responsible for the establishment of substation in the platform, and commit to the daily management of substation. Each power plant reports the next day power generation right transaction-related information in the platform. ‘Network province collaboration’ bidding mode specific implementation process is as follows:

(i) The day-ahead unit offers and wind power forecast. The power plant reports power generation right transaction quotations and the unit active output adjustable interval day ahead. According to the price level, the schedule order is determined. Each province (district) power company carries out the load forecast and wind power output forecast. (ii) The provincial unit generation right transaction. The province (district) company arrange the provincial generation right transaction according to the province power unit offer sorting and load forecasting.

(iii) Trans-provincial transaction arrangements. The provinces (district) report the province’s transaction information to the regional network company after the completion of the transaction organisation. If the province company cannot meet the needs of the transaction, it will apply for trans-provincial power generation rights to the regional network company. The regional network organises trans-provincial transactions according to the adjustable margin of each provincial (district) power unit.

(iv) Real-time call. According to the day-ahead provincial transactions and trans-provincial trading plan, the day real-time calls are arranged. Temporary calls may be made in accordance with the order of the unit offers.

(v) Transaction costs calculation. After the completion of the unit call, the provincial power generation right transaction costs are calculated by the province (district) power company and the trans-provincial transaction costs are calculated by the regional network company.

4 Research on the generation right transaction market mechanism

4.1 Capacity standard for generation right bidding

Considering in the actual operation of the grid, the frequent changes in the unit output will bring a lot of pressure to the system operation safety and the economic operation of the generating units, this paper, combined the scheduling and thermal power unit operating characteristics, sets the rule that the initial participation capacity shall not be <5% of the rated capacity of the unit when the unit participates in power generation right bidding.

In the current ‘two rules’, the paid peak shaving is the peak shaving operation mode in which thermal power unit active output is <50% of its rated capacity. In order to encourage the thermal power units to participate in the transaction of power generation rights, the bidding mechanism of power generation rights is appropriate to reduce the standard of unit participation in transactions (that is, to raise the limit of paid peak shaving).

According to survey on the thermal power units from the scholars and the power plant operation manual [13, 14], the thermal power plant peak shaving rate is generally between 30 and 60%, of which 200/300 MW unit minimum stable load without entering oil can be reduced to ~50%, and 600 MW unit can be reduced to ~40%. In order to encourage thermal power units to participate in the transaction of power generation rights, consider appropriately to increase the depth of peak shaving adjustment instead of the current ‘unit output below the rated capacity of 50’.

The current paid peak shaving reference is <50% of the rated capacity. After considering the unit’s reporting capacity (5% of the rated capacity), the power generation right transaction standard is increased to (50+\(x\))% of the rated capacity, the part >50% (i.e. \(x\)% will generate the incremental transaction costs, which will be allocated among the wind farms; parts below 50% [i.e. (5−\(x\))%] are shared by some wind power enterprises and the non-participation thermal power enterprises.

Wind power enterprises increases the power generation right transaction costs \(\Delta C_P\):

\[
\Delta C_P = p_{thermal} \left( x + \frac{5 - x}{2} \right) \Delta Q \cdot H
\]  

(1)

\(p_{thermal}\) is the thermal generation right cost; \(x\) is the thermal power unit the peak shaving rate; \(\Delta Q\) is the calling power; \(H\) is the length of time for call.
Wind power enterprises obtain the proceeds from the power generation right transactions \( F_{\text{wind}} \):

\[
F_{\text{wind}} = p_{\text{wind}}(5 - x)\Delta Q \cdot H
\]  

(2)

where \( p_{\text{thermal}} \) is the generation right bidding price offered by the thermal units, \( p_{\text{wind}} \) the grid purchase price of the wind power, \( \Delta Q \) the capacity brought by adjusting 1% of the rated output capacity, and \( H \) the duration of the power generation right transaction.

The revenue of wind power enterprises is no less than the cost:

\[
F_{\text{wind}} \geq \Delta C_p
\]  

(3)

Take the grid purchase price of the wind units \( p_{\text{wind}} \) as 0.61 ¥/kWh and the grid purchase price of the thermal units as 0.5 ¥/kWh. We can get:

\[
x \leq 2.05
\]

According to the calculation, the interval of generation right transaction participation standard (paid peak shaving limit) can be improved <2.05%, so divide the generation right trade participation in accordance with 52% of the standard capacity of the rated capacity. If the thermal power unit output decreased, the part >52% of its rated capacity attends the free peak shaving and the part <52% of its rated capacity attends the generation right transaction.

4.2 Ceiling of the bidding price in generation right transaction

In the power generation right bidding market mechanism, in order to prevent the power plant unit to raise the transaction price without limit, the quotation ceiling is set. With the increase in the depth to adjust the output, the power generation costs of the thermal power units will be increasing in a non-linear manner. In order to encourage the replacement of power generation right units more selectively, the subquotation mechanism is divided into three ranges: first range: 52% > load rate ≥ 45%; second range: 45% > load rate ≥ 40%; third range: load rate < 40%.

Assume that the output of the thermal power unit is reduced by \( x \)% from the load rate of 52%, and the cost of the thermal units is \( c \) ¥/kWh, the grid purchase price is \( p \) ¥/kWh, the bidding price of the generation right transaction is \( p^* \) ¥/kWh. After the unit output decline, the power generation coefficient of change is \( k \), and before the power generation right transaction, the thermal power unit profit \( F_{\text{thermal}} \):

\[
F_{\text{thermal}} = 52% (p_f - c) P_N
\]  

(4)

After the transaction, the thermal power unit profit \( F'_{\text{thermal}} \):

\[
F'_{\text{thermal}} = (52 - x)% (p_f - c) P_N + P_N \cdot x \cdot p_t
\]  

(5)

After the transaction, the profit of the thermal unit should increase:

\[
F'_{\text{thermal}} \geq F_{\text{thermal}}
\]  

(6)

(i) The first bidding range: The output capacity of the thermal power unit is generally between 30 and 60%, of which 200/300 MW unit can be reduced to ~50% without entering oil, 600 MW unit can be reduced to ~40% without entering oil. In this range, the thermal power unit power generation costs change little, the coefficient of variation \( k \) is 1.2, solution:

\[
p_t \geq 0.464
\]

The bidding price range can be set as 0–0.5 ¥/kWh.

(ii) The second bidding range: The second range only focuses on the load rate between 40 and 45%, so the thermal unit profit after transaction is:

\[
F'_{\text{thermal}} = (52 - x)% (p_f - c) P_N + 7% P_N \cdot p_t + (x - 7) % P_N \cdot p_t
\]  

(7)

As most of the medium capacity units are difficult to achieve such a load rate directly, the entering fuel oil is needed to maintain the unit, so the cost of electricity will rise significantly, the coefficient of variation \( k \) is 1.5:

\[
p_t \geq 0.631
\]

So the second bidding price range can be set as 0.5–0.7 ¥/kWh.

(iii) The third bidding range: The third range only focuses on the load rate <40%, and the other peak shaving capacity can be cleared by the bidding price in other ranges. So, the thermal unit profit after transaction is:

\[
F'_{\text{thermal}} = (52 - x)% (p_f - c) P_N + 7% P_N \cdot p_t + (x - 12)% P_N \cdot p_t
\]  

(8)

In the third peak shaving adjustment interval, most of the unit has been difficult to run stably, and the oil is needed to help to maintain combustion. The equipment life will be affected, and the operation will be more difficult. Power generation costs will raise substantially, the coefficient of variation \( k \) is taken as 2.1:

\[
p_{t} \geq 0.808
\]

So, the third bidding price range can be set as 0.7–0.9 ¥/kWh.

Above all, the generation right bidding price ranges can be summarised in Table 1.

4.3 Cost clearing method during the transaction

The parties involved in the power generation right transaction are thermal power units and renewable energy units. Owing to the differences of thermal power unit capacity and model, some heating units or small units are difficult to participate in power generation right transactions. Considering the obligation of the thermal power unit to systematically shave the peak load, the thermal power unit involved in the power generation right transaction should obtain a certain compensation fee when transferring the power generation right, which is shared by the thermal power plants and the renewable energy power plants which are not involved in the power generation right transaction. When the system has peak shaving demand, the greater the output of thermal power units is, the smaller system’s peak shaving

| Load rate of thermal units | Bidding floor, ¥/kWh | Bidding ceiling, ¥/kWh |
|---------------------------|-----------------------|------------------------|
| 52%>load rate≥45%         | 0                     | 0.5                    |
| 45%>load rate≥40%         | 0.5                   | 0.7                    |
| load rate<40%             | 0.7                   | 0.9                    |
contribution is, the more fees they should share. Therefore, according to the difference of thermal power plant actual load rate, there are three steps to increase the proportion of the share in turns, which is called the ‘step sharing’. First of all, correct the generation of sharing thermal units in step:

\[ W'_i = \sum_{j=1}^{3} W'_j \cdot k_i \]  \hspace{1cm} (9)

where \( W'_i \) is the corrected generation of the thermal unit \( i \); \( W'_j \) the actual generation of the thermal unit \( i \) in step \( j \); \( k_i \) the correction factor in step \( j \); among them, the load rate <70% of the partial power is the first step; the load rate between 70 and 80% of the partial power is the second step; the load rate >80% of the partial power is the third step. Corresponding correction factors are \( k_1 = 1 \), \( k_2 = 1.5 \), and \( k_3 = 2 \).

The shared cost \( f_i \) of thermal unit \( i \):

\[ f_i = F_{\text{tot}} \frac{W'_i}{\sum W'_j + \sum W'_j} \]  \hspace{1cm} (10)

where \( F_{\text{tot}} \) is the total cost of the generation transaction and \( W'_j \) the generation of the wind farm \( j \).

At the same time, in order not to seriously affect the operation of power generation enterprises, the ceiling of the amount of cost shared by thermal power plants and renewable energy in electric power generation rights trading are set. The ceiling of the amount of cost per kilowatt hour shared by the thermal power plant is half of the thermal power desulphurisation benchmark price; the shared cost of renewable energy per kilowatt hour is no more than the thermal power desulphurisation benchmark price.

5 Case study
In a provincial power grid in northwest region, in a typical day and night, there are 11 thermal power units with the capacity of >200 MW planned to start, the output of which is ~2150 MW, and there are 8 wind farms with the output of 550 MW needing the power generation right transactions due to the serious abandoning wind problems. In accordance with the power trading transaction bidding mechanism described in this paper, the implementation process is described below.

5.1 Wind power forecast and unit quotation
According to the day-ahead load forecast and the power output prediction, due to the phenomenon of serious wind abandonment, it is planned to reduce the output of thermal power units by 200 MW. After the price offer, there are four units to apply for power generation right transaction offer as shown in Table 2.

5.2 Arrange the province power generation right transactions
The province according to the power generation right transaction quotation, the capacity of 63 MW provided by the thermal power unit cannot meet the needs of wind power, and all participating units are required to call. Thus, it can be obtained that the clearing price of the first step can be the highest price, that is, 0.5 ¥/kWh.

5.3 Apply for the trans-regional generation right transaction
As the province has a demand of 200 MW for power generation right transactions, the provincial thermal power plant units can provide a total capacity of 63 MW, and 137 MW capacity still missing. Thus, there is the need to arrange the trans-regional generation right transaction by regional grid company. The regional grid companies organise its direct power plant to provide power replacement capacity of 85 MW, and neighbour province transactions

| Table 2 Generation right offered price among provincial thermal units |
|-------------------------|------------------|-----------------|-----------------|-----------------|
| Units                  | Capacity, MW     | Planned output, MW | Minimum output, MW | Price offered, ¥/kWh |
| thermal unit #1        | 330              | 171              | 155 (47%)        | 0.48            |
| thermal unit #2        | 325              | 170              | 153 (47%)        | 0.45            |
| thermal unit #3        | 300              | 156              | 141 (47%)        | 0.5             |
| thermal unit #4        | 300              | 156              | 141 (47%)        | 0.5             |

| Table 3 Offers for the direct thermal units |
|-------------------------|------------------|-----------------|-----------------|
| Units                  | Capacity, MW     | Planned output, MW | Minimum output, MW | Offers, ¥/kWh |
| direct unit            | 600              | 345              | 260 (43%)        | 0.5           |

52 MW, of which the load rate of direct power plant dropped to the second step. The offer is shown in Table 3.

5.4 Real-time calls and cost calculations
Regional and provincial companies arrange the real-time scheduling in accordance with the power generation transaction plan, and calculate and allocate the cost of electricity in accordance with the participating power. The power plant involved in the transferring power generation right is compensated (by 1 h) as shown in Table 4.

Thermal power plant gains compensation costs (according to 1 h electricity) ¥85,300 via transferring the power generation right. According to the transaction cost allocation method, the compensation costs are allocated by eight wind farms and the seven thermal power units which are not participating the power generation right transactions proportionally. The allocation results and the upper limit of the allocation are shown in Fig. 1.

The maximum cost of the unit is RMB 0.88 million. The upper limit cost of the unit with the maximum cost is RMB 35.300. The minimum cost is 0.21 million. The upper limit cost of the unit with the minimum cost is RMB 1.68 million. The allocated costs for all units are far less than the upper limit of cost allocation, so the allocation of power generation right transaction costs did not have a significant impact on the power plant.

We can see that through the power generation bidding mechanism, thermal power units participating in the transfer of power

| Table 4 Offers for the direct thermal units |
|-------------------------|------------------|-----------------|-----------------|
| Units                  | Capacity, MW     | Actual output, MW | Compensated cost, per thousand ¥ |
| thermal unit #1        | 330              | 155 (47%)        | 8.3             |
| thermal unit #2        | 325              | 153 (47%)        | 8.0             |
| thermal unit #3        | 300              | 141 (47%)        | 7.5             |
| thermal unit #4        | 300              | 141 (47%)        | 7.5             |
| direct unit            | 600              | 260 (43%)        | 28              |
| trans-regional aid     | —                | —                | 26              |

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6 Conclusion

This paper studies the trading mechanism to promote the consumption of renewable energy. According to the status quo of the regional power grid operation, the ‘network province cooperation’ power generation right transaction bidding mechanism is designed. This mechanism is based on the actual situation of the current grid dispatching management, in which firstly the provincial power generation right bidding by the provincial grid company, and then the regional network company organizes the trans-provincial power generation right transaction. In order to promote the enthusiasm of thermal power units to participate in the generation right transaction, a reasonable power generation right bidding capacity standard is calculated. At the same time, the bid transaction quotation ceiling is developed in so that the unit can avoid the occurrence of malicious offer while obtaining a reasonable income.

Then, according to the actual output of a typical day and night in a northwest province, this paper carries out the simulation calculation of the power generation right transaction bidding. After the simulation analysis, it can be found that the thermal power units participating in the power generation right transaction can obtain the higher compensation price than the grid purchase price without generating the actual production cost. This can effectively improve the enthusiasm of the thermal power unit, and the displacement capacity increases the wind power output from the original plan 550 to 750 MW. The problem of the abandoning wind has been greatly alleviated. The results show that the bidding mechanism cannot only effectively promote the consumption of renewable energy, but also make the wind farm and thermal power units get higher returns. The enthusiasm of both parties will be greatly improved, so that the mechanism has a strong implementation.

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